Agrometeorological Aspects of Extreme Weather Events

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PREFACE

Occurrence of weather aberrations and extreme weather events and their impact on agriculture is a major concern today. However, it is possible to adapt to or mitigate the adverse effects of such events if advance forecast is possible. For instance, an advance information on the delay in the start of rainy season is helpful in the distribution of seeds of short duration varieties or a change in the cropping pattern itself. Once the crop is sown, a forecast on the mid-season drought will aid in adoption of cultural practices to minimize its ill effects. Thus, forecasts with a reasonable window enable farmers to organize and carry out appropriate cultural practices to cope with aberrant weather. Pre-season and mid-season forecasts and their effective dissemination are already proved beneficial under Indian conditions. Measures like pre-season agronomic corrections, control operations against pest and diseases, supplementary irrigation, re-scheduling crop harvests are few examples that proved beneficial to farmers. However, a localized weather forecast will be more useful to farmers.

Current research efforts under the National Agricultural Research System (NARS) are mainly aimed at making Indian agriculture resilient to climatic change/variability. This also includes management of extreme weather events and ways to minimize the losses from weather extremes. The All India Coordinated Research Project on Agrometeorology (AICRPAM) demonstrated the utility of weather forecasting for agriculture at a localized scale and its fast dissemination using ICTs through their model and novel project at Bijapur in Karnataka. In the light of the benefits observed in this centre, there is a dire need to up-scale this approach covering the entire country. Realizing the importance of adapting Indian agriculture to extreme weather conditions, Department of Science and Technology (DST), Government of India has decided to organize the SERB School on “Agrometeorological aspects of extreme weather events” at CRIDA. I believe this school will sharpen the skills of participants in managing agriculture in their respective zones in the event of extreme weather.

The lecture schedules for the SERB School are well planned and the faculty is drawn from various research institutes and disciplines working in the field of Meteorology, Agrometeorology and related disciplines. It is heartening to note the heavy response for participation in this SERB School from scientists of different Universities/Institution across the country. The efforts made by the reviewers and editors in compiling and editing the lecture notes and bringing them in the form of a book are commendable. I believe that this publication will be of great use to provide information regarding the practices and procedures to be followed in managing the extreme weather conditions.

(B. Venkateswarlu)
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Basic Concepts,
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BASIC CONCEPTS OF AGROMETEOROLOGY

B.V. Ramana Rao

Life demands food. The production of food depends upon four factors namely

- Plant and genetic material, Weather, Soil and Water

Many other factors like management practices, size of the holding and enterprising nature of the farmer may also contribute to the success or failure of agricultural production. But weather plays a more decisive role. The farmer will have very little control on the weather. Weather will influence the agricultural production through its effects on soil chemistry and physics, plant growth and development, yield and yield components and in every phase of animal growth and production as well. So, the basic philosophy of agricultural meteorology is to make use of the science of meteorology in the interest of food production. Agricultural meteorology can be broadly defined as the science which deals with the interaction between the atmosphere and the plants and farm animals.

Therefore, the aim of agricultural meteorology is to make use of all the products of meteorological services including

- Historical data base, which can be analysed for crop planning, soil and water management strategies, identification of extreme weather events that might cause decline in productivity and evaluate the climatic shifts including inter seasonal and intraseasonal variability of weather factors trends, if any that might provide clues on climate change and if possible the impact of such variability on crop production.

- Long, medium and short range weather forecasts issued by the meteorological department for taking decisions in crop planning and management, impact of changing weather conditions on biotic interferences to the crop growth and guide the extension officials and farmers from time to time.

- Global weather parameters like El Nino, Southern Oscillation etc which may have severe effect on seasonal climates within different agroclimatic regions and their impact on crop production.

Agricultural Climatology

The agricultural production potential primarily depends upon the availability of moisture in the soil through precipitation (water received over the soil from the atmosphere either in solid or liquid form) and the soil moisture storage capacity which depends upon the clay content and depth of the soil. The other important factor is the thermal regime. The growth and development of the crops is generally believed to take place when the mean daily temperatures are above 5°C. In tropical regions, the mean daily temperatures are much higher than 5°C throughout the year and therefore crops can be grown round the year, if water is available. In high altitude locations and in the interior regions beyond tropics, the mean daily temperatures will be less than 5°C during the winter season and therefore arable crop production is restricted to warm weather season only.

Therefore, the agricultural climates all over the world are classified based on the two parameters i.e., the moisture regime and thermal regime.

Crop Growth and Development

The distinction between crop growth and development can be recognized by the fact that growth represents the increase in weight and volume of the total plant or various plant organs while development represents the consecutive phenological stages through which it passes. The two processes, growth and development are inter related. The factors influencing crop production can be divided into three major groups:

(i) Yield defining factors like radiation.
(ii) Yield limiting factors like water availability and nutrients.
(iii) Yield reducing factors like weeds, pests and diseases.

Phases of Crop Growth

Generally, the crops can be considered to pass through important phases which can be distinguished from each other clearly under ideal conditions.

(i) During the first phase, the crop consists of individual plants which do not shade each other and the growth rate increases. A major part of the assimilates is invested in leaf growth and the increase in leaf area is proportional to the solar radiation intercepted. The plant weight increases at constant rate when water is not a limitation.

(ii) During the second phase, crop covers the soil completely and growth rate is constant if there is no limitation of water. A major part of the dry matter accumulation during the phase depends upon the growth rate and duration of the phase.

(iii) The crop is maturing and the growth rate is decreasing

The major environmental factors influencing phenological development are temperature and day length. The crops have a threshold temperature below which no growth takes place. By summing the daily temperatures above certain the threshold value (base temperature) during a particular phase, the number of thermal units (sometimes referred as degree days) required for completion of the phase can be obtained. The fraction of thermal units made available to the crop compared to the thermal units required for a particular phase will provide a numerical value of the development stage.

Starting from the date of sowing, the first phase covers germination of seeds, emergence of seedlings and vegetative phase. The second phase covers fifty per cent flowering, grain formation and grain filling stages. The third phase covers physiological and harvest maturity stages.

Potential Evapotranspiration

Evaporation of water takes place from the soil as ‘soil evaporation’ and the leaves of the plants as ‘transpiration’. The combined loss of water due to evaporation from soil and transpiration from the crop is called ‘Evapotranspiration’. The water loss due to evapotranspiration depends upon the ‘water availability’ to the plants through soil moisture storage, rainfall and or irrigation. Therefore Penman (1948) introduced the concept of ‘potential evapotranspiration’ (PET) which is defined as the maximum amount of water that can be lost through evapotranspiration from short grass covering the entire soil when water is not a limiting factor. He developed a mathematical expression which is popularly known as Penman’s method for computing the potential evapotranspiration using weather data such as temperature, wind speed, vapour pressure deficit, radiation etc. At many of the places, the data required for estimating the potential evapotranspiration may not be available. Therefore, Thornthwaite (1948) also developed a formula to calculate the potential evapotranspiration using temperature data. Later Monteith improved the Penman’s equation for more reliable estimation of PET which is now widely used as Penman-Monteith’s equation.

Crop Water Requirement (ET_0)

The actual amount of water required by the crop for evapotranspiration is called water requirement of the crop. The water requirement of the crop depends upon what is known as Leaf Area Index (LAI) i.e., the leaf area of the crop per unit area of the soil.

The water requirement of the crop is equal to the potential evapotranspiration when the leaf area index is 3.0 and slightly increases with increase in leaf area index beyond 3.0.

When the crop canopy is not completely shading the ground, the crop intercepts only a part of the photosynthetically active radiation (the solar radiation that forms the visible light and it is approximately about 0.45 times the incoming solar radiation) depending upon the leaf area index and it is given by the formula

$$f_n = f_0(1 - e^{-k*LAI})$$

where f_n = Intercepted photosynthetically active solar radiation
f_0 = Incoming photosynthetically active radiation
k = Extinction coefficient for visible light which depends upon the geometry of the crop
LAI = Leaf area index

When the crop is not fully shading the ground, the crop uses only a part of the incoming radiation and therefore, the water requirement of the crop is lower than the potential evapotranspiration.

The crop water requirement can be estimated using the equation

$$ET_0 = K_c * PET$$

Where K_c = Crop coefficient which depends upon LAI
PET = Potential evapotranspiration

Actual Evapotranspiration (AET)

When there is no shortage of water to the crop, the actual evapotranspiration of the crop is same as the water requirement of the crop. Otherwise the actual evapotranspiration is equal to the amount of water available in the soil as soil moisture storage.

Total Dry Matter Production

The total dry biomass produced by the crop during its life cycle is known as total dry matter production (DMP). The total dry matter production from a well managed crop without being affected by biotic interferences like weeds, pests and diseases and not subjected to weather hazards like floods, high temperatures, cold waves etc is directly proportional to the water used by the crop. It is also directly proportional to the total photosynthetically active radiation (PAR) intercepted by the crop during its life cycle.

DMP α Total water used by the crop for evapotranspiration during its growth cycle.

DMP α Total PAR intercepted by the crop during its life cycle.

Economic Yield

Crops are not grown for just total biomass production. The crops are therefore grown for their storage organs like tubers, pods or grains. These storage organs grow only during the later part of the growth cycle after roots, leaves and stems have been produced. The grain yield can be estimated from the total dry matter production using the relationship

$$\text{Grain yield} = \text{Total dry matter production x Harvest Index}$$

Therefore, harvest index is the ratio of grain yield to the total dry matter production and generally ranges from 0.3 to 0.4 depending upon the nature of the crop.

Climatic Classification

As the agricultural production potential of a region is mostly governed by two factors namely precipitation (P) and potential evapotranspiration (PET), the climates are generally classified using the concept of moisture index (MI) which is given by the formula

$$MI = \left(\frac{P\text{-}PET}{PET}\right) \text{ x } 100$$

Value of MI	Climate type
< -66.6	Arid
-33.3 to -66.6	Semi-arid
-66.6 to 99.9	Sub-humid
≥ 100	Humid

UNESCO also suggested a method of climatic classification based on the ratio of precipitation to potential evapotranspiration, which is as follows:

P/PET	Climate
< 0.20	Arid
0.2 to 0.50	Semi-arid
0.5 to 0.99	Sub-humid
≥ 1.00	Humid

In tropical countries, where temperature is not a limitation for growing crops / vegetation round the year, the UNESCO classification suggests the relationship between the climate and water availability period as follows, with the assumption that water received through precipitation is not lost through run-off and deep drainage.

Climate	**Water availability period in days**
Arid	< 73 days
Semi-arid	74 to 182 days
Sub-humid	183 to 364 days
Humid	365 days

Therefore, the cropping patterns under rainfed conditions in tropical regions can be related to the climatic type as follows:

Climatic region	**Cropping pattern under rainfed conditions**
Arid	Grasses, shrubs, short duration pulse crops and pearl millet
Semi-arid	Short, medium and long duration crops, Inter cropping systems if the soils are deep with high water holding capacity
Sub-humid	Rainfed rice based cropping systems, horticultural crops
Humid	Rice based cropping systems, plantation crops

Therefore, climate of the region plays a major role in the choice of crops and cropping systems under rainfed conditions in tropical regions depending upon the nature of the soil.

CROP-WEATHER RELATIONSHIP STUDIES

P. Vijaya Kumar

Importance of Weather

Weather directly or indirectly influences the crops in their growth cycle. The growth, development and productivity of crops are the resultant of many physical and physiological processes, each of which are affected individually or jointly by weather parameters. Though weather or climate is the least manageable natural resource, understanding of its interaction with agricultural parameters was found to be a powerful tool to develop weather based management strategies in agriculture that will enhance benefits from positive interactions and minimize the losses from negative interactions (Virmani, 1994).

The principal weather parameters which affect crop growth and yield are: Precipitation (amount and distribution), air temperature (Maximum and Minimum), moisture content of the air (Relative humidity, SVPD), solar radiation or sunshine hours and wind speed.

Changes in Concept of Crop-weather Relationship Studies

Over the years, lot of changes in the concepts of crop-weather relationships have been evolved. The crop-weather relationship studies in earlier years were based on statistical techniques like correlation, simple and multiple regression, step-wise regression, etc. It was believed by Agrometeorologists working on dryland agriculture that rainfall is main factor for variation in yields of dryland crops. Crop yields were related with rainfall during different stages of the crop growth to identify the critical stages of the crop. Experience and logic prompted them to look for some more parameters other than rainfall for accurate prediction of crop yields. Though total amount of seasonal rainfall showed some amount of relation with final yield, it was not representing the actual water available for plant growth as it does not account the losses through drainage, runoff and also the influence of the water holding capacity of the soil. The proposition of potential Evapotranspiration concept simultaneously by Penman (1948) and Thornthwaite (1948) and the introduction of water budgeting by Thornthwaite (1948) and the modification of the same by Thornthwaite and Mather (1955) brought in an appropriate independent variable, i.e., water use or Evapotranspiration for prediction of crop yields. Later, de Wit (1958) developed an equation to relate dry matter yield (Y) to transpiration as:

$$Y = m\ T/E_o$$

Where T is transpiration in cm, E_o is average free water evaporation rate (cm/day) and m is a crop factor.

The ratio of actual evapotranspiration to potential Evapotranspiration (AE/PE) known as Index of Moisture Adequacy (IMA) has found its use, later, in crop-weather relationship studies. The non-accountancy of crop factor in water balance models was corrected by introduction of models by researchers like Frere and Popov (1979), Ritchie (1972), etc. The simple (FAO) water balance model developed by Frere and Popov (1979) introduced an index called Water Requirement Satisfaction Index (WRSI) for predicting crop yields.

Although water supply plays a dominant role in agriculture, other climatic factors also influence the performance of crops and to understand the effect of more weather parameters, multi-variate crop-weather relationships were developed.

All these statistical models developed with data from a given place though have higher predictability, suffer from location-specific bias. To overcome the site-specific problem, concerted scientific effort for development of dynamic crop simulation models which are generic in nature and are applicable universally was initiated across the globe.

Effects of Different Weather Parameters

Solar radiation:

Crop production is in fact exploitation of solar energy. Solar energy (solar radiation) is the driving force and only source of energy for photosynthesis (Monteith 1973).It is one of the main factors influencing biomass, yield and its quality.

When water and nutrients, diseases and insects are not limiting factors, crop growth is determined by the amount of solar radiation intercepted and carbon dioxide assimilated. Three aspects of solar radiation are important for plant processes: Intensity, duration (i.e., photoperiod or day length), and quality. Low intensity of solar radiation during grain filling phase negatively influences grain yield of cereal crops.

The length of the day or photoperiod determines flowering and has a profound effect on the content of soluble carbohydrates present. A majority of plants flower only when exposed to certain specific photoperiods. It is on the basis of this response that the plants have been classified as short day plants, long day plants and day neutral plants. When any other environmental factors is not limiting, the longer duration of photoperiod increases photosynthesis.

Radiation and water use efficiencies:

Radiation use efficiency (RUE**)** and water use efficiency (WUE) are of outstanding importance in crop simulation models. They can be used for simulation of crop yield using either of the following equations.

Yield = Radiation absorbed*RUE*HI (1)

Yield = Total water use*WUE*HI (2)

Where HI is the harvest index of a crop

The 1st equation is used in water unlimited and light limited conditions and the 2nd equation is used in water limited conditions.

Radiation use efficiency: The concept of resource capture introduced for the first time by Monteith (1977) showed that the accumulated dry matter production of a wide range of crops and orchards in Britain was linearly related to accumulate intercepted solar radiation. The radiation use efficiency is the direct outcome of this concept because RUE is nothing but the slope of the linear relation between accumulated dry matter and cumulative radiation. The RUE defined as the quantity of biomass produced per unit of intercepted radiation (g MJ^{-1}), provides a measure of the "efficiency" with which the captured radiation is used to produce new plant material. In the absence of stress, RUE is often conservative, ranging between 1.0 and 1.5 g MJ^{-1} for C_3 species in temperature environments (Russell *et al*., 1988), 1.5 to 1.7 g MJ^{-1} for tropical C_3 species (Monteith, 1990) and up to 2.5 g MJ^{-1} for tropical C_4 cereals. RUE values of some important crops were given in Table-1. Though in the early studies, it was reported to be stable, subsequent studies of RUE showed large variability due to both physical factors (Vijaya Kumar *et al*., 1996) and biological factors (Wright *et al*., 1993).

Table 1 : Radiation and water use efficiency of some crops

Crop	RUE (g/MJ)	WUE(g/Kg)
Maize	1.5	2.9-6.7
Sorghum	1.2	2.9-6.7
Groundnut	0.4	1.4-3.3
Soybean	0.75	1.4-3.3
Wheat	1.2	1.25-2.5
Castor	1.2	0.88-1.31
Chickpea	0.62	2.1-4.1
Pigeon pea	0.9-1.3	0.6-0.7

Water use efficiency: Using the approach of Tanner and Sinclair (1983), a mechanistic expression relating biomass accumulated to the amount of Evapotranspiration, i.e., water use efficiency was derived. In other words, water use efficiency (WUE) is the amount of dry matter produced by a crop per unit of water transpired. Initially, WUE was considered to be conservative parameter (de Wit, 1958). Later, it was observed that, WUE of many species is inversely proportional to the mean value of saturation vapour deficit of the atmosphere in both water limited and energy limited conditions (Tanner and Sinclair, 1983). WUE of C_4 cereals were observed to be higher than C_3 species. WUE of crops grown during milder post-rainy season were higher than those grown during summer.

Temperature:

Temperature is an important factor not only to plants but also for all the biological species because of following factors: (a) Physical and chemical processes within the plants are governed by temperature. (b) The diffusion rate of gases and liquids in soil-plant-atmospheric system changes with temperature.

Temperature affects crops by causing (i) variations in duration of phenological events or crop development. (ii) variation in magnitude and time of occurrence of peak in biomass, (iii) significant increase / decrease in growth rates, (iv) variation in growth pattern deviating from sigmoidal curve and ultimately affecting grain yield or harvest index.

Crop development and weather:

Development refers to the timing of critical events in the life cycle of a plant. Duration of growth for a particular species or cultivar is usually almost directly proportional to temperature, over a wide range of temperature. Duration of particular stage of growth for a particular species could be predicted using the sum of mean daily air temperatures (Wang, 1960). Several synonymous terms have been used to describe the process of summation of temperatures to predict plant growth duration (Nuttonson, 1955). These include the terms degree-days (°C d), day-degrees, heat units, thermal units and growing degree days.

Growing degree-days (GDD): Since 1730, when Reaumer introduced the concept of heat unit or degree-day, it has been used successfully in Agricultural Sciences.

A degree-day or a heat unit is the departure of the mean daily temperature above the threshold temperature or base temperature. This minimum threshold is the temperature below which no growth takes place. The threshold temperatures vary with crop species and for majority of crops, ranges from 4.5 to 12.5°C. They are higher for tropical crops and lower for temperate crops. The growing degree-day (GDD), an extension of the degree-day concept, is defined as a day on which mean daily temperature is one degree above the minimum temperature required for growth of a particular crop. The growing degree-days can be calculated using the formula

$$GDD = \sum (T_a - T_b)$$

Where T_a = Average daily temperature and T_b is the base or threshold temperature.

T_a can be calculated as $\frac{T_{max} + T_{min}}{2}$

In spite of some limitations, degree-day concept with some modifications is widely used for forecasting crop development and maturity.

Degree days provide good approximation for insect growth also. An opposite effect to degree days is observed in some temperate fruit trees. They require certain amount of chilling days or hours below a certain temperature before they set to fruit.

Combined influence of temperature and photo-period :

Though development of crops is mainly driven by temperature, some plant species respond to photo-period or day length. The photo thermal effects on phenology in many crops were reported. For all tropical and sub-tropical species, the warmest temperature combined with shortest photo period hastened flowering and fruit maturity (Keating *et al*, 1998). However, all temperate species both flowered and matured sooner at the warmest temperature combined with longest photo period.

Temperature thresholds :

Every crop and crop variety has its threshold minimum, optimum and maximum temperature requirements known as cardinal points. They are:

Minimum temperature: It is the temperature below which no growth occurs. For typical cool season crops, it ranges between 0 and 5°C and for hot season crops; it is between 15 and 18°C,

Optimum temperature: It is the temperature at which maximum plant growth occurs. For cool season crops, it ranges between 25 and 31°C and for hot season crops between 31 and 37°C.

Maximum temperature: It is the temperature above which the plant growth stops. For cool season crops, it ranges between 31 and 37°C and for hot season crops; it ranges between 44 and 50°C.

Low temperature affects: Low temperature affects several aspects of crop growth, viz., survival, cell division, photosynthesis, water transport, growth and finally yield.

High temperature affects: High temperature adversely affects mineral nutrition, shoot growth and pollen development resulting in low yield. Adverse effects of high temperature during critical growth stages of some major crops were mentioned in Table - 2.

Table 2 : High temperature effects on key development stages of five major arable crops

Crop	Effect
Wheat	T > 30°C for > 8 hrs can reverse vernalisation
Rice	T > 35°C for > 1 hr at anthesis causes spike let sterility
Maize	T > 36 °C reduces pollen viability
Potato	T > 20°C reduces tuber initiation and bulking
Cotton	T> 40ºC for more than 6 hours causes bolls to abort

Source: Acock and Acock (1993)

Rainfall or water use:

Rainfall is an important parameter in agriculture. All plants need water to survive and rainfall is the main source providing water to plants. While normal rainfall is vital to healthy plants, too much or too little rainfall can be harmful to crops. Plants need varying amounts of rainfall to survive. Desert plants require small amounts of water while tropical plants need much higher rainfall. Water is an essential component in the process of photosynthesis. The movement of water out of the plant stomata, known as transpiration is an inevitable consequence of assimilation of carbon dioxide. As transpiration or water use and photosynthesis are inter related, a linear relation between crop yield and seasonal transpiration was established by Hanks (1974) as follows:

$$Y=m*(T/E_0)$$

Where Y=Yield, T=Seasonal transpiration and E_0 is average seasonal free water evaporation and m is a crop factor. This equation gave very good fit for several crops grown in different years in different locations.

During the growth of many plants there are periods during which they are especially susceptible to drought stress-for example the time of transition from the vegetative to the reproductive phase in cereals. The magnitude of the water deficit is important in addition to its timing and duration.

The effects on yield of a water shortage at different growth stages of a number of crops are reviewed in Doorenbos and Kassam (1979), where the response of yield to water supply was quantified through the yield response factor (K_y), which relates relative yield decrease to relative evapotranspiration deficit. Values of K_y for individual growth periods and for the total growth period for several crops are presented in Table-3.

Methods to Evaluate Crop-weather Relationship

The three commonly used approaches are: (i) Correlation techniques (ii) Crop weather analysis model (iii) Crop growth simulation models

Correlation analysis provides a measure of the degree of association between variables. Regression analysis describes the effect of one or more variables (independent variables) on a single variable (dependent variable).

Regression and correlation procedures can be classified according to the number of variables involved (a) Simple (If only 2 variables, one independent and another dependent) (b) Multiple (If more than 2 variables)

The procedure is termed linear, if underlying relationship is linear or non-linear, if otherwise

Table 3 : Yield response factor (K_y), the relative decrease in yield per relative deficit in evapotranspiration, for different crop growth periods (Doorenbos and Kassam 1979)

Crop	Vegetative period			Flowering period	Yield formation	Ripening	Total growing period
	Early	Late	Total				
Cotton			0.2	0.5		0.25	0.85
Groundnut			0.2	0.8	0.6	0.2	0.7
Maize			0.4	1.5	0.5	0.2	1.25
Pea	0.2			0.9	0.7	0.2	1.15
Potato	0.45	0.8			0.7	0.2	1.1
Safflower		0.3		0.55	0.6		0.8
Sorghum			0.2	0.55	0.45	0.2	0.9
Soybean			0.2	0.8	1.0		0.85
Sugarcane			0.75		0.5	0.1	1.2
Sunflower	0.25	0.5		1.0	0.8		0.95
Winter Wheat			0.2	0.6	0.5		1.0
Spring Wheat			0.2	0.65	0.55		1.15

Regression equations are broadly of four types:

(i) Simple linear regression (ii) Multiple regression (iii) Simple non-linear regression (iv) Multiple non-linear regression Simple and multiple regressions widely used for crop weather relationship studies can be written as

$$Y=a+b*X$$

Y is the dependent variable, example-Yield
X is the independent variable, example-Rainfall, temperature etc

$$Y=a+b1*X1+b2*X2+\ldots\ldots+bk*Xk$$

k =Number of independent variables
R^2 is coefficient of determination

There must be enough observations to make n greater than (k+1)

Multi Collinearity:

Multi collinearity in regression equations occurs when predictor variables (independent variables) in the regression model are more highly correlated with other predictor variables than with the dependent variable. It commonly occurs when a large number of independent variables are incorporated in a regression model.

Searching for best regression:

There are 2 ways in which relationship between dependent variable and k independent variables be specified (i) Based on accepted biological concepts, secondary data, past experience etc. (ii) Based on the data collected

Four procedures commonly used for specification of appropriate relationship between X and Y are (a) Scatter Diagram (for simple regression) (b) Analysis of variance technique (not relevant for CWR studies) (c) Test of significance technique (for elimination of unnecessary variables) (d) Step-wise regression technique (for identifying the sequence of importance of each variable).

Standardizing variables:

The following standardization procedures help to reduce experimental error and biases (i) Yields from different varieties to be adjusted to a “standard” “base” variety (ii) Weather variables are to be measured within specific stages of plant development rather than within specified weeks or months (iii) Yields are to be culled to remove those reduced by disease, hail, pests and other factors (iv) Reduction in experimental error can be accomplished through use of simulated evapotranspiration amounts rather than precipitation, to measure effects of droughts.

DATABASE MANAGEMENT OF EXTREME AGROMETEOROLOGICAL EVENTS

A.V.M. Subba Rao

One important consequence of global warming is the increase in the frequency and intensity of extreme weather events. One of the major developmental issues in agricultural meteorology, which is also linked to humanitarian aid, are natural disasters which have a major impact on agricultural productivity since the economic cost associated with all natural disasters has increased 14-fold since the 1950s. Strictly speaking, extreme Agrometeorological events include the direct and indirect impacts of extreme weather events in agriculture, taken in the broadest sense to include crops, livestock husbandry, fisheries and forestry.

The systematic collection of information related to the frequency and impact of disasters provides an invaluable tool to governments and institutions in charge of funding planning and relief activities. However, there is a lack of international consensus regarding best practice for collecting data on natural disasters. Along with the complexity of collecting information in disasters due to the constraints of time, funding, and the complexity of the situation there also remains huge variability in definitions, methodology, sources, and data points collected.

Agrometeorological services are operationally used by individual farmers in developed countries, and by agricultural or development services in more than half the countries of the world. Its contribution to agricultural production forecast is sought in virtually all countries. The climate database is used for the development of practical criteria in planning and management of irrigated and rainfed crop production system (Martin Smith, 2000). Agroclimatic information is essential for agricultural planning. It facilitates the development of sustainable and economically viable agricultural systems. In view of the continuous demand for enhancing the food production to meet the needs of the ever-increasing population, the importance of understanding the influence weather and climate parameters at the micro region level is the need of the hour.

Extreme Weather Events

An extreme (weather or climate) event is generally defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable. Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of weather or climate events that are, individually, not extreme themselves (though their accumulation is extreme). As well, weather or climate events, even if not extreme in a statistical sense, can still lead to extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system, or by occurring simultaneously with other events.

Extreme Events in India

India being mainly an agricultural country the economy and further its growth purely depends on the vagaries of the weather and in particular the extreme weather events. Basically, the climate of India is dominated by the summer monsoon (June to September). The entire year is, however, divided into four season : (i) Winter (January and February) (ii) Pre-monsoon or Hot Weather season (March . May) (iii) Southwest or Summer Monsoon season (June - September) (iv) Post monsoon season (October . December). Year to year deviations in the weather and occurrence of climatic anomalies / extremes in respect of these four seasons are

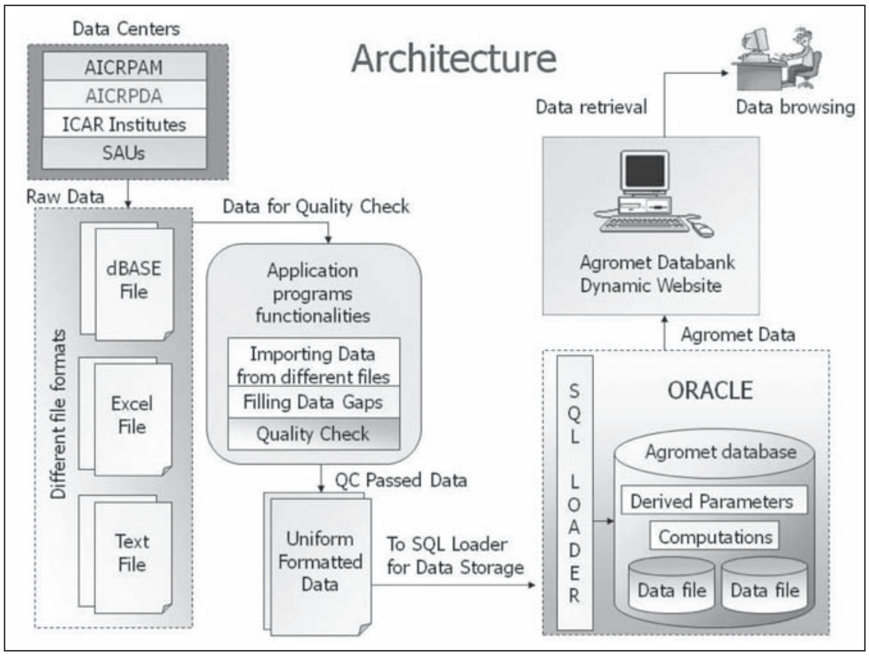
- Cold wave, Fog, Snow storms and Avalanches
- Hailstorm, Thunderstorm and Dust storms
- Heat wave
- Tropical cyclones and Tidal waves
- Floods, Heavy rain and Landslides, and
- Droughts

In India, naturally occurring extreme events do lot of damage to property as well as lives of human beings and animal. Over 40 million hectares (12 per cent of land) is prone to floods and river erosion; of the 7,516 km long coastline, close to 5,700 km is prone to cyclones and tsunamis; 68 per cent of the cultivable area is vulnerable to drought and hilly areas are at risk from landslides and avalanches. The year 1999 witnessed a super cyclone striking the eastern coast of India (Orissa State). It was a major natural disaster affecting the subcontinent in recent years. The droughts of 1972 and 1987, the heat wave in 1995 and 1998 and cold wave in 2003 killing several hundred people are still fresh in public memory. The drought and failed monsoon of 2002, in particular, an unusually dry July, is matter of concern for scientists and planners. However, many may not remember that the worst drought in India during the last century occurred in 1918. Unfortunately, the information on extreme weather events lie scattered. There is a need to gather information on extreme weather events and prepare a database, which in turn help us to do research on adaptation strategies to reduce the impacts on Agriculture and allied sectors.

Agromet Database

Primarily, weather and climate information in hand improves production and quality, reduce the production losses and risks, decrease the costs and increase efficiency in the use of water, labour and energy, conserve natural resources and decrease pollution by agricultural chemicals or other agents that contribute to the degradation of the environment. Recent weather data and weather forecasts are used mostly in current agricultural operations and on the other hand climate information is used for planning purposes.

National Data Centre (NDC) under the aegis of IMD is the sole custodian of all Meteorological Data being collected from various parts of India. The data are available for more than 125 years. The mandate is to preserve quality controlled data and supply for Weather Prediction, Aviation, Agriculture, Environmental studies, Oceanography and Shipping and Researchers of various Institutions and Universities. Major Agromet data provided by IMD is on crop Weather Calendar Scheme, Experimental Data, Dew, Desert Locust MET, Evapotranspiration, Evaporation, Day's Summary Data, Synoptic Hour Data, Weekly Surface Data and Soil Moisture Data. Crop based data is one of the limitation in the IMD data base.



In ICAR, along with the state agricultural universities, large scale experimentation, crop growth modeling and simulation studies motivated the premier organization to have its own crop based database along with weather/climate. In view of the importance and the immediate need to centralize the database system for helping the researchers and planners, a "Central Agrometeorological databank facility" was established at CRIDA. Primarily, All India Coordinated Research Project on Agrometeorology (AICRPAM) centers (25) provide crop and weather data for this databank. This data is used to characterize climates, monitoring and issuing contingencies for the standing crops and monitoring droughts etc. The working principle of the Agromet databank is presented in the figure. The database contains Eight Basic weather parameters viz. Maximum and Minimum temperature, Rainfall, Wind speed, Relative humidity (morning and evening), Sunshine hours & Evaporation. Crop data contains the date of sowing, harvesting, phenology and yield attributes. Further, with the available database AICRPAM and its centers have characterized the climates and developed the crop weather and pest weather relationships and thumb rules. Collection of weather data (rainfall in general and temperature where ever it is available) at block/mandal/tehsil level has been initiated to strengthen Agrometeorological research at micro- level and Agromet Advisories under varying climatic conditions.

Extreme Weather Databases and Management

Unfortunately, extreme weather events are highly location specific and the data availability is a question. Highly scattered data that too compilation need to be made from technical & research papers, news items, Radio and TV reports etc. The extreme events/ natural hazards are classified into 4 categories viz. Geophysical, Meteorological, Hydrological and Climatological. Earth quake, volcanic eruption, landslides fall under Geophysical events. Meteorological events comprise of Tropical storms, thunder storms, squalls, hail storms, Extra tropical storms (western disturbances). Heavy rainfall, River flood, flash flood and storm surges fall in the domain of Hydrological events. Landslides, Avalanches etc are also part of Hydrological events. Finally the climatological events include Heat and cold waves, frost, Fog, drought and wild fires. So under these four categories only Meteorological, Hydrological and climatological events are important for agriculture and allied sectors.

Data Collection

Agriculture is the most vulnerable area to abnormal weather conditions and weather extremes. Data collection on Extreme event is a typical task since each extreme weather event is unique in scale and location. The events many times occur beyond the vicinity of weather observatory network. In India, IMD had published records of extreme events in chronological order in recent years. The State Agriculture Universities and ICAR institutes, local NGOs and Department of Agriculture are some of the other sources where we can get some information on the extreme events. Other government departments such as NIDN,CWC,DAC, NRAA, News Papers, TV news Reports can also provide information. Some external sources like Munich Re, EM-DAT website, Brussels, Belgium are also providing worldwide Extreme events information.

Criteria for Identifying the Extreme Weather Events

When the Extreme Weather Events are to be identified by analyzing from the daily weather data of different locations it requires some criteria for each individual event. IMD follows some criteria for all the extreme weather events as presented below;

Cold wave			
	a)	Normal	Minimum temperature is 10°C or more
		Cold wave	Minimum temperature 5°C to 6°C below normal
		Severe cold wave	Minimum temperature 7°C or more below normal.
	b)	Normal	Minimum temperature is less than 10°C.
		Cold wave	Minimum temperature 4°C to 5°C below normal.
		Severe cold wave	Minimum temperature 6°C or more below normal.
Drought		Moderate	When SW monsoon rainfall departure is between -26% and -50%.
		Severe	When SW monsoon rainfall departure is less than -50%
Dust storm		Moderate	Wind speed between 39 to 74 kmph and horizontal visibility limited to 500 meters
		Severe	Wind speed 75 kmph and horizontal visibility limited to 50 meters
Gale		strong	Wind speed >= 75 kmph
Hailstorm		Slight	Sparse usually small in size and often mixed with rain.
		Moderate	Fall abundant enough to whiten ground.
		Heavy	Includes at least a proportion of large stones
Heat wave		Moderate	Maximum temperature 6 to 7°C above normal.
		Severe	Maximum temperature >= 8°C above normal.
Snow		Moderate	7.6 to 34.9 cm in 24 hrs
		Heavy	35.0 cm in 24 hrs.
Squall		Moderate	Surface wind speed (in gusts) upto 80 kmph
		Severe	Surface wind speed (in gusts) = 80 kmph
Thunder storms		Moderate	Loud peals of thunder with frequent lightning flashes), moderate to heavy rains and maximum wind speed 29 to 74 kmph.
		Severe	Continuous thunder and lightning, heavy rains and maximum wind speed = 75 kmph

Other criteria for cyclones, fog, frost etc are provided by IMD in the Mousam journal published twice every year. In the software for warning the weather data need to be arranged and the criteria applied and the frequency of the event is computed for the location. Time of occurrence and duration of certain event is a must to record. Sometimes, short period stay of an event may not cause any damage to crop or even crop can adjust automatically. But beyond a certain point the crop may come under stress particularly in the event of heat and cold wave.

Collection of Agriculture and Allied Sector Information

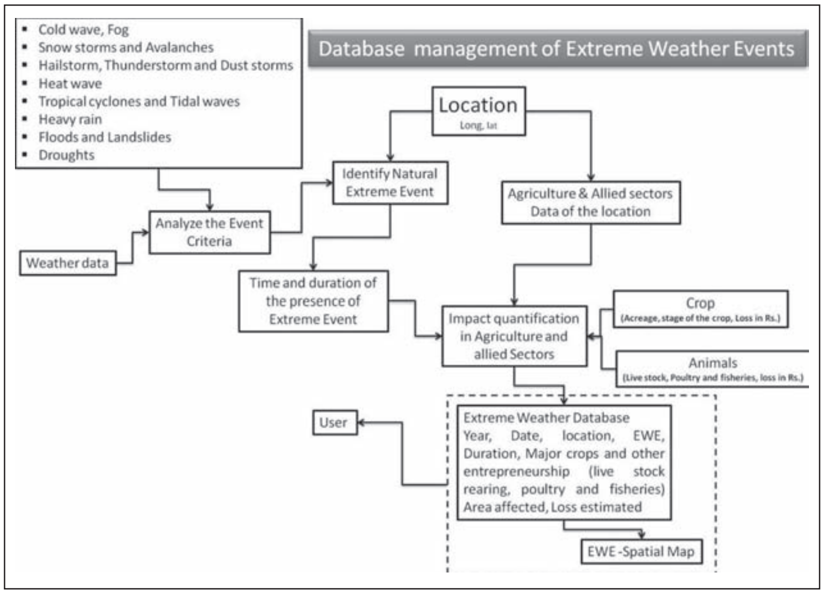
In order to assess the impact of Weather Extremes in any area which is prone to a kind of extreme weather event, there is need to get the information such as the major crops grown in the area, acreage, growth stage of crop, Number of poultries, Fish tanks and major live stock. This helps while assessing the impact of EWE on the major crop of the location or the major live stock / Poultry. Fisheries particularly in flood prone areas might be at loss owing to flood water take away fish from the tanks.

Collection of Quantified Impact Information

Any Extreme weather event causes some impact major/ minor on the human, agriculture, livestock, poultry and fisheries in a location. The information of loss or damage may be collected from the government agencies like Department of Agriculture. The areal extent of damage is estimated and satellite maps are provide by the Indian Space Research Organization centers viz. NRSC and SAC need to be incorporated in the database.

Database Management

Finally, Agrometeorological extreme event database may be formed and the reports may be designed to have in a tabular form or as a spatial map through appropriate analysis and development of software. User may be interested to know about the areal extent of the damage caused by the weather extreme needs to get the numerical information as well as the spatial map to visualize the areal extent on a map. The block diagram below developed at Data Bank, CRIDA shows in detail various steps involved in entry, analysis and output/retrieval procedure involved in case of extreme events.



Future Requirements

Extreme weather Events are highly localized in some cases and in some cases they may extend beyond the state boundaries. in order improve the management of Extreme Agrometeorological Events database, there is a need to improve the continuous weather data collection mechanism by establishing dense network of Automatic Weather Stations, Rain gauge networks, Satellite observations and information, live information from TV and News networks should be collected, compiled and stored in a server. This will be further analysed, to generate spatial maps and report to all the concerned departments to take necessary relief activities on war footing to reduce the impacts. This may ultimately improve the early warning system and relief activities.

BASIC PRINCIPLES OF AGRO-CLIMATIC ANALYSIS - 1

P.S.N. Sastry

Analysis

Analysis means examination, investigation, scrutiny, enquiry, interpretation, assessment and several other things. This requires appropriate data, logic and reasoning. There is no limit to analysis and it is an unending process. For example, take a chalk piece. Let us see in how many ways one could look at it and analyze its characteristics. We can talk of its dimensions, structure, colour, texture, malleability etc., Its Physico-Chemical characters: dryness or moisture content, porosity, moisture absorbing capacity, capillary rise when immersed in liquid or water, moisture retention capacity etc.,

- Reactions when chemicals are applied:. Absorptivity, sedimentation properties etc.,

- Atomic structure, binding forces between molecules and atoms, heating, cooling rates, when moist or dry or in combination with other elements etc., **-**Thus ***options for analysis are immense and almost unlimited***. "There is a beginning, but no end" to analysis. The first thing to do is to set an objective **-**what is it we like to get out of analysis. It can be used to do research or for operational purpose i.e., Develop theory and for practical use. Often, theory and practice do slightly differ, needing compromise or adjustments. Let us remember that approximations, assumptions, rounding off (like number of decimal points to be used) are to be done for meaningful expression depending on the magnitude of the parameter and accuracy with which it could be measured and its importance in a mathematical expression. More decimal places do not mean more accuracy.

Weather, Climate, Meteorology, Climatology

In daily practice, we generally use these terms loosely and synonymously –they almost mean the same to the common man. However, when one deals with weather or climate ***for scientific purposes,*** terminology commonly used (colloquial expression) should not be confused with their definition and appropriateness..

Weather: Denotes current state of elements like atmospheric pressure, rain, temperature, wind etc., depicting— 'Short term' aspects.

Climate: Summary of weather elements over a period of time; over a week, season, year, average over a number of years, decades , centuries etc., **-**'Long term' aspects.

Meteorology: Deals with physics, statics, dynamics, chemistry and mathematical relationships of weather elements and systems associated with them.

Climatology: Deals with statistical summary of the weather elements and associated systems –right from a week to centuries. No physics or chemistry or mathematics is involved here and usually observed data are considered as mere numbers, and statistically analyzed with all seriousness. Meteorological statistics should be viewed differently.

Agro-meteorology; Agro-climatology

Now we come to an important aspect of use of these two terms. As soon as we introduce the phrase "**AGRO**"**-**one should recognize that the plant, animal, insects, bacteria, fish etc., have "**LIFE**" in them and we can talk of "***life cycles***". This is often ignored in practice and climatic ***analysis*** is synonymously named as ***agro-climatic analysis***. This is not appropriate. In climatic analysis, we **do not** introduce any element involving living organisms or plants/animals, but blindly have been using the word 'agro-climate' for the same. Now one may examine the question:. Why should, introduction of the word "agro", make the analytical approach different and is of such importance?

The well known terms "Life" and "Life cycle" were used above. Living organisms go through different growth stages during their life time. It is common knowledge that a child's reaction to hot / cold weather is naturally different from the response of a youth/middle-aged/ old persons. In the same manner, as they pass through different growth stages, plants, animals, insects etc., behave differently (have different tolerance or optimum limits) ***to the same level of imposition of*** stress environment— heat, cold, rain, drought or pest-disease etc., So while carrying out agrometeorological or agroclimatic analysis, the growth stage has to be ascertained first. This should be the starting and ***reference point for analysis***. In fact what is popularly known as "phenology" or "phenological or growth stage" is fundamental or basic entity before one starts agroclimatic analysis. So, reaction of living organisms relating to agriculture (agro) and its environment has to be determined and involved.

Physiology is the study of the ways in which living organisms stay alive and grow. Ecology is the study of relations between populations of living organisms and their environment. Studies on Interaction between these two, constitutes biometeorology.—i.e., ***Organism's response to environmental stimuli***.

Now we discuss a few statements which constitute basic principles in agro-analysis involving living organisms like plants, animals, insect-pest/disease producers.

Reaction of Organisms to a given Set of Environmental Conditions is Variable

The case of a child, youth, old age persons had been mentioned earlier. While analyzing data, recognize that tolerance limits to the same level of stress would differ and depend on growth stages. This means that before analyzing data, information about ***threshold values of stress parameters with respect to growth stages*** is of prime importance. One has to gather information to define tolerance limits of organisms to weather elements at each growth stage. This is otherwise known as "Definition of agro-meteorological information" (of crops etc.,) with respect to growth stage and is the first step in analysis. This can be achieved in several ways in practice. (a) Field observations (b) Growth chamber studies (c) Published literature (d) Gap filling experiments (e) Simulation techniques. We may now briefly examine advantages and some limitations of these techniques.

Field observations: Data can be collected from frequent field observations on the parameters of interest and at the frequency relevant to the objective. e.g., crop phenological event dates and duration, corresponding weather information. Preferably these are to be collected from control plots and non-stressed conditions (of water, fertilizer, etc.,). This can be carried out at several locations as per standard and uniform practice or local practices. Simultaneously weather information may be tabulated daily for the corresponding phenological durations of the concerned crop. Early, normal and late sowings can be the treatments, carried out over a period of three to five seasons as feasible, to get different sets of relevant data for further analysis. This has the advantage that data are gathered under natural environment, under constantly varying weather- -day and night and corresponding crop response. In growth chambers, there are limits for maintaining dynamic round-the-clock weather changes encountered in the open field.

Growth chamber studies: Data can be gathered and defined using growth chamber experiments to measure crop response for selected pre-determined thresholds of temperature, moisture, wind, CO_2 levels etc. Limitations are: Variations that could be tested get limited in number, dynamic field conditions cannot be reproduced, and replication is costly with difficulty in maintenance. Advantage is that for certain specific problems of intensive research, such as, developing or testing a theory, these are most useful. For definition of threshold values for agromet information, these are relatively less preferable than direct field observations. The results from growth chamber studies further need conversion factors to make the results relevant for field operations with respect to crop response ***obtained at fixed thresholds*** to correspond to ***dynamic field response*** of crops, insect pest/diseases etc., Unlike a growth chamber or climatrons, atmosphere in the open field offers an open, natural crop growing environment.

Published literature: Information may be gathered from published literature about crop response to weather. However, presently most of the reports are from correlations or regressions worked out at individual locations and show ***year-to-year inconsistency***. Reason is that for the same treatment, one year maximum temperature may be a significant factor, in the very next year rainfall may be shown as significant and in another year, temperature and humidity become significant. This is due to high weather variability in the individual seasons and one should not draw any significant conclusion about the threshold value of weather for critical crop response. Unknowingly, heterogeneity gets introduced here in analysis. More over, data from different locations shows different weather elements as significant or otherwise, making it infructuous to draw any valid/stable conclusion. Hence, accepting threshold values from correlations and regressions reported in literature needs most selective and cautionary approach. ***Items of practical significance to agricultural operations may not always be statistically significant.*** Statistical significance does not always mean practical significance.

Gap filling experiments: For certain growth stages, threshold values may not be readily available in literature or in past experiments. These can be purposefully obtained through carefully laid out field experiments or growth chamber studies over a limited time period.

Simulation techniques. Feeding field data on available phenology, growth, and yield parameters for three to four seasons into dynamic crop-weather simulation models, threshold values can be identified to define agro-meteorological information. Iterative procedures may be needed sometimes. This is a useful technique provided too many assumptions are ***not built into the computer simulation program***. If such assumptions are there - like linear increase in growth with increments in weather parameters or soil moisture, without setting an upper and lower limits to crop height, stem diameter, root growth and yield, the worked out thresholds are likely to be erroneous and meaningless. Otherwise, used with care and appropriateness, this is a useful technique.

Readjustment of Living Organisms to their Environment: (Adaptation and Acclimatization)

Living organisms tend to develop tolerance to stress:

Over a period of time, living organisms tend to develop tolerance to stress. Thus ***initial reaction to stress may not indicate final adjustment.*** An example is "temporary" wilting appearance of leaves ***vs***. 'permanent wilting' usually noticed during hot weather or low soil moisture conditions depending on the duration of stress condition. Leaves also regulate their dynamic heat load to a limited extent by regulating transpirational evaporative cooling. In course of time, this is also governed by the concepts "**Concentration and Dosage**" that operate here. Concentration is the ***level of stress*** (low, moderate or severe), and dosage is the ***time duration and frequency of occurrence.*** Most of the time, these are measured in our experiments, but not given due importance except in case of insecticides or pesticide application. In case of environmental stress like drought, water logging of cropped fields and wilting, these are important considerations. "***Repetition may diminish or increase the effects of stress leading to final adjustment".*** In the case of living organisms, now it would be relevant to talk of **'Acclimatization', 'Adaptation', 'Elastic limit'** in response to environmental stress.

Acclimatization and Adaptation are two different things. Adaptation is a temporary limited measure. Acclimatization takes long time, may be with slightly less efficiency in output than in the original condition. Introduction of Murray or Jersey buffaloes in India is an example. They can be provided air-cooling conditions for adaptation, but have to get acclimatized to local environment in the longer run for wider utilization.

Acclimatization: When a species is introduced into new environment, initially they do not get adjusted to the new conditions. However, through artificial techniques like providing air-cooling, humid chambers, fabric cover, shelters etc.,(to nearly correspond to the environment of their origin) it would be possible for the living organisms to make them adjust to the local conditions. They get adapted with these props in the new environment (***ADAPTATION***). Living organisms exhibit tolerance to some degree of stress (***elasticity***), but break down beyond this ***elastic limit***. If left in the open without such props, initially they may yield low, but with passage of time -say one or two decades), they get ***acclimatized*** to local environment but still yield slightly less than the original potential. Thus with passage of time they get acclimatized. This feature has relevance to adaptation and acclimatization in the Climate Change scenario, which does not appear to have received much attention.

Synergetic and Antagonistic Responses to Stress:

A ***Synergetic response*** is one in which the combined effect of two or more stresses, **operating simultaneously**, is greater than the sum of the responses to each stress **operating separately**. One stress can enhance or offset the other. ***Antagonistic response*** is competitive, with a reduction in total final response. In multi-stress conditions, averaging of data, which is often resorted to in data analysis, tends to destroy specific responses to stress exhibited by living organisms.

Hysteresis effect: In relation to plants and animal life, this refers to time taken for onset of stress and its withdrawal. Onset of heat waves, floods, water logging etc., could be sudden, but the time for recovery and rates of withdrawal of such stress could be slower and longer in time, resulting in loss of productivity. It needs yet to be analyzed in depth.

Signal and Noise: One person's '**signal'** may be '**noise'** to the other. This important concept, often ignored, helps us in selection of equipment, data collection, methodology to be followed to save cost and time. For example : If one wants to know evaporation of water from a large lake or water body, he can get the information by measuring water levels once a week or fortnight with a level scale and need not resort to Penman-Monteith method involving energy balance determinations used in micrometeorological research.. Another example, if our objective is to find average temperature of a city or forest area, measuring temperature using micro-scale fast response sensors like thermistors or thermocouples would provide ***unwanted information***— a "**noise**". Mercury- in- glass thermometer with slow response and damping fluctuations used in Stevenson screen would conveniently meet our requirement —and this is considered a "**signal**" Both instruments have their immense utility if employed at their appropriate place, but are to be chosen depending on the objective. Measurements, data collection and analytical techniques and approach should be appropriate, commensurate with objective on hand. It therefore follows that**: Purpose of investigation and END USE** determine these factors. Purpose could be**:**

(a) Advance Planning and survey: Here, gross estimates with lesser accuracy are permissible. Empirical techniques and estimates which serve the purpose are an example.

(b) For Practical Use and Field operations: Absolute values are always not needed. Differences or ***relative values*** can be used. **e.g.,** for knowing evaporation, should one use pan evaporation or Penman's method or energy balance method, or Turc's method etc., Here, most of the time we would be interested in year-to-year variations over a 'Mandal' or district level.. If previous years had experienced temperatures around 35degrees in a month, if this year's corresponding temperatures are around 30 degrees, the question could be**:** what would be reduction in evaporation? Employing the results using the same method in both the years, (which may not be very highly accurate needed from theoretical considerations) one could obtain relative differences between these two years and use this relative increase or decrease in evaporation as a rough measure for practical purpose. This is permissible under certain conditions for field operational activity since the land may be partly under use for crop growth, parts of it could be under use as fallow, industry and construction work, parks etc., but represents aerial average. However, when one is interested in microclimate, this would provide grossly inaccurate results.

(c) For academic work and development or improvement of theory: In this case, most rigorous techniques, absolute values, highest accuracy in measurement, are needed**.**

Thus, ***methods and design of experiments, instrumentation, measurement, analytical techniques differ*** in each case though we deal with same weather element—say temperature, evaporation or ET, etc.,. Let us try to understand and realize this ***objective-dependent*** distinction and not mix up these in our hurry to achieve some sort of a 'result'.

Sampling of Atmosphere — Space and Time Variability.

Weather Varies both in Space and Time.

Space variability: This has three components. **Micro, Meso- and Macro space scales.**
Roughly, these are represented by the following space / experiment considerations.

Micro scale: e.g., Field plots, village level, Leaf-air interface environment. (temperature, moisture, CO_2, wind, leaf dimension). Temperature and humidity profiles (for spray schedules, inversions, and research) single leaf ***vs***. canopy behaviour studies etc.,

Meso scale: a city, mandal levels: Nature of crop cover, Cultural practices in surrounding fields. Heat islands, etc., are also to be noted.

Macro scale: district, state, country, continent, etc., (regional level).—Heat and cold waves. Extra tropical Cyclones, Jet streams, Upper air circulation, Anticyclones .etc.,

Sampling techniques:. Data collection methods and analysis, instruments used, network spacing, periodicity of analysis ***differ in each case***. We have to plan accordingly with respect to the objective. ***viz***., survey / exploration, research, or practical application.

Weather systems do not respect geographical boundaries. Half the district or state may be under influence of a weather system like a cyclone, heat/cold wave, but the other half may not come under its influence. Sticking to administrative boundaries at the initial stage of analysis becomes unrealistic and meaningless. Tracks of weather systems and their extent are the important considerations. How to overcome this in analysis would be the question. **Methodology** is simple. —Gather data from all individual locations affected by weather system (heavy rainfall, flood, or drought, heat wave etc.,) ***irrespective of the administrative boundary***. Make a plot of the elements in map form and draw isolines for each of the elements measured. The distribution of weather appears as a contiguous system. This is the **synoptic approach** such as that used in daily weather maps. Now, over this map, one can superpose a transparency with mandal, district or state boundary map which enables extraction of data for the area of one's interest. **Isolines provide the desired guidance for action, values at individual locations become less important and areas affected by a 'system' can be easily demarcated for any ameliorative action.**

Time sampling considerations: Selection of times of the day for observation, frequency of observation, time period to be selected for averaging of observations, where necessary, constitute time sampling technique. Just as in space considerations, it depends on the objective, type of equipment available, their characteristics etc.

Over a district some stations may receive more than normal rain or below normal rain (over a specified period of time). When rainfall amounts are averaged for the district, drought occurrence over some parts of the district does not show up. So, both time and space scales are important. ***Sequential, intermittent or bunched type*** of rainfall (or of any such event) occurrence, or its absence, should be noted in the analysis before concluding that a particular region is affected by stress. Superposition method would be most useful..

Sequential occurrence, time and space scales: One may ask why? Sequential /intermittent occurrence or absence of rainfall (or stress) can make all the difference for growth characteristics and their analysis. For example, the first four days may be rainless or may not receive rainfall and the subsequent three days may receive high rainfall. When drought is computed over the whole week using weekly rainfall total, the effect of the first four rainless days (drought, pest/ disease etc.,) on crop response may not show up. On the other hand, if rain had occurred on alternate days, it does not result in stress condition. It can be concluded that, **averages** over weekly or monthly periods **do not reflect nature of "Weather Sequence"** which can be intermittent or consecutive (heat wave, cold wave, frost, water logging etc.,)**.**

Thus, an important thing to note is that **'Time' and 'Space' go together** in design of experiments or routine observation, and analysis. Particularly with respect to weather observations, one has to make a distinction between "Universal standards" set by WMO and followed at National level (for routine observation and reporting), and ***problem-specific requirement*** for agricultural operation purposes. Here, depending on the objectives, availability of equipment, local changes have to be made in the design of experiments and time-space sampling, and hence, need arises for ***problem-specific definition*** of 'rainy day', 'dry day', 'crop water requirement' etc. Exposure of instruments for collection of field data needs amendments to, and deviation from, WMO standards**.** National Weather Organizations such as India Meteorological Department have necessarily to conform to WMO standards, but for research and operational use, time and space sampling, data collection should invariably ***depend on the objective and end use of the data so collected*** and not necessarily the one followed for routine observations by National Meteorological Services. Many a time, we fail to do so. This is a serious drawback in data collection and analysis in crop-weather research.

Aliasing: Daily weather variations being mostly random in nature, one procedure that needs immediate attention of researchers is how to plan and utilize the measurement of instantaneous / spot values at fixed intervals, or averaged values that are themselves separated by fixed intervals of time. One may miss the effect of some significant events that would have occurred between the chosen fixed intervals for observation. Such an error is knows as **"aliasing".** Simple examples are**:** effect of passing clouds on radiation incidence on crop canopies and transmission to ground level, or temporary variation in stomatal activity, effect of gusty winds of short duration on temperature measurements, etc. Too much randomness in observations is also not desirable. To avoid the effect of aliasing, (1) continuous recording of weather parameters is desirable where feasible and (2) In spot sampling, apart from fixed interval observations, inclusion of a few random observations in the design of experiment, is advisable. This is more relevant to micro or meso-scale meteorological or spot observations.

Lag time: Often, one comes across a lag time in response to a stress event in certain parameters and not in the others. In relating stress to response, it is important to recognize that a lag time may be present, and that it may be variable. In routine weather observations, solar radiation maximum and temperature maximum exhibit a lag time of about two hours. There are several similar situations in response of living organisms to environmental variations. This aspect needs sufficient attention in agro-climatic analysis.

Short-term – Weather-induced Stresses

Concepts of phenology based definitions for optima and adverse crop growth situation, atmospheric and soil drought, heat advection effects on crop growth over short periods like a few days or weeks though enunciated in the nineteen seventies, have not received sufficient utilization in our analysis. Analysis based on these concepts would provide answers for short-period-weather-induced adverse effects and extreme events in relation to certain phases of crop, insect or animals. This needs priority attention. These may not be statistically significant, but are of high significance to understand and forecast short-period- environmental-adverse effects on crop growth and thus of practical significance in day-to-day agricultural operations and weather based advisories. A single day's intense rainfall for a couple of hours could lead to prolonged water logging. Advected heat flow for a couple of days at sensitive crop growth stages could drastically influence crop yield. Their frequency being low, often does not show up (or lost in averaging data) to be of any significance in statistical analysis, but in practice, agricultural scientists are well aware of the attendant losses in yield and productivity. ***In analyzing extreme weather events, one need not search for a time series; it remains an "extreme" event.*** In the context of early, normal and late sowing, early medium, long duration crop varieties, introduction of new cultivars once in four to five years, specific case studies of short-duration-weather-induced stresses assume significance. These are all induced by weather systems (either local or widespread), and thus cannot be said to occur rarely or at random. They do not provide any data series but need specified design in analytical approach and methodology. This is a challenge in agroclimatic analysis.

Variation and Change: Variation and change are the two terms frequently mentioned while talking of "Climate Change". Perhaps we are reacting the same way to these two different things though we know the distinction between the two. Ice ages covering hundreds of years were there in the past history leading to extinction of some species and giving way to new species in both structure and size.. In the context of weather, "Variation" is one which can be experienced and understood in one's life time, but "Change" on the other hand, is the one that covers relatively far, far, longer periods—epochs which goes beyond one's life time. Before using this terminology, it would be useful to keep historic past in mind to avoid confusion between the two. Certain minimum amendments like mulching, irrigation, shelterbelts etc., may be provided, but otherwise man has nil or very limited control on Global scale phenomena and environmental effects on crop growth. To counter man's intervention, automatic adjustments and adaptation take place in the atmospheric environment and nature, even beyond troposphere, at Global level. This should be particularly noted when we talk of "Climate Change". We unintentionally pollute the environment (impair) and talk of ameliorative safety measures (repair). Is this not "Impair and repair" situation.

Scope for innovation in analysis: This is one area that has **not been receiving** sufficient attention in agroclimatic analysis and modeling—whether statistical or dynamic simulation. In medical procedures of the past, in absence of modern tools, feeling the pulse of a disease afflicted person gave immense scope to, taking an integrated and holistic view of the body's physiological system functioning, through logic and reasoning. Sophisticated instrumentation and techniques should be viewed as only highly helpful, time saving tools that improve accuracy and speed of measurement, analysis and application but cannot replace logic and reasoning in an integrated manner to understand and explain cause-effect aspects in our approach to research on living, dynamic crop-weather systems and analysis.

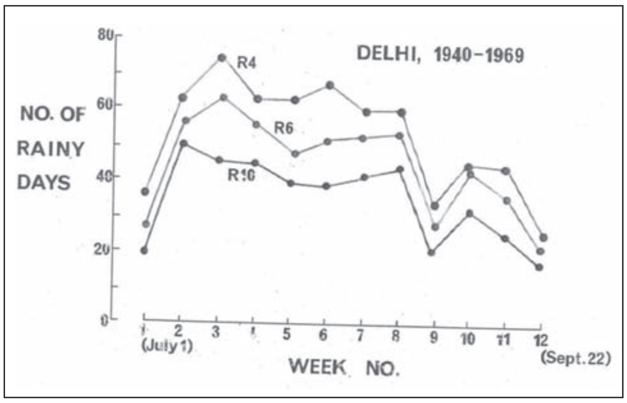
BASIC PRINCIPLES OF AGROCLIMATIC ANALYSIS - II

P.S.N. Sastry

A few basic principles and principal features of agro-climatic analysis were discussed earlier. Some of the suggested/ modified approaches to agroclimatic analysis are illustrated and discussed in this section.

Defining a "Crop Rainy Day":

Conventionally, for climatological purposes, "Rainy day" has been defined as a day with rainfall of ≥ 2.5mm/day as per universal standard practices and followed by India Meteorological Department. However, it is useful to introduce a ***"Crop rainy day"*** so as to relate minimum essential rainfall for crop growth which would be ***commensurate with PET or water requirements of the crop species at a location in relation to soil moisture availability and growth phase***. Crop rainy day can be defined for each crop species, for each growth stage since water needs of crop vary with these. It is well known that rainfed crops like pearl millet, corn, cotton, paddy etc., raised in the *kharif* season, need different levels of moisture for growth. Pearl millet needs less water compared to paddy. So, the difference in soil moisture requirement (crop water requirement) should adequately be reflected in agroclimatic analysis. This means that, one has to modify the lower limit of 2.5mm/day (conventional rainy day) and introduce a dynamic 'crop rainy day' with relevant threshold value of daily rainfall for purposes of analysis **(Fig. 1)**. To start with, it may look arbitrary, but with availability of more specific information about water requirement of major crops (or for that matter, for each crop), such a crop rainy day can be defined and used for agro-climatic analysis which would thus differ from routinely used rainy day analysis. The definition should also be relevant to Potential Evapotranspiration at any given location, rooting depth at any given growth stage to reflect the availability of stored soil moisture. On the same analogy, one can define a "crop dry day" **(Table 1a,b)** to denote the stress periods when rainfall does not meet crop water needs and gradually gets closer to wilting condition. In such an analysis, similarly, one can define a "dry" or "wet week" ***to take care of sequential occurrence*** or otherwise of dry or wet days or weeks for different crop growth stages. Probabilities of rainfall or drought occurrence could also be derived for individual crop species at a same location. Such definitions can be used to identify sequential occurrence of rainy or dry events in relation to growth phases and consequent effects on yield potential. **Analysis should be crop-weather oriented and not simply climate-oriented.**



(Sastry, 1976)

Fig. 1 : Crop rainy days with different thresholds 4, 6, 10 mm/ day

Table 1a : Frequency of continuous dry days during the weekly periods of July-October (Based on data of Delhi for the period 1940-72)

Station : New Delhi	**Frequency in 33 years**																
Number of continuous dry days in the week	Week nos. (1st weekends on 7th July. 17 th week ends on 27th Oct)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Four	29	20	17	20	22	17	19	23	26	23	26	28	31	32	32	32	33
Seven	16	10	7	9	7	11	6	8	14	16	13	21	21	25	29	29	32

Table 1b : Distribution of dry periods in the crop phases of maize at New Delhi
(I. Sowing and germination. II. Vegetative period. III. Tasselling period, IV. Grain filling and maturity)

Year	Week no																	X Dry week	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Rainfall July-Oct mm	Drought class
1951		x	x	x		x		x	x	x		x	x	x	x	x	x	214	Disastrous
1940	x	x					x		x	x	x	x		x	x	x	x	527	Severe
1952		x								x	x	x	x	x	x	x	x	360	Moderate
1942		x				x						x		x	x	x	x	522	Light
1961	x			x							x			x		x	x	925	unaffected
		I				II					III				IV				

(***Sastry, 1976***)

South West monsoon seasons and agroclimatic analysis: It is well recognized that across the country, there are different dates for onset and withdrawal of monsoon rains. For climatic purposes, "South West monsoon season" broadly covers the period June to September. ***In actuality***, monsoon season correspondingly varies between early June to late October in the South to mid July to September in the Northern regions of the country. In agroclimatic analysis, this local variation should be taken into account when describing **crop growing season *(kharif)***. Knowing fully well that around Delhi, Punjab, Haryana regions, monsoon does not start till late June or early July, the full month of June which is almost devoid of rains for three weeks, is included in kharif season, and, averaging or totaling rainfall for the whole month. This naturally gives an erroneous picture of rainfall situation in the respective states, and treats **rainy and non-rainy periods** in the same month as a **single entity** or ***at par***, ***introducing unintended heterogeneity into data series*.** As an example, in Delhi and neighbouring locations, 3mm of rain in the first week of June gets averaged with 30mm rain in the last week. "No rain" period" and "heavy rain period" get mixed up. This is not a rare case, but that prevails year after year. SW monsoon season used by National Meteorological Services has a different and particular purpose. It need not be treated by ***agroclimatologists*** as synonymous with ***kharif season*** related to actual crop growing season in agro-climatic analysis. For every location or state or agroclimatic region, ***kharif season should be defined separated from the conventional SW monsoon season.*** This is the first change that can be brought about in our approach to analysis.

Homogeneity –*Vs*. Heterogeneity

This is one point agroclimatologists should ponder over before choosing a method for statistical analysis of a data series. Perhaps for the chosen parameter for analysis, in its simplest terms, coefficient of variability reflects the level of homogeneity of a data series. Weekly rainfall in the dry land regions often shows high variability—of the order of 100 to 200 percent depending on the month chosen. Often it is seen that rainfall probabilities are derived with all seriousness for summer months— April, May, and winter months –December to February when very meager and sparse rainfall is expected in a week or a month. Is it necessary to repeatedly do such an exercise without scrutinizing the basic data, which does not ultimately result in any usable values? On the face of it, examination of basic data itself shows up that rainfall received in certain areas in winter and summer months is too low for carrying out any meaningful probability analysis. In the Indian context, it would be more fruitful to analyze maximum temperature probabilities in summer and minimum temperature probabilities in winter rather than spending time on rainfall probability analysis in summer and winter.

Before attempting rigorous analysis, efforts could be made to bring some sort of homogeneity in data series that may be available for more than a century. Now, if one further ponders over rainfall data series (it is the most important parameter for crop growth and also from data availability point of view) it would be useful to divide kharif rainfall into groups— high rainfall years, normal rainfall years, and low rainfall years based on departure percentage from normal as a first step, to form three groups which may exhibit some sort of homogeneity in each group. One familiar with weather systems in the country causing very high or very low rainfall in kharif may not feel far wrong in doing so. Most of the High rainfall years are perhaps caused by a nearly similar weather system occurring in such years. Similarly, drought could be traced to be associated with a particular weather system which is similar in many years of drought occurrence.

In this connection another point to be noted is that Western coast of India, and several North-Eastern regions receive very heavy rainfall during kharif seasons and analysis of a 10 or 20 year rainfall would provide probability values of high stability with longer validity period. Rainfall magnitude in these regions, as such being high, less emphasis could be laid to describe drought as far as agriculture is concerned. In the preliminary analysis in such regions, using past experience, preset threshold values of departure from normal rainfall could well describe relative status of rainfall in a given year.

Hysteresis effect: ***Sudden onset and slow withdrawal of stress*** such as Cold wave effects, Heat stress, water logging, etc., As an example, in conditions of high ET, stomatal closure occurs almost instantaneously, but after stress gets abated, it takes a while for the stoma to open fully. Thus rates of processes (or response) during the recovery period taken for stress decrease, would be different from those observed prior to, or during the onset of stress. May be, it would be profitable to measure such rates where feasible for incorporation into dynamic process-oriented crop-weather models. An injured organism does not work to full capacity during the period of recovery even if most favourable environment is provided. Such a factor is taken into account in the computation of WRSI, where once the crop is affected by moisture stress, the index does not return to starting value even if the stress gets abated due to subsequent rainfall.

Atmospheric and soil drought during *kharif* season: 'Atmospheric drought' when appropriately defined, represents the effect of amount, frequency and sequential, intermittent or bunched type of occurrence of rainfall on crop growth. 'Soil drought' reflects moisture availability status in the root zone due to antecedent rainfall. 'Soil drought' that might occur a few days later than incidence of atmospheric drought, takes into account ***cushioning effect provided by soil moisture storage*** for a few days even after rainfall failure. This aspect has not been much recognized so far, in agroclimatic analysis. For different ranges of seasonal rainfall, drought intensity on the crop could differ from season to season. Using past data series, atmospheric and soil drought frequencies and probabilities can be worked out, applying 'crop-specific definitions' to identify crop drought in the different growth phases. In the Delhi region, seasonal rainfall of 911mm could result in moderate drought in certain seasons whereas, a season with 422mm rainfall could exhibit light drought conditions **(Table 2,3)**. Interestingly, such a simple analysis could bring out the significance of defining drought with reference to both atmospheric and soil conditions instead of merely looking at it as a departure from normal rainfall. So, we should find some way to bring out such differences irrespective of total rainfall received in a season.

Table 2 : Frequency of drought intensity in the Delhi region (based on the data for the period 1940-1980)

	Frequency in 41 years			
	Disastrous	**Severe**	**Moderate**	**Light or No drought**
Atmospheric Drought	2	5	9	25
Soil Drought	6	5	10	20
Range of total seasonal rainfall (mm)	142-214	358-657	262-911	422-1126

(Sastry & Chakravarty 1984)

Table 3 : Drought frequency during crop phases of corn (Based on data for the period 1940-1980)

	Frequency in 41 years	
	Tasselling phase	**Seasonal Value**
Atmospheric Drought	21 (51%)	8 (20%)
Soil Drought	15 (37%)	14 (34%)
Soil and atmospheric drought during the same year	12 (29%)	6 (15%)

(Sastry & Chakravarty 1984)

Soil Moisture Storage Depletion Rates during Dry Spells

It is useful to estimate soil moisture depletion rates for different *kharif* seasons differing in seasonal rainfall. Data for bare soil conditions in the 0-60cm depth for three seasons is shown in **Table 4**. Results show that as the season progresses, and as moisture is accumulated in the soil profile due to earlier rainfall occurrence, depletion rates during dry spells occuring later within the season show a decrease. As could be expected, low depletion rates correspond to relatively high rainfall years and higher depletion rates to relatively low rainfall seasons during within-season dry spell periods. However, there is need for quantitative determination of such depletion rates for every location which would be handy in assessing further water requirements in any current season for inclusion in weather based agro-advisories. Similar data can be built up through such analysis for crop covered soils. Regional agroclimatic maps can also be prepared on these lines.

Table 4 : Soil moisture storage depletion rates during dry spells (0-60cm) IARI, New Delhi

Year	Rainfall from 1st June to 14th October (mm)	Duration of Dry Spell	Storage Depletion mm/day
1970	723	AUG 19 TO 24TH	6.3
		AUG 29 TO 7TH SEPT	5.4
		SEPT 16 TO 4TH OCT	3.9
1971	940	AUG 3 TO 8TH	3.6
		AUG 16 TO 30TH	2.4
		SEPT 7 TO 18TH	1.8
		SEPT 20 TO 14TH OCT	1.3
1972	647	AUG 18 TO 23RD	7.4
		AUG 29 TO 13TH SEPT	4.9
		SEPT 16 TO 30TH	4.9
		OCT 1 TO 14TH OCT	3.1

Water balance based indices: After computing weekly water balance, several indices are generated to assess moisture adequacy in the root zone. Usually, a single value of such index is utilized to identify probability of drought or potential moisture conditions at a location. In place of using a single value for all crops and other purposes at the location, different levels of index values can be utilized to carry out further analysis for each growth phase. This is again based on the principle that each crop has different tolerance limits to drought even in the individual growth phases. The **tables 5, 6** here illustrate this. Here a value of <0.5 and >0.7 of an index are used to define drought and potential moisture conditions in case of pearl millet. For paddy, corresponding values defined are <0.75 and >1.0 and then probabilities for drought or potential moisture are derived. Thus, while determining probabilities for drought or potential moisture conditions, moisture adequacy index value (or any similar index) chosen has relevance to the characteristics of particular crop taken up for analysis. Using crop phenology, root growth characteristics, water need levels in terms of soil moisture availability of different crop species, attempts should be made to bring some sort of dynamism in threshold values of several moisture-based indices like MAI, SMI, WRSI, Aridity indices etc., Such an approach to crop-characteristic, based on ***crop-species-specific*** agroclimatic analysis would be more meaningful for their practical application.

Table 5 : Probability of occurrence of soil moisture indices at different growth stages of *kharif* crops in Delhi region (Victor and Sastry, 1984)

Growth phase	Duration	Probability of SMI	
		Drought	Potential Moisture
Pearlmillet		SMI≤0.5	SMI ≥0.7
Sowing and germination	2 weeks(2-15 July)	0.67	0.27-0.28
Tillering	4 weeks(16 Jul-12Aug)	0.42-0.60	0.31-0.37
Flowering	2 weeks(13-26 Aug)	0.40-0.42	0.41-0.44
Ear emergence and maturity	5 weeks (27 Aug- 30 Sep)	0.42-0.64	0.23-0.38
Sorghum		SMI ≤0.5	SMI ≥0.8
Sowing and germination	1 week(2-8 Jul)	0.67	0.24
Panicle initiation	3 weeks(9-28 Jul)	0.56-0.67	0.22-0.26
Flowering (Anthesis)	4weeks(30 Jul-26Aug)	0.40-0.47	0.28-0.36
Maturity	5 weeks(27 Aug-30 sep)	0.42-0.64	0.15-0.30

Growth phase	Duration	Probability of SMI	
		Drought	Potential Moisture
Peanut		SMI ≤0.5	SMI >0.8
Germination and establishment	4 weeks(2-29Jul)	0.56-0.67	0.22-0.25
Flowering and pod development	8 weeks (30 Jul- 23Sep)	0.40-0.63	0.15-0.36
Corn		SMI ≤0.6	SMI ≥0.9
Germination	2 weeks(2-15 Jul)	0.70	0.16-0.19
Vegetative	7 weeks (16 Jul- 2 Sep)	0.49-0.64	0.11-0.24
Tasselling	3 weeks (3-23 Sep)	0.54-0.70	0.08-0.19
Ripening and maturity	5 weeks(24 Sep- 28 Oct)	.69-1.00	0-.12
Upland Paddy		SMI ≤0.75	SMI ≥1.00
Vegetative	10 weeks (2 Jul- 9 Sep)	0.61-0.76	0
Reproductive	2 weeks (10-23 Sep)	0.66-0.81	0
Maturity	4 weeks (24 Sep- 21 Oct)	0.78-1.00	0

Table 6 : Probability of occurrence of soil moisture indices during reproductive stage of *kharif* crops

	Probability of SMI	
	Drought	Potential Moisture
Pearl millet	0.40 to 0.42	0.41 to 0.44
Sorghum	0.40 to 0.47	0.28 to 0.36
Peanut	0.40 to 0.63	0.15 to 0.36
Corn	0.54 to 0.70	0.08 to 0.19
Upland paddy	0.66 to 0.81	0

Victor & Sastry (1984)

Choice of a water balance index for analysis: More than a dozen indices had been developed over the past century to assess moisture availability and drought using rainfall and soil information. Initially one would be tempted to test performance of each such index at a particular location. After this exercise is done, it would be useful to ***identify a single index and methodologh*** which suits a particular location from application point of view. In the long run, using multiple indices to express dryness or wetness at a location would create confusion to the users. This aspect should be kept in mind while recommending an analytical procedure for evaluating moisture adequacy or drought. This is true in case of analysis of Evapotranspiration where umpteen procedures are available in literature.

Occam's razor: One may argue that currently used sophisticated crop growth simulation models take care of such crop-specific differences. Some sections of the models depend on several assumptions and use fixed values such as allocation ratios. **"Occam's razor"** (or sometimes written as Okham's razor) operates here. As early as in the 14th century, he, a philosopher, enunciated the principle that "***the fewest possible assumptions are to be made in explaining a thing".*** This is one point to remember in data analysis.

Atmospheric and soil drought are not reflected in the models. Mostly they are designed for potential conditions with no stress. These are excellent tools, but are mostly designed for non-stressed conditions. It is necessary to include in them an element of contribution of soil or atmospheric drought, advected heat stresses that lead to a decrease in projected yield potential. For operational use, it would be convenient to adopt simpler soil-plant-atmosphere-water models such as those developed by Campbell-Diaz which are simple for routine in-season use, not involving assumptions, or elaborate growth processes or genetic coefficients etc., but based on current weather and soil moisture information.

Water Requirement Satisfaction index: This is being frequently used following Frere and Popov's criteria. However, in an exercise for Saurashtra and nearby regions, based on the principle that water requirements of different crops vary from each other, and also with sowing time (early, normal, late), growth stage (pheno-phase), and location, such criteria were redefined with different thresholds. Water requirements of major crops grown in Gujarat state (Pearl millet, sorghum, groundnut and cotton crops) are shown in **(Table7a,b)**. Results for Jamnagar station show that, ***varied WRSI thresholds, different from fixed threshold limit*** suggested by Frere and Popov for characterizing drought of different intensities, can be identified for different crops which vary from each other at that same location. This is the type of modification that one has to make while applying indices developed elsewhere, not necessarily using the same index value that was derived by Frere and Popov for their work.

Table 7a: Mean pheno-phasic and seasonal water requirements of major kharif crops for Anand and Junagadh locations in Gujarat State, (Sahu and Sastry, 1993).

Water requirements in mm											
Stations	Pearl Millet					Sorghum					
	Growth Phases					Growth Phases					
	I	II	III	IV	Seasonal Total	I	II	III	IV		Seasonal Total
Anand	40	105	60	107	312	40	74	125	116		355
Junagadh	38	96	60	98	292	38	67	117	107		329
	Groundnut					Cotton					
Stations	Growth Phases					Growth Phases					
	I	II	III	IV	Seasonal Total	I	II	III	IV	V	Seasonal Total
Anand	81	99	94	98	372	29	90	340	138	28	623
Junagadh	72	94	86	95	347	26	77	329	139	32	603

Table 7b: Rainfall, Drought and Water Requirement Satisfaction Index at Jamnagar, Gujarat State, (Sahu, 1991).

Year	**Drought Class**	**Rainfall(mm)**	**WRSI**			
			Pearl Millet	**Sorghum**	**Groundnut**	**Cotton**
1984	No Drought	672	90	92	99	74
1986	Mild	246	78	--	--	--
	Severe		--	67	62	35
1985@	Moderate	187	56	--	--	--
	Severe		--	49	48	26
1987	Disastrous	48	13	9	11	6

@ Late onset of monsoon

Allocation ratios of photo-synthates between plant parts: Allocation ratios (between leaves, stem, roots, seeds, etc.,) in different crops differ from season to season depending on the weather and crop growing conditions. Results of analysis for irrigated Brassica crop at different pheno-phases for two seasons are shown in **Fig.2.** This type of information on allocation ratios could be developed and used in crop-weather model simulations depending on the intensity of atmospheric dry periods such as those prevailing in post flowering stage or grain growth stages of crops. One cannot use the same average allocation ratios for all the years, which may exhibit year-to-year variability in environmental conditions.

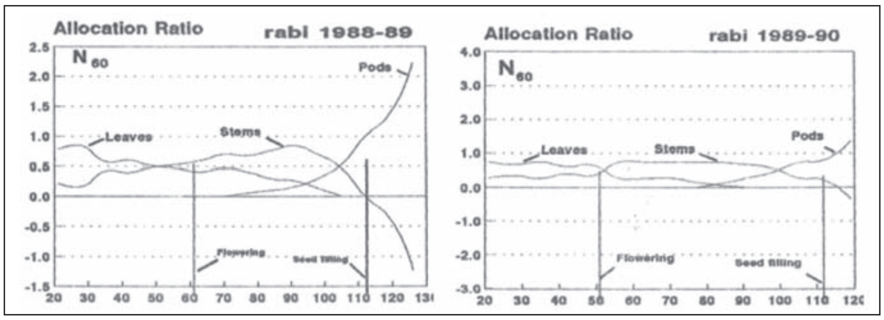
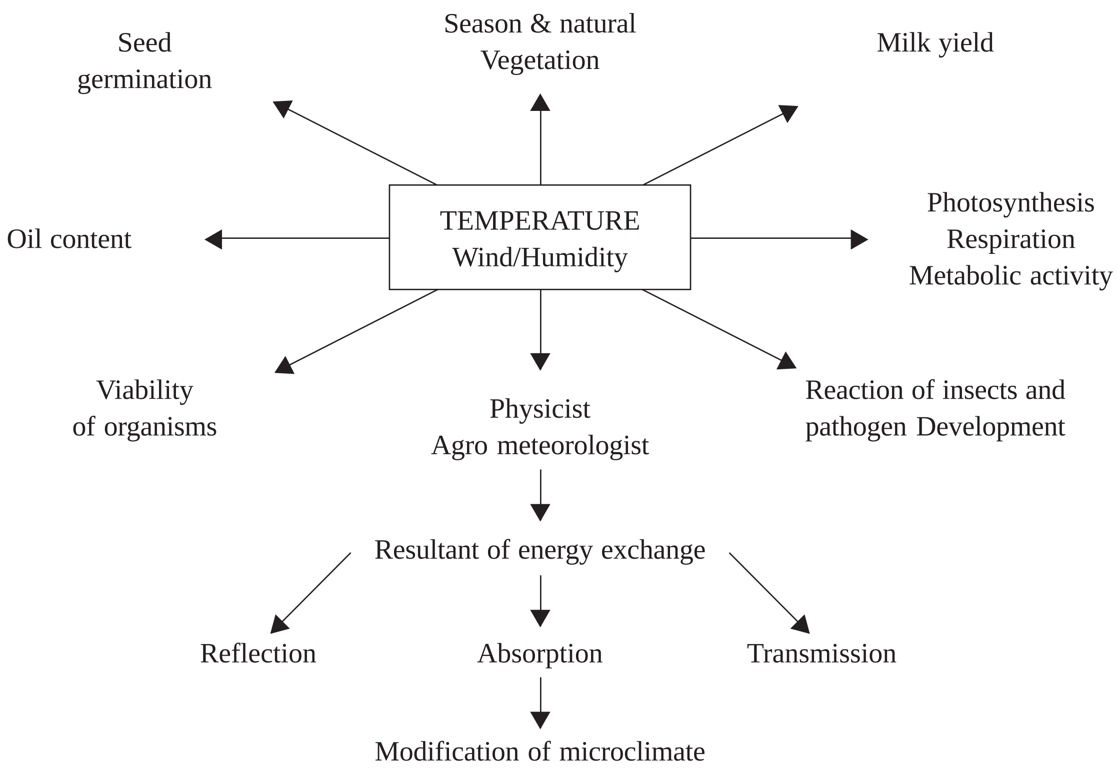


Fig. 2 : Dry matter allocation ratios in mustard crop

Temperature, wind and relative humidity: Frequently it is noticed that in developing prediction models for pest/ disease periods, wind speed is not considered. It should be noted that these are **inter-dependent entities**. If any one of them varies, the other two parameters vary automatically. In place of relative humidity (a non-conservative parameter), saturation deficit or vapour pressure (a conservative parameter) would be an appropriate choice for analysis. Wind, temperature and moisture (or relative humidity) should not be separated –***all should be measured though you may highlight the one of your interest***. Interaction among these is non-linear. For any reason, even if only temperature values are taken for correlation or regression for analysis, data on wind speed and relative humidity (preferably saturation deficit values) should invariably be kept on hand. Situations where these operate together in crop-weather relations is shown below.



In conclusion, ***Agroclimatic analysis*** (***long term***) and ***Agro-weather analysis*** (***representing in-season monitoring of data and immediate analysis***) should go together in formulation of weather-based agro-advisories for agricultural operations. Thus both statistical relations and dynamic simulations could be put to beneficial use.

MODELING CROP WATER USE IN DRYLANDS - CONCEPTS AND APPLICATIONS

B. Bapuji Rao

Dryland agriculture still remains the backbone of Indian agriculture, as large areas of cultivated land are rainfed, which contribute about 42 per cent to country's food basket. Characterization and understanding of the environment is imperative to dryland agricultural research. To formulate judicious soil and crop management practices for varied dryland conditions, the crop growth processes under stress conditions are to be properly understood. Information on moisture deficits in different periods is very helpful in crop planning. The efforts are on for some years to develop models that would predict the crop water use pattern. An attempt is made here to present a comprehensive review of the currently available agro-hydrological models and to illustrate the basics behind the development of such models.

Some of the currently available agrohydrological/soil water balance models are listed in Table 1. They differ in complexity, operation and purpose. The models also differ in the use of theoretical or empirical descriptions of the process in the model. These can be broadly classified as:

(a) Agroclimatic models **-** These are usually single layer models used for regional characterization of environments for water availability.

(b) Management models **-** In these models the soil profile is divided into two or three layers. Information generated on soil moisture availability is used for soil and crop management.

(c) Physical process models **-** The soil profile is divided into many layers for studying the flow processes more precisely.

Table 1 : List of some agro-hydrological models

Name of the model	Reference	Name of the model	Reference
Versatile Soil Moisture Budget (VSMB)	Baier *et al.* (1979)	Unnamed	Lascano and van Bavel (1986)
		Unnamed	Norman and Campbell (1983)
		Unnamed	Place and Brown (1987)
WATER	Burt *et al.* (1980)	Unnamed	Rama Prasad (1984)
Unnamed	Belmans *et al.* (1983)	PLANTGRO	Retta and Hanks (1980)
Unnamed	Brisson *et al.* (1992)	Unnamed	Robinson and Hubbard (1990)
Unnamed	Cordery and Graham *et al.* (1989)	SPAW	Saxton *et al.* (1974)
SMEP	Edey (1980)	Unnamed	Seliorio and Brown (1979)
Unnamed	Greacem and Hignett (1984)	Unnamed	Stockle and Campbell (1985)
SWATRE	Feddes *et al.* (1976)	SIMBAL	Stuff *et al.* (1975)
Unnamed	Jagtap and Jones (1989)	EMWATBAL	Van Bavel and Lascano (1987)
SWACRO	Feddes *et al.* (1984)	Unnamed	Victor *et al.* (1988)
Unnamed	Hansen (1975)	Unnamed	Visser (1974)
Unnamed	Holst and Madsen (1984)	Unnamed	Vossen (1990)
Unnamed	Jones and Smajstrla (1980)	Unnamed	Wright *et al.* (1994)

Model Components

The basic components of all the soil water balance models (Fig. 1) are not independent but they are interrelated. For instance, amount of runoff depends partially on the rainfall intensity, hydraulic properties of the soil, and surface water content. Precipitation or irrigation is usually measured and the other components of water balance are estimated, in the same units.

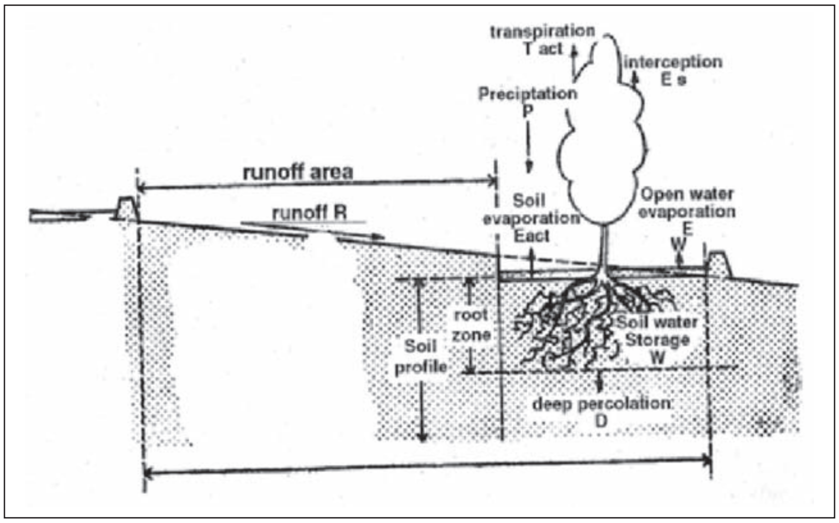


Fig. 1 : Components of the water balance in a typical basin area

Surface Runoff and Infiltration

Whenever rainfall occurs, some amount of water often runs off and becomes unavailable to the crop. Therefore, to estimate the recharge of soil profile it is important to estimate the amount of runoff that occurs with each rainstorm. Various approaches have been made to estimate this component in water balance models. Some models do not consider runoff and deep drainage separately. Any amount of water input into the soil after the soil profile is full to its maximum storage capacity (field capacity) is considered as water loss (runoff + deep drainage). However, in some models the runoff or infiltration is estimated to calculate profile recharge. Kanemasu *et al.*, (1978) calculated effective precipitation (Pe) and runoff as follows:

$$Pe = R\ 0.75 \text{ when } R > 25.4 \text{ mm and } Pe = R \text{ when } R = 25.4 \text{ mm}$$

Therefore, runoff = R-Pe

Baier *et al.* (1979) used a simplified relationship between moisture content in the topsoil zone and daily total precipitation to estimate infiltration into the soil. On days with rainfall 25.4 mm, the total amount of rainfall is considered to infiltrate into the soil. On days with rainfall 25.4 mm. the amount of infiltration (Infl) into the soil is less than the daily rainfall, because it is limited by run- off as a function of rainfall and the moisture already in the top zone of soil, and is computed as

$$Infl = 0.9177 + 1.811 \log RR_i - 0.97\ [S_{j(i-1)} C_j] \log RR_I$$

where, RR_i = rainfall on day I,

$S_{j(i-1)}$ = soil moisture in the j^{th} zone on day i-1,

C_j = available water capacity of the j^{th} zone j = 1

The remainder of the daily rainfall is assumed to be lost as runoff. Dale *et al.* (1982) employed the same relation in their SIMBAL model for cropland drainage effects on soil moisture and evapotranspiration.

Soil Water Recharge and Drainage

The soil profile in the water balance models is either considered as a single layer or divided into discrete layers of either uniform or variable thickness. Infiltration and redistribution of water throughout the layered soil profile is often treated in several ways. In simple models, the infiltrated water is freely transmitted to lower layers by gravity or out of the profile if it was the lower most layer. The upper limit of water for each layer is set at field capacity. When the antecedent water content plus inflow of water exceeds field capacity of that layer then the excess water is allocated to next lower layer. This process is repeated for all layers and excess water from the lowest layer is considered as deep drainage. In this method upward movement or redistribution of water is not allowed unless it is an added feature.

In the Versatile Soil Moisture Budget (VSMB) of Baier *et al.* (1979), the partitioning of infiltrated water to each zone is simulated by the following function.

$$Infl_{ij} = \{ 1- [S_{j(i-j)} / C_j) b\} \{Infl_i - Infl_{in}\}$$

where, $Infl_{ij}$ = new infiltration into each zone of soil

$S_{j\{i-1)}$ == soil moisture in the j^{th} zone on day i-1

C_j = available water capacity of the j^{th} zone b = percolation coeff. ranging from 0 to 1.

This equation is applied only when the ratio of soil moisture to capacity in any zone is less than 0.9. The amount of water that can infiltrate into and remain in each zone cannot exceed the deficit (DEF) for that zone (j) and day(i). The DEF is given by

$$DEF_{ji} = C_j – S_{j(i-l)} + AE_{ji}$$

In addition, the VSMB assumes that the amount of water that can be budgeted to the j^{th} zone can never exceed what remains from the total water infiltrated after water has been budgeted to zones 1 to j-l. If, after all zones have been recharged, there is still infiltration water remaining, then this water is allocated to subsurface drainage. This means that the infiltration is distributed over the zones as a function of the amount of infiltration, the relative moisture content in each zone, and the percolation coefficient (b). The percolation coefficient is the fraction of water infiltrating to the next zone. For b=0, the water content of each zone must reach field capacity before the remaining water infiltrates into the next zone. For b= 1, a fraction of the infiltration water percolate to the next zone before field capacity is reached, depending on the moisture content in the upper zone. This feature of the infiltration equation was found to be useful in heavy textured soils.

In WTGROWS - a wheat growth model of Aggarwal *et al.* (1994), the amount of water available either by rainfall or irrigation after deducting runoff is allocated to various soil layers starting from the surface layer. In this model, inter layer fluxes of water are considered only at the time of rainfall or irrigation and at all other times the fluxes are considered negligible. Depending upon the amount of water available, the layers are charged to field capacity. Water in excess of field capacity of a layer, if available, is immediately drained to the next layer. The amount water above field capacity of the bottom layer is drained out of the profile and is not available for crop use. Similar procedure was adopted for profile recharge in COTTAM model of Jackson *et al.* (1990).

In the other method of profile recharge, it is customary to use Darcy's unsaturated flow equation, in which each layer is assumed to be uniform in moisture content, capillary pressure, and unsaturated conductivity. Mathematical solutions vary from the simple finite difference with large time steps to finite element with near analytical results. There are several models considering soil water movement in response to pressure-head gradients in accordance to the Darcy and continuity equations, for example, SWACROP of Feddes *et al.* (1978), SPAW of Saxton *et al.* (1974) and Rama Prasad (1984). This treatment of water flow can be used to represent nearly all situations including upward or downward flow between layers, widely varying characteristics within the profile, time distribution of infiltration and redistribution among layers, water tables and plant water withdrawal. But this approach requires specifications of the soil water retention and hydraulic-conductivity curves, upper boundary conditions of precipitation and potential evapotranspiration (PET) and a lower boundary condition appropriate for the site under consideration. The choice of which soil water movement calculation to employ depends upon the accuracy required. For readily drained soils where withdrawal of water by the profile development and casual accuracy is required, the free flow procedure would suffice.

Potential Evapotranspiration (PET)

The estimation of potential evapotranspiration (PET) is essential to know the evaporating power of the environment so crop evapotranspiration (ET) could be estimated. Soil moisture models use different methods for estimating PET. In IBSNAT crop models, PET is calculated using an equilibrium evaporation concept developed from the Priestley and Taylor (1972) model. The equation calculates the approximate daytime net radiation and equilibrium evaporation, assuming that stomata are closed at night and no ET occurs then. Equilibrium evaporation, E_{eq}, is computed in CERES - Maize model of John's *et al.* (1986) as

$$E_{eq} = R_s(4.88* 10^{-3} – 4.37 * 10^{-3*\alpha}) (T+29)$$

where, R_s = solar radiation, MJ m^{-2} day^{-1}

α = albedo of crop soil surface

T = average daily temperature (°C), estimated as

$T = 0.6 * T_{max} + 0.4 * T_{min}$

$T_{max,}$ T_{min} = daily maximum and minimum temperatures (°C), respectively

The PET is then computed by

$PET = 1.1 * E_{eq}$ if $5< T_{max} \leq 35°C$

$PET = E_{eq} [1.1 + 0.05 (T_{max} -35\}$ if $T_{max}> 35°C$

$PET = E_{eq} *0.01\, e^{[0.18 (Tmax+20)]}$ If $T_{max} >5°$

The PET is calculated as the equilibrium evaporation times 1.1 to account for the effects of unsaturated air. The multiplier is increased above 1.1 to allow for advection effect when the maximum temperature is greater than 35°C, and reduced for temperatures below 0°C to account for the influence of cold temperatures on stomatal closure.

The versatile soil moisture budget (VSMB) of Baier *et al.* (1979) uses regression formulae for estimating PET from various combinations of available meteorological data. For the sites where these regression equations are not available, the VSMB calculates PET from the daily maximum (T_{max}) and minimum (T_{min}) temperatures and radiation at the top of the atmosphere (Q_a) as

$$PET = 0.0034 [T_{max}*0.928] + 0.933 (T_{max} – T_{min}) + 0.0486 Q_a – 87.03]$$

The Penman's formula has been used to compute PET in several models like WTGROWS of Aggarwal *et al.* (1994) and WATER of Burt *et al.* (1980). In determining the PET, primarily the choice of method should be based on the type of meteorological data available.

Actual Evapotranspiration

The actual evapotranspiration (AET) is generally estimated by two approaches in water balance models as

(a) using crop coefficients and soil dryness curves

(b) separating: evapotranspiration into evaporation and transpiration.

Crop coefficients

Crop coefficients are generally empirical ratios of crop ET (ET_c) to some reference ET (PET) that have been derived from experimental data according to the relationship $K_c = ET_c/PET$

where, K_c = crop coefficient for a particular crop for a given growth phase and soil moisture condition – dimensionless

ET_c = daily crop ET (mm)

PET = daily reference ET (mm)

The reference ET characterizes the evaporative demand determined by meteorological conditions and a standard crop surface and K_c indicates the relative ability of a specific crop - soil surface to meet that demand. Since PET is affected by many variables, it cannot be simplified for all climate and crop situations. This is because of the effects of relative leaf area and the morphological and physiological characteristics of the reference crop canopy on the energy exchange and aerodynamic diffusion processes within the atmosphere over a field. Different methods have been proposed for estimating PET for either grass or alfalfa with corresponding crop coefficients (Doorenbos and Pruitt, 1979; Wright, 1981).

Normally, the crop coefficient includes the effects of evaporation from both plant and soil surfaces and is dependent upon available soil water within the root zone and the wetness of the exposed soil surface. Soil water depletion data obtained by gravimetric or neutron probe methods and lysimetric data can be used to obtain K_c values.

Table 2 : Crop coefficients (Kc) values for different crops and weather conditions (after Doorenbos and Pruitt, 1979)

Crop	Crop stage	Humidity >70 %		Humidity <20%	
		wind speed 0-5 (m/sec)	wind speed 5-8 (m/sec)	wind speed 0-5 (m/sec)	wind speed 5.8 (m/sec)
Wheat	3	1.05	1.10	1.15	1.20
	4	0.25	0.25	0.20	0.20
Maize	3	1.05	1.10	1.15	1.20
	4	0.55	0.55	0.60	0.60
Cotton	3	1.05	1.15	1.20	1.25
	4	0.65	0.65	0.65	0.70
Millet	3	1.00	1.05	1.10	1.15
	4	0.30	0.30	0.25	0.25
Groundnut	3	0.95	1.00	1.05	1.10
	4	0.55	0.55	0.60	0.60
Sorghum	3	1.00	1.05	1.10	1.15
	4	0.50	0.50	0.55	0.55
Soybean	3	1.00	1.05	1.10	1.15
	4	0.45	0.45	0.45	0.45
Sunflower	3	1.05	1.10	1.15	1.20
	4	0.40	0.40	0.35	0.35
Potato	3	1.05	1.10	1.15	1.20
	4	0.70	0.70	0.75	0.75
Onion (dry)	3	0.95	0.95	1.05	1.10
	4	0.75	0.75	0.80	0.85
Cabbage & Cauliflower	3	0.95	1.00	1.05	1.10
	4	0.80	0.85	0.90	0.95
Carrot	3	1.00	1.05	1.10	1.15
	4	0.70	0.75	0.80	0.85
Sugarbeet	3	1.05	1.10	1.15	1.20
	4	0.90	0.95	1.00	1.00
Radish	3	0.80	0.80	0.85	0.90
	4	0.75	0.75	0.80	0.85

The K_c for different crops are presented in Table 2. A generalized crop coefficient curve (Doorenbos and Pruitt, 1979) is presented as Fig 2. The Kc values for growth stages 1 and 2 for the crops in Table 2 can be obtained by interpolation from Fig 2. A crop coefficient curve represents the seasonal variation of the empirically derived K_c values. Once this curve has been developed for a given location, daily crop ET can be estimated. The variation in time of season of the crop coefficient has not proven to be generalizable because it is often management, site and weather specific as evident from the values furnished in Table 2. Values of K_c may be management specific as a result of planting date, plant population and row spacing. It may be site specific because of large-scale soil spatial variability and may not be reproducible from one year to the next for a given location because weather sequences are usually not reproducible from year to year. Crop coefficients are dependent on weather because air temperature, radiation and frequency of rainfall effect E_s and E_p directly and temperatures influence

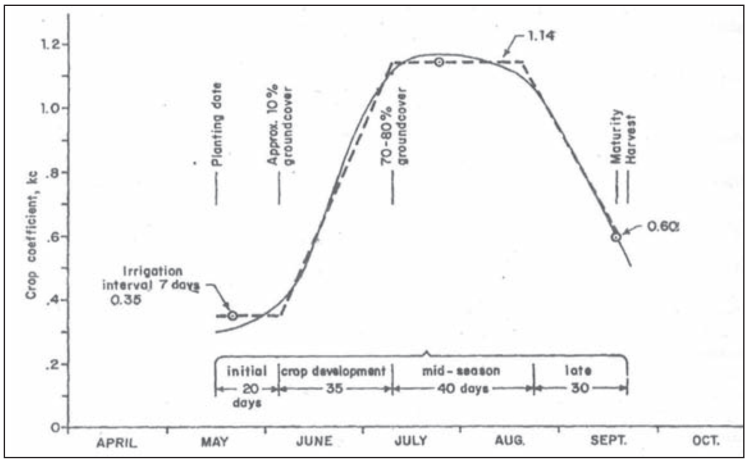


Fig. 2 : A typical crop coefficient curve

the rate of crop development. Hanks (1985) compared crop coefficients measured at Logan and Davis for the same crop. The crop coefficient curve differed markedly for the two locations, especially early in the conditions where the soil surface is dry. He attributed this site specificity to the dependence of Es on the rainfall frequency and amount or irrigation regime when plant cover is low and concluded that the crop coefficients vary from year to year. Wright and Jensen (1978) recognized this limitation of the crop coefficient procedure and developed a crop coefficient curve that was based only on conditions where the soil surface is dry. Their model accounts for increased evaporation when the soil surface is wet and efficiently reduced the estimation of ET of snap bean during the leaf area development. Wright (1982) defined these modified crop coefficients, designed to represent conditions where the soil surface is dry but water is readily available, as "basal ET crop coefficients (K_{cb})". Estimates of an adjusted crop coefficient in terms of K_{cb} were accomplished through use of the following equation:

$$K_a = K_{cb} + (1-K_{cb})\,[1-(t/td)^{0.5}]\,f(w)$$

where, K_a = adjusted crop coefficient
t = number of days after major rain or irrigation
t_d = usual number of days for the soil surface to dry
f(w) = relative proportion of the soil surface originally wetted

Most of the adjustment is needed in the first few days after wetting the soil. The usefulness of this adjustment procedure may be extended mainly to arid regions where evaporative conditions are relatively uniform during the season and t_d may indeed be constant for a given soil. In humid regions, it may be necessary to accommodate the unpredictable temperature and radiation conditions by considering the constant rate stage of soil evaporation and its upper limit (Ritchie and Johnson, 1990). However, the above equation helps to diminish the year-to-year variation of the crop coefficients caused by varying frequency of rainfall and irrigation. Ritchie and Johnson (1990) proposed the following relationship which incorporates the effects of temperature and leaf appearance and expansion for the influence of varying plant population on ET as:

$$K_s{+}p = (E_s + Ep)/PET$$

where, Ks+p = a daily crop coefficient based on separate calculation of E_s and E_p.

The calculations of E_s and E_p require prediction of daily values of LAl and a temperature-based relation for leaf area development can accomplish this. Several authors have developed relations to evolve Kc values as a function of thermal time or days after emergence. Sammis *et al.* (1986) applied the following polynomial for estimating K_c values of winter wheat and spring barley as

$$K_c = B_o + B_1\sum G + B_2\sum G^2 + B_3\sum G^3$$

where, $\sum G$ = accumulated growing degree days starting from planting
B_1 = regression coefficients.

The CALEX/COTTON irrigation module program has been evaluated by Plant *et al.* (1992) with the following relation for K_c as

$$K_c = 0.038 + 21.158\,x - 56.579\,x^2 - 263.86\,x^3$$

where, x = DD / 10000
DD = total elapsed growing degree days >15°C

The K_c values for spanish peanuts were determined from the third-order polynomial (Elliott *et al.*. 1988) as a function of the fraction of the peanut growing season as

$$K_c = -1.644 + 12.05\,F - 17.155\,F^2 + 7.499\,F^3$$

where, F = fraction of the growing season (ratio of days since planting to days between planting and harvesting)

In this case, a growing season length of 140 days was assumed when calculations of F were made. Since this polynomial relationship gives a negative result for small values of F, a minimum value of 0.4 for K_c is suggested.

A second order polynomial equation has been employed by Idike *et al.* (1982) for estimating K_c of corn as function of days after emergence as

$$K_c = 0.152 + 0.0164\,D – 0.00012D^2$$

where, D = days after emergence of the crop

A third degree polynomial has been fitted for spring wheat, barley, canola. sugarbeet and potatoes by Foroud *et al.* (1992) with a lower and upper limit of 0.1 and 1.2 for K_c respectively.

Soil dryness Curves

Depending on the energy available in the atmosphere, a saturated soil is able to provide all or part of the water requirement of the plant for transpiration. This depends on soil characteristics, crop type, crop stage and the magnitude of PET itself. As the soil dries, its hydraulic conductivity decreases, and water moves more slowly towards the roots. Only in certain circumstances AET becomes equal to the PET, and normally the former is a fraction of the latter. When the moisture tension becomes too high, AET becomes less than PET. This break - off tension is higher for lower values of PET and vice - versa. It is high for some crops like horsegram (drought - resistant) and low for sugarcane. For a given crop it is higher during the initial and late stages than during mid-season stage (Rama Prasad, 1984). In the range of plant available water i.e., amount of water from field capacity (FC) to permanent wilting point (PWP), the amount of available soil water gradually decreases to become near zero when PWP is reached. Contradictory viewpoints exist on the availability of soil moisture and the versatile soil moisture budget of Baier *et al.* (1979) who have used 8 types of relationships between the available water for plants and the ratio AET /PET. From these, an adjustment factor ‘z’ was proposed for different types of soil dryness curves as:

$$Z = [AET / PET] / [AW / AWC]$$

where, AW = available water in the zone concerned on a given day
AWC = available water capacity of that zone

The AET on a given day can thus be computed as

$$AET = [AW/AWC] * Z * K_c * PET$$

Separating PET into Evaporation and Transpiration

Several types of models are available for calculating E_s and $E_{p.}$ Because of their differences in their purposes and organization, they can be broadly categorized according to Addiscott and Wagenet (1985) into (a) deterministic or stochastic (b) mechanistic or functional and (c) rate or capacity types.

The deterministic models produce a unique outcome for a given set of events. However, due to the spatial variability of the mediating processes there will be a certain degree of uncertainty associated with the results. Stochastic models have been developed to accommodate this spatial variability and to quantify the degree of uncertainty. Stochastic models produce an uncertain outcome because they include one or more parameters that are random variables with an associated probability distribution. But stochastic models have been applied little in modeling ET (Ritchie and Johnson, 1990).

Most models used for estimating E_s and E_p are deterministic and can be further categorized as mechanistic or functional. The mechanistic models are based on dynamic rate concepts and incorporate basic mechanisms of processes such as Darcy’s law or Fourier’s law and the appropriate continuity equations for water and heat fluxes respectively. Functional models are usually based on capacity factors and treat processes in a more simplified manner, reducing the amount of input required. Mechanistic models are useful primarily as research tools for better understanding of an integrated system, and are usually not used by non-authors due to their complexity. On the other hand, the functional models have modest input requirements making them useful for management purposes. Because of their simplicity, functional models are more widely used than mechanistic models and independently validated.

The most important causes of unproductive loss of water is direct evaporation from the soil surface and especially so under arid and semi-arid conditions where deep drainage can generally be ignored. Thus, the ratio of soil evaporation to transpiration is of decisive importance for overall water use efficiency. Evapotranspiration can be divided into two parts as follows

(a) firstly, under fallow conditions evaporation proceeds at a rate depending upon soil type, frequency of wetting and evaporative demand; and

(b) secondly, under a cropped situation evaporation and transpiration proceed and in turn depend on the soil type, evaporative demand, available water in the root zone and the type of crop cover at different stages of crop growth.

Soil Evaporation (Es)

There are several mechanistic models available on E_s in which general equation of water flow is used. Some of these models predict evaporative losses of water from a bare soil (Gardner and Gardner, 1969: van Bavel and Hillel. 1976; Hillel and Talpaz, 1977; Lascano and van Bavel, 1986). Some models facilitate the separate calculation of E_s and E_p in the presence of a crop (Feddes *et al.* 1976; Norman and Campbell, 1983; Huck and Hillel, 1983; Lascano *et al.*, 1987). Functional models are less evident in the literature and some models that have been used to calculate E_s and E_p separately are the models of Ritchie (1972), Hanks (1974), Kanemasu *et al.* (1976) and Tanner and Jury (1976). Because of the complexity in applying mechanistic models, the review presented here mostly deals with functional models.

The rate of evaporation from the soil can be grouped into several stages. During the first stage, which may last for only one to three days in mid-summer, the rate of evaporation is controlled by heat energy input and is about 90 percent of PET (Jensen *et al.* 1990). The duration of first stage is influenced by the rate of evaporation, soil depth and hydraulic properties of the soil (Gardner and Hillel, 1962). By noting the changes in albedo, the transition from first to second stage of drying can be identified (Jackson *et al.* 1976). Immediately after wetting, the evaporation rate from a wet bare soil is approximately same as that from a free water surface, the duration of which is again dependent on soil type and evaporative demand of the atmosphere. The period is shortened under coarse textured soils. This relates to the amount of water retained in the top 10 cm of soil layer (Reddy, 1993).

During the second or falling stage, the surface has begun to dry and evaporation is occurring below the soil surface. Water vapor reaches the surface by molecular diffusion and mass flow caused due to the fluctuations in soil air pressure. The dry surface soil greatly influences the effective internal resistance. After the mulch has been formed then the rate of evaporation is less than PET and the rate is controlled by soil characteristics like hydraulic conductivity but not by the meteorological conditions. During the second stage the cumulative evaporation tends to increase with the square root of time for a given soil and evaporation potential as

$$Es\ dt = K\ (t-t_1)^{0.5} \text{ if } t > t_1$$

where, K = empirical constant for a given soil that depends on the soil characteristics and water content (Black *et al.* 1969)

t_1 = time at which the falling stage begins.

The value of K can be determined experimentally from cumulative evaporation data for a single drying cycle of a given soil. Several direct measurements of the coefficient K in a diversity of soils have consistently resulted in values of about 3.5 mm $day^{-0.5}$. Mason and Smith (1981) used a value of 5 in their model. Thus, the cumulative loss of water after an irrigation or rain can be approximated by

$$E_c = 0.9\ PET\ dt \text{ for } t<t_1 \qquad E_c = 0.9\ PET\ dt + K\ (t-t_1)^{0.5} \text{ for } t>t_1$$

where, Ec = cumulative evaporation

t_1 = time since evaporation began

Ritchie (1972) summarized Ec at t_1 and K value (Table 3) for several soils.

Table 3 : Typical coefficients for second stage evaporation

Soil	Ec (mm)	K (mm $day^{-0.5}$)
Adelanto clay loam	12	5.08
Yolo loam	9	4.04
Houston black clay	6	3.50
Plain field sand	6	3.34

PLANTGRO model of Retta and Hanks (1977) computes E_s on the assumption that E_s occurs only from the top layer, usually of 20 to 30 cm in thickness, as

$$E = PET\ t^{-0.5}$$

where, t = time in days since last irrigation or rain.

It also allows the top layer to lose moisture below wilting point to the air-drying moisture content. The amount of water that may be lost by evaporation after the soil has reached its permanent wilting water content is taken as equal to the amount of water lost when the first 10 cm of the top layer is dried to air-drying. Thus during the constant rate stage, the evaporation occurs at the potential rate until the upper limit of stage 1 evaporation (U) is reached (Ritchie and Johnson, 1990). This U is reached more rapidly under condition of high PET than under low PET. Ritchie and Johnson (1990) reported value of U to be about 5 mm in sands and heavy shrinking clays to about 14 mm in clay loams. Mason and Smith (1981) assumed a value of 7 mm.

However, contradictory view point exists on the second-stage evaporation rates. Arora *et* al. (1987) used the following empirical relation for sandy loam soils

$$E = PET\ t^{-0.30}$$

It was also assumed that the top 30 cm soil layer contributed towards soil evaporation. Hill *et a1*. (1979) used the following relation to estimate E_s as

$$E_s = E_p / 2\ (2^{t-1}) \quad \text{and} \quad E_p = K_s * PET$$

where, E_p = potential soil evaporation
K_s = soil evaporation factor which depends on the value of Kc.
t = time in days since the last soil surface wetting.

It is subject to the constraint that the surface soil cannot be drier than air-dry. The top 10 cm soil is assumed to be dried by evaporation and transpiration to the wilting point and then by evaporation only to air dry.

However, Ritchie's (1972) model is the most frequently used model for E_s. This has been used by Cull *et* al (1981), Mason and Smith (1981), Sharpley arid Williams (1990) and Jain and Murthy (1985).

The calculation of E_s in the Ritchie's (1972) model requires prediction of the net radiation distribution through the canopy to the soil surface. Ritchie and Burnett (1971) quantified the influence of partial cover on ET and found that LAI of sorghum and cotton were more generally related to plant evaporation (ET) as fractions of PET than ground cover or plant dry weight. The empiricism used to estimate ET from crops with an adequate supply of water in the root zone usually make ET a function of PET, LAI or plant cover.

In the presence of canopy, the fraction of energy (Rso) supplied to the soil surface depends on crop cover or leaf area index (LAI) and is given by

$$R_{so} = R_{ns} / R_n = \exp(-0.4\ LAI) \text{ for } LAI < 2.7$$

where, R_{ns} & R_n = 24 hour net radiation at soil surface and above the crop canopy, respectively.

Thus, the soil evaporation during the constant rate stage (stage 1) is calculated using a Priestley - Taylor type equation (Ritchie, 1974);

$$E_{sp} = \frac{\Delta}{\Delta+\gamma}\ \theta_n R_{so}$$

where, $\theta_n = 0.92 + 0.4\ [R_{ns} / R_n]$ for LAI < 2.7 and $\theta_n = 1$ for LAI >2.7

Some of the functional relations reported in the literature are presented here. CERES-Maize model of Jones et al. (1986) computes potential soil evaporation as

$$Esp = PET\ [1.0 - .0.43\ (LAI)] \text{ for } LAI < 1$$
$$\text{and } Esp = (PET / 1.1)\ e^{-0.4\ (LAI)} \text{ for } LAI > 1$$

In this case, a modified Preistley-Taylor equation is used to calculate daily values of PET although other equations could be used. The potential rates for PET and Esp are equivalent in this example when applied to bare soil conditions (i.e., LAI = 0).

For wheat crop of North-Western part of India, Jain and Murthy (1985) computed Esp as

$$E_{sp} = 0.1\ \frac{\Delta}{\Delta+\gamma}\ R_n \exp(-0.428\ \text{LAI})$$

Sammis *et al.*,(1986) used the following relation for winter wheat and spring barley to compute daily soil evaporation as $Es = PET * e^{-0.623\ LAI}$

In a water balance model that was used to calculate dry matter yield of wheat, Hanks and Puckridge (1980) computed potential soil evaporation as a function of LAI and dry matter production (DM) in g m^{-2} as

$$E_{sp} = [PET - T_p]\ [1 - DM/2000]$$

where, $T_p = 0.9$ PET if LAI>3 and
$T_p = 0.9$ PET (LAI/3) if LAI <3

In the Soil Water Leaf Extension of Winter Wheat and Wheat Growth [SWLEWW-WTGRO) model of Farshi *et al.* (1987) for the values of ground cover (Gc) smaller than 0.45, it was assumed that PET of winter wheat was equal to ET_o, the PET of a full grown grass cover. The PET was separated into potential transpiration and evaporation on the basis of predicted values of leaf area index as

$$Gc = 1 - \exp(-0.6\ LAl)$$

$$E_p = PET \quad \text{if } Gc = 0$$

$$E_p = 0.9\ (1 - Gc)\ PET \quad \text{if } Gc > 0$$

The equation was used for LAI up to 3.5. For LAI >3.5, it was assumed that the crop covers the ground surface completely, consequently Gc was put equal to 1.

In an attempt to simulate water content under barley using simple empirical approach, AL-Kahfaf *et al.* (1989) estimated bare soil evaporation using the expression

$$E_s = a\ (t)^b - a\ (t\text{-}l)^b$$

where, a,b = empirical coefficients depending on soil type
t = time after irrigation (days).

The potential soil evaporation was calculated as

$$Esp = PET \quad \text{if } Fs < 0.08$$

that is, if PET is not higher than the value of 'a', otherwise $E_{sp} = 7.24$ mm $day^{-1.}$ Further, they used

$$E_{sp} = (1.21 - 2.343\ Fs)\ PET \quad \text{if } 0.08 < Fs < 0.48$$

$$E_{sp} = 0.08\ PET \quad \text{if } 0.48 < Fs$$

where, Fs is fraction of degree of shading which is the ratio of LAl at any given time to the maximum value of LAl during the season under non-limiting water conditions.

Plant Transpiration (E_t)

As the case with modeling $E_{s,}$ there are also mechanistic and functional models for estimating plant transpiration. Two classical examples of mechanistic models are Penman-Monteith model (Monteith, 1973) and the EMWATBAL model (Lascano *et al,* 1987). They differ in their input requirement and detail but were stated to have good theoretical basis, the former being simpler than the latter and intended to calculate E_t or AET. Both these models operate on 1-hour time step and Penman-Monteith has been used extensively to estimate AET in recent years. This equation requires hourly input or estimates from empirical functions for humidity, temperature, net radiation, soil heat flux, heat storage rate in the canopy air column, transport resistance from the leaf surface to instrument height (r_a), and the resistance of the crop (r_c). However, use of this relation to predict AET in applications such as irrigation scheduling is a problem because the required meteorological inputs are difficult to obtain. The value of the surface resistance is a complex function of many climatological and biological factors (Monteith, 1985). All the meteorological variables that must be known are dependent to some extent on the properties of the vegetation. Thus, they must be estimated on the basis of previous experience or calculated from models of the exchange processes (McNaughton and Jarvis, 1984).

The other mechanistic model, EMWATBAL calculates the water and energy balance for both the soil surface and crop canopy. This model calculates water evaporation and transpiration fluxes. At each time step, the model calculates and updates values of water content and temperature for each soil layer. From these values the inter-layer fluxes of water and heat below the soil surface are calculated. At the soil surface the net radiation, latent, sensible, and soil heat fluxes are calculated from an energy balance equation. Instead of assuming that evaporation at the soil surface occurs at the equilibrium rate corresponding to the net radiation flux above that surface (Ritchie, 1972), the EMWATBAL calculates evaporation at the soil surface by finding the surface temperature that satisfies the energy and water balance at the soil surface following van Bave1 and Hillel (1976). The model requires information on soil water retention curve and the unsaturated hydraulic conductivity for each soil layer, and the number and thickness of the soil layers that determine the geometry of the soil system. Plant inputs are the relation between leaf conductance and leaf water potential, the root distribution as a function of soil depth and time, and the LAI as a function of time. Weather inputs are daily total solar radiation, daily maximum and minimum air and dew point temperatures, daily wind speed, and the quantity of rain or irrigation as a function of time of day. In addition, initial values of the water and temperature profiles must be specified at the start of the simulation period. The daily weather data will be disaggregated into hourly values using empirical relations to produce 24 estimated values from one or two measured values.

Though EMWATBAL is a mechanistic model, it uses empirical relations also. For example, several polynomials were used to compute short wave absorptance of the crop (ABSC), of the soil (ABSS), and the view factor from soil to sky (FTSR), all as a function of LAI, as

$$ABSC = 0.5809\ LAI - 0.2231\ LAI^2 + 0.04640\ LAI^3 - 0.004759\ LAI^4 + 0.0001875\ LAI^5$$

$$ABSS = 0.825 - 0.6447LAI + 0.2646LAI^2 - 0.05695\ LAI^3 + 0.005937\ LAI^4 - 0.0002355\ LAI^5$$

$$FTSR = 1.0 - 0.6780\ LAI + 0.2052\ LAI^2 - 0.02799\ LAI^3 + 0.001383\ LAI^4$$

Further, the LAI is estimated with third-order polynomials as a function of calendar day number (CD). For the irrigated cotton crop, this relationship was given as $LAI = 105.6713 - 1.61088\ CD + 0.008035084\ CD^2 - 0.0000130257\ CD^3$ and for the dryland cotton crop, the relation was given as

$$LAI = 70.93205 - 1.13014CD + 0.005848976CD^2 - 0.0000097607CD^3$$

Ritchie and Johnson (1990) have identified several problems that may reduce the use of a mechanistic model for prediction purposes and for supporting farm decisions such as irrigation scheduling. Mechanistic models may provide the information needed to derive some of the empiricism upon which functional models are based.

The second type of models for estimating E_t are functional models. These are quite widely used in many crop growth models because they require few inputs, most of which are readily obtainable. In an earlier attempt to estimate the evaporation rates from developing cotton and grain sorghum canopies under water non-limiting conditions, Ritchie and Burnett (1971) estimated the potential transpiration (T_p) as

$$T_p = PET\ (- 0.21 + 0.70\ LAI^{0.5}),\ 0.1 \leq LAI \leq 2.7$$

The non-linearity of the relation between T_p and LAl is stated to be the result of two interacting factors

(a) less competition for radiation per unit of leaf area during initial stages of plant growth and

(b) the partitioning of a large fraction of net radiation at the dry soil surface between plant rows to sensible heat flux causing increased canopy temperature and consequently increased T_p (Ritchie and Burnett, 1971).

Upper limit of 2.7 of LAl represents minimum requirement of LAI necessary for full cover of canopy. For crop canopies with LAl >2.7, T_p = PET. When LAl <0.1, T_p is considered negligible.

The T_p is computed from actual (Ea) and potential soil evaporation (Esp) and PET by Brisson *et al.* (1992) using the following relation

$$T_p = (PET - E_p) [\beta + (1 - \beta) Es/Espl$$

where, the value of β was 1.1, which simulates a 10% increase in Tp/PET between wet soil conditions ($Es=E_p$) and dry soil conditions (Es=0).

The potential transpiration for a wheat crop was estimated by Hanks and Puckridge (1980) using the relations already explained which are reproduced here, as

$$T_p = 0.9 \text{ PET if LAI is } 3$$

$$T_p = 0.9 \text{ PET } (LAl/3) \quad \text{if LAI is } 3.$$

Assuming that T_p is largely controlled by evaporative demand and degree of shading under non-limiting water conditions, AL-Kahfaf *et al.* (1989) estimated T_p using the following functional relations

$$T_p = 0 \quad \text{if } Fs< 0.08$$

$$T_p= [l - (1.21 - 2.343 Fs)J \text{ PET} \quad \text{if } 0.08 <Fs<0.48$$

$$T_p= 0.92 \text{ PET} \quad \text{if } 0.48 < Fs$$

where, Fs = fraction of degree of shading.

In most of the soil water balance models like that of Farshi *et al.* (1987), Murthy *et al.* (1992) and Sammis *et al.* (1986), the T_p is calculated as

$$T_p = PET - E_s$$

where, E_s is calculated by one or the other method.

In CERES-Maize, the calculation of E_t is through a functional model on the lines of Ritchie (1972). The functional model for estimation of E_s has been described earlier. Where the soil water is non-limiting the functional model calculates E_t using the relationships

$$E_t = PET (1.0 – e^{-LAI}) \quad \text{if LAI} \leq 3$$

$$E_t = PET \quad \text{if LAI} > 3$$

$$\text{and if } E_s + E_t > PET, \text{ then } E_t = PET - E_s$$

This conditional equation was felt necessary because values for E_s and E_t are calculated independently and their sum can exceed the potential rate on a given day because Eq (1.56) and (1.57) are for estimating E_t when the soil surface is dry.

Once the potential transpiration (Tp) is computed, most of the models estimate actual transpiration (E_t) on the basis of soil water availability. As the soil dries, the conductivity of soil to water flow decreases, thereby decreasing the uptake of water by the root system. Actual transpiration (E_t) by the crop falls below the potential transpiration demand (T_p). There are essentially two approaches to estimate E_t. In the first approach T_p is decreased in proportion to the water deficit in the rooting zone. The transpiration from sorghum or corn as observed by Ritchie (1973) is not affected by soil water deficit until the available water (θ_A) in the root zone is less than 0.3 of the maximum available moisture content (θ_{max}). Thus, when the available water content in the root zone is in between 1 and 0.3 of the maximum, E_t is considered equal to $T_{p.}$ When available water content is less than 0.3 of the maximum then

$$E_t = T_p \theta_A/0.3 \theta_{max}$$

The concept was used by Cull. *et al.* (1981) for cotton crop. However, Hanks (1974), Sammis *et al.* (1986) and Abdul Jabbar *et al.* (1983) assumed a value of 0.5 of $\theta_{max.}$ Singh and Wolkewitz (1988) adopted the critical value of 0.65 to 0.84 for different growth stages of wheat. In the second approach, potential water supply (Pw) by the root system is considered in relation to the potential demand by the crop (T_p). If water supply is greater than demand, then demand is the actual transpiration. If water supply falls below the demand due to water deficits in the soil, then supply is the actual transpiration.

Chapter - II

The Indian Monsoon and Weather Events

MONSOON CONCEPT AND ITS FEATURES

V.U.M.Rao

In an agricultural country like India, the success or failure of the crops and water scarcity in any year is always viewed with the greatest concern. A major portion of annual rainfall over India is received during the southwest monsoon season (June-September). Regional rainfall has large year-to-year fluctuations. Monsoon affects the livelihood of millions of people in Africa and Asia. Agriculture, irrigation and power generation is closely linked with the monsoon rains in this part of the world. A study of monsoon is therefore important for research scientists as well as operational forecasters. The term 'monsoon' is derived from an Arabic word 'mausim', which means season. The word monsoon is applied to such a circulation, which reverses its direction every six months, i.e., from summer to winter and vice-versa.

Monsoon is a large-scale seasonal wind system, blowing over vast areas of the globe, persistently in the same direction, only to be reversed with change of season. They affect the largest land masses. Asia is the only continent in the world having regular visits of monsoons of completely reversing and persistent wind regimes. Australia and Africa are also affected by monsoons, though not to the same extent as Southeast Asia. North America also shows monsoonal tendencies. But here monsoon wind is neither persistent, nor the seasonal wind shifts are so consistent.

Following the Great Indian Drought of 1877, H.F. Blanford, who had established the India Meteorological Department in 1875, issued the first seasonal forecast of Indian monsoon rainfall in 1884. Later, in the early part of the 20th century, Sir Gilbert Walker initiated extensive studies of global teleconnections which led him to the discovery of Southern Oscillation. Walker introduced, for the first time, the concept of correlation for long-range forecasting of the Asian summer monsoon and his findings are relevant even today.

Walker and Hadley Cells

The principal monsoon of the world are the summer and winter monsoon of Asia and the monsoonal circulations over west and east Africa. These monsoons appear to be dominated by circulation that are either aligned in a north-south or an east-west direction. The rising branch of each circulation is located near a source of heat while the descending limb occurs over a heat sink. These cells are named Hadley and Walker cells.

Principal Rain Bearing Systems

Some of the important rain bearing systems are: (i) monsoon lows/depressions in the Bay of Bengal; (ii) fluctuations in the intensity of location of a monsoon trough over the plains of India and Pakistan; (iii) mid tropospheric low pressure systems over the Gujarat coast; (iv) off-shore vortices, and (v) low-level equatorial jet stream along the eastern coast of Africa.

Ramage (1971) prescribed the boundaries of the monsoons to an area enclosed between 35°N and 25°S and between 30°W and 173°E (Fig.1). The phenomena of monsoon is explained by different theories, such as (a) differential heating of land and water (b) seasonal shifting of the tropical and inter-tropical wind belts (c) upper atmospheric wind movements and jet streams and (d) most recently linked to El Nino and La Nina effects.

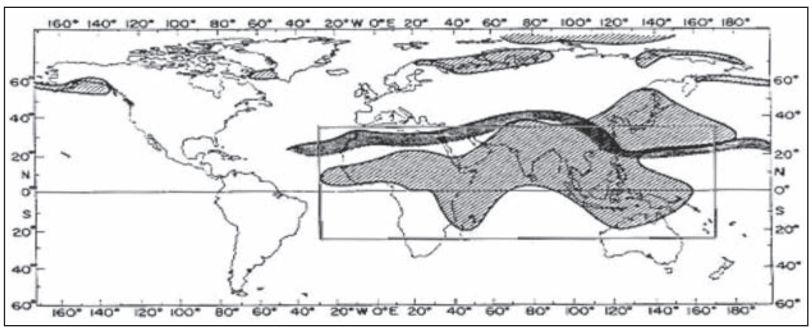


Fig. 1: Map showing the areas affected by monsoon (Ramage, C.S., 1971). Hatched area is Monsoonal and the rectangle broadly indicates the extent of the monsoon regime

Regional Aspects of Monsoon

Regional features of monsoon occur on a smaller scale but more often coupled with the planetary scale flow patterns. Broadly the world over, following four regional components of summer and winter monsoon have been identified:

Monsoon Areas

1) Summer monsoon over Indian sub-continent, east and south-east Asia
2) West African monsoon
3) Winter monsoon over east and Southeast Asia
4) Australian summer monsoon.

Indian Monsoons

Features of Indian monsoons are:

a) Tropical location of Indian sub-continent,
b) Himalayas-the mountain barrier to the north of the land mass, cold and dry air mass
c) Monsoon is controlled by high and low centres developed over north-western region of the Indian sub-continent,
d) High temperatures (about 40-45 °C) creates pressure gradient over India,
e) Extreme low pressure points (up to 700 mb) that develop in the NW region, actively attract the prevailing wind from the Indian Ocean,
f) Continental Tropical Convergence Zone (CTCZ) shifts to the northern plains (30°N),
g) Series of atmospheric depressions,
j) Retreating monsoon (also called north-east monsoon) starts from northern regions by first week of October,
k) North-east monsoon is also accompanied by cyclones causing large scale damage to life and property along the eastern coast of India.

South-west Monsoon

Indian agriculture is a gamble in the hands of monsoon. Southwest monsoon prevails from June to September over India; it gives 70% of Indian annual rainfall. The regions receiving the largest amounts of rainfall are along the west coast of India and the states of Assam and West Bengal in north-east India. The summer (south-west) monsoon approaches India from south-westerly direction. The normal date of arrival of the monsoon over Ceylon and the islands in the Bay of Bengal is towards the last week of May. There after, it reaches the extreme south of the Indian peninsula about a week later (June 1).

The onset of southwest monsoon over Kerala signals the arrival of monsoon over the Indian subcontinent and represents beginning of rainy season over the region. From 2005 onwards India Meteorological Department (IMD) has been issuing operational forecasts for the monsoon onset over Kerala using an indigenously developed statistical model with a model error of ± 4 days.

Advance of Monsoon Over Andaman Sea

The normal date of advance of monsoon over Andaman Sea is 20th May. It is expected that monsoon flow will start appearing over Andaman Sea by the following week and is likely to cover the Andaman Sea around to its normal date. Past data suggest absence of any one-to-one association between the date of monsoon advance over Andaman Sea and the date of monsoon onset over Kerala (Fig. 2).

Fig. 2 : Normal onset date of monsoon over India

Northern Limit of Monsoon (NLM)

Southwest monsoon normally sets in over Kerala around 1st June. It advances northwards, usually in surges, and covers the entire country around 15th July. The NLM is the northern most limit of monsoon up to which it has advanced on any given day.

Forecast for the 2010 Monsoon Onset over Kerala

For predicting the 2010 monsoon onset over Kerala, the model based on Principal Component Regression technique used the following six predictors:

i) Minimum Temperature over North-west India,

ii) Pre-monsoon rainfall peak over south Peninsula,

iii) Outgoing Long wave Radiation (OLR) over south China Sea,

iv) Lower tropospheric zonal wind over southeast Indian ocean,

v) Upper tropospheric zonal wind over the east equatorial Indian Ocean, and

vi) Outgoing Long wave (OLR) over south-west Pacific region.

Onset of the Monsoon

As the sun moves northwards across the equator in the northern hemisphere, the continents surrounding the Arabian Sea begin to receive large amounts of heat; not only in the form of radiation from the sun but also as heat emitted from the earth's surface. As a consequence of this larger input of heat, a trough of low pressure forms over this region. It extends from Somalia northwards across Arabia into Pakistan and northwest India. Towards the end of May, the heat low is well established and a southwesterly wind spreads northwards over the Arabian sea, the bay of Bengal and the Indian sub-continent. The onset of southwesterly winds over the west coast of India is often sudden, it is referred to as the burst of the monsoon over India (Fig.2).

South-west Monsoon Onset over Kerala

The criteria declaring the onset of monsoon over Kerala are:

Rainfall : If after 10^{th} May, 60% of the available 14 stations enlisted, viz. Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassery, Kannur, Kasargode and Mangalore report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the 2nd day, provided the following criteria are also in concurrence.

Wind field : Depth of westerlies should be maintained upto 600 hPa, in the box equator to Lat. 10ºN and Long. 55 ºE to 80ºE. The zonal wind speed over the area bounded by Lat. 5-10ºN, Long. 70-80ºE should be of the order of 15 - 20 Kts. at 925 hPa. The source of data can be RSMC wind analysis/satellite derived winds.

Outgoing longwave radiation (OLR): INSAT derived OLR value should be below 200 wm-2 in the box confined by Lat. 5-10ºN and Long. 70- 75ºE.

Progress of Monsoon

The subsequent progress of the monsoon may be conveniently traced in the form of two branches of the monsoon, namely, the Arabian Sea branch and the Bay of Bengal branch. We first consider the Arabian Sea branch, which gradually advances towards north to Bombay by June 10. The advance from Trivandrum to Bombay is achieved in about ten days, and is fairly rapid.

In the meantime, the progress of the Bay of Bengal branch is no less spectacular. It moves towards north to the central Bay of Bengal and rapidly spreads over most of Assam by the first week of June. On reaching the southern periphery of the Himalayan barrier, the Bay branch of the monsoon is deflected westwards. As a consequence, its further progress is towards the Gangetic plains of India rather than towards Burma. The arrival of the monsoon at Calcutta is slightly earlier than at Bombay. The normal date of arrival at Calcutta is June 7, while the Arabian Sea branch of the monsoon normally reaches Bombay by June 10.

By mid-June the Arabian branch spreads over Saurashtra-Kutch and the Central parts of the country. Thereafter, the deflected currents from the Bay of Bengal and the Arabian Sea branch of the monsoon tend to merge into a single current. The remaining parts of west UP, Haryana, Punjab and the eastern half of Rajasthan experience first monsoon showers by the first of July. The arrival of the monsoon showers at a place like Delhi often raises doubts, whether the first monsoon showers will arrive from the east as an extension of the Bay of Bengal branch or from south as an extension of Arabian

Sea branch. By mid-July the monsoon extends into Kashmir and remaining parts of the country, but only as a feeble current because by this time it has shed most of its moisture. The normal duration of summer monsoon varies from two to four months over various regions. It begins to withdraw from Punjab and Rajasthan by the middle of September. The withdrawal of the monsoon is a far more gradual process than its onset. In general terms, the monsoon usually withdraws from north-west India by the beginning of October and from the remaining parts of the country by the end of November.

Early or late onset of monsoon does not provide any clue as to its total behaviour in terms of its rainfall. It also does not give any indication whether the monsoon will progress normally. But it is usually observed that the progress of monsoon is arrested after its initial northward movement by about 500 km. For further progress a fresh surge is necessary, which is created by low pressure developed northwards along the coast carrying with it the monsoon current. The sea level trough hardly extends about 100 km westward. High intensity rainfall occurs even in the sector ahead of depressions and cyclonic storms. The extent of area over which rainfall occurs may be of the order of about 800-1000 km around the storm centre. As the system dissipates, the extent of rainfall increases but with much reduced intensity. The monsoon depressions, even while they are on land, derive necessary moisture either from Bay of Bengal or the Arabian Sea or both, depending on their location.

Break Monsoon

The summer monsoon is associated with short period rainfall fluctuations. The hundred-day monsoon over India from 1 June to mid September is characterized by heavy rain followed by lean periods. A period of lean rainfall is known as a “break monsoon”, where rain fall shifts towards the Himalayan Mountain region.

Monsoon Trough

This is a semi-permanent feature of the monsoon. Monsoon trough over India at surface (1000 h Pa) runs from Ganganagar to Calcutta, roughly parallel to the southern periphery of the Himalayan mountains. Vertically this trough extends up to about 6 kilometres. At about 4 km, it runs from Bombay to Sambalpur. It’s position is by no means unique nor stationary. It shows north-south migrations both at the surface and in depth.

Withdrawal of the Monsoon

The monsoon begins to withdraw from northern India around mid-September (Fig.3). By the end of October it has usually withdrawn from the region north of 15°N and from Bangla Desh and Mayanmar. Finally it withdraws form the extreme south of the Indian Peninsula and Sri Lanka by December. About the time of the monsoon withdrawal, the subtropical westerly jet stream again reappears over the northwestern end of the Himalayas. Thereafter, it moves southwards to its usual location south of the Himalayas by the end of October. The easterly jet which has a feature of the onset disappears rapidly after the recession of the monsoon by early October. This system is associated with movement of sub-tropical anticyclone.

Fig. 3 : Normal withdrawal date of monsoon over India

Some Features of Withdrawal SW Monsoon

a) Withdrawal from extreme north-western parts of the country is not attained before 1st September.

b) After 1st September: The following major synoptic features are considered for the first withdrawal from the western parts of NW India.

i) Cessation of rainfall activity over the area for continuous 5 days.

ii) Establishment of anticyclone in the lower troposphere (850 hPa and below)

iii) Considerable reduction in moisture content as inferred from satellite water vapour imageries and tephigrams.

Further Withdrawal from the Country

- Further withdrawal from the country is declared, keeping the spatial continuity, reduction in moisture as seen in the water vapour imageries and prevalence of dry weather for continuously 5 days.

- SW monsoon lastly withdraws from the southern peninsula and hence from the entire country only after 1st October, when the circulation pattern indicates a change over from the south-westerly wind regime.

Monsoon Forecast in India

A 16-parameter power regression and parametric model developed by Gowariker *et al.* were introduced operationally by IMD in 1988. A minor modification was made to the model in 2000, involving the replacement of four parameters as with time they had lost their correlation. The year 2002 turned out to be an all-India drought year with an overall rainfall deficiency of 19%, while IMD had predicted a normal monsoon resulting in a lot of attention being focused on IMD's prediction methodology. This highlighted the need to review the current long range forecast models and attempt to develop new credible models. In 2003, IMD introduced several new models for long range forecast of south-west monsoon season (Jun–Sep). IMD's new statistical models were introduced in 2007. Long range forecast schedule as 1st stage forecast is scheduled in April and a 2nd stage forecast in June, in addition, to the forecast for date of monsoon onset over Kerala in May. Specifically three major issues were addressed to improve the models. (i) A smaller but more physically linked predictor data set was used. Search for new predictors. (ii) Ensemble Method was used instead on relying on a single model. (iii) A New non-linear technique was adopted.

The parameters used in long range forecast are given in below.

S. No	New Predictors	Used for forecasts in
1	North Atlantic Sea Surface Temperature (December +January)	April and June
2	Equatorial SE Indian Ocean Sea Surface Temperature (February + March)	April and June
3	East Asia Mean Sea Level Pressure (February + March)	April and June
4	NW Europe Land Surface Air Temperatures (January)	April
5	Equatorial Pacific Warm Water Volume (February +March)	April
6	Central Pacific (Nino 3.4) Sea Surface Temperature Tendency (Mar+Apr+May) – (Dec+Jan+Feb)	June
7	North Atlantic Mean Sea Level Pressure (May)	June
8	North Central Pacific wind at 1.5 Km above sea level (May)	June

July is the rainiest month of the southwest monsoon season and the lack of rains in July have the most critical impact on agriculture. A separate 8-parameter power regression model for July rainfall is developed by IMD and being used for long range forecast for four broad homogenous regions of India which are given below.

S No	Homogenous regions	States
1	Northwest India	Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, Chandigarh, Delhi, Uttarakhand, Uttar Pradesh, Rajasthan
2	Central India	Gujarat, Madhya Pradesh, Maharashtra, Goa, Chhattisgarh, Orissa
3	Northeast India	Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Sikkim, West Bengal, Jharkhand, Bihar
4	South Peninsula	Andaman & Nicobar Islands, Andhra Pradesh, Tamilnadu, Puducherry, Karnataka, Kerala, Lakshadweep

As a part of ongoing efforts to improve the long range forecast capabilities, IMD has initiated experimental dynamical forecast system forecast for the 2009 south-west monsoon rainfall. For this purpose, observed sea surface temperature data of March have been used.

In addition, IMD prepares operational long range forecasts for the Winter Precipitation (Jan to March) over Northwest India and Northeast Monsoon rainfall (October to December) over South Peninsula. For this purpose, separate statistical models have been developed.

North-east Monsoon or Winter Monsoon:

The south-west monsoon period is the principal rainy season over most of India. But over Tamilnadu in peninsular India, the principal rainy season is from late October to December. This is known as north-east monsoon. The spectacular change that takes place between the two monsoons is the change of the wind direction from south-west to north-east over the Bay of Bengal, the Indian peninsula and Arabian Sea. An interesting question that often raised is concerned with the possibility of the south-west and the north-east monsoon co-existing over the extreme south of the Indian peninsula. It may be recalled in this context that the winter monsoon sets in over the southern half of the peninsula in October. Although it may seem theoretically possible for both monsoon systems to affect peninsular India, in reality, such situations are comparatively rare. The south-west monsoon is for all practical purposes in the last stages of its withdrawal toward the end of October. The onset of north-east monsoon is a gradual process. It is often difficult to specify its period of arrival over Tamilnadu, which is the main beneficiary of its rainfall. In fact, on many occasions there is no clear distinction between the withdrawal of summer monsoon over peninsular India and the onset of winter monsoon. North-east monsoon season is also the season of cyclonic storms in the Bay of Bengal. Though they are destructive in nature, they give copious rainfall over the areas in their path. In this respect, they may be considered as necessary evils. Rainfall in the southern states of Tamilnadu, Andhra Pradesh, Karnataka and Kerala during November and December is attributed by and large to the winter or north-east monsoon.

Monsoon Mission

In 2012 very recently, Earth System Sciences Organization (ESSO) of Ministry of Earth Sciences (MoES), Government of India, launched the “National Monsoon Mission” (NMM) with a vision to develop a state of the art dynamical prediction system for monsoon rainfall on all different time scales (ESSO, 2012).

Long Range Forecast for 2012 South-west Monsoon Season

India Meteorological Department (IMD) issues various monthly and seasonal operational forecasts for the rainfall during the south-west monsoon season. Operational models are reviewed regularly and improved through in-house research activities. Operational forecasts for the southwest monsoon season (June – September) rainfall over the country as a whole are issued in two stages. The first long range forecast for the all India monsoon rainfall is issued in April and the forecast update is issued in June.

The 5-parameter ensemble statistical forecasting system was also used to prepare probability forecasts for five pre-defined rainfall categories. These are deficient (less than 90% of LPA), below normal (90-96% of LPA), normal (96-104% of LPA), above normal (104-110% of LPA) and excess (above 110% of LPA). The climatological probabilities in percentage for the above categories are 16%, 17%, 33%, 16% and 17%, respectively. *The predicted probabilities based on the 5-parameter ensemble forecasting system for these 5 categories for the 2012 southwest monsoon season are 8%, 24 %, 47%, 17% and 4%, respectively.*

IMD-IITM Experimental Dynamical Model Forecasting System

Since 2004, IMD has been generating the experimental dynamical long range forecast for the southwest monsoon rainfall using an atmospheric general circulation model. Ministry of Earth Sciences (MoES) has recently initiated the **Monsoon Mission programme** with an objective to improve the monsoon forecasts over the country in short range to long range time scales. Indian Institute of Tropical Meteorology (IITM), Pune is responsible for implementing the dynamical model framework for long range forecasts and coordinating research work on improving long range forecasts using dynamical models. For this purpose, IITM, Pune has recently implemented the state-of-the-art coupled climate model, the Coupled Forecasting System (CFS) developed by the National Centers for Environmental Prediction (NCEP), USA. Under the monsoon mission program, IITM, Pune along with other national and international partners including IMD are working on to improve the skill of the CFS model for more accurate long range forecasts of monsoon rainfall. IMD has now adopted the latest high resolution research version of the coupled model (CFS Version 2) being implemented at IITM.

Other Forecasts by National and International Institutions

In addition, IMD has taken into account the experimental forecasts prepared by the national institutes like Space Applications Centre, Ahmedabad, Centre for Mathematical Modeling and Computer Simulation, Bangalore, Center for Development of Advanced Computing, Pune and Indian Institute of Tropical Meteorology, Pune. Operational/experimental forecasts prepared by international institutes like the National Centers for Environmental Prediction, USA, International Research Institute for Climate and Society, USA, Meteorological Office, UK, Meteo France, the European Center for Medium Range Weather Forecasts, UK, Japan Meteorological Agency, Japan Agency for Marine-Earth Science and Technology, Asian-Pacific Economic Cooperation (APEC) Climate Centre, Korea and World Meteorological Organization's Lead Centre for Long Range Forecasting - Multi-Model Ensemble have also been taken into account.

Sea Surface Temperature Conditions in the Equatorial Pacific & Indian Oceans

After the disappearance of moderate to strong La Nina conditions in May 2011, weak La Nina conditions reemerged in early August, 2011 and became weak to moderate during the later part of 2011. The weak/moderate La Nina conditions continued till the first half of February 2012. It started weakening subsequently and at present the event is in transition towards the ENSO neutral conditions. The latest forecasts from a majority of the dynamical and statistical models indicate moderate probability (about 53%) for the ENSO neutral conditions to prevail during the monsoon season. There is also noticeable probability (about 39%) for emergence of weak El Nino conditions during the later part of the monsoon season. However, the probability of reemergence of La Nina conditions during the monsoon season is very less. It is important to note that in addition to ENSO events, many other factors such as the Indian Ocean Sea surface temperatures (SSTs) also influence monsoon performance. Recent forecasts from a few coupled models suggest the possibility of development of a weak negative Indian Ocean Dipole event during the second half of the year.

Forecast for the 2012 South-west Monsoon Rainfall

The experimental forecast for the 2012 monsoon season using the IMD – IITM dynamical prediction system using February initial conditions *indicates that the rainfall during the 2012 monsoon season (June to September) averaged over the country as a whole is likely to be 100% of long period model average (LPMA).*

IMD's long range forecasts for the 2012 south-west monsoon season (June to September) are as follows:

(a) Southwest monsoon seasonal rainfall for the country as a whole is most likely to be Normal (96-104% of Long Period Average (LPA)) with the probability of 47%. The probability (24%) of season rainfall to be below normal (90-96% of LPA) is also higher than its climatological value. However, the probability of season rainfall to be deficient (below 90% of LPA) or excess (above 110% of LPA) is relatively low (less than 10%).

(b) Quantitatively, monsoon season rainfall is likely to be 99% of the LPA with a model error of ± 5%. The LPA of the season rainfall over the country as a whole for the period 1951-2000 is 89 cm.

First & Second Stage Forecasts issued respectively in April and June, 2012

This year, the first stage forecast was issued on 26th April and Second stage forecast was issued on 22nd June. Summary of IMD's long range forecasts for the 2012 south-west monsoon season (June to September) issued in two stages are given in the table below. In the last column, the actual rainfall received upto 31 July is also given.

Region	**Period**	**Forecast (% of LPA)**		**Actual Rainfall Received so far (1 June- 31 July) % of LPA**
		1st Stage	2nd Stage	
All India	June to September	99 ± 5	96 ± 4	81
Northwest India	June to September	-	93 ± 8	64
Central India	June to September	-	96 ± 8	85
Northeast India	June to September	-	99 ± 8	90
South Peninsula	June to September	-	95 ± 8	77
All India	July	-	98 ± 9	87
All India	August	-	96 ± 9	-

Details of the 5- parameter operational model used for preparing the forecast :

During the second half of the monsoon season (August to September) the long period average (LPA) of the rainfall over the country as a whole is 43.5cm (49% of the average season rainfall) based on the 1951-2000 climatology. The coefficient of variation (C.V) of the rainfall time series is 15%. For the forecast of August - September rainfall over the country as a whole, a new Principal Component Regression (PCR) Model based on 5 predictors has been used. The model error of 5-parameter PCR model is 8% of LPA.

The 5-parameter PCR model was also used to prepare probability forecasts for the pre-defined 3 (tercile) categories of rainfall during the second half of the monsoon season. These are below normal (<94% of LPA), near normal (94-106% of LPA), above normal (>106% of LPA). The tercile categories have equal climatological probabilities (33.33% each). The forecasted probabilities for the rainfall during the second half of 2012 southwest monsoon season over the country as a whole in percentage for the above tercile categories are 62%, 33%, and 5% respectively.

SST conditions in Pacific and Indian Oceans :

The weak to moderate La Nina conditions prevailed over the equatorial east Pacific during later part of 2011 continued till first half of February 2012, after which it started weakening and dissipated in the early April 2012. As of now, ENSO neutral conditions are prevailing. But El Nino conditions are building up in the equatorial Pacific with sea surface temperature (SST) anomalies of 0.5 ^{o}C observed over much of the equatorial east Pacific during the recent two weeks. The latest forecasts from a majority of the dynamical and statistical models indicate strong possibility (with a probability of about 65%) for weak to moderate El Nino conditions to emerge during the next two months. Therefore, the El Nino conditions are likely to have adverse impact on the rainfall over the country during the second half of the monsoon season.

Over Indian Ocean, the latest forecasts from some climate models indicate possibility for the development of a weak negative Indian Ocean Dipole (IOD) event during the next few months. Therefore, IOD may not have much influence on the monsoon.

Summary of the forecast outlook for the rainfall during the second half of the 2012 Southwest monsoon rainfall

(a) The rainfall during August is likely to be normal (96 ± 9% of LPA) as was forecasted in June.

(b) Rainfall over the country as a whole for the second half (August to September) of the 2012 southwest monsoon season is likely to be below normal (<94% of long period average (LPA)).

(c) Quantitatively, rainfall for the country as a whole during the period August to September, 2012 is likely to be 91% of LPA with a model error of ± 8%.

(d) Based on the rainfall distribution over the country till date and outlook for the second half of the season, the seasonal rainfall of the entire southwest monsoon season (June to September) is likely to be deficient (< 90% of LPA).

TROPICAL CYCLONES AND STORM SURGES: THEIR CHARACTERISTICS AND IMPACT

A.V.R. Krishna Rao

A **tropical cyclone** is an intense low-pressure center surrounded by a spiral band of clouds, in which thunderstorms that produce strong winds and heavy rain, are embedded. They are generated over warm oceans where the temperature, not only of the surface but up to a depth of 60m, is above 26.5 deg C. Tropical cyclones strengthen when water evaporated from the ocean rises, resulting in condensation of water vapour contained in the moist air. The characteristic that separates tropical cyclones from other cyclonic systems is that at any height in the atmosphere, the center of a tropical cyclone will be warmer than its surroundings; a phenomenon called "warm core" storm systems. The term "tropical" refers both to the geographical origin of these systems, which usually form in tropical regions of the globe, and to their formation in maritime tropical airmass. The term cyclone is derived from a Greek word meaning "Coils of a Snake". This was first used by Henry Paddington, an officer in the Kolkata Port, in the middle of the last century for tropical revolving storms in the Bay of Bengal and the Arabian Sea. These two seas combinely are referred as North Indian Ocean (NIO). Depending on its location and strength, a tropical cyclone is referred to as **hurricane**, **typhoon**, **tropical storm**, **cyclonic storm**, **tropical depression**, and simply **cyclone**.While tropical cyclones can produce extremely powerful winds and torrential rain they are also able to produce high waves, damaging storm surge, and tornadoes. The associated winds are often exceeding 200 kmph, rainfall exceeding 50 to 100 cm in a day, and very high storm tides often exceeding 7 meters in height, bring disaster to the coastal areas. In extreme cases, a wind speed of 320 kmph gusting to 360 kmph, rainfall of 120 cm in 24 hours and storm surge of 13 to 14 m, have been recorded, in association with tropical cyclones. Out of these three destructive phenomenon, the most destructive one is the storm surge which causes 90% of the loss to life and property. The storm surge is a rapid increase in sea level along the coast, which is primarily caused by wind at the time of cyclone crossing the coast. The impact of tropical cyclone is, however, place and time dependent and is not on its strength alone. They develop over large bodies of warm water, and lose their strength if they move over land due to increased surface friction and loss of the warm ocean as an energy source. This is why coastal regions experience significant damage from a tropical cyclone, while inland regions are relatively safe from strong winds. Heavy rains, however, can produce significant flooding inland, and storm surges can produce extensive coastal flooding up to 40 km from the coastline. Although their effects on human populations can be devastating, tropical cyclones provide relief from drought conditions. They also transport heat energy from the tropics toward temperate latitudes, thus maintaining the thermal equilibrium in the Earth's troposphere.

The rotation of the winds around the center, is anti-clock wise in the Northern Hemisphere (i.e.) in our Indian latitudes. It is clockwise in Southern Hemisphere. Tropical cyclones are named to provide easy communication between forecasters and the general public regarding forecasts and warnings. Sometimes storm can last for a week or longer and more than one storm can be occurring in the same basin at the same time. Names can reduce the confusion about which storm is being described. Convention of naming the storms started in India very recently, from October 2004. Till that time the cyclones were referred by the basin of origin, years and date.

The tropical cyclones in the north Indian Ocean are classified by the associated surface wind speed, estimated or observed, as given below:

The amount of deficiency of pressure at the centre determines the severity of the cyclone. Till half the way from periphery to the centre the horizontal rate of decrease of pressure is gentle. Thereafter the decrease becomes rapid as one approaches the centre. This rapid decrease of pressure, coupled with coriolis' force, gives rise to very strong winds of 100-200 kmph or even more. This revolving system moves as a whole. The direction of movement has a pole ward component in both the hemispheres. Another feature that one has to note is that air parcels do not move round on circular paths. They move more or less on spiral path towards the centre.

System	Pressure deficiency @ (hPa)	Associated wind knots (kmph)
Low Pressure Area	1.0	<17 (32)
Depression	1.0 -3.0	17-27 (32-50)
Deep Depression (DD)	3.0 -4.5	28-33 (51-59)
Cyclonic Storm (CS)	4.5-8.5	34-47 (60-90)
Severe Cyclonic Storm	8.5-15.5	48-63 (90-119)
Very Severe Cyclonic Storm (VSCS)	15.5 – 65.6	64-119 (119-220)
Super Cyclone	>65.6	>119 (>220)

@system's centre to outer edge (periphery)

In more than 75% of the cases, the movement in Indian seas is West North West wards or North West wards. The average distance covered per day is 360-480 km per day (15-20 kmph). They may change the direction of movement towards North or North East. At that time the cyclone may become stationary for some hours or the speed may decrease to 10 kmph or even less. After recurvature they may move faster at 25 kmph or more. Just before crossing the coast also the cyclones may move faster than the normal speed. The cyclones in the Bay of Bengal after recurvature may move to Bangladesh coast or Myanmar coast.

One measure of the size of a tropical cyclone is determined by measuring the distance from its center of circulation to its outermost closed isobar. If the radius is less than two degrees of latitude in extent or 222 km , then the cyclone is "very small" or a "midget". A radius between 3 and 6 degrees latitude or 333 to 670 km, are considered "average-sized". "Very large" tropical cyclones have a radius of greater than 8 degrees or 888 kilometres, The cyclones over northwest Pacific Ocean are the largest on earth on average, and those over North Atlantic and North Indian ocean are roughly half their size.

Climatology and Seasonal Distribution

The average annual frequency of tropical cyclones in the north Indian Ocean is about 5 (about 5.6% of the global annual average). The frequency is more in the Bay of Bengal than in the Arabian Sea, the ratio being 4:1. The cyclones that form over Bay of Bengal are either develop *in situ* over South East Bay of Bengal and adjoining Andaman Sea or re-intensify when the remnants of typhoons over North West Pacific move across South China Sea to Indian Seas. As the frequency of typhoons over North West pacific is quite high (about 35 of the global average), the Bay of Bengal also gets its increased share. On the other hand, the cyclones over Arabian Sea either originate *in situ* over South East Arabian Sea or remnants of cyclones from the Bay of Bengal that move across South Peninsula. As the majority of cyclones over Bay of Bengal weaken over land after land fall, the frequency of migration into Arabian Sea is low. In addition to this, the sea surface temperatures over the Arabian Sea are lower than those over Bay of Bengal. Out of the six tropical cyclones, 2-3 intensify into the severe cyclonic storms.

The monthly frequency of cyclone formation in the North Indian ocean shows a bimodal variation with primary peak in November and secondary peak in May. During the monsoon season, these disturbances move west wards. Since the time available for the system over the ocean is not large enough before encountering the Indian Land mass, they do not attain the intensity of a tropical cyclone. Moreover, the vertical wind shear over this area is also more and hence these systems do not intensify into cyclonic storms, during monsoon season. The number of cyclones effecting state wise of the maritime states is given above (Fig1a & b).

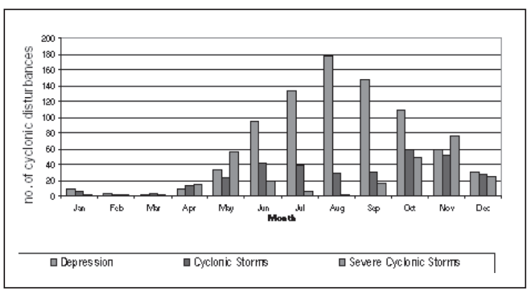


Fig. 1a : Monthly distribution of cyclones. First linerepsentsno.of depressions, the second cyclones and the third no of severe cyclones

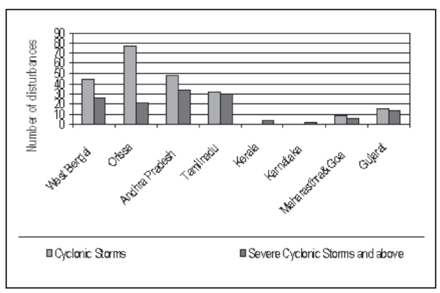


Fig. 1b : Statewise distribution of the cyclones, first line is no.of cyclones and the second one is no.of severe cyclones.

As mentioned earlier, severe tropical cyclones inflict heavy losses on the Coastal population, in the form of storm surge, strong winds and heavy rains. The effects of high winds and storm surge are concentrated within a few km of the coast. But the heavy rainfall, associated with these systems affect areas hundreds of kilometers from the coast which may lead to flooding. The only positive consequence of a cyclone is that it produces rainfall essential over vast areas on the land when it crosses the coast, making a few reservoirs full.

The total energy liberated, in the form of latent heat is enormous. The tropical cyclone being a poor heat engine., converts only 3% of the heat energy into kinetic energy. It is estimated that a tropical cyclone releases heat energy at the rate of 50 to 200 exajoules (10^{18} J) per day. This rate of energy release is equivalent to 70 times the world energy consumption by humans or to exploding a 10-megaton nuclear bomb every 20 minutes.

Life Cycle of a Tropical Cyclone

The average life period of storms and depressions in the North Indian Ocean is about 4-5 days in the post monsoon months. Storms of hurricane intensity have an average life period of 2-4 days in the North Indian Ocean, as against the world's average of 6 days. The cyclone, when it forms, draws water vapour from the areas beyond the area of formation as well as Warm Ocean below especially in the mature phase. The entire life period of tropical cyclone is divided in four stages. They are (a) formative stages (b) Developing stage (c) Mature stage and (d) Decaying stage.

Formative stage:

- In this stage, a large oceanic area is involved, where the winds are variable, gusty at some places , with showery precipitation. The wind strengthens asymmetrically and rotates in an anticlockwise direction. Elliptical or circular wind circulations develop over the inter tropical convergence zone, the birth place of the cyclones. Satellite cloud top temperatures indicate the height of the clouds as 10 km or more Spirally banded structures of the clouds with clear spaces in between can be seen in the satellite pictures..

Development Stages:

During this phase the pressure fall continues. The wind speed increases, the pressure over the central parts of the low pressure area falls by 5 or even 10 hPa during the course of a day or two. The decrease of pressure towards the centre can be as much as an hpa for every 30 km and the winds increase to 50 kmph or more. In this stage the meteorologists call it as a depression. This remains as a depression as long as the maximum winds encountered are less than 60 kmph. From this stage onwards the area of the low atmospheric pressure, the depression and the associated winds system together with the weather phenomenon, would start moving along the oceanic area. The entire system moves at the rate of 300-500 km per day towards West or West North West. Only some depressions develop into the next phase.

Mature Phase:

- In this phase, the depr.ession intensifies into a cyclonic storm, as the maximum wind speed exceeds 33 knots or 60 kmph. The classification of the system is made as per the strength of the surface wind as indicated in the table above. Over the Indian seas, it is rare that the pressure deficiency of the centre be more than 60 hPa. In the mature phase of a severe cyclonic storm the wind system near the surface is found to consist of four parts as given below

- In a *calm central area*, often circular in shape varying between 10 and 30 km in diameter, the winds are very light or absolute calm prevails. The skies are mostly clear or lightly clouded. There is no rain. The temperature is significantly warmer than in the cloudy and rainy area outside this area. This is called eye of the storm. The satellite is able to see the sea surface as there are no clouds. The eye appears as a dark spot at the centre of a large patch of bright clouds.

- An *inner ring of strong winds* (speeds more than 90 kmph), 50 to 150 km in width around the central area forms. In this annular area, pressure falls inwards at the rate of 1 hPa for every 30 or 40 km distance. Torrential rains occur here. The clouds grow to a height of 14 to 16 km.

- An *Outer Storm area* forms, within which the winds are less strong 20-30 kmph. There is an asymmetry of rainfall patterns, clouds, winds etc., about the centre or eye of the storm. Rainfall is not continuous. The cloud pattern consisting of spiral bands are seen in the satellite picture

- In the *outer most storm area*, weak, anticlockwise circulation prevails. Over this area, the spiral cloud bands are thin, elongated and consists of sparse cloud cells. Winds are weak, rainfall is showery and light.
- Storm surge is associated with this phase.

Dissipating Phase:

The tropical storms begins to lose their intensity when they move out of the environment of warm moist tropical air, or move over land or move under an unfavourable large scale flow aloft. In the process of recurvature, under the influence of a westerly trough, they may move to the regions where ocean temperatures are cooler. When the storm enters the land, it rapidly weakens as the central pressure is filled up at a rate of 2 hPa/hr. This weakens the radial pressure gradient and the radius of maximum wind expands outward. The lack of supply of water vapour over land and the friction it offers are responsible for the weakening of the system. However, the rainfall from already available moisture continues for a day or two over the coastal area, though the system decreases in intensity. As a depression also, it gives copious rainfall along its track ,while weakening steadily.

Tropical cyclones in north Indian Ocean generally weaken only after entering the land. Since the sea surface temperatures are above 27°C in the post monsoon season, cyclones weakening due to cooler sea surface temperature does not arise. Some of them, decay over the ocean by entering into strong vertical wind shear zone generally prevailing in the northern parts of the northern Indian ocean.

Cyclogenesis:

In the early stages of the development over the ocean a low pressure area forms, and a cluster of vertically developed clouds form as a result of vertical currents due to the converging winds. These cumulonimbus clouds give rise to thunderstorms. During the thunderstorms, latent heat is released, as vapour changes to liquid form which falls as rain. Due to the heat release, the atmosphere gets heated up. If that heat is not taken away due to wind shear, as the air column becomes warmer, the pressure at the surface falls further. As the pressure decreases, more winds converge towards the centre of the low, resulting in further cloud development. This is a cycle of development and is known as Conditional Instability of Second Kind (CISK) by which the cyclone development is explained.

Structure of a Tropical Cyclone

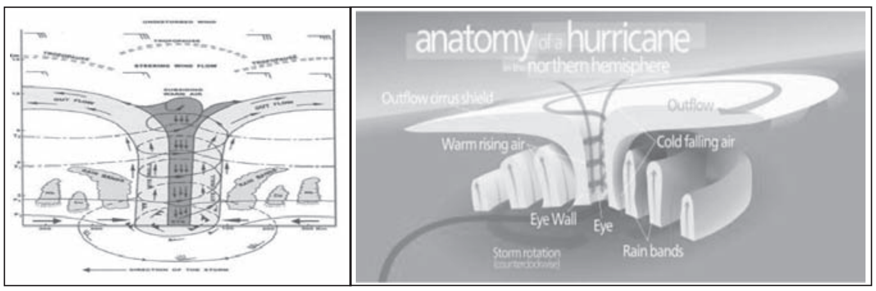


Fig. 2 : Schematic three dimensional view of the hurricane

When the cyclone is fully developed in the matured stage and if eye forms, then the vertical structure of the storm may look somewhat like the one shown in the fig. 2

During the mature stage, the circulation expands and in moving storms, hurricane winds may extend several hundreds of kilometers from the centre to the right of direction of motion (in NH). A well formed inner ring of maximum winds encircles the ‘eye” where pressure stops falling, wind is light, rainfall ceases and clouds disappear. Even in this stage, the system may undergo wide fluctuations in its intensity; pressure in the centre may increase or decrease by as much as 60 hPa in a day.

An analysis of observations of maximum winds associated with the cyclonic storm in the northern Indian ocean during the past one century suggests that only on 10% occasions wind speed exceeds 100 knots. The estimated highest maximum surface wind speeds in the North Indian ocean is about 145 knots.

EYE: Three basic types of eye formation are seen. They are circular, concentric and elliptical as shown in the fig.3

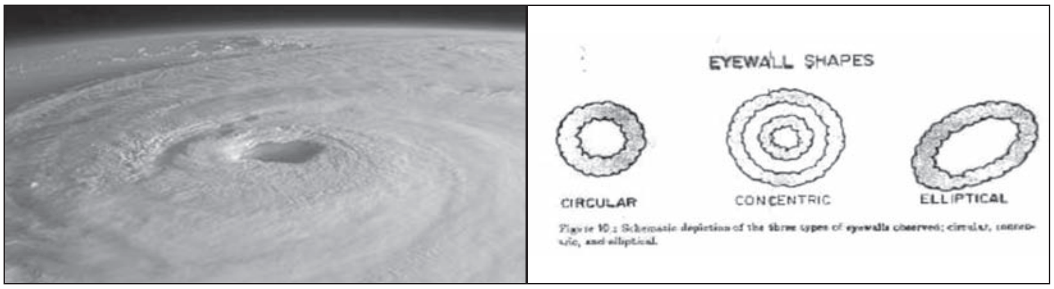


Fig. 3 : Types of cyclone eyes

Rainfall

The rainfall maxima are separated by a minimum to the north of land fall point in the east coast and the highest maxima occurs close to the centre to its south. The belt of heavy rainfall extends more to the north than to the South. Rainfall amount of the order of 35 to 40 cm would occur with severe cyclonic storms and 20-30 cm in the case of cyclonic storms.

The rainfall distribution in a severe cyclone is shown in fig. 4. Heavy rainfall occurs in the right front quadrant. When the cyclone is in mid ocean the max. rainfall occurs at 1000-1200hrs local time while the minimum occurs at 1800hrs local time.

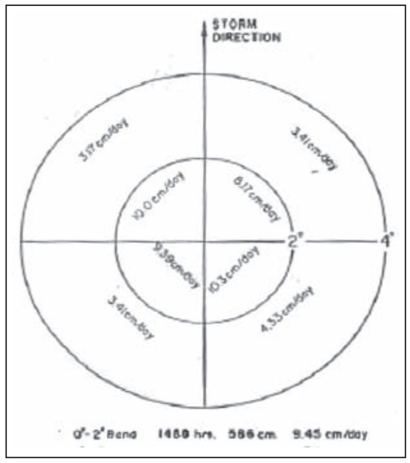


Fig. 4 : Fig.4 Mean precipitation around tropical cyclones (Frank 1977a).

Storm Surges

A **storm surge** is an offshore rise of water associated with a, tropical cyclone. Storm surges are caused primarily by strong winds pushing on the ocean's surface. The wind causes the water to pile up higher than the ordinary sea level. Combined effect of low pressure and persistent wind over a shallow water body is the most common cause of storm surge flooding problems. When referring to storm surge height, it is important to clarify the reference point. In areas where there is a significant difference between low tide and high tide. Storm surges are particularly damaging when they occur at the time of a high tide. The **figure 5** explains the mechanism of surge inundation when a cyclone crosses the coast. The height of the surge and the consequent inundation caused by it depend on :a)central pressure b) intensity of the storm c) size of the storm d) speed of the storm, e) angle of approach to the coast f) shape of the coast line, g) local bathymetry and h) local features. Significant surges effect almost all parts of the Indian east coast and coast of Bangladesh and the most intense and frequent occurrences have been in the North Bay of Bengal causing heavy destruction to life and property. The highest surge, so far a record in the world occurred in 1876 in Bangladesh and it was 40 ft above mean sea level. The surge is generated due to interaction of air, sea and land. The surge occurs at the time of landfall of the cyclone and to the north of the cyclone centre. Storm surge is inversely proportional to the depth of the sea water. If the water is shallow, the surge is high. If the astronomical tide is high , at the time of storm crossing the coast, the surge height is compounded and the destruction that it can cause is immense. The water bodies are polluted with the saline water. The saline water inundation of the fields destroys not only the crops but make the fields also unfit for cultivation for some time to come. The occurrence of the surge is so sudden that there may not be any time to react to save oneself from drowning.

The storm surge associated with Chirala cyclone of 1977 was 5.5 m and that with the Supercyclone of Orissa in 1999 was 7m. A Surge of 5m occurred during Machilipatnam cyclone of May 1990.

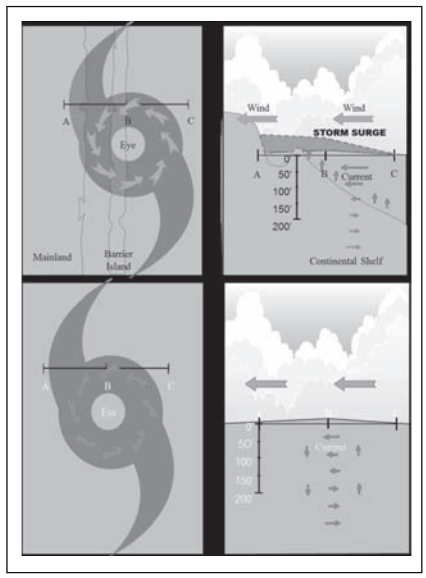


Fig. 5 : Phenomenon of storm surge

CYCLONE WARNING SYSTEMS AND DISSEMINATION FOR EFFECTIVE REMEDIAL MEASURES

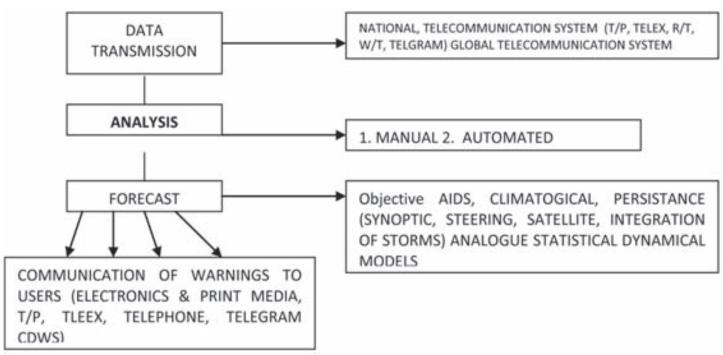
A.V.R. Krishna Rao

Prior to the satellite era, the cyclones when they are in the open sea are monitored through the observations sent by ships plying in the neighborhood. As the cyclone approaches the coast, when the coastline comes under the influence of the cyclone, the systems are monitored with the help of observations from the coast. The observations on pressure falls, changes in the wind direction and speed and the sky conditions of the obtained from the coastal surface stations are closely monitored to assess the location of the system and its movement in addition to the surface and synoptic observations, whose frequency is increased to hourly from the usual once in three hours, as the cyclone approaches the station. Upper air observations are also used to track the cyclone. The help of Radar (Radio Detection and Ranging) is also taken in monitoring the location and movement of an approaching cyclone. A RADAR installed at a coastal station can detect a tropical cyclone by the cyclone’s characteristic spirally shaped cloud bands. However, due to curvature of the earth, clouds even at heights of 12 kms can be detected only upto 400 km from the station. To see the full cyclone, the centre has to be only 200 km away. Any cyclone when it comes within three hundred kilometers, will have its centre identified by our coastal radars. IMD operates a network of cyclone detection Radars (CDR’s) at Kolkata, Paradeep, Visakhapatnam, Machilipatnam, Chennai and Karaikal along the East coast and Goa, Cochin, Mumbai, and Bhuj along the West Coast. These are being replaced by Doppler Weather Radars (DWR’s). DWR’s have already been installed and made operational at Chennai, Kolkata, Visakhapatnam and Machilipatnam. An indigenously developed DWR (Radar by Indian Space Research Organization) has been installed at Srihari Kota. Conventional weather Radars can look deeper into a weather system to provide information on intensity, rain rate and vertical extent. The DWR’s have the capability to probe internal motion of the hydrometeors. This facilitates to derive information on velocity and turbulence structure. DWR’s provide vital information on radial velocity from which wind field of a tropical cyclone in the reconnaissance area of the Radar can be derived. A number of other derived parameters useful for cyclone monitoring and prediction can also be made available.

Since the advent of weather satellite after 60’s, the cyclones could be detected right from the genesis in the mid ocean and be tracked at regular intervals till their land fall. Now no cyclone can go undetected. Since no surface observation in the mid ocean are available, satellite is the only source for such information. The geostationary satellite (Stationary with respect to the earth) monitors the same area every time. Hence it is most useful and convenient in tracking the cyclones. The Satellite techniques can be used to find out the centre of the cyclone and intensity of the system. It can also be used to derive various parameters which are useful for monitoring and prediction of the cyclones and associated disastrous weather.

Observation – Analysis – Forecast System of Tropical Cyclones

SATELLITES	AIRCRAFT	RADAR	RAWINSONDES	SURFACE DATA
POLAR ORBITING	AIREPS		(PILOT BALOONS)	LAND/SHIPS
GEOSTATIONARY	RECONNAISSANCE			DRIFTING BUOYS



Forecast of tropical cyclone:

Forecast of tropical cyclones involves track prediction and intensity prediction. For track prediction both numerical as well as synoptic methods are used while numerical methods are used for intensity prediction. Structure is indicated above

Interaction of tropical cyclones:

Sometimes two tropical cyclones, which are in close proximity, interact with each other. It is found that the relative motion of two adjacent cyclones is composed of a cyclonic orbit around the centroid coupled with a mutual. The rate of orbit increases as they spiral inward towards one another. This is known as “Fujiwara Effect”. This type of situation occurred in November 1977 when two cyclones, one in the Bay of Bengal off AP Coast and the other in the Arabian Sea off the Karnataka Coast were located. The Bay Cyclone moved NW and crossed Andhra Coast near Chirala, while the Arabian Sea Cyclone moved South Eastwards and weakened over Kerala coast.

Sometimes when the tropical cyclones are under the influence of a trough in the Westerlies and re-curve to the North East wards. If such movement continues beyond tropical latitudes, they may gradually acquire extra tropical cyclone properties and continue as an extra tropical cyclone.

Cyclone Warning System in India

Organizational structure:

At New Delhi, the Regional Meteorological centre was re-designated by WMO as Regional Specialized Meteorological Centre (RSMC), Tropical Cyclones, New Delhi, from July 1988. It is assigned the responsibility of issuing Tropical weather outlooks and Tropical cyclone advisories for the benefit of the countries in WMO/ESCAP panel, bordering Bay of Bengal and the Arabian sea. The countries are Bangladesh, Maldives, Myanmar, Oman, Pakistan, Srilanka and Thailand. A cyclone warning division is also co-located in New Delhi.

Working under these centers are three Area Cyclone Warning Centers (ACWC) at Kolkata, Chennai and Mumbai and the three cyclone warnings centers (CWC) at Bhubaneswar, Visakhapatnam and Ahmedabad. The CWC’S Visakhapatnam, Bhubaneswar and Ahmedabad function under ACWC’S Chennai, Kolkata, and Mumbai respectively. CWC Visakhapatnam caters for Andhra Pradesh Coast, CWC Bhubaneswar for Orissa Coast and CWC, Ahmedabad for Gujarat, Daman and Diu coast. M.C. Hyderabad liaises between CWC Visakhapatnam and the officials of Government of Andhra Pradesh.

The present organizational structure for cyclone warning is a three tier system. ACWCS / CWCS actually perform the operational work of issuing the bulletin and warnings to the various user interests, while the cyclone warning Directorate, New Delhi and the Deputy Director General of Meteorology (Weather forecasting), Pune through Weather Central, Pune coordinates and guides the work of ACWCS/CWCS, exercises supervision over their work and takes necessary measures for continued improvement and efficiency of the storm warning systems. The ultimate responsibility of issuing operational storm warnings for the respective areas rest with the ACWCS and CWCS.

Warning Bulletins:

Disaster Managers expect longer lead time and improved accuracy of land fall forecast. But the present state of the art has limitation to meet these requirements, though there has been considerable improvement in these forecasts due to the availability of modern computer and observational tools like Satellite and Radars. In order to cater to the needs of the officials concerned in the disaster mitigation work, IMD has introduced since 1999 a 4-stage warning system, to be issued to the Disaster Mitigation Managers.

a) Pre Cyclone Watch: Issued when a depression forms over the Bay of Bengal, irrespective of the distance from the coast, and likely effect on Indian coast. It is issued in the name of Director General of Meteorology and is issued at least 72 hours in advance of the commencement of adverse weather. This bulletin is issued once a day, to all the Chief Secretaries of the concerned maritime states.

b) Cyclone Alert: Issued at least 48 hours before the commencement of bad weather when the cyclone is located beyond 500 km from the coast. Frequency is once in every three hours.

c) Cyclone warning: Issued at least 24 hours before the commencement of bad weather when the cyclone is located within 500 km from the coast. Information about time/place of land fall are indicated in the bulletin. Confidence in the estimation increases as the cyclone comes closer to the coast.

d) Post land fallout look: It is issued 12 hours before the cyclone land fall, when the cyclone is located within 200 km from the coast. More accurate and specific information about the time/place of land fall and associated bad weather are indicated in this bulletin. In addition, the interior destruction likely to be caused due to the cyclone are included in this bulletin.

These centres issue various bulletins to cater to the needs of public, fishermen and for the shipping. They are

a) Coastal weather bulletin:

This is issued by ACWC/CWC for coastal shipping.

- Twice a day based on 03UTC (Universal Time Coordinated) and 12 UTC charts. Frequency increases to three times /day in case of a depression, six time s /day in case of a cyclone. However provision is made to issue a special bulletin at any time in case of sudden intensification or weakening. This bulletin is framed based on Sea area bulletin . This bulletin contains the information about the present location, expected movement, expected weather, wind, rainfall, state of sea, storm surge, port warnings and warning for fishermen. Based on this, numbered Cyclone warning Bulletins are issued with all the above information

b) Sea area bulletin:

- These are issued by ACWC for deep Sea. Normally twice a day based on 03 UTC and 12 UTC charts. Twice a day in case of depression/deep depression (additional bulletin 18 UTC), six times a day in case of a cyclone. There is also a provision for special bulletin. The bulletin contains significant system, expected weather, Wind, state of sea, port warning etc.,

c) Fisherman warnings:

A fisherman warning is a warning message for fisherman who live in coastal areas or may go into sea. Danger to fisherman due to the storm are strong winds, and associated high waves due to which fishing boats may capsize. Hence, the fisherman are issued warnings when one of the following conditions of the weather is expected along and off any coast

1) Strong offshore and onshore winds (with speed exceeding 45 kmph). 2) Squally weather, frequent squalls with rain, or persistent, strong gusty winds (20 kts or 36 kmph) accompanied by rain. 3) Gales and state of sea very rough or above normal wave heights (4 meters or above).
2) These warnings are disseminated to fisherman through (1) port, (2) Fisheries Officials (3) AIR Broadcast. These warnings are broadcast on a routine 4 times a day (0600 hrs mid day, evening and midnight) from the AIR Stations in the local language. During a cyclonic weather, such warnings are covered in the cyclone bulletin sent to AIR station at hourly or 3 hourly intervals for frequent broadcast. The fisherman warnings issued at midday are incorporated in the general weather bulletin by forecasting offices in maritime states. The warning bulletin contain information about 1) Synoptic situation 2) signals hoisted and 3) Advice not to venture into the sea.

Port warnings:

The strong winds or high seas pose danger to ports. Moreover, if a storm is at high seas, the ships moving off the port may experience very rough weather. Therefore, the port is informed and advised to hoist appropriate signals which can be seen by mariners both during day and night. There are Eleven signals. During day cones & drums are used for hoisting the signals while lights are used in the night time.

The features are as follows:

- Port Officers are warned by IMD about disturbed weather likely to affect the ports
- On receipt of the warnings the port officials hoist appropriate visual signals.
- Ports are warned 5 to 6 times a day during the cyclone storm.

- Warning contains information about location, intensity, expected direction of movement, expected land fall point and the type of signal the port should hoist.
- Port warning signals are given below

In consultation with the DDGM (WF) Pune and the concerned ACWC, numbered cyclone warning bulletins are issued by the cyclone warning division, New Delhi.

The bulletin contains information about:

Synoptic situation, present location of the cyclone, expected movement and time and place of land fall point, warning about expected storm surge, warning about wind strength, warning about rainfall, likely damage to occur due to winds, indicate about evacuation of people from low lying areas, state of sea, signals hoisted at ports and warning for fisherman not to venture into the sea. These bulletins are issued twice a day for dissemination.

Cyclone Warnings Dissemination

After the warnings are prepared, it is also important to see that these bulletins reach the users in time. For this purpose various means are used to disseminate the warning bulletin. They are

- 1) T/P (Internet), 2) Telephone, 3) Telefax, 4) VHF/HFRT(Internal), 5) Cyclone warning Dissemination System (CWDS), 6) Police Wireless, 7) AFTN (For aviation), 8) Internet (Emails), 9) Websites, 10) Radio/TV Network, 11) Interactive Voice Response System and 12) Mobile Phones
- T/P and VHF/HFRT are used to exchange information among the Departmental Offices.The relevant warnings or other information is available in the cyclone page of IMD’s Website (www.imd.gov.in)
- IVRS stands for Interactive Voice Response System. The requests for weather information and forecasts from the general public are automatically answered by this system. For this purpose, one has to dial a toll free number “18001801717” from anywhere in the country. This system has been installed at 26 Meteorological centers/Regional Meteorological centers. The data on maximum and minimum temperature and rainfall for a large number of towns/cities are provided. The local weather forecasts of cities and multi-hazard warnings including cyclone warnings are also provided.
- The chances of all land based systems becoming nonserviceable due to the adverse weather during the cyclonic storm are more. Even in these conditions, to reach the affected population for the dissemination of the warnings, satellite based warning system called Cyclone Warning Dissemination System (CWDS) has been designed. It is designed by Indian Space Research Organization (ISRO) and is implemented by IMD in the mid eighties. This is unique warning system which is tried nowhere in the world. Experience during the past 24 years, in case of so many cyclonic situations indicate the success and the reliability of this mode of warning which is very effective. It gained considerable confidence of the public of this country.
- The receiving sets are installed in Taluk office or MRO Office not only for their safety but for the availability of the persons to receive the message at any time of the day. The working of the system is shown in fig.1.

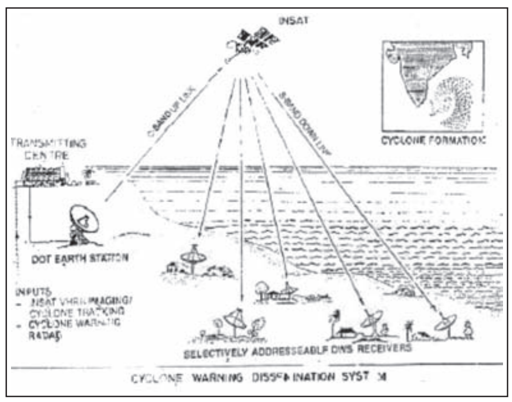


Fig. 1: Cyclone Waning Dissemination System (CWDS)

Each set is allotted a digital code, by pressing of which at the control station a siren is hooted for a minute to attract the attention of the public and / or officials manning it. The controlling stations are the concerned ACWC’s

- The warnings are generated in English and local languages (Tamil, Telugu, Bengali, Marathi, Gujarathi, Oriya etc.,)
- All the codes of the sets for which the warning message is to be disseminated are activated by the control station and the relevant warning message is read out in English and concerned local language.
- This is one way communication only. Latest version sets have a facility to acknowledge the receipt of the message.

- At present, 252 sets are installed, spread over coastal area of maritime districts along the East and West Coasts of India.
- Through World Bank assistance Government of Andhra Pradesh had installed 100 digital CWDs receivers along Andhra Coast. For this purpose a digital uplinking station also functions at Chennai.

For the general public, the bulletins are disseminated through broadcast by Radio and TV. The frequency of broadcast by AIR, New Delhi is twice a day as National Bulletin in English and Hindi and the local language of the concerned area. These bulletins are also broadcast through Regional AIR stations frequently in local language and the frequency becomes hourly as the cyclone approaches the coast. If necessary, the concerned Radio station extends the broadcasting timings throughout the night. The information about the approaching cyclone is disseminated through newspapers and scrollings on the TV. Interviews with the concerned Meteorologist are also Telecast for the information to reach the public, in the news cycles.

Apart from this, the cyclone warning messages are sent to the Collectors of the districts likely to be affected and the Chief Secretary of the concerned state. The State Government takes necessary steps to inform the local population through police wireless, or their own wireless network. The warnings are disseminated in the villages and hamlets of fisherman through TOM in the local language. The concerned administrative officials make necessary arrangements for evacuation of people from the vulnerable coastal areas, to safer places to avoid the danger from Storm Surge, which inundates all low lying areas. In addition, the Meteorologist of the concerned CWC briefs the Collectors, personally from time to time, to give updates about the cyclone movement.

Area cyclone warning centers (ACWC's) and cyclone warning centers (CWC) maintain close liaison with the concerned state governments in the state and district level on cyclone related activities. The cyclone warning bulletins are communicated to the Chief Secretary, Revenue Secretary, Special Relief Commissioner, State Control Room, State Disaster Management Authority and concerned District Collectors. ACWC/CWC organizes the pre-cyclone preparedness meeting under the Chairmanship of Chief Secretary of the State, where all the high State Government Officials from various departments participate and the preparedness for the cyclone is reviewed and necessary actions are ordered, in case of those departments which are short of complete preparedness.

IMD has established linkages/Institutional arrangements with Disaster Management Agencies both at the centre and in the states. During normal weather conditions two bulletins are transmitted to control Room of National Disaster Management Division (NDMA). At the time of a depression developing over north Indian Ocean, which has the potential to affect Indian Coast, special bulletins at least three times a day are issued to NDM. When the system becomes a cyclonic storm, the cyclone warning bulletins are issued every three hours. The four stage warning procedure as mentioned earlier, is followed for issuing bulletins to NDM Control Room. When the system weakens, or not going to affect Indian Coast, a de-warning message is also issued to NDM control room. The centres and local committees of various departments dealing with disaster management issues meet at the time of crisis and take necessary follow-up actions.

International Responsibilities

Regional specialized meteorological centre (RSMC) for tropical cyclones New Delhi being one of six such centres all over the world, issue the following advisory to the Rim (surroundings) countries of Bay of Bengal and Arabian Sea.

- Tropical Weather outlook for WMO/ESCAP panel member countries.
- Special tropical weather outlook for WMO/ESCAP panel member countries
- Tropical cyclone advisory for Panel Member countries.
- Tropical cyclone advisory for International Aviation is issued at 00, 06, 12 & 18 UTC

INDIAN TSUNAMI EARLY WARNING SYSTEM

T. Srinivasa Kumar

The great Sumatra earthquake of 26th December, 2004 with magnitude Mw of 9.2, was rated as the world's second largest recorded earthquake. This earthquake generated a devastating tsunami, which caused unprecedented loss of life and damage to property in the Indian Ocean rim countries. The tsunami was considered as one of the deadliest natural hazards in the history, killing over 230,000 people in fourteen countries. In India, it claimed 10,745 lives according to official estimates. In response to this disaster, the Ministry of Earth Sciences (MoES) has taken up the responsibility of establishing the Indian Tsunami Early Warning System (ITEWS) which is based at and operated by Indian National Center for Ocean Information Services (INCOIS), Hyderabad.

Observation Network

The Indian Tsunami Early Warning Centre (ITEWC), which is in operation since October 2007, comprises of a real-time network of seismic stations, Bottom Pressure Recorders (BPR) and Tide gauges, functions round the clock 24 x 7 to detect tsunamigenic earthquakes, to monitor tsunamis and to provide timely advisories to vulnerable community by means of latest communication methods with back-end support of a pre-run model scenario database and Decision Support System.

Seismic data monitoring: One of the most critical aspects of tsunami warning system is to estimate earthquake parameters with reasonable accuracy in shortest possible time. This calls for a well-distributed network of broad-band seismic stations communicating data in real time. As part of the Indian Tsunami Early Warning System, a Real Time Seismic Monitoring Network (RTSMN) has been established by India Meteorological Department (IMD). The network comprises of 17 Broadband seismic field stations transmitting real time data through V-SAT communication to the Central Receiving Stations (CRSs) located at IMD at New Delhi and INCOIS, Hyderabad simultaneously for processing and interpretation. In addition to this, around 300 global seismic stations data are also being received at INCOIS (Fig. 1.).

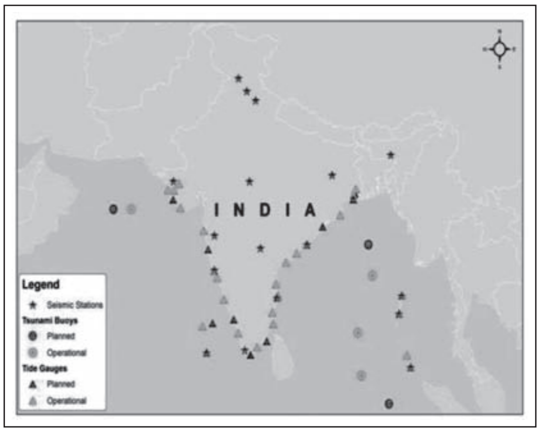


Fig. 1: Tsunami Observation Network

Sea-level data monitoring: In order to confirm the generation of a Tsunami, it is necessary to have Open Ocean and coastal sea level data from Bottom Pressure Recorders and Tide Gauges. The real-time data from these sensors located closer to the tsunamigenic zones ensures quick detection of tsunami signal, thus providing us with more response time, in case a tsunami is generated. A real-time network of 7 BPRs is planned in coordination with National Institute of Ocean Technology (NIOT) for monitoring sea level data in open ocean. Four BPRs are deployed in the Bay of Bengal and two in the Arabian Sea and currently 4 are operational. The communication is through International Maritime Satellite Organisation (INMARSAT) and the data is being received at both INCOIS and NIOT.

A real time network of Tide gauges has been established by the Survey of India (SOI). The network is designed to measure and monitor the progress of tsunamis. The network comprises 36 tide gauges and currently 26 are operational. In addition to this, INCOIS also receives real-time data from around 70 international tide gauges and BPR networks being installed by countries such as Australia, Indonesia, Malaysia and Thailand etc.

Modelling:

To overcome the problems associated with extremely small timelines and low accuracies associated with qualitative tsunami warning, the concept of scenario database using tsunami pre-run simulations was implemented at ITEWC using TUNAMI-N2 (Tohoku University's Numerical Analysis Model for Investigation of Near-field Tsunamis, version-2) model. The Tunami N2 model is customized for Indian Ocean region to predict travel times, directivity maps and surge heights for different scenarios and indicates the extent of inundation of seawater into the land. For operational forecasting a large database of open ocean propagations scenarios (around 50,000) has been generated for epicentres separated by 100 km distance along the entire Sunda and Makran subduction zones for the combination of different magnitudes and depths. As an improvement to the concept of static scenario database, ITEWC now uses 1000 unit sources covering both tsunamigenic regions in the Indian Ocean. Each unit source is of length 100 km and width 50 km, that represents a rupture caused by a M 7.5 earthquake with a slip of 1m. During any earthquake event, the basic unit source open ocean propagation scenarios are selected from the scenario database which are dynamically combined and scaled up or down with slip parameter depending on earthquake's location and magnitude, to resemble actual situation.

Decision supporting system:

In order to monitor real-time data from different sensors and generate automatic advisories based on decision making rules, DSS application software has been developed. The DSS plays crucial role in optimizing the data from available resources within a short period to choose best available option, in decision making.

Operational Procedure and Types of Bulletins

Warning Centre services for an earthquake event commence whenever earthquakes are recorded with magnitudes ≥ 6.5 within Indian Ocean and magnitudes ≥ 8.0 outside Indian Ocean. Duty officers respond immediately and begin their analysis of the event. The analysis includes automatic and interactive processes for determining the earthquake's epicenter, depth, and time of origin, as well as its magnitude.

The types of products issued by Warning Centre include Public and Exchange Tsunami Bulletins. Public products contain Earthquake information and tsunami-genesis potential of the Earthquake. Exchange products contain Coastal Forecast Zones (CFZs) tagged with results of forecast model such as Estimated Wave Amplitudes, Estimate Time of Arrivals and Threat level. The CFZs are high resolution spatial boxes of 100 X 50 km, extrapolated to district level information. As the Exchange products need an expert interpretation they are provided only to authenticated agencies through secured means.

Notification messages :

The warning centre issues brief Notification Messages alerting the recipients as and when a bulletin is issued. The notification messages contain earthquake parameters as well as web links to the detailed Bulletins.

Types of bulletins :

Following is brief description about Types of Bulletins issued by Warning Centre. The bulletins/notifications issued for an event are numbered sequentially. These are identified by the header "**NTWC-INDIA-yyyymmdd-hhmm-bulletin number**".

For Indian Ocean earthquakes, Warning Centre issues **Bulletin-1** that contains preliminary earthquake information and a qualitative statement on its tsunamigenic potential based on the following criteria **(Table 1)**:

Table 1: Criteria for Tsunamigenic potential based on preliminary earthquake parameters

Magnitude (Mw)	Product Type
6.5 ≥ M ≤ 7.5	Small potential to generate local tsunamis that can be destructive along the coast located within 100 km of the earthquake epicenter
7.6 ≥ M ≤ 7.8	Potential to generate regional tsunamis that can be destructive along the coast located within 1000 km of the earthquake epicenter
≥ 7.9	Potential to generate ocean-wide tsunamis that can be destructive along entire coastline of the Indian Ocean.

Based on preliminary earthquake parameters, the nearest matching scenario from pre-run model scenario database is selected. If pre-run model scenario indicates Estimated Wave Amplitude (EWA) < 0.2 m then **Bulletin-2** is issued with **NO THREAT** information. However, the monitoring of sea-level observations continues.

If the Estimated Wave Amplitude > 0.2 m, then **Bulletin-2** is issued with Estimated Time of Arrival (ETA), Estimated Wave Amplitude (EWA) and Threat Category **(WARNING / ALERT / WATCH)** for each of the coastal forecast zones.

The criteria for generation of different threat types (**WARNING / ALERT / WATCH)** for a particular region of the coast are based on the available warning time (i.e. time taken by the tsunami wave to reach the particular coast). The threat criteria are based on the premise that coastal areas falling within 60 minutes travel time from a tsunamigenic earthquake source need to be warned based solely on earthquake information, since enough time will not be available for confirmation of water levels from BPRs and tide gauges. Those coastal areas falling outside the 60 minutes travel time from a tsunamigenic earthquake source could be put under a Alert/Watch status and upgraded to a Alert/Warning only upon confirmation from water-level data.

The criteria for considering an area under different Threat levels **(WARNING/ALERT/WATCH)** are as follows **(Table 2)**:

Table 2 : Threat level status criteria

Pre-run Model Scenario Results			
ETA ≤ 60 mins		ETA ≤ 60 mins	
EWA (M)	Threat Status	EWA (M)	Threat Status
>2	WARNING	>2	ALERT
0.5 to 2	ALERT	0.5 to 2	WATCH
0.2 to 0.	ALERT	0.2 to 5	WATCH

As and when the revised earthquake parameters become available, or else if earthquake elapsed time exceeds > 60 mins, before the realtime sea-level data becomes available, then a supplementary to the Bulletin-2 (**Bulletin-2 Supplementary-xx**) is issued with revised Threat (WARNING / ALERT / WATCH) information.

If a Threat (WARNING / ALERT / WATCH) is issued or if there is otherwise the possibility of tsunami generation, Warning Centre monitors the sea level gauges such as open ocean BPRs and coastal tide gauges near to the epicenter.

If the readings from sea level gauges confirm generation of tsunami, Warning Centre issues **Bulletin-3** with Threat (WARNING / ALERT / WATCH) information from model scenario as well as **observed water levels** (Table 3). As and when subsequent real-time observations become available or after 60 mins from the time of previous bulletin issuance, **Bulletin-3 Supplementary-xx** is issued. Bulletin-3 Supplementary-xx messages also contain Threat Passed information for individual Zones.

The **FINAL bulletin** is issued when there are no significant water level changes from multiple sea level gauges or 120 mins after the last exceedance of 0.5 M threat threshold at the last Indian coastal point.

However, as local conditions would cause a wide variation in tsunami wave action the ALL CLEAR determination is made by local authorities.

Table 3: Actions based on threat status

Threat Status	Action to be taken	Dissemination To
WARNING	Public should be advised to move in-land towards higher grounds. Vessels should move into deep Ocean	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media
ALERT	Public should be advised to avoid beaches and low-lying coastal areas. Vessels should move into deep Ocean	MoES, MHA, MEDIA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media

WATCH	No immediate action is required	MoES, MHA MoES, MHA, MEDIA, NCMC, NDRF Battalions, SEOC, DEOC
THREAT PASSED	All clear determination to be made by the local authorities	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media

MoES : Ministry of Earth Sciences

MHA : Ministry of Home Affairs

NDMA : National Disaster Management Authority

NCMC : National Crisis Management Centre

NDRF Battalions : National Disaster Response Force

SEOC : State Emergency Operations Centre

DEOC : District Emergency Operations Centre

Bulletin formats :

Tsunami Bulletins are generated in all common data exchange formats such as .txt, .html, .kml and .dbf.

- **Notification Messages** are issued in **text format**
- **Tsunami Bulletins** are issued in both text and **html formats**
- **Graphics** are made available in jpg or png format on the **website**
- **Spatial data** is made available in dbf format through the **ftp site**

Dissemination Methods

Presently, tsunami warning bulletins disseminated to the Ministry of Home Affairs (MHA) control room, Ministry of Earth Sciences (MoES), National Disaster Management Authority (NDMA) as well as Andaman & Nicobar Administration through Fax, Phone and Emails. Considering that A&N islands are close to the tsunamigenic zones, special priority is given to disseminate tsunami bulletins to the concerned authorities during an event through multiple dissemination modes. For instance, tsunami bulletins are also disseminated through four Electronic Display Boards installed in A&N Islands. Earthquake information, tsunami bulletins as well as real-time sea level observations are also made available on a dedicated website for officials, public and media. Users can also register on the website for receiving earthquake alerts and tsunami bulletins through emails and SMS. Warning Centre publishes all earthquakes of magnitude ≥6.5 on web. Exchange bulletins can be viewed only after proving login credentials. Users can download the information in .kml, .txt, and .dbf format through the links provided in each bulletin. The following is the link for National Tsunami Warning Centre's website http://www.incois.gov.in/Incois/tsunami/eqevents.jsp

Performance of Warning Centre

One of the most critical aspects of tsunami warning system is to estimate earthquake parameters with reasonable accuracy in shortest possible time (i.e., within 10 minutes for local events). The earthquake location and its magnitude are two other critical parameters to be estimated so that right scenario can be chosen. An acceptable error of ± 0.2 in magnitude and 30 km in location during initial estimates is considered good for tsunami warning applications and it is also extremely important to be able to do this consistently. Since its inception in October 2007 till April 2012, the Warning Centre successfully monitored 306 earthquakes of M >6.5, out of which 56 are in the Indian Ocean region (both on land and under-sea). For all these events, the average elapse time of Warning Centre for earthquake detection is 6 min (Target 10 minutes). The average difference in magnitude of Warning Centre estimate with international agencies such as USGS is 0.2 (Target 0.3), average focal depth difference is 22.5 km (Target 25 Km), and average earthquake location difference is 30 km (Target 30 Km). The above statistics indicate that the earthquake parameters estimated by ITEWC are comparable with those estimated by international agencies and fall within the target set up by ICG/IOTWS.

Mock drills, Training and Workshops

To reduce the vulnerability to tsunami hazard, communities should have a warning system and emergency response teams and well prepared communities who understand the risks they face and take necessary actions based on that knowledge. INCOIS conducts regular Communications Tests, SOP Workshops, Tabletop (TT) Exercises and Tsunami Drills to ensure failsafe dissemination of advisories, development of SOPs and enhancing the preparedness and the response of communities to tsunami warnings.

Mock Tsunami Drills

The first Mock Tsunami Drill in Indian Ocean, IOWave09 Exercise, was carried out on October 14,2009 to evaluate the readiness of the tsunami warning centre and its various logistical and organizational components and to identify areas for refinement and improvement. The main goal of the exercise was to increase awareness and enhance preparedness. India carried out the IOWave09 in a readiness style involving communication and decision making at local government levels, without disrupting or alarming the general public. ITEWC, in its capacity as the National Tsunami Early Warning Centre and the Ministry of Home Affairs in its capacity as the Disaster Management Office were the main national stakeholders in this exercise.

ITEWC participated in the second Mock Tsunami Drill (IOWave11) to test its Standard Operating Procedure (SOP) and end-to-end communication links. The mock tsunami drill was conducted on October 12, 2011 between 06:30 Hrs to 18:30 Hrs IST and Warning Centre issued total 15 notification messages to all participating agencies through email, fax and SMS. A total of 54 recipients from Disaster Management Authorities participated in the tsunami drill. At the national level, this was a first-of-its-kind tsunami drill that involved evacuation of the coastal communities. The participant agencies have taken the drill down to different levels, involving their field units, local officials, line departments and public, as appropriate. Authorities executed village/community level evacuation in Odisha (6 villages), Puducherry (1 village) and Maharashtra (10 villages).

At the regional-level, ITEWC, which is recognized as one of the Regional Tsunami Service Provider (RTSP), issued bulletins to 23 other countries in the region through email, Fax, SMS, GTS and web.

Communications Tests (COMMs Tests)

In line with the recommendations of the ICG/IOTWS, Communication Tests were held quarterly in the year of 2011 and every 6 months in the year of 2012. Till now 6 COMMs tests were held and ITEWC participated in all these COMMS tests and disseminated tsunami notifications to the National Tsunami Warning Centre (NTWC) and Regional Tsunami Service Provider (RTSP) contacts through email, fax, SMS, GTS as well as website. Feedback received from NTWCs regarding the receipt/non-receipt of bulletins issued during the COMMS test through different communications modes analyzed by the secretariat and the COMMS test team to identify the loop holes and improve the emergency communication system.

User Guide

ITEWC user guide was prepared, which includes detailed information to the users on ITEWC's facilities, procedures, criteria for action, along with sample messages. It includes a description of ITWC's monitoring system: seismic data, sea level data, warning center message dissemination, public safety actions and guidance on what the user can expect from the tsunami warning center, including how to interpret messages for action, definitions of terms, and what to do when warnings are issued. These user guides are being shared with all the user agencies.

Future Plans

While the ITEWC has been performing as per its design standards, the Japan tsunami of March 2011 has brought to the fore several important issues that have to be addressed for improving the accuracies of tsunami warning systems. Water level inversion, real-time inundation modeling, real-time estimation of focal mechanism of earthquake to show the style of faulting and incorporation of GPS data into the warning chain are a few key issues that ITEWC has taken up on priority. The recent communication tests and Mock Tsunami Drill have also brought to the fore several issues with the last mile communication of warnings, as well as the awareness and response mechanisms. The ITEWC is working with all stakeholders involved to improve upon these aspects.

Chapter - III

Drought Events

DROUGHT - IT'S CAUSES, CONCEPTS, INDICES AND IMPACT ON AGRICULTURAL PRODUCTION

B.V. Ramana Rao

Drought is universally acknowledged as a phenomenon associated with shortage of water compared to the demand. There is no single definition of drought which is applicable all over the world. Drought affects the life of the people in many ways including

- Decline in agriculture production and failure of crops
- Shortages in fodder supply to the cattle resulting in either death of animals or migration of people with their cattle
- Shortage in power production from hydroelectric projects leading to inadequate power supply for industries, shortfall in industrial output, decline in working opportunities to skilled labour
- Inadequate power supply for pumping of ground water wherever feasible and over-dependence on petroleum products as source of energy
- Rural unemployment, migration of rural people to urban areas, distress sale of cattle, inability to pay off loans taken for investment in agricultural production
- Shortage of drinking water for people and animals
- Starvation of people and deaths
- Import of food grains and postponement of development activities due to diversion of public funds

Therefore, occurrence of droughts have multi dimensional impact on lives of people in drought affected areas.

There are three major types of droughts and are generally termed as meteorological, hydrological and agricultural droughts.

Meteorological Drought

Meteorological droughts occur either due to considerable decrease in annual / seasonal rainfall compared to normal rainfall or due to failure of rains for prolonged period within the rainy season. Many times, there may be more annual/ seasonal rainfall causing floods due to abnormal / heavy rains for extended period preceded / followed by prolonged periods without any rain. Meteorological drought is the primary cause for occurrence of droughts.

Hydrological Drought

Hydrological droughts occur due to decrease in water availability in surface/ underground water resources. Hydrological droughts can be caused by

- Delayed release of canal water due to inadequate water availability in major reservoirs as a result of failure of rains in catchment areas.
- Decline in ground water levels either due to inadequate recharge of ground water or due to over exploitation of ground water.
- Drying of surface water bodies like lakes, tanks, wells etc due to reduced inflow or inadequate ground water recharge.

Therefore hydrological droughts will have severe impact on power generation, decline in industrial output, crop productivity in irrigated areas, scarcity of drinking water and decline in productivity even in inland fisheries.

Agricultural Drought

Agricultural drought is the condition wherein the water availability to the crops get diminished either through precipitation / soil moisture availability / shortage of water for irrigation. The agricultural droughts can be classified into five major types in dryland areas (Ramana Rao, 1992).

Early season droughts:

The early season droughts occur in association with the delay in commencement of sowing rains or with the occurrence of early rains followed by a prolonged dry spell during the main rainy season which we call as southwest monsoon season or *kharif* season in most parts of the country except in south eastern peninsular India where northeast monsoon season is the main rainy season.

Mid season droughts:

Mid season droughts occur in association with long gaps between two successive rain events if the moisture stored in the soil falls short of water requirements of the crop after its initial establishment till grain filling stage initiates. The mid season droughts result in stunted growth, wilting of crops, reduced plant population and less flowering. If gap between two successive rain events is too long and soils are shallow with low water holding capacity, the crops may even wilt completely. It is generally known that the mid season droughts may lead to reduction in crop productivity by 30 per cent or even more.

Late season or terminal droughts:

Late season or terminal droughts occur due to

- Either inadequate soil moisture and or inadequate rainfall during the period from grain filling to physiological maturity of the crop and
- Early withdrawal of monsoon rains

The late season droughts at times result in shortfall of crop productivity up to 70 per cent even.

Apparent droughts:

While the rainfall in the region may be adequate for one crop but may not be so for some other crops. One good example is that of paddy grown under rainfed conditions in sub-humid regions of India. Whenever there is failure of rainfall in these areas, the water availability for paddy may be inadequate and some other crops like maize, sorghum, finger millet etc can be grown with success. Therefore apparent droughts occur due to mismatching of the cropping patterns in relation to the rainfall/ moisture availability patterns in some of the regions.

Permanent droughts:

Permanent droughts are associated with inadequacy of soil moisture / rainfall to meet the water requirements of crops during most of the years. In the arid and even in some of the seasonally dry tropical regions, the rainfall is somewhat assured for a shorter period of just 6 or 7 weeks or even less. In these regions crops are grown for subsistence, although the rainfall is not adequate to grow even short duration crops of 60 to 75 days. The crops are often subjected to moisture stress due to inadequacy of rainfall and soil moisture within the cropping season most of the years. Wherever crops are grown during post rainy season, the crops would invariably encounter moisture stress during the grain filling stage leading to very low yields. Therefore, droughts are common and very frequent in some of the regions identified as drought prone areas or regions with permanent droughts.

Droughts in irrigated areas:

Crops are grown with supplementary irrigation during the rainy season and with complete irrigation during the dry season. Generally, farmers prefer to grow paddy during kharif season and especially wheat during dry season in north India or high value commercial crops like sugarcane, turmeric, cotton etc in irrigated areas. Droughts in irrigated areas occur mostly due to

- Failure of rainfall when there is shortage of availability of irrigation water.

- Late release of canal water due to failure of rains in the catchment areas of reservoirs/tanks
- Drying up of ponds, lakes and wells.
- Decline in water table for ground water due to inadequate ground water recharge.
- Inadequate flow of water into the reservoirs and decline in water storage etc.

Quantification of Droughts/Drought Indices

The world Meteorological Organisation (1975) grouped drought indices under the following headings.

- Rainfall
- Rainfall and temperature
- Rainfall and potential evapotranspiration,
- Water balance parameters

Characterisation of droughts based on rainfall:

Rainfall is the most important factor influencing the occurrence of drought and practically it is not possible to characterize the droughts without using information on rainfall/precipitation.

Meteorological drought:

According to India Meteorological Department, drought is said to have occurred over a region when the total annual rainfall received is less than 75 per cent of the 'normal' value of the region. When the deficit in annual rainfall is between 25 to 50 per cent in the region, it is termed as moderate drought. When the deficit in seasonal rainfall is more than 50 per cent in the region, it is called severe drought.

Moisture index:

Palmer (1965) developed a moisture index based on rainfall. The Index which is popularly known as Palmer's Drought Index is calculated using the equation

$$I_k = 0.50\, I_{k-1} + M_k \div 48.55$$

where, I = Drought intensity, K = Current month, M = Moisture anamoly index

The monthly index values generally vary from -4 to +4

The Palmer's Drought Index is generally applicable in areas where moisture in the soil gets accumulated due to melting of snow in extra tropical latitudes.

Standardized precipitation index:

Scientists at Colorado State University developed the concept known as Standardized Precipitation Index which is calculated using the equation

$$SPI = \frac{X_i - \overline{X}_i}{\sigma_i}$$

where, X_i = Rainfall received during i^{th} period, $\overline{X}$ = Normal rainfall for i^{th} period,
σ_i = Standard deviation of rainfall during i^{th} period

SPI can be estimated on monthly, seasonal or annual basis. Mc Kee *et al.*, (1993) gave the following categories to define drought of various intensities as follows:

SPI Values	Drought Intensity
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ 2.00	Extreme drought

Hargreaves method:

Hargreaves (1971) used the concept of Moisture Availability Index MAI which can be calculated as

$$MAI = \frac{PD}{PET}$$

Where, PD = Rainfall that can be expected with a probability of 75 per cent
PET = Potential evapotranspiration

He described moisture availability conditions based on the value of MAI as follows:

MAI	Moisture deficit classification
0.00 to 0.33	Very deficit
0.34 to 0.67	Moderatelly deficit
0.68 to 1.00	Somewhat deficit
1.00 to 1.34	Adequate moisture
>1.34	Excessive moisture

Cocheme and franquin's method:

Cocheme and Franquin (1967) considered matching the duration of crop growth cycle with the availability of water through rainfall and classified water availability periods by comparing the water received through precipitation with potential evapotranspiration as follows:

$P > PET$	Humid period
$P \geq PET/2$	Moist period
$PET/2 < P \geq PET/4$	Moderately dry period
$PET/4 < P \geq PET/10$	Dry period
$P < PET/10$	Very dry period

They considered that the growing season commences when $P \geq PET/2$ during the main rainy season and ends when the P/PET reaches 0.25. The sowing dates of various crops can be adjusted such that the reproductive stage coincides with the peak period of water availability. This method can be applied for rainy season crops only as it does not consider the water storage capacity of the soils and therefore may not correctly assess the length of the growing season in vertisols.

Water balance parameters:

The water balance models generally consider that the precipitation received is equal to the sum of actual evapotranspiration i.e., the amount of water used by the crop for soil evaporation and transpiration from the crops, water lost through run-off and deep drainage and change in the soil water storage as expressed by the equation

$$S + P = AET + R + D$$

Where, P = Rainfall received
AET = Actual amount of water used by the crop for evapotranspiration
R = Water lost through run-off
D = Water lost through deep drainage
S = Soil moisture storage

The water balance involves some of the assumptions as follows:

i. The actual evapotranspiration is equal to the water requirement of the crop when there is adequate water either through the precipitation and / or soil moisture storage. The water requirement is calculated as K * PET where K = Crop coefficient which depends upon the nature of the crop and stage of growth of the crop; PET = Potential evapotranspiration.

ii. The run-off and deep drainage occurs only when the precipitation exceeds the soil moisture storage.

iii. The soil moisture storage is considered as the water available in root zone of the crop, and depends on nature of the soil, clay content of the soil and depth of the soil.

iv. Soil moisture or precipitation more than requirement of the crop will be added to the soil moisture storage. When the precipitation is less than the water requirement of the crop, the deficit will be met from the soil moisture storage unless and until the soil moisture storage is near zero.

Therefore, the water balance concept can be used to estimate the water used by the crop for evapotranspiration compared to its water requirement. So, the crop experiences moisture stress whenever the water used by the crop for evapotranspiration is less than the water requirement of the crop.

Frere and Popov (1979) introduced the concept of water requirement satisfaction index (WRSI) which is the percentage of the ratio of water used by the crop for evapotranspiration to the total water requirement of the crop.

Water use yield relationships:

The total dry matter produced by the crop is directly proportional to the amount of water used by the crop for evapotranspiration, i.e.,

$$DM \propto ET_o$$

Where, DM = Total dry matter produced by the crop

ET_o = Total water requirement of the crop during its life cycle.

The grains or pods will form the grain yield or economic yield (Y) and it is given by

$$Y = HI \times DM$$

Where, HI = Harvest index i.e., the fraction of the dry matter produced which forms grain yield.

The HI usually ranges from 0.3 to 0.4 for most of the arable crops.

Impact of agricultural droughts:

The agricultural droughts affect the overall development in many ways as

- There will be more demand for electricity and petroleum products for pumping water for irrigation where there is failure of rain
- The agro based industries will be affected by inadequate supply of agricultural produce like sugarcane for sugar mills, oilseeds for oil mills, cotton for textiles and weavers etc thereby creating unemployment among the skilled and unskilled labour as well.
- The agriculture labour in rural areas will not have enough work in farming and are compelled to migrate to urban areas to work as manual labour.
- The government has to import food grains by spending precious foreign exchange.
- The government is compelled to postpone several development activities and divert the funds allocated for development to provide drought relief measures.
- There will be fodder shortage for the cattle and animals and the government has to incur enormous expenditure for transport of fodder from surplus areas. Otherwise there will be death of cattle due to starvation.
- The government is required to incur huge expenditure in supplying drinking water for the people and live stock and in critical conditions even for domestic use.
- The farmers whose livelihood is only agriculture will be caught in debt traps and will be compelled to sell their assets like gold etc.

The agricultural drought will affect even the people living in urban areas as prices of agricultural commodities, fruits, vegetables etc will increase considerably when the supplies are less.

DROUGHT DETECTION, MONITORING AND EARLY WARNING

G.G.S.N Rao

Drought occurs virtually in almost all the countries both in dry and humid climates, though it is strongly believed that it is confined mostly to arid and semi-arid and sub-humid climates. Drought in its spatial extent and severity vary on seasonal and on annual time scales (WMO bulletin No-1006, 2006). In many countries viz., Australia, China, India, USA and over Africa, drought occurs over a portion of the country in each year. Drought by itself is not a disaster, however it turns to be a disaster, which depends on its impact on local people, environment economies and their ability to cope with and the time taken to recover from it. Therefore, Drought Risk Management involves drought monitoring and development of early warning systems.

Droughts may be studied with respects to different aspects such as 1) Historical aspects of droughts over a region 2) Real time assessment, its monitoring and status of droughts and 3) Prediction of droughts. Drought monitoring can be accomplished through weather data collection and its analysis over a large region, periodic measuring of water levels in both surface reservoir and below ground and remotely sensing the crop water stress. In recent years, applications of satellites, has gained popularity in monitoring real time basis crop water status over a large area. Different nations use different methods to monitor droughts in their respective regions. Large international co-operations among various countries in exchange of data, information is working well and several organization like WMO, FAO have been extending support to various drought related networks in developing countries in Africa and Asia through liberal funding.

Drought Detection in India

IMD monitors the incidence, spread, intensification and cessation of drought (near real time basis) on a weekly time scale, based on aridity anomaly index (Fig 1) and publishes an outlook for drought in the subsequent weeks. These maps shall help to assess moisture stress experienced by crop plants. Based on the above, Aridity anomaly report for southwest monsoon season for the whole country and for northeast monsoon season for five meteorological sub-division *viz.*, Coastal Andhra Pradesh, Rayalaseema, South Interior Karnataka, Tamil Nadu, Pondicherry and Kerala are prepared and sent to IMD H.Q and to various Agricultural authorities of State and Central government and Research Institutes on operational basis. Also IMD computes SPI at monthly and seasonal time scale and are uploaded in the IMD website regularly (Fig 2).

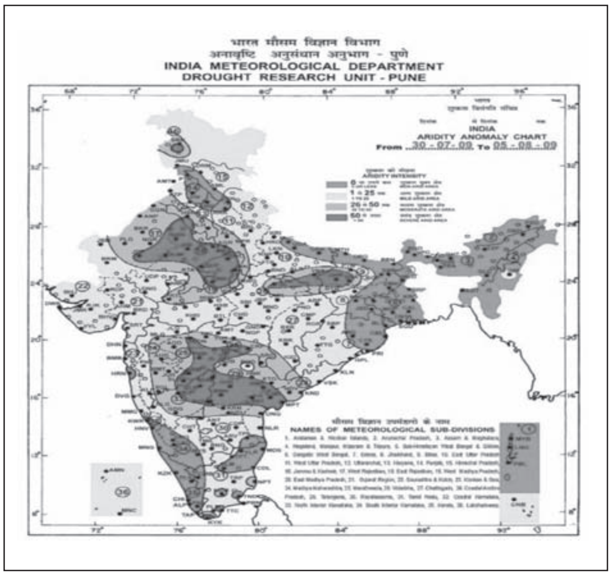


Fig. 1 : Aridity index iindex nomaly index for 30th SMW 2009 in India

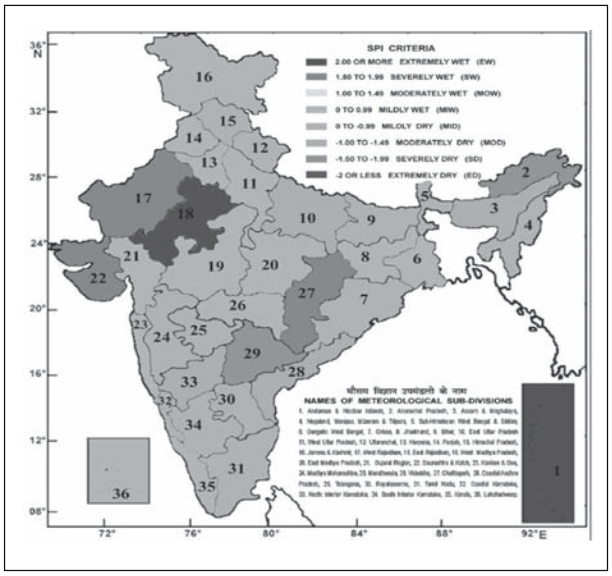


Fig. 2 : SPI map of September 2011 in India

National Agricultural Drought Assessment and Monitoring Systems (NADAMS) operating by National Remote Sensing Centre (NRSC), uses both moderate and coarse resolution data for drought monitoring by computing NDVI values at different spatial scales. It monitors agricultural droughts using space technology inputs since 1989 and provide near real time information on prevalence, severity and persistence of agricultural drought at sub-district level. Along with agricultural crop conditions, it also generates products on drought related parameters such as rainfall, cropped area etc at fortnightly/ monthly intervals. At present it covers 13 states in India which are predominantly agricultural based and prone to droughts. The information is communicated through e-mails to the users' *viz.*, Ministry of Agriculture, Government of India, Directors of Agriculture of different states, relief/revenue Commission of States, IMD and State Remote Sensing Application centres. The products related to agricultural droughts generated by NRSC for the states of Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu are put on its website (Fig 3).

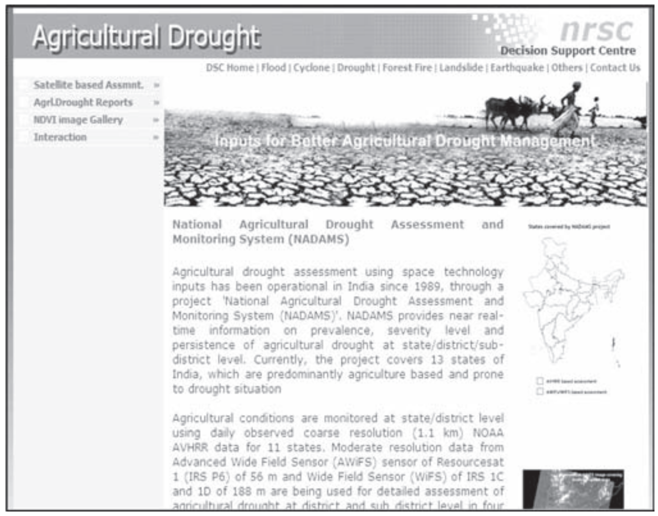


Fig. 3 : Agricultural drought situation in different states shown in NRSC webpage

At the National level, Crop Weather Watch Group (CWWG) an inter ministerial mechanism headed by Ministry of Agriculture, GOI has been working as a nodal agency since 1979 in all matters related to droughts which includes, monitoring, assessing and management. This group under the chairmanship of Additional Secretary, Ministry of Agriculture meets every Monday during the rainy season (June-September) and evaluates information and data furnished by IMD and other scientific and technical organizations on the likely impacts of deviations in weather parameter on the agricultural crop conditions and its productivity. The composition and role of different agencies in drought detection and monitoring is given (Table 1) below (Samra, 2004)

Table 1 : Composition and role of CWWG of the Ministry of Agriculture, Government of India (Samra, 2004)

Partners	Tasks
Additional Secretary, Ministry of Agriculture	Chairperson of the Group; promotes overall coordination
Economic & Statistical Adviser, MoA	Report behavior of agro-climatic and market indicators
India Meteorological Department	Rainfall forecast and progress of monsoonal conditions
Central Water Commission'	Water-availability monitoring in major reservoirs
Plant Protection Division	Watch pests and diseases outbreak
Crop Specialists	Crop conditions and production
Agricultural input supply divisions	Supply and demand of agricultural inputs
Agricultural extension specialists	Report on field-level farm operations
Ministry of Power	Manage electrical power for groundwater extraction
Indian Council of Agricultural Research	Technical input and contingency planning
National Centre for Medium Range Weather Forecast	Provide medium-term forecasts

Drought monitoring at State government level is carried out mostly by Disaster management cells operating in the respective state governments. Some states like Karnataka monitors drought by its Drought Monitoring Cell from rainfall departure and SPI maps prepared at weekly intervals and storage levels in the surface reservoirs during the season.

Criteria for Declaration of Drought

At National level, India Meteorological Department (IMD) is the sole agency for monitoring drought conditions and has evolved and standardized techniques to forecast the onset of SW monsoon and subsequent rainfall and the expected departures of regional rainfall from the normal value. The onset and progress of SW monsoon is continuously monitored throughout the season. It also identifies and monitors the regions with rainfall deficits. The weekly and special reports on monsoon form a basis for an early signal on the initiation of drought conditions over different parts of the country. At the regional scale, State Agricultural Departments of different states closely monitor the progress of agricultural activities like sowing, irrigation, seeds and fertilizers availability, etc. and hydrological information at weekly intervals along with the daily distribution of monsoonal rains, dry spells and their duration over the state. Week-wise information is compiled at each state and submitted to Crop Weather Watch Group (CWWG), which is nodal agency under the Ministry of Agriculture to monitor the drought over the country and prepare contingency plans to effectively manage the drought. The exchange of information with similar kind of group at state level serves as triggering mechanism to activate drought response system.

Monitoring and information management system at different levels and at different periods viz., daily, weekly, fortnightly, monthly and seasonally by CWWG are summarized as below:

Table 2 : Details of CWWG monitoring and information management

Parameters	Agency				Communication mode
	National	State	District	Field	
A. Meteorological					
Delay in the onset of monsoon	W	W	D	D	Wireless/Fax/Telephone/e-mail
Dry spells during sowing	W	W	D	D	Wireless/Fax/Telephone/e-mail
Dry spells during critical crop growth periods	W	W	D	D	Wireless/Fax/Telephone/e-mail
B. Hydrological					
Water availability in reservoirs	W	W	D	D	Wireless/Fax/Telephone/e-mail / Written Reports
Water availability in tanks / lakes	F	F	F	W	Written Reports
Stream flow	F	F	F	W	Written Reports
Groundwater level	S				Written Reports
Soil moisture level	F	F	F	F	Written Reports
C. Agricultural					
Delay in sowing	W	W	W	W	Wireless/Fax/Telephone/e-mail
Sown area	W	W	W	W	Wireless/Fax/Telephone/e-mail
Crop vigor	F	F	F	W	Written Reports
Change in cropping pattern	W	W	W	W	Wireless/Fax/Telephone/e-mail
Supply and demand of agricultural inputs		W	W	W	Wireless/Fax/Telephone/e-mail

D=Daily; W=Weekly; F=Fortnightly; M=Monthly; S=Seasonal (Pre and Post-rains)

Drought declaration is a state subject while the Central Government only facilitates the financial and institutional process. Traditionally in India, the District Administrator (Collector/Dist Magistrate) recommends the declaration of drought only after crop production estimates are available through Annawari / Paisawari / Gidawari system. Generally, area with less than 50 percent of the above system are considered to be affected by the droughts. Final figures on crop losses are only available in December and the Government of India sends a team of experts to the drought affected regions to assess the drought status after its declaration. Based on this report State Government submits the requirement for relief and release of funds.

Indicators for Drought Declaration

There are number of indicators available for monitoring droughts and every indicator has some limitation due to non-availability of required data and reliability of data to compute indicators. In this regard, the Manual for Drought Management (2009) provided guidelines to declare drought based on combination of important indicators which were identified based on wide ranging consultations with meteorologists and agricultural scientists. The guideline is as follows:

Rainfall deficiency, the extent of area sown, NDVI and MAI are recommended as four standard monitoring tools which could be applied in combination for drought declaration. Since this information on these indicators is available at the level of Taluka / Tehsil / Block, drought may be declared by the State Government at the level of these administrative units on the basis of observed deficiencies. It recommended that at least three out of four indicators must satisfy the criteria for drought declaration. The limits set for four indicators, as per Manual for Drought Management (2009) are as follows:

Rainfall deficiency

- The State Government could consider declaring a drought if the total rainfall received during the months of June and July is less than 50 percent of the average rainfall for these two months and if there is an adverse impact on vegetation and soil moisture as measured by the vegetation index and soil moisture index. Such a rainfall deficit would cause so much damage to agriculture crops that it would be difficult to revive crops.
- The State Government could consider declaring a drought if the total rainfall for the entire duration of the rainy season of the state, from June to September (the south-west monsoon) and or from December to March (north-east monsoon), is less than 75 percent of the average rainfall for the season and there is an adverse impact on vegetation and soil moisture, as measured by the vegetation index and soil moisture index.

Area under sowing

Sowing is another important indicator of the spread and severity of drought. Sowing operations are linked to rainfall and availability of water. Mostly, farmers undertake sowing operations at the commencement of the monsoon. If sowing fails due to water stress, farmers sow a second or even a third time. Therefore the *area under sowing* provides reliable information on the availability of water for agricultural operations.

Drought conditions could be said to exist if the total sowing area of *kharif* crops is less than 50 percent of the total cultivable area by the end of July / August, depending upon the schedule of sowing in individual states. In such situations, even if rainfall revives in the subsequent months, reduction in the area under sowing cannot be compensated for and the agricultural production would be substantially reduced. The State Government should, therefore, consider declaring a drought, if the total area sown by the end of July / August is less than 50 percent of the total cultivable area along with the other indicators.

In case of *rabi* crops, the declaration of drought could be linked to the area of sowing being less than 50 percent of the total cultivable area by the end of November / December along with the other indicators.

The Agriculture Department(s) in the State Government(s) provides data on crop-wise sowing operations; generally available for all the Talukas / Tehsils / Blocks and is compiled for all the districts in a State.

Normalized difference vegetation index (NDVI)

The National Agricultural Drought Assessment and Monitoring System (NADAMS), operated by the National Remote Sensing Centre (NRSC), Hyderabad, an institution under ISRO issue a bi-weekly drought bulletin and monthly reports on detailed crop and seasonal condition during the *kharif* season. These reports present the Normalized Difference Vegetation Index NDVI) and Normalized Difference Wetness Index (NDWI) maps from the data obtained from National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA-AVHRR) and Indian Remote Sensing (IRS) satellite (Wide Field Sensor (WiFS) data. They provide quantitative information on sowings, surface water spread and District / Tehsil / Taluka / Block level crop condition assessment along with spatial variation in terms of maps. At present, 11 agriculturally important and drought-vulnerable States, *viz*., Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Rajasthan, Tamil Nadu and Uttar Pradesh are receiving these reports.

It is necessary that the States declare drought only when the deviation of NDVI value from the normal is 0.4 or less. However, the NDVI value needs to be applied in conjunction with other indicators and values. The NDVI must not be invoked for the declaration of drought in isolation from the other two key indicators.

Drought Monitoring Mechanism in India

Monitoring of droughts in India is carried out by both State and Central Governments. India Meteorological Department (IMD) and National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO) are primarily responsible to monitor drought using ground level weather data and Remote Sensing data, respectively. At the State level, the respective Agricultural Department and the state level Remote Agency, monitor the rainfall distribution and droughts. Few states have their own Drought Monitoring agencies/cell viz., Karnataka is one such example. India Meteorological Department (IMD) under Ministry of Earth Resources, GOI monitors weather across the country on daily basis and prepares rainfall deviation maps at weekly intervals. Similarly the cumulative rainfall departure maps at sub-divisional level for different seasons *viz.*, Mar-May (Spring/summer season), June-September (Monsoon) October-November (Post monsoon) and December-February (Winter) are also prepared and displayed on its website (www.imd.gov.in) regularly (Fig 4).

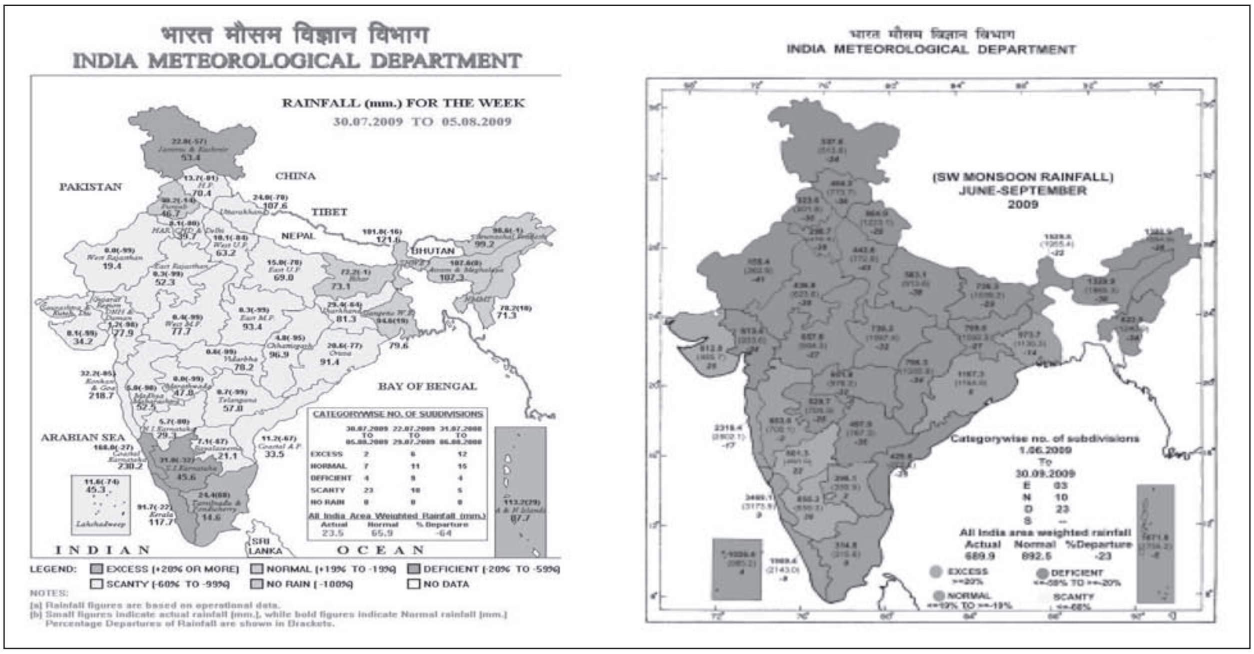
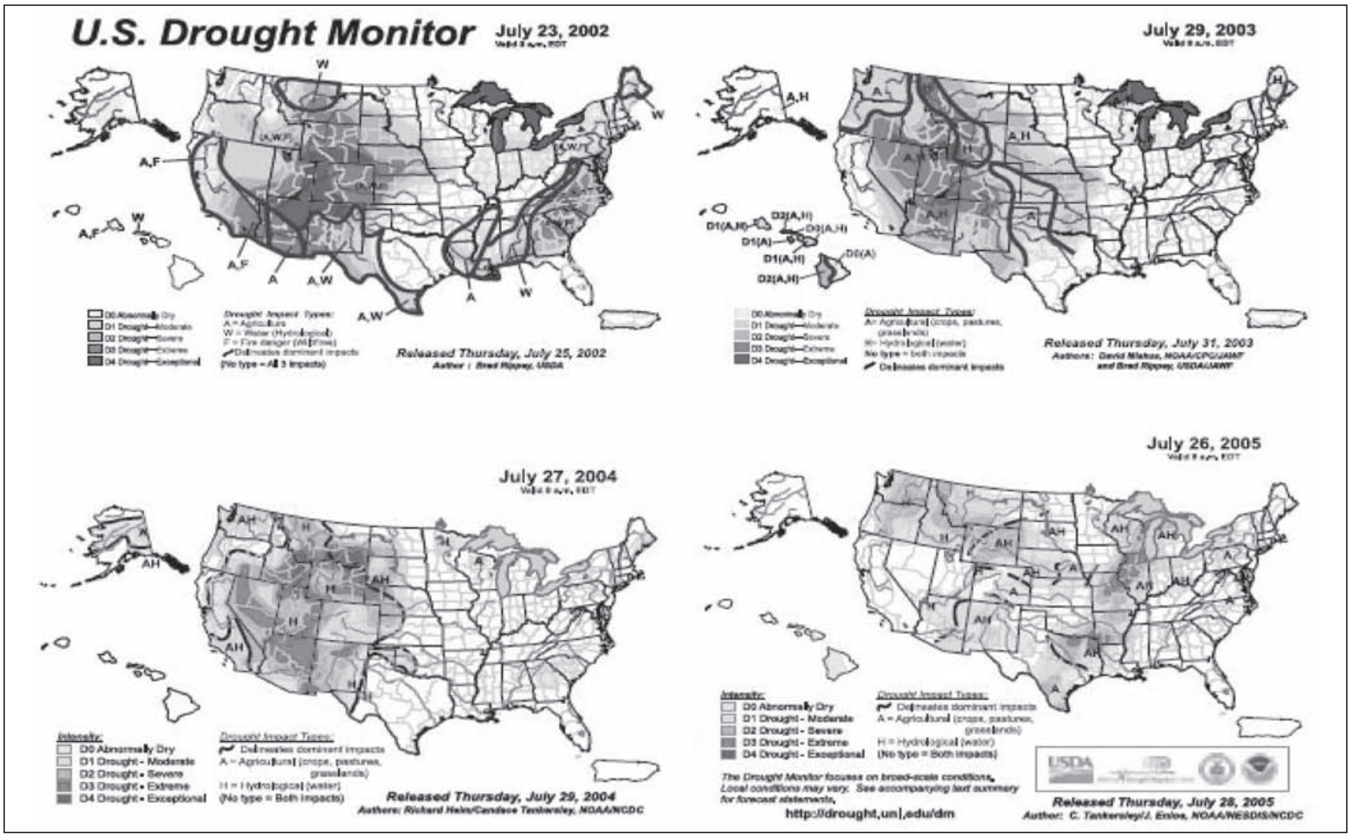


Fig. 4 : Weekly and cumulative rainfall departure map of India during Monsoon 2009

Drought Monitoring Using Climatological, Hydrological and Combination Approaches in Different Countries

Early warning signals of drought helps in reducing the impact if it is delivered to decision makers on a timely and appropriate format along with measures to be implemented. There are variety of indicators both physical and biological that can be monitored for identification of spatial distribution of drought, its onset and end over a given region. Though rainfall deficiency is the primary factor in computing droughts, other factors such as water levels in the reservoirs, soil moisture, crop conditions etc. need to be considered for assessing the severity of drought. Therefore efficient drought warning systems must integrate rainfall with other parameters. In this endeavor, the United States of America has been the world leader in monitoring droughts scientifically and was successful in integrating several drought indicators such as Palmer Drought Severity index (PDSI), SPI, Stream flows, Vegetation Health, Soil moisture status and impacts on crops and a few ancillary indicators such as reservoir levels, surface water supply index, river basin snow water equivalent and pasture and range conditions for drought monitoring programme on weekly basis. The spatial extent of drought in US on a weekly basis is produced by NDMC (Fig 5).

USDM classifies droughts on a scale from one to four (D1-D4), where D1 denotes Moderate drought, D2- Severe drought D3- Extreme drought and D4-exceptional droughts. D0- indicates abnormally dry areas which are either heading to drought or recovering from drought, but still experiencing droughts. The map also shows the sectors that are currently experiencing direct or indirect impacts using the symbols *viz.*, A (Agriculture, crops , live stock pasture and grasslands), H (hydrological) and W (water supplies). For example the symbol D2 (A) on the map indicate the severe drought conditions affecting agricultural sector.



(Source: WMO, 2006)

Fig. 5 : Spatial distribution of drought in U.S. for the years 2002 - 2005

Romania: In Romania, agricultural drought phenomenon at different stages is monitored by assessing the soil moisture. Daily weather data collected over the country is used to compute ETo by either Penman-Monteith method/cropwat model. A 10 day period cumulative soil moisture for wheat and maize crop at different depths of 0-20, 0-50 and 0-100 cm is estimated and soil moisture reserve (m^3/ha) which is the percentage capacity of available soil water to Cumulative Soil Moisture and the soil water deficit (m^3/ha) is computed from simple water Balance model.

B**ulgaria:** In Bulgaria, the National Institute of Meteorology and Hydrology (NIMH) is responsible for providing data to research and operational activities in the field of meteorology, agrometeorology and Hydrology. The agrometeorological networks under NIMH collects and maintains the weather data and implement experiments. Monthly bulletins on crop conditions are prepared and distributed through mass media communication system. It also monitors soil moisture up to 100 cm depth at a 10 day interval and spatial maps are prepared to identify regions affected by soil droughts.

Portugal: The Portuguese Meteorological Institute (PMI) monitors the climate and drought conditions in the country and Palmer Drought Severity Index (PDSI) is used to characterize droughts. This index has been adapted and calibrated to climate conditions of Portugal. A separate unit viz. drought observatory is working in the above institute to look in to the problems related to drought. The spatial distribution of drought conditions are presented in monthly PDSI maps and are used to monitor spatial and temporal variations in droughts across mainland. These maps help in taking appropriate measures to minimize the losses associated with droughts.

Russia: Currently drought monitoring in Russia is mostly carried with six popular indices of which three are moisture dependent and the remaining three are temperature dependent that are widely used by Russian scientists, though the scientist have developed more than 50 indices over the period. They are

1) Hydrothermal coefficient (HTC) developed by Selyaninov (1928)
2) Moisture index by Shashko (1985)
3) Water supply Index (Protserov, 1949)
4) The number of days with RH ≤ 30% (N_o)

5) The number of days with maximum temperature > 30°C (N_T)

6) Productive moisture reserves in soil layers of 0-20 cm (Wo-20), 0-50 cm (Wo-50) and 0-100 cm (Wo-100) under winter, early spring and late spring grain crops.

   All these indices can be determined using standard hydrometeorological data. Based on the range of values, the intensity of droughts can be categorized as extremely severe, severe, moderate, weak or no drought.

Russian meteorological satellites have also been used for drought monitoring. A Drought Monitoring Center (DMC) is in operation in All Russian Research Institute of Agrometeorology (ARRIAM).

China: Since 1995 drought monitoring in China is being done by computing SPI values at 10 days interval and the responsibility lies with National Climate Center (NCC) of China Meteorological Administration (CMA). A comprehensive index (CI) was developed to monitor drought situation and put it in to operation on daily basis. CI is a function of last 30 and 90 day SPI and the corresponding PET values . This index is used to monitor real time drought conditions on daily basis.

$$CI = aZ_{30} + bZ_{90} + cM_{30}$$

Where, Z_{30} and Z_{90} are SPI of recent 30 and 90 days which represent abnormal conditions on monthly and seasonal scale.

M_{30} is average moisture index (Im) of recent 30 days represents water deficit

$$M = \frac{P-PE}{PE}$$

Where, P is precipitation; PE is Potential evapotranspiration; a,b,c are constants having values of 0.4, 0.4 and 0.8 respectively

Drought intensity is characterized based on the values of CI which is as follows.

Drought intensity	**Value of CI**
No drought	-0.6 to 0
Weak	-1.2 to -0.6
Moderate	-1.8 to -1.2
Severe	-2.4 to -1.8
Extreme	< -2.4

Daily rainfall data collected from more than 600 stations is used to compute CI value on daily basis and spatial maps of CI are prepared

Indonesia: Drought in Indonesia is mostly associated with EI-Nino events (Boer and Subbiah, 2005). Rainfall anomalies are closely watched by Bureau of Meteorology and Geophysics (BMG) for monitoring drought in the country. Also Remote Sensing indicators such as NDVI are used for monitoring drought in the country.

Australia: In Australia nation-wide drought watch on a routine basis is carried out by Australian Bureau of Meteorology since 1965 based on a simple index of rainfall deficiency. The systems utilizes the monthly rainfall datasets of 600 raingauge stations that record and report on daily basis. The Drought Watch Service in Australia uses accumulated rainfall percentiles over successive months to identify regions of rainfall deficiency or excess. Areas with accumulated rainfall below 10^{th} or 5^{th} percentile for 3 months or more termed as seriously/ severally deficit.

African Countries: For monitoring droughts in African countries, the United Nations Development Programme established a regional Drought Monitoring Centre (DMC) at Nairobi and a sub-centre in Harare in 1989 for covering 24 countries in the eastern and southern African sub-region (WMO, 2006). During 2003, The DMC Nairobi became a specialized Institution as Institution for Climate Predictions and Applications Centre (ICPAC). The participating countries are Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda and United Republic of Tanzania. The ICPAC is monitoring climate and predicting weather to develop early warning systems to minimize climate-risks in the greater Horn of Africa. The drought products generated for different parts of the region can be viewed through its website http:// www.Icpac.net. In addition to monitoring of droughts by ICPAC in the region, some countries have their own mechanism to monitor drought in their parts.

Early Warning and Decision Support System

Drought being a slow motion disaster, its early detection and warning allows for activation of drought management plans which include both mitigation and emergency purposes. This type of information to the administrators, policy makers etc. would give ample time to react and minimize the losses associated with droughts. Early warning systems along with the actions to be carried out identified from Decision Support System shall act as drought proofing mechanism against all odds due to droughts. It requires uninterrupted flow of information on climate, soil moisture, stream flow, ground water, lake and reservoir levels from various agencies and integrate them to arrive at early warning system. The resources inventory of historical data on the above parameters plus the social and economic data shall help in developing location specific Decisions Support System (DSS) for taking appropriate measures to reduce losses. The system functions at three levels *viz.*, 1) Receiving forecasts and advisories from scientific organisations. 2) Monitoring key drought indices at National and Regional level and 3) Provide necessary advisories region wise through effective dissemination mechanism. There are many institutions and research workers across the world who have developed methodology for early detection of drought and DSS for various regions.

India Meteorological Department provides long range forecast of seasonal and total rainfall for the entire country. Also rainfall summaries at weekly intervals and aridity index values from water balance computations and their departures at meteorological sub divisional level are prepared. The Agromet unit of IMD in coordination with SAU's issues weekly / bi-weekly agromet advisory bulletins from 127 agromet field units (AMF). With the expansion of Agro-advisory network in the recent years, currently agromet advisories are being issued at district levels and likely to expanded this facility at sub-district level shortly.

The State Agricultural Universities prepare crop planning bulletins on annual basis considering the long term weather and other parameters data on soil, land use, water resources and the changing cropping pattern based on market demand and remunerative prices. Monitoring of state level weather and the crop conditions during the current season, agro-advisory bulletins are prepared and disseminated through effective mass communication media and ICT. Each SAU has its own website and the advisories, crop plans and contingency plans etc. are prepared in local languages and made available to the public.

The Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, monitors the weather conditions daily and closely watches the moisture deficit zones during rainy season (June-September) and provides latest crop conditions status in the country based on the input provided by the 25 centers of AICRP on Agrometeorology and other 25 centers of AICRP on Dryland Agriculture. State wise weather based agro-advisories are prepared from forecasted weather on weekly basis during the crop growing season (Jun-Sep) and the same is sent to ICAR H.Q, New Delhi for preparation of crop contingency plans at National level and the same is also updated in the *"webpage of www.cropweatheroutlook.in"* regularly.

A methodology to monitor the incidence and spread of drought in the western Rajasthan using departure of aridity index (Ia) from its normal values and expressed as percent was developed by Ramakrishna *et.al* (1984). The study was intended to identify the pattern and behaviour of drought occurrence and its spread in the subsequent months. As a case study, two severe drought years *viz.*, 1918 and 1968 were analysed. The monthly departures of I_a values during the crop season June –September for the 11 districts of western Rajasthan were computed and monthly departure maps of I_a were prepared (Fig 6).

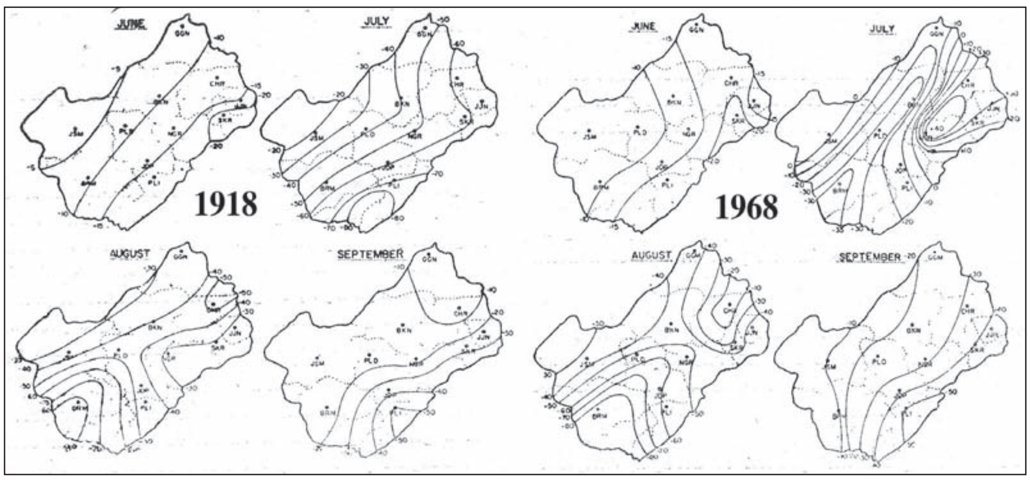


Fig. 6 : Monthly departures of aridity index during 1918 and 1968 over western Rajasthan

A perusal of the above diagram indicates that the zone of maximum drought intensity changed both in its intensity and location indicating a sequential pattern of drought spread and decay over the region. It can be further observed that the droughts initially originate in northeast region around July (in Churu and Jhunjhunu), spread further in a south-westerly direction during August (Barmer region) and dissipate with an easterly movement (Pali region) during September.

Software for Drought Detection, Monitoring and Early Warning

A software for drought detection and monitoring and early warning was developed by the Scientists of CRIDA as a part of consultancy programme with Government of Andhra Pradesh (Vijayakumar *et al*., 2011). This was intended to use in each district for early detection of drought. The Government of Andhra Pradesh is likely put into operation from 2012 rainy season at all the districts on a trial basis.

In this software, moisture adequacy index and water requirement satisfaction index were used. A crop-specific water balance model was used for obtaining these indices. The input and output for the model is given below:

Input: Rainfall, Maximum and minimum temperature, Crop coefficient, Yield response factor, Available water holding capacity (AWC) of the soil, Latitude and longitude, maximum crop yield and crop duration

Output: Runoff, Deep drainage, Drought signals, and Relative yield

The input and output frames are given in Fig 7. The software that was developed, not only provides drought signals during the crop-growing period, but also estimates yield at the end of the season. The software was so designed that even a technical officer at sub district level can use it. Provision was made in the software to estimate the sowing date (date of onset of monsoon) based on daily rainfall. Based on the onset date, the appropriate crops and crop varieties that are to be grown for a particular date will be displayed for different soil types of the State.

The software would assess the water requirement of a crop from the library in which weekly water requirement of all the major crops is stored. During the crop-growing period, whenever the signal of drought appears, the software estimates the water requirement from that date till the end of crop. It also estimates the amount of rainfall likely to occur at 50% probability till the end of crop (stored in the library). The amount by which the likely occurrence of rainfall going to fall short of the water requirement of the crop is also displayed. The software had the capability to record and update at weekly intervals the information on the total area sown in different sub district levels. A library of the normal cropped area (total of all crops) in each mandal is stored in the software and percentage of area sown is displayed at weekly intervals for declaring drought or no drought situation. Mandal may be declared, as drought affected, if the total cropped area does not exceed 50% of the normal by July 31 as this is considered as one of the norms followed by Government of India.

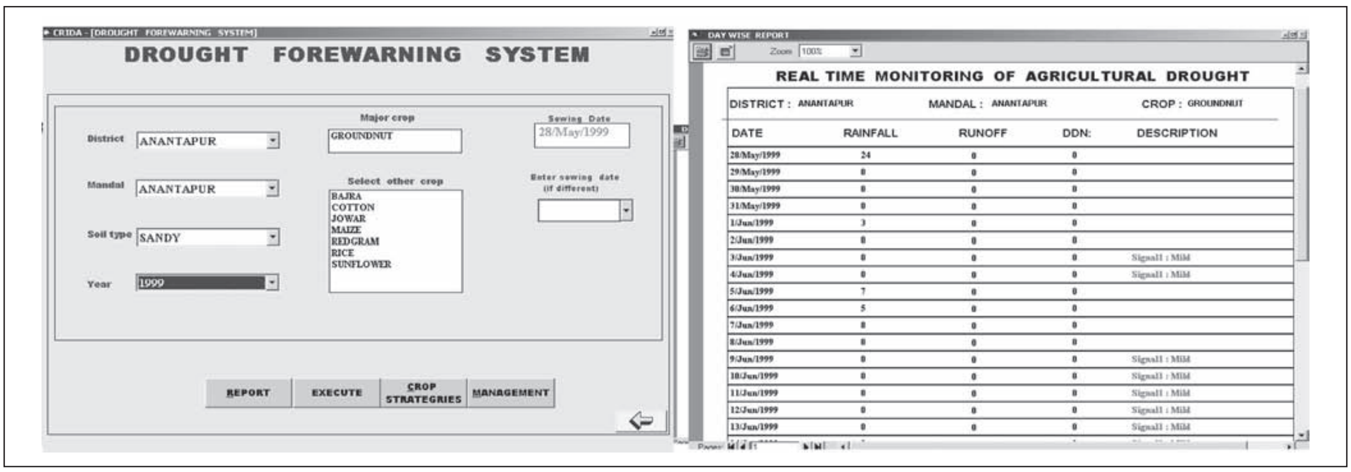


Fig. 7 : Drought forewarning system (sample input)

Thus drought detection, monitoring and developing early warning systems plays significant role in managing droughts efficiently. In view of the climate change expectations in near future, a good international cooperation is essential in minimizing the impacts on human society. Also accuracy of forecast needs to be improved to take appropriate measures.

DROUGHT MANAGEMENT IN PLANTATION CROPS

GSLHV Prasada Rao

Drought may be a relative term used in case of deficit rainfall or soil moisture stress. Breaks or failure in monsoon may lead to droughts. The *kharif* foodgrains production across the country is dependant on the monsoon rainfall and its distribution under rainfed conditions. At the same time, it is the northeast monsoon, which is important in case of Tamil Nadu and Jammu and Khasmir. In tropical monsoon climates where monsoon is assured, it is the summer rainfall, which is critical in case of plantation crops as they are perennial in nature and the availability of soil moisture round the year is very important for survival of the crops. There are different types of drought viz., meteorological, hydrological, agricultural, physiological and atmospheric droughts (Fig. 1).

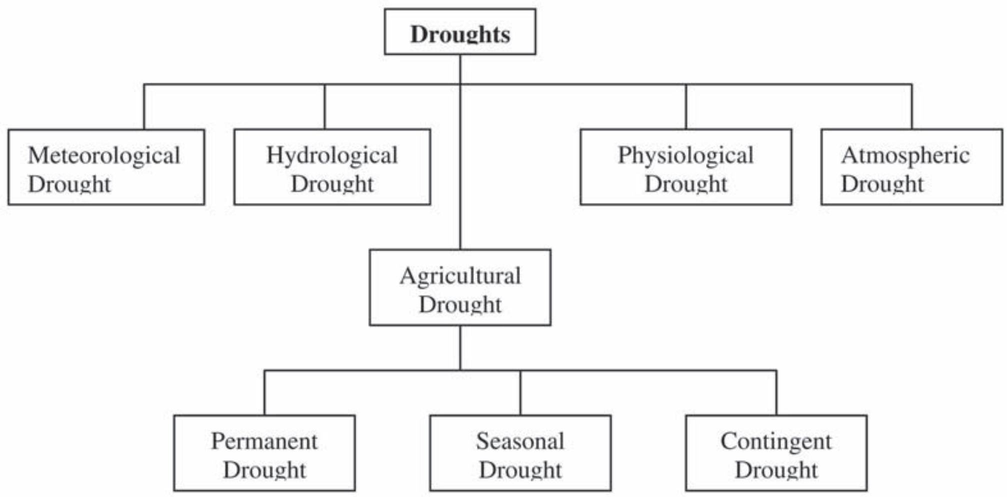


Fig. 1 : Different types of droughts

Meteorological drought: If the rainfall decrease is more than 25 per cent of the normal over an area, it is known as the meteorological drought as per the India Meteorological Department.

Hydrological drought: Meteorological drought, if prolonged, results in hydrological drought with marked depletion of surface water and consequent drying of reservoirs, lakes, streams and rivers, cessation of spring flows and fall in ground water table.

Agricultural drought: It occurs when soil moisture and rainfall are inadequate during the growing season to support healthy crop growth and maturity, causing extreme stress and wilting.

The agricultural droughts can further be classified as follows:

Permanent drought: It is found in arid areas where there is no enough precipitation to satisfy the water needs of plants. In such areas, agriculture is impossible without irrigation throughout the season.

Seasonal drought: It occurs in areas with well defined wet and dry seasons as in most of the tropics. Drought can be expected every year owing to seasonal changes in atmospheric circulation patterns. Agriculture is possible during rainy season or with the use of irrigation during dry season.

Contingent drought: It is characteristic of humid and sub-humid areas and occurs when over a period of time, the rain fails to fall. Contingent drought constitutes a serious hazard to agriculture because of its unpredictability. (ie. monsoon breaks).

Physiological drought: It occurs when plant functions fail physiologically due to waterlogging or due to water deficit. Interestingly, the definition of physiological drought is based on both water deficit and excess water unlike other droughts defined based on deficit rainfall or soil moisture stress.

Atmospheric drought: It can be defined based on the vapour pressure deficit over the crops or in the lower atmosphere, which may lead to no rainfall for prolonged periods.

Several workers have studied the incidence of drought over India using different criteria. Most of them classified the droughts based on the deficiency of rainfall during the monsoon period. Mooley (1984) studied the origin, incidence and impact of droughts over India and identified 1877, 1899,1918, 1972 and 1987 as the phenomenal drought years. The effect of drought on the total food grain production of the country in 1987 was less by about 34 million tonnes (138.41 million tonnes in 1987-88 as against 172.18 million tonnes in 1988-89). However, the effect of drought on plantation crops in Kerala was not felt during 1987 due to break in monsoon during July. At the same time, the total plantation crop production was severely affected due to unprecedented drought that occurred in Kerala during summer 1983. It revealed that the agricultural droughts with reference to plantation crops of Kerala should be classified based on the distribution of rainfall during summer, but not based on rainfall that is assured during the monsoon. Moreover, normally the plantation crops are never under soil moisture stress during the monsoon as rainfall/soil moisture is assured.

In Kerala, the distribution of rainfall is totally different from South to North of the State. In the South (Trivandrum), the distribution of rainfall is bi-modal while being uni-modal in the North (Kannur and Kassragod districts). As a result, the crops that are grown in the South experience relatively less soil moisture stress when compared to that of northern districts of Kerala. For effectiveness of precipitation, the concept of potential evapotranspiration was introduced and defined evapotranspiratlon (PET) by Thornthwaite (1948) and Penmann (1948). The PET was defined as the combination of evaporation and transpiration when the surface is completely covered with vegetation and there is an abundance of soil moisture. It depends upon a number of factors including temperature, incoming solar radiation, wind speed and saturation vapour pressure deficit. A number of empirical formulae are available in literature for computing potential evapotranspiration based on meteorological data. Penman's method of estimating potential evapotranspiration is widely used as the method considers both energy balance and aerodynamic components. The CROPWAT software developed by FAO in 1990 could be used for computing reference evapotranspiration (ETo) of crops based on surface air temperature, humidity, wind speed and sunshine hours.The following table gives the computer output of reference evapotranspiration (Eto) according Penman-Monteith formula (Table 1).

Table 1 : Reference Evapotranspiration at Vellanikkara for the year 2000 using CROPWAT

Reference Evapotranspiration ETo according Penman-Monteith							
Country: India **Altitude:25 meter**				**Meteo Station : Vellanikkara (2000)** **Co-ordinates: 10.00 N.L 76.00 E.L**			
Month	**Max. Temp (°C)**	**Min. Temp (°C)**	**Humidity (%)**	**Wind (km/day)**	**Sunshine hours**	**Radiation (MJ/m²/day)**	**ETo-Penman (mm/day)**
January	32.9	23.2	60	170	9.2	11.7	5.09
February	33.3	22.8	67	89	8.6	12.8	4.63
March	35.6	23.9	67	77	9.7	15.1	5.39
April	34.0	24.6	74	62	7.2	13.4	4.60
May	33.7	24.4	72	70	8.5	14.2	4.87
June	29.6	22.8	86	74	3.3	9.5	3.03
July	28.8	21.9	82	91	4.8	10.7	3.43
August	29.12	22.6	87	82	3.1	9.6	3.01
September	30.7	23.0	81	77	5.9	11.9	3.88
October	30.7	22.7	80	65	5.6	11.0	3.60
November	33.3	23.1	66	137	6.7	10.6	4.33
December	30.4	22.0	59	187	7.9	10.2	4.66
YEAR	32.0	23.1	73	98	6.7	11.7	1536

The computed ETo underestimates from December to April while coincides in remaining months when compared to that of open pan evaporation (Fig. 2).

This was due to abnormal seasonal fluctuations in vapour pressure deficit and the amount of solar radiation received. However, as a whole, the Penman is the best suited for computing reference evapotranspiration when compared to that of other formulae and it can be used under field conditions for irrigation requirement of crops. The underestimate of reference evapotranspiration of modified Penman-Monteith during winter can be attributed due to strong winds that blow through Palakkad gap (Fig. 3).

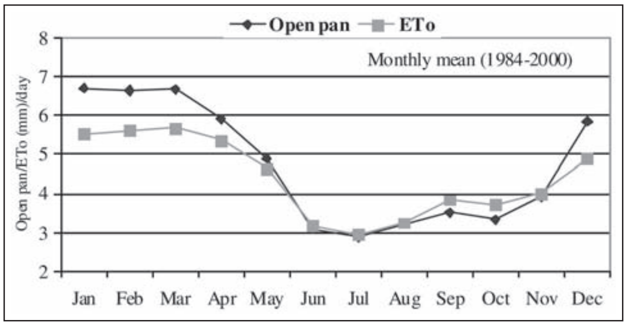


Fig. 2 : **Mean m**onthly Potential evapotranspiration (modified Penman-CROPWAT) versus open pan evaporation (1984-2000) at Vellanikkara

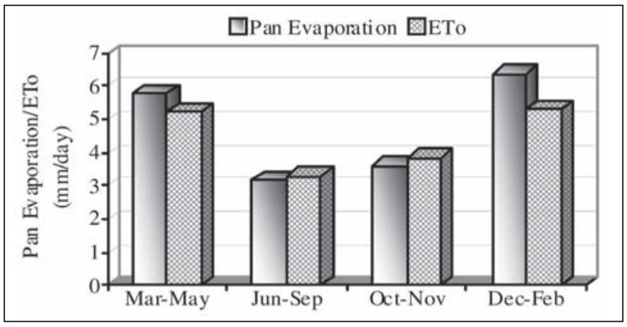


Fig. 3 : Season-wise potential evapotranspiration (modified Penman-CROPWAT) versus open pan evaporation at Vellanikkara from 1984 to 2000

Based on pan coefficient, the reference evapotranspiration could be worked out using pan evaporation. The pan coefficient worked out as 0.83 for winter and 0.89 for summer under the climatic conditions that prevail over Palghat and Thrissur regions.It was worked out using the regression equation Y=bX, where Y is reference evapotranspiration, X is pan evaporation and b is constant.The computational methods give the potential evapotranspiration while evapotranspiration can be worked out under direct measurements. The ratio between the evapotranspiration and the potential evapotranspiration gives the crop coefficient.

$$Kc = \frac{\text{ET requirement of a crop}}{\text{Potential evapotranspiration}}$$

or ET requirement of a crop = Kc x PET where, Kc is crop coefficient, ET -evapotranspiration and PET -potential evapotranspiration.

For many of the dry land annual crops, Kc from the time of sowing to establishment is 0.3 to 0.6 increasing to a maximum of 1.0 to 1.3 when the crop canopy covers most or all of the incoming solar radiation. When the crop attains physiological maturity, Kc declines to approximately 0.5. The values of Kc for number of crops are available in literature and vary from 0.6 to 1.2.

Though the rainfall is the main source for water supply of plants, the plant growth does not depend on rainfall alone, but it should balance the evapotranspiration of crops. Based on rainfall and potential evapotranspiration, crop growth periods can be adjusted. For most of the crops, the period during which rainfall exceeds the PET is the best suited for the maximum growth period. Of course, this is the period during which surplus rainfall leads to run off and in the absence of drainage facilities, the crops are subjected to waterlogging and it is detrimental to crops. The early vegetative phase including sowing period and the later phase, that is, ripening period can be adjusted when the rainfall is less than PET (the rainfall should be at least 50% of PET). The above conditions hold good in India wherever crops are grown only under rainfed conditions. At the same time, it does not hold good under rainfed conditions of Kerala as the rainfall is abundant during the monsoon season. The surplus water during the first crop season leads to waterlogging which is detrimental to crops. The second and third crops suffer due to soil moisture stress and crop failure is a common phenomena during the above seasons if irrigation is not assured. The irrigation schedule or surplus water could be determined based on precipitation and potential evapotranspiratiaon of a particular location. The pan evaporation could be taken into account in place of potential evapotranspiration wherever pan evaporimeter data are available for operational use. The weekly rainfall and open pan evaporation were compared to explain water deficit and surplus periods with reference to crops (Fig 4).

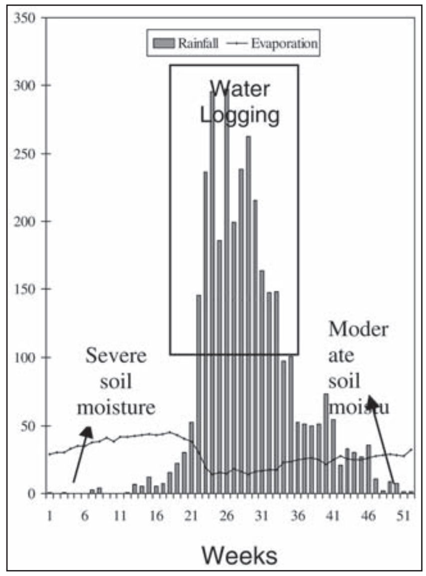


Fig. 4 : Weekly rainfall versus evaporation at RARS, Pilicode (1983-1998)

Based on ETo and precipitation, irrigation requirement of different crops can be computed using CROPWAT, which needs information on crop management and crop coefficients during different crop stages. Other classical examples are IBSNAT-DSSAT- CERES models, developed for decision making on agrotechnology transfer across different agroclimatic zones of the world.

The accumulation of moisture in soils starts with the onset of pre-monsoon showers/monsoon rains, reaches its field capacity with the progress of rains. In the absence of rains during off-season, the accumulated soil moisture is used for plant growth. The choice of crop and successful crop harvest depend on the availability of soil moisture. The availability of moisture varies between soils depending upon its water holding capacity. The water holding capacity is the difference between field capacity and permanent wilting point. It depends mostly on the mechanical composition of soils. Considering the above, Thornthwaite (1948) developed a book-keeping water balance procedure based on precipitation and potential evapotranspiration. In similar lines, Frere and Popov (1979) developed a cumulative water balance based on decade/weekly precipitation and potential evapotranspiration taking into account crop coefficient factor, which varies from crop to crop, and within the crop from stage to stage. They also introduced the water requirement satisfaction index. It correlated well with the yield. Using water balance parameters, several indices such as index of moisture adequacy, humidity index, aridity index, moisture index could be worked out. The above climatic indices based on moisture regime are widely used for delineating climatic zones, defining climatic droughts as well for explaining crop yields based on the type of climatic indices used. The thermal use efficiency is also used for climatic zonation based on thermal regime (and potential evapotranspiration). A number of thermal indices viz., Stress Degree Days (SDD), Canopy Temperature Variation (CTV), Temperature Stress Days (TSD), Crop Water Stress Index (CWSI) have been developed outside India based on Infrared thermometry for irrigation management. However, such studies are scanty in India. Of course, they are more crop-soil-climatic specific and complicated in case of plantation crops.

Most of the plantation crops suffer due to soil moisture stress during summer. In case of coconut, the nut yield is affected in the following year up to 30 to 50 per cent depending upon the variety and crop management due to severe soil moisture stress during summer. The following criteria are developed for assessing agricultural droughts with reference to coconut based on the index of moisture adequacy (Table. 2).

Table 2 : Mean index of moisture adequacy (Ima) and intensity of drought

Intensity of drought	Mean Ima (%) from December to April
No drought	<30
Moderate	25-30
Large	20-25
Severe	15-20
Disastrous	<15

Based on the above criteria, the intensity of agricultural droughts was worked out for the period from 1942 to 1997 using the climatological data at RARS, Pilicode. Out of 41 agricultural drought years, 11 each fell under moderate and large, 12 severe and seven under disastrous categories. It showed that 46.4 per cent of the years fell under severe and disastrous droughts (Fig. 5).

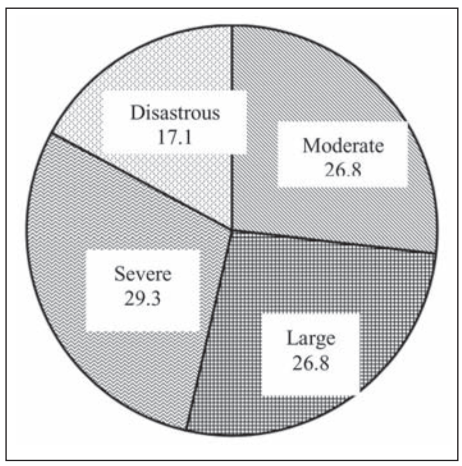


Fig. 5 : Percentage frequency and intencity of agricultural droughts

From the above, it is evident that the plantation crops that are grown in the low-and-mid-lands of Kasaragod district experienced severe soil moisture stress almost in half of the years. It was probably one of the reasons, why, the fluctuations in plantation crop production was noticed very often. In the recent past, the occurrence of disastrous droughts in summer 1979, 1983, 1989, 1997 adversely affected the plantation crop production to a great extent.

The irrigation requirement of coconut was worked out at RARS, Pilicode using the reference evapotranspiration (modified Penman method has been generally accepted as a reliable method to determine evapotranspiration from climatic data) and crop coefficient. The irrigation requirement varied from 1106 litres/palm/month in December to 1488 litres/palm/month in April. The total irrigation requirement from December to May was worked out as 7807 litres (Table 3).

Table 3 : Irrigation requirement of coconut

Month	ETo (mm)	Water requirement (mm) (ETo x 0.75)	Irrigation requirement (l) ($\pi^2 h$)
December	3.79	2.84	1,106
January	3.95	2.96	1,154
February	4.56	3.42	1,204
March	5.01	3.76	1,464
April	5.26	3.95	1,488
May	4.76	3.57	1,391
Total			7,807

ETo-Reference evapotranspiration, r- Radius of coconut basin- 2 metres, 0.75 – Crop coefficient of coconut

Coconut growers can very well adopt the irrigation quantities during summer as recommended above wherever water is available which will improve coconut yield significantly as the yield per palm is well below the normal under rainfed conditions due to prolonged dry spell from November to May. In another experiment, a field experiment was taken up at RARS, Pilicode, Kasaragod where the palms were provided basin irrigation at the rate 450 litres/palm/week till the water became available during summer and leaving the palms without watering further till the onset of monsoon. The yield was better in the above treatments when compared to that of pre-treatments‘ yield. The quantity was arrived at 450 litres/palm/week taking the evapotranspiration of coconut as 5 mm per day.

The agroclimatic analysis is a useful tool in not only drought management but also in water/nutritional management as the nutritional uptake is maximum when optimum soil moisture is available to the plant. It is one of the reasons, why, a particular fertilizer element responds positively when optimum soil moisture is available while negatively when soil moisture is not sufficient. Similarly, it is yet to be understood on uptake of nutrients when evapotranspiration is limited - or below optimum due to near zero vapour pressure deficit in atmosphere, which is not uncommon during rainy season extending three to four months in tropical monsoon climates. In such situations, location specific agroclimatic analysis will be of immense use for sustenance of agricultural production.

APPROACHES TO IMPROVE DROUGHT ADAPTATION OF CROPS

Udayakumar M.

Drought is the most important constraint to realize the potential yields of crops. Moisture stress during the crop growth period, accounts for about 30 to 70 per cent loss in productivity in the country. In India, as in many other parts of semi-arid regions of the world, 78 per cent of the area under agriculture is rainfed and is inescapably linked to the vagaries of the monsoon. Out of the total gross cultivated area of the country, 56 Mha is subjected to inadequate and highly variable rainfall. The National Commission on Agriculture (MOA 2010) identified 337 districts of the country as drought prone.

Improving crop productivity with limited water under rain-fed conditions and saving irrigation water are objective of national priority. Though drought from the conventional meteorological view point is defined as the prolonged absence of rainfall to cause a reduction in soil water status below that of the potential evapotranspiration of that location, the present day definition of drought is more complicated. With increasing demand for water even the irrigated agro-ecosystem might experience moisture stress. Hence, the emphasis must be to increase the adaptation of crop plants to water limited conditions and to develop crop genotypes that would produce more with less irrigation. In this context, one of the major global agenda has been to improve water productivity of crop plants with an emphasis of achieving "more crop per drop".

Plants have evolved diverse adaptive strategies to cope with water-limited environments. From the ecological perspective, these diverse plant physiological mechanisms have their relevance in enhancing stress adaptation. However, from the agronomic perspective, mechanisms that can sustain growth under water limited environment need greater emphasis. The Agronomic concept of a drought resistant variety: A Drought tolerant genotype gives acceptable productivity under water limited conditions. Drought tolerant trait is a plant character or biochemical mechanism that facilitates growth and cell survival under stress. Several recent studies provided convincing evidences that comprehensive crop improvement under drought stress is possible only when diverse plant traits/mechanisms are "pyramided" onto a single superior genetic background. Hence, the major focus of the global research community has been to devise strategies for achieving the formidable challenge of trait pyramiding, to improve drought stress tolerance in crops.

The critical inputs to achieve the complex task of improving adaptation to drought are;

a. Drought tolerant traits that are relevant to improve crop adaptation.

b. Precise phenotyping for drought traits.

c. The genes/QTL that regulate adaptive mechanisms.

d. Novel and comprehensive breeding strategies to pyramid these traits.

A) Drought Adaptive Traits

The past decade has witnessed a significant increase in efforts towards analyzing the relevance of drought adaptive traits. The drought tolerant trait is a plant character/biochemical mechanism that facilitates the normal growth and cell survival under water limited conditions (Reynolds and Tuberosa, 2008). On the contrary, genotypes with potential drought tolerant trait/s need not be productive. In this context the concept of breeding for drought revolves around the approaches (strategic) to evolve a genotype with several drought adaptive traits.

The adaptive traits include two groups: 1) Traits which are inherent to the genotype and may not upregulate under stress known as constitutive traits. 2) Traits/mechanisms which are upregulated under stress known as acquired traits. (Fig. 1)

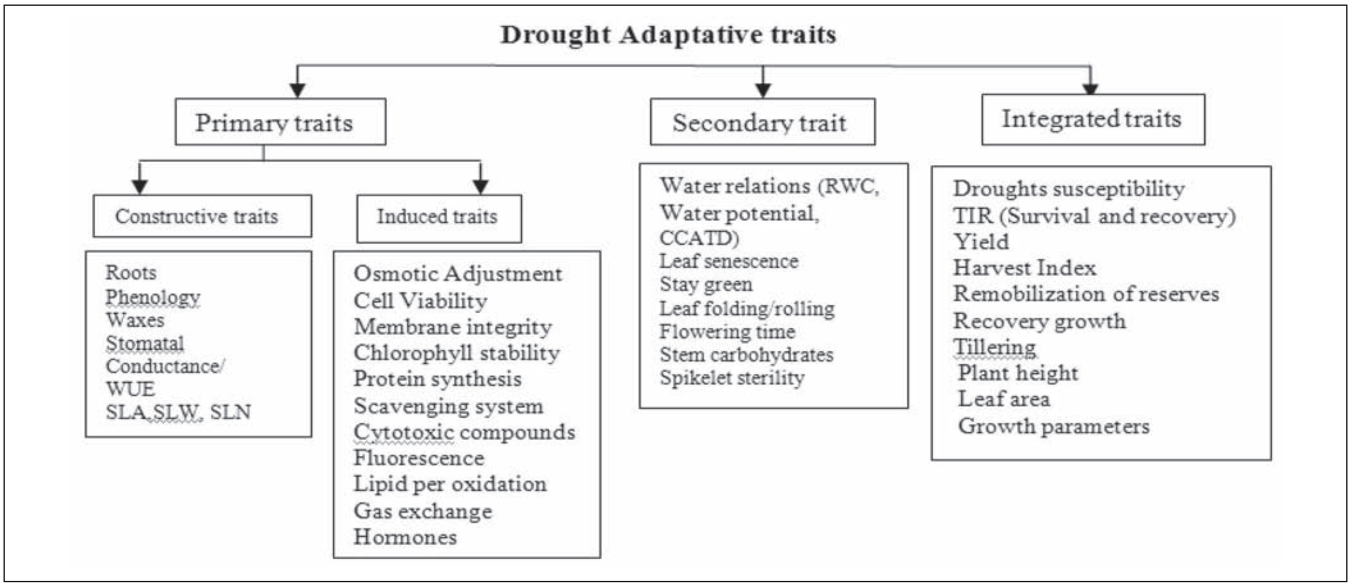


Fig. 1 : Schematic representation of plant traits/mechanisms involved in drought adaptation

Constitutive traits:

These include roots, WUE, epicuticular waxes and phenology. Genes controlling these traits are poorly understood. The root is the most crucial organ for meeting transpiration demand at a reasonably high leaf water status, on the condition that water is available in the rooting zone. High root length density increases the number of contact points between root and soil. White and Kirkegaard (2010) showed that root contact as driven by extensive root branching and long root hairs is a prime determinant of moisture extraction from dry soil. Phenomenal literature supports several root characters relevant for stress adaptation and many reports have shown that genotypes with higher quantum of roots maintained the leaf temperature cooler for longer period under stress.

Water use efficiency is important trait to sustain growth under water limited conditions. It is a quantitative measure of biomass produced per unit of water transpired by the plant and describes a plant's photosynthetic rate relative to the rate at which it transpires water to the atmosphere. Under water deficit conditions plants maximize WUE by reducing transpiration rate. WUE has greater impact on growth when the differences in WUE are independent of transpiration rate. Considerable genotypic variability in WUE has been reported in many species including rice (Cabuslay *et al*., 2002) and hence a relevant trait to improve plant water relations.Water conservation through waxes is emerging as a potential trait. Non-stomatal water loss regulated by waxes occurs all through the day and night and hence has relevance. Besides, it plays a predominant role in leaf reflectance characters and hence in dissipating heat load. Inspite of the fact that stomatal opening and closing is highly dynamic and the regulatory mechanisms are quite complex, stomata still play a dominant role in water conservation. In this context, constitutive factors like stomatal frequency and induced characteristics like stomatal closing and opening has significance and relevance in water conservation (Maroco *et al*., 1997).

Acquired traits:

These mechanisms are upregulated under stress when the tissue water potential decreases. The genes that regulate these mechanisms are often referred as stress responsive genes have been the focus of research over the last two decades. Significant achievements have been made in characterizing transcriptome and several EST database are developed and now available for scientific community ((http://www.Arabidopsis.org/, http://www.tigr.org/). Besides, the role and relevance of many stress responsive genes regulating the specific cellular level tolerance mechanisms has been very well characterized. Several overexpression and downregulation studies demonstrated the relevance of stress responsive genes in imparting tolerance (www.plantstress.com) (Table 1).

Table 1 : Some of the validated genes for abiotic stress tolerance

Gene name	Species	Phenotype	Reference
AtNCED3	Arabidopsis	Reduced transpiration and drought resistance	Iuchi *et al*., 2001
VuNCED1	Creeping bent grass	Salinity and drought resistance	Aswath *et al*., 2005
2-Cys Prx	Potato	Antioxodative action and heat tolerance	Kim et al., 2011
SOD	Arabidopsis	Heat tolerance	Im et al., 2009
SOD1	Rice	Salt tolerance	Prashanth et al., 2008
GST	Rice	Salt and chilling resistance	Zhao and Zhang, 2006
P5CS	Rice	Resistance to water and sainity stress	Su and Wu, 2004
mt1D	sorghum	Salt and drought tolerance	Maheswari et al., 2010
AtLEA4	Arabidopsis	Drought resistance	Olvera-Carrillo et al., 2010
SpERD15	Tobacco	Drought resistance	Ziat et al., 2011

B) Precise Phenotyping for Drought Traits

The precise phenotyping of stress responsive mechanisms and traits has now emerged as a crucial component in the area of drought research. Infact, the lack of progress in identifying trait donor lines, developing robust QTLs for stress responsive adaptive traits and to validate the relevance of stress specific genes, accurate phenotyping is the major constraint. Over the last decade, a phenomenal emphasis has been to develop tools and techniques for precise phenotyping of diverse stress adaptive traits.

Thus, the success in future breeding endeavours is strongly linked with the ability for accurate phenotyping of these complex drought adaptive traits in large number of germplasm accessions and breeding lines. In this, emphasis is being laid to develop precise tools and techniques to accurately phenotype the drought adaptive traits in large number of accessions. Further, for the best exploitation of the relevance of these drought adaptive traits, it is essential to screen these traits under precisely maintained stress levels. This crucial requirement led to identifying the rain-free locations for drought nurseries and to the development of managed drought environment facilities for accurate maintenance of desired soil moisture regimes.

Different tools/techniques are available to phenotype for the stress adaptive traits (Table 2). Oxygen isotope quantification is another potential option to quantify transpiration rate and thus root traits (Sheshshayee et al 2005; Ehab et al., 2010) (Fig. 2).

Table 2 : Different tools/techniques available for phenotyping stress adaptive traits

Traits	Tools/Techniques
Water status	RWC
Water potential	Psychrometer, Pressure chamber
Osmotic adjustment	Quantification of osmotic potential using osmometer
WUE	Gravimetry, IRGA, ^{13}C discrimination, SLA,SLN
Canopy temperature	Infrared thermometer
Water mining – phenotyping for roots	Mini lysimeter, root structure, Oxygen isotope discrimination
Waxes	Colorimetric assay
Stomatal characters	Stomatal conductance-IRGA, Stomatal index/frequency –impression method
Intrinsic tolerance	TIR, survival and recovery
Oxidative stress	MDA, membrance integrity
Stay green	Chlorophyll content, SPAD meter
Remobilization of reserves	Water soluble carbohydrate estimation, biomass estimation

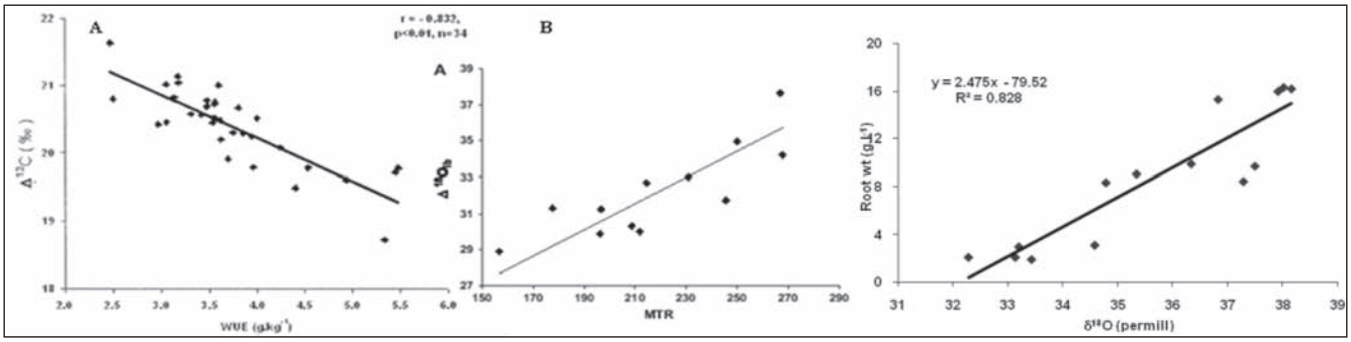


Fig. 2 : Relevance of stable isotope ratios as surrogates for complex physiological traits; (A) Carbon isotope discrimination as a measure of WUE; (B) Oxygen isotope enrichment as a measure of mean transpiration rate and; (C) Oxygen isotope enrichment as a measure of root traits; Stable isotope ratios were analyzed using an Isotope Ratio Mass Spectrometer using the leaf samples.

Other constraint in phenotyping for drought traits is that many techniques are not amenable for large scale screening. This lacuna is in fact a major bottle-neck to exploit many validated drought adaptive traits. Yet another constraint is destructive sampling for assessing traits, which again imposes limitations. In recent years, focus has been to develop "non-contacting" high throughput sensor based phenotyping approaches. Several passive and active reflectance sensors and many laser based techniques and other imaging tools are being employed for high throughput measurements of plant water status, canopy temperature and even for aerial growth and biomass estimation. The significance, potential and limitation of these new imaging techniques and phenomics platforms with automation need to be examined. In summary, identifying relevant traits and precise phenotyping of these traits should keep pace with the developments in genomics and genotyping technologies.

C) The Genes/QTL that Regulate Adaptive Mechanisms

Genes for improving drought tolerance traits:

Understanding the stress responses in plants provided initial insights into stress responsive mechanisms and thus leading to cloning and molecular characterization of genes that regulate the stress adaptive mechanisms. Many functional genes regulating these mechanisms have been characterized and their relevance in imparting drought tolerance has been validated by diverse molecular tools like mutant analysis, over expression studies, RNAi and Virus Induced gene silencing approaches. Transgenics expressing several functional genes governing osmoprotection (Cortina et al., 2005),molecular chaperons(Valente et al., 2009), detoxifying enzymes (Zhu et al., 1999), transporters (Gisbert et al., 2000), ABA biosynthesis and lipid metabolism regulating genes (Xiao et al., 2009) provided evidences that improving specific adaptive mechanisms can enhance stress tolerance. Several stress specific transcription factors from different families like leucine zipper (bZIP), AP2/EREBP, NAC, MYB, Zinc finger, WRKY and NF families have been characterized and their relevance is validated (Zhu et al., 2002, Shinozaki et al., 2003; Umezawa et al., 2006, Yang et al., 2010). The impact and mitigation of drought, the validated genes regulating drought, molecular biology and genetic resources for various crops is being updated and available at plantstress.com. The database indicate that among the reported transgenics with 634 diverse genes of which 42% are regulatory genes, followed by osmo-protectants (16%) and transporters (14%) (Fig. 3)

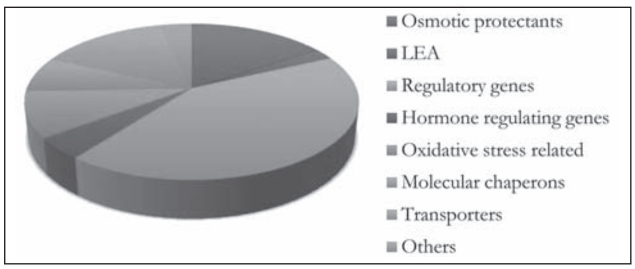


Fig. 3 : Pie chart depicting total number of stress resistant genes evaluated by transgenic or mutant approach; The genes identified to impart abiotic stress resistance by various researchers were grouped based on their function at www.plantstress.com. This chart represents the number of genes characterized under each functional group.

QTL for drought adaptive traits:

Genetic engineering approaches rarely attempted to improve adaptive traits other than those associated with cellular level tolerance. The lack of translating the lab success in improving drought tolerance to the field conditions arises from the fact that most of the plant trait associated with tissue water relations, carbon gain, phenology etc, are polygenic and exhibit quantitative inheritance. This necessitates the adoption of a focused molecular breeding program which in turn relies on the discovery of robust QTL and markers either linked or associated with such loci.

Quantitative traits are those that are regulated by many genes and show a continuous variability between two extremes. Identification of genomic regions (QTL) that govern the variability in such quantitative traits has great relevance in breeding to improve specific traits. It is estimated that the marker assisted QTL introgression can lead to the trait improvement in significantly less time than the time taken to achieve the same results through conventional methods (Chapman et al., 2005 and Fig. 4). Success in the accurate identification of QTL depends not only on the development of an appropriate mapping population segregating for the trait of choice, but mainly on the appropriate phenotyping and molecular characterization strategies. Realizing the importance of this potential technology, several diverse molecular breeding initiatives have been launched globally and also in India. This resulted in an explosion of scientific information in this area in many crop species of economic importance leading to an exponential increase in the discovery of QTL conditioning various traits of agronomic importance including drought tolerance traits. A number of such QTL have since been validated and the biochemical or physiological functions elucidated.

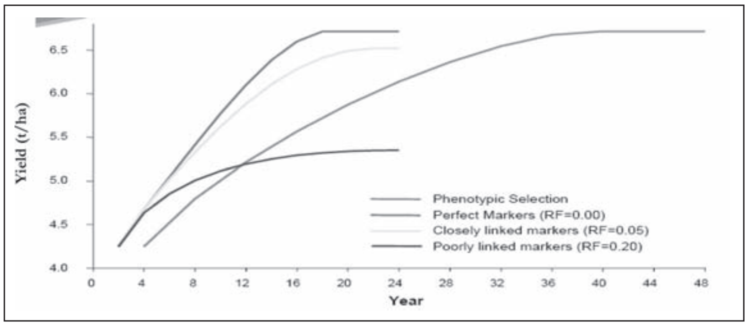


Fig. 4 : Evidences proving the relevance of MAS in crop improvement; Molecular breeding significantly enhances the success in crop improvement through a remarkable reduction in the time taken for achieving yield improvement. Perfectly linked markers have a great relevance (Chapman et al., 2005).

Very few drought QTLs are being used for MAS: Despite this global initiative on QTL discovery and their validation, the utility of such information has been far from even being satisfactory, (Fig. 5).

The reason for such an increasing gap between QTL discovery and their translation in MAS program can be summarized as follows;

1. Lack of co-dominant informative markers such as SNPs and SSRs in most crops.
2. Inability for a high throughput SNP and SSR genotyping in large number of accessions.
3. Inadequate crop genetic resources of trait specific mapping populations and/or diverse panel of germplasm accessions
4. Choice of traits and non-availability of accurate high throughput phenotyping techniques.
5. Low probability of the QTL being effective in a different genetic background.

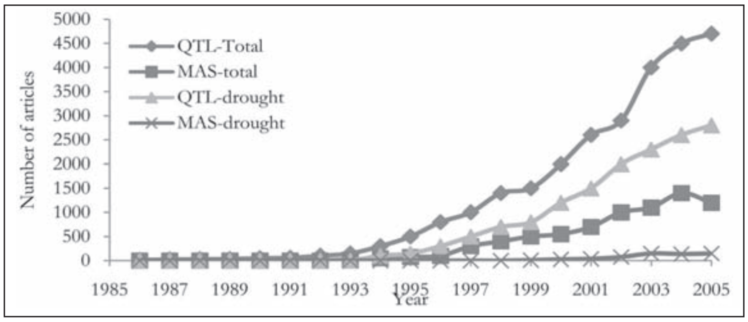


Fig. 5 : Summary of the efforts leading to QTL discovery and their use in MAS; A significant gap between QTL discovery and their utilization in MAS is depicted. The total number of QTL discovered for drought tolerance traits is significantly lower than that for other biotic stress tolerance traits. This data illustrates the requirement of more robust discovery and validation of QTL that govern specific drought tolerance traits.

Association Mapping: An Approach for the Discovery of QTL for Diverse Traits:

In recent years, there has been an increased interest in QTL discovery using population genetic approaches also referred to as Linkage Disequilibrium mapping or simple terms Association mapping. This approach relies on the use of diverse accessions of a crop species that have typically undergone almost infinite cycles of meiotic re-combinations. This approach utilizes the existing genetic variability in the phenotypic traits as well as the molecular diversity on the whole genome and hence the technique represents a high level of resolution in QTL detection. One of the most striking advantages of this approach is the possibility of assessing the genetic variability in diverse traits in one single panel of germplasm accessions. Furthermore, since germplasm, landraces and other accessions are used in association mapping, the identified QTL will have a greater probability of successful expression in a target genome. Based on these features, association mapping would be the most appropriate strategy for QTL tagging for traits of relevance in enhancing drought tolerance.

D) Novel and Comprehensive Breeding Strategies to Pyramid these Traits

Breeding for improved drought tolerance:

There are now consensuses that further improvement of crop growth and productivity under water limited conditions can only be achieved through trait based breeding strategies. The goal is to introgress several diverse and complex traits on to a single genetic background. The phenomenal knowledge gain in the area of stress responses of crop plants and the success in characterizing and validating the drought adaptive traits and finally progress made in discovery of genes and QTLs that govern the observed variability in the traits of choice provided well defined options to improve drought tolerance of crops.

i) Conventional trait based breeding: Conventional breeding program has generally sought to improve dehydration avoidance rather than dehydration tolerance as strategies to improve adaptation to drought stress. The relevance of trait pyramiding conventionally has been demonstrated in one of our studies. Initially Rice germplasm accessions have been phenotyped extensively for few drought adaptive traits. Thanu has been identified as high water use efficiency type and IET 15963 has deep root system. Introgressed population of these two genotypes has been developed and progenies have been extensively phenotyped for these traits to identify superior segregants having both the traits. Some of the introgressed lines with high root growth and WUE showed significantly higher productivity under semi irrigated aerobic conditions. One of the lines KMP-175 with better roots, WUE and high yield has been identified and tested for field level tolerance (UASB) (Fig. 6).

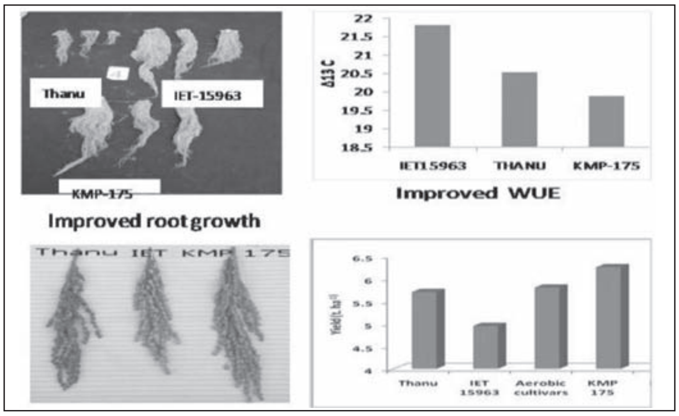


Fig. 6 : Trait based breeding program to develop introgressed line KMP-175

ii) Marker assisted selection as a strategy for gene pyramiding: During the past couple of decades, marker assisted selection (MAS) has emerged as a potential strategy for introgressing such polygenic traits. Most of the drought tolerance traits show polygenic inheritance and hence MAS is the most appropriate strategy of crop improvement. For instance, submergence tolerance was improved by introgressing the Sub-I locus into several released rice varieties. Similarly, drought tolerance of maize was significantly improved by introgressing the Anthesis to silking interval (ASI) QTLs and in rice by introducing a few root-QTL. Upland rice varieties Birsa Vikas and Dhanu III developed with improved traits by MAS are quite promising.Besides, for a complex problem of improving drought tolerance, several traits need to be simultaneously introgressed. This can be achieved by developing a population called MAGIC (Multi-parent Advanced Generation Intercross) derived from superior trait donor lines. The population is derived from crossing more than 8 parents, the subsequent F_1 derived from each pair of the crosses are again intercrossed and subsequent recombinants are selected using foreground as well as background selection.

Pyramiding the traits by Double haploids: The Doubled haploid technology is emerging as a potential approach for trait introgression. Application of this technology in breeding programs can significantly reduce the number of generation required for fixation of genetic segregation and improve selection efficiency (Wedzony et al., 2009). In this approach the trait donor parents are crossed and subsequently the F1 hybrid plants are used to produce. Doubled Haploid Lines (DHLs) through anther/microspore culture. However the crucial aspect is the ability to identify the desired recombinants. Therefore the primary pre-requisite are; a) The ability to generate large number of DHLs. b) To phenotype the recombinants for the desirable trait or identify the recombinants by foreground selection using markers associated with the trait of interest.

Pyramiding the traits by transgenics: Transgenics- potential option for pyramiding drought traits Manipulation of a particular metabolic pathway, provided tolerance to certain extent, but it is difficult to achieve the required level of tolerance as several mechanisms are involved in cell adaptation to dehydration stress. To address this, emphasis was shifted to identify stress specific regulatory genes, which coordinate the expression of a group of genes. However pyramiding different traits is necessary to achieve field level tolerance. Besides cellular level tolerance improving the traits associated with plant water relations (PWR) like water mining, WUE and water conservation has relevance and field level tolerance can be achieved only by introgressing these two important traits – CLT & PWR.

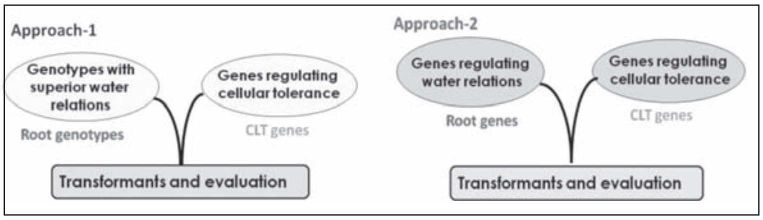


Fig. 7 : Different approaches adopted to pyramid diverse drought adaptive traits

Transgenics has now emerged as potential options to pyramid the traits. Two different approaches were adapted to pyramid the traits. i) To overexpress validated regulatory genes associated in improving CLT in the background of the genotype with superior water relations (ii) To co-express genes that regulate root characteristics as well as CLT mechanisms (Fig. 7).

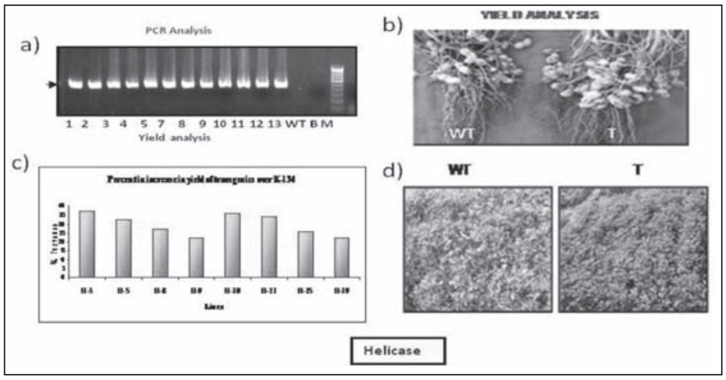


Fig. 8 : a) PCR analysis of transgenics expressing PDH45,b) Photograph showing pod number in plants c) % increase in yield in helicase transgenics d) (a) Stay green phenotype of Helicase (H-19) transgenic

Approach 1

The important steps in achieving this objective is initially identification of recipient genotypes with superior water relations, identify candidate genes to improve cellular level tolerance, develop transformation protocol to generate large number of transgenic events and rigorous evaluation to identify superior events which are moisture stress tolerant besides being productive under stress.

With this conceptual objective, groundnut transgenics were developed with superior stress tolerance and productivity. The approach has been, initially identifying genotypes with superior water relations and use them as recipient genotypes to express validated upstream regulatory genes which improve cellular level tolerance. Based on stress response of groundnut and stress EST developed, the choice of upstream genes associated with cellular level tolerance has been Helicases (PDH45) and AP2/ERF family DREB transcription factors.

The groundnut transgenics developed expressing Helicase with superior water relations showed increased water use efficiencies, chlorophyll stability and cellular tolerance. Some of them were stay green both under moderate and severe stress conditions. Besides, these transgenics showed superior growth rate and yield under controlled soil growth conditions (Fig. 8) (UASB).

Approach 2

The scientific strategy in this approach has been to pyramid two important drought adaptive traits mainly water mining and CLT mechanisms. To achieve this goal, relevant genes regulating these mechanisms were identified. Alfin1 is a candidate gene to improve roots, PDH45 and HSF4 to improve CLT mechanisms. Transgenic groundnut plants co-expressing these upstream genes showed improved root growth with lower canopy temperature under stress. The transgenics under NaCl and Drought stress conditions showed improved tolerance. Besides being tolerant, some promising transgenics showed higher canopy transpiration, stay green nature and significantly higher productivity (Fig. 9) (UASB).

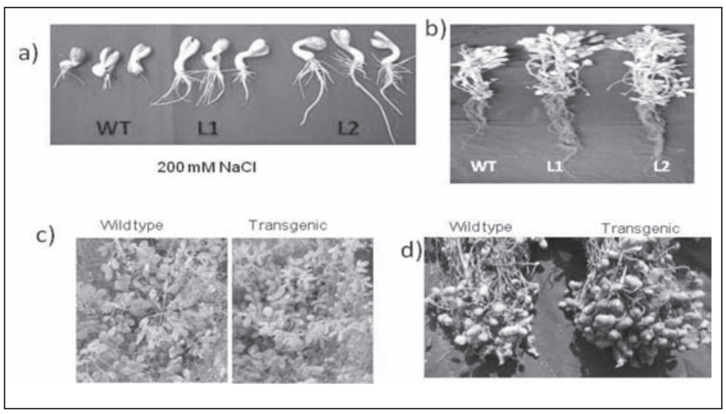


Fig. 9 : Groundnut Transgenics coexpressing Alfin1, PDH45 and HSF4 a) Salinity stress tolerance of transgenics b) root growth analysis c) staygreen nature of transgenics d) Pod yield in transgenics

CROP HEALTH MONITORING USING REMOTE SENSING

Shibendu Shankar Ray

Crop health monitoring is essential for crop production forecasting, drought assessment, crop management, precision farming and many other agricultural activities. Conventionally, crop health is monitored either visually or by various laboratory techniques, such as measurements of biochemical (e.g. chlorophyll, leaf water, leaf nitrogen) and biophysical (e.g. LAI, biomass), disease intensity scaling, etc. These techniques are, time consuming and many times may not provide a complete picture.

Remote sensing, which is defined as the collection of information (through measurement of reflectance of the targets in various wavelengths) about an object without physical contact, has been a very effective source of information (Navalgund et al. 2007). Remote sensing data - because of its typical properties like, capability to achieve a synoptic view, potential for fast survey, capability of repetitive coverage to detect the changes, low cost involvement, higher accuracy, and use of multi-spectral data for increased information - provides a better alternative compared to traditional methods for crop condition assessment and health monitoring, which involve large manpower and extensive field experimentation.

Vegetation Reflectance

In order to appreciate the role of remote sensing for crop health assessment, we need to understand the reflectance pattern of vegetation. Vegetation reflectance is primarily influenced by the optical properties of plant materials (e.g. chlorophyll, carotenoid, water, proteins, lignin, cellulose, sugar, starch, etc.). Plant materials are composed largely of hydrogen, carbon, oxygen, and nitrogen (Kokaly and Clark, 1999). Thus, the absorption bands observed in reflectance spectra of vegetation arise from vibrations of C-O, O-H, C-H, and N-H bonds, as well as, overtones, and combinations of these vibrations (Curran, 1989). The absorptions from the different plant materials are similar and overlapping, so a single absorption band cannot be isolated and directly related to chemical abundance of one plant constituent.The absorption and reflection of solar radiation is the result of many interactions with different plant materials, which varies considerably by wavelength. Water, pigments, nutrients, and carbon are each expressed in the reflected optical spectrum from 400 nm to 2500 nm, with often overlapping, but spectrally distinct, reflectance behaviour.The optical spectrum can be partitioned into four distinct wavelength ranges:

- Visible: 400 nm to 700 nm
- Near-infrared: 700 nm to 1300 nm
- Shortwave infrared 1 (SWIR-1): 1300 nm to1900 nm
- Shortwave infrared 2 (SWIR-2): 1900 nm to 2500 nm

The typical reflectance pattern for any vegetation shows high absorption due to chlorophyll at 650nm (red region) and high reflection due to leaf internal structure at 750nm (NIR region) and water absorption at 950nm and 1450nm (SWIR region) (Figure 1). The whole range of 400-2500 nm is useful for agricultural purposes due to various absorption features in different regions (Table 1).

Table 1. Common spectral features for crops and soils (Source: Datt et al., 2003)

Spectral Region (nm)	Indication
400-700	PAR region- Photosynthetic pigments
680	Chlorophyll Absorption
700-750	Red Edge (Chlorophyll)
1080-1170	Liquid water inflection
1700- 1780	Various leaf waxes and oils
2100	Cellulose
2100-2300	Soil properties
2280-2290	Nitrogen/Protein

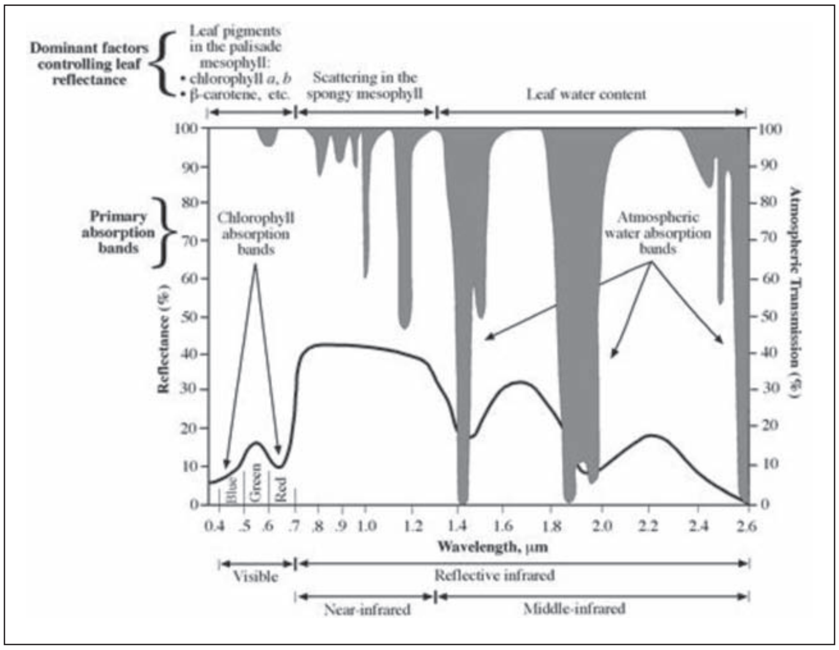


Fig. 1 : Leaf spectral characteristics (from Jensen, 2007)

Vegetation Indices

The differential vegetation responses at different spectral regions have been used to develop various arithmetic formulae, commonly known as Vegetation Indices (VI). The VIs reduce the multispectral remote sensing data to single numbers for assessing vegetation characteristics, such as, species, leaf area index, biomass, stress etc. (Ray and Dadhwal, 1995). VIs are also related to fractions of absorbed total solar and photosynthetically active radiation, canopy photosynthesis, stomatal conductance and land surface albedo. Also as a result of different arithmetic combinations VIs reduce the additive and multiplicative errors associated with atmospheric effect, solar illumination, soil background effect and sensor viewing geometry (Liang, 2004).

The Normalized Difference Vegetation Index (NDVI) is one of the oldest, most well-known, and most frequently used VIs. It is computed as the ratio of difference and sum of the reflectance in near-infrared and red wavelengths (Rouse et al., 1973). NDVI values range between -1 to +1. An area containing a dense vegetation canopy will tend to have positive values (say 0.3 to 0.8) while clouds and snow fields will be characterized by negative values of this index. Other common VIs are SR (Simple Ratio), PVI (Perpendicular vegetation index) and SAVI (Soil adjusted vegetation index) and its different variations (Table 2). The SR index is another old and well known VI.The value of this index ranges from 0 to more than 30. The common range for green vegetation is 2 to 8. The Perpendicular Vegetation Index (PVI) of Richardson and Wiegand (1977) used the red and near infrared bands to calculate the perpendicular distance between the vegetation spot on the NIR-Red scatterplot and the soil line. SAVI, defined by Huete (1988) is less sensitive to soil reflectance at low LAI than NDVI. Although Huete (1988) found the optimal adjustment factor (L value) to vary with vegetation density, he used a constant L = 0.5, since this reduced soil noise considerably throughout a wide range of vegetation amounts.Numerous modifications of SAVI concept have been reported (Barret and Guyot, 1991). A further development of the SAVI concept is the transformed SAVI (TSAVI) (Baret and Guyot, 1991), where instead of an optimized value the slope and intercept of the soil lines were used. Qi et al.(1994) defined the modified SAVI (MSAVI) that replaced the constant L in the SAVI equation with a variable L function, such as: MSAVI = (1 + L)*(NIR - R) / (NIR + R + L), with L = 1 - 2a*NDVI*WDVI, where WDVI (= NIR-aR) is the weighted difference vegetation index (Clevers, 1988), and a is the slope of the soil line. With an iterative procedure they tried to improve MSAVI by minimizing the soil effects and finally arrived at MSAVI2. Rondeaux et al. (1996) showed that the value of L parameter is critical in the minimization of soil reflectance effects, and proposed the optimized SAVI (OSAVI) where L=0.16 was the optimized value. The Enhanced Vegetation Index (EVI) was developed to improve the NDVI by optimizing the vegetation signal in LAI regions by using the blue reflectance to correct for soil background signals and reduce atmospheric influences, including aerosol scattering (Huete et al., 1997). This VI is, therefore most useful in LAI regions, where the NDVI may saturate.The Atmospherically

Resistant Vegetation Index (ARVI) is an enhancement to the NDVI that is relatively resistant to atmospheric factors (Kaufmanand Tanre, 1996).

Red Edge

Another important feature of spectral profile used for crop health monitoring is the Red Edge. The spectral region of the red-NIR transition (700-750 nm) is known as the red edge, and it has been shown to have large information content for vegetation spectra (Horler *et al.*, 1983). The red edge region marks the boundary between the process of chlorophyll absorption in red wavelengths and within-leaf scattering in near infrared wavelengths(Curran, *et al.*, 1990).The slope of this region is a strong indicator of crop health. When a plant is healthy with high chlorophyll content and high LAI, the red edge position shifts towards the longer wavelengths; when it suffers from disease or chlorosis and low LAI, it shifts towards shorter wavelengths (Pu *et al.*, 2003).The importance of red edge has been documented by many workers (Elvidge and Chen, 1995, Jain *et al.*, 2007)

Table 2 : Some commonly used Vegetation Indices

Index	Computation	Reference
NDVI (Normalized Difference Vegetation Index)	$(\rho_n - \rho_r)/(\rho_n + \rho_r)$	Rouse *et al.* (1973)
SR (Simple Ratio)	ρ_n / ρ_r	Birth & McVey (1968)
PVI (Perpendicular Vegetation index)	$(\rho_n - a\,\rho_r - b)/(a^2 + 1)^{0.5}$ a and b are slope and intercept of the soil line ($NIR_{soil} = a.R_{soil} + b$)	Richardson & Wiegand (1977)
WDVI (Weighted difference Vegetation Index)	$\rho_n - a\,\rho_r$	Clevers (1988)
SAVI (Soil Adjusted Vegetation Index)	$(\rho_n - \rho_r)(1+L) / (\rho_n + \rho_r + L)$, L=0.5	Huete (1988)
MSAVI2 (Modified SAVI)	$(1 + L)^* (\rho_n - \rho_r) / (\rho_n + \rho_r + L)$, with L = 1 - 2a*NDVI*WDVI	Qi et al. (1994)
OSAVI (Optimized SAVI)	$(1+0.16)(\rho_{800} - \rho_{670})/(\rho_{800} + \rho_{670} + 0.16)$	Rondeaux et al. (1996)
MSR (Modified SR)	$MSR = ((\rho_{800} - \rho_{670})-1) / ((\rho_{800} + \rho_{670})^{0.5} + 1)$	Chen (1996)
RDVI (Renormalized Difference Vegetation Index)	$RDVI = (\rho_{800} - \rho_{670}) / (\rho_{800} + \rho_{670})^{0.5}$	Roujean and Breon (1995)
EVI (Enhanced Vegetation Index)	$EVI=2.5^*((\rho_n - \rho_r)/(\rho_n + 6\rho_r - 7.5\rho_b + 1))$	Huete et al. (1997)
ARVI (Atmospherically Resistant Vegetation Index)	$ARVI=(\rho_n - (2\rho_r - \rho_b)/(\rho_n + (2\rho_r - \rho_b))$	Kaufman&Tanre (1996)

ρ_n, ρ_r, ρ_b are the reflectance in Near-infrared, redand blue bands, respectively. The numbers, such as 800, 670 represent the particular wavelength in nm.

Crop Stresses

Healthy vegetation contains large quantities of chlorophyll, the substance that gives most vegetation its distinctive green color. In referring to healthy crops, reflectance in the blue and red parts of the spectrum is low since chlorophyll absorbs this energy. In contrast, reflectance in the green and near-infrared spectral regions is high. Stressed or damaged crops experience a decrease in chlorophyll content and changes in the internal leaf structure. The reduction in chlorophyll content results in a decrease in reflectance in the green region and internal leaf damage results in a decrease in near-infrared reflectance. These reductions in green and infrared reflectance provide early detection of crop stress. The crop stresses can be due to water, nutrient or pest/disease. In the following sections, some of these stresses have been assessed using remote sensing.

Water Stress

Satellite monitoring of vegetation water stress is of particular interest in precision agriculture, which relies on timing of irrigation to ensure crops do not suffer from water stress and produce maximum potential yield under limited water conditions (Ghulam et al., 2008). Canopy temperature has been suggested as a water stress indicator in several studies. The temperature of canopy (which can be measured by thermal bands in remote sensing), when compared with ambient temperature gives an indication about water stress in crops. This is because, if crop is not water stressed, transpiration occurs at potential condition and hence canopy temperature remains lower compared to air temperature, as evaporation causes cooling. Jackson et al. (1977) used canopy temperature (Tc) minus air temperature (Ta) as an index to study the water status of the crops, relating Tc-Ta to productivity and crop water requirements and developed crop water stress index (CWSI).Moran et al.(1994) introduced the concept of Vegetation Index/Temperature Trapezoid, used NDVI to take into account vegetation cover and computed the Water De?cit Index (WDI) using the scatter plot of Tc-Ta against NDVI. Kogan (1995) developed two indices, i.e. VCI (Vegetation Condition Index) and TCI (Temperature Condition Index) for monitoring drought. While VCI is the percentage of NDVI with respect to its maximum amplitude, TCI is the percentage in brightness temperature (derived from channel 4 of NOAA AVHRR) with respect to its maximum amplitude.

Water absorption bands in short-wave infrared region (SWIR) have also been used to assess vegetation water status. Two indices developed using reflectance at SWIR are: Normalized Difference Infrared Index[NDII = $(R_{850} - R_{1650})/(R_{850} + R_{1650})$] by Hardisky et al. (1983) and Normalized Difference Water Index[NDWI = $(R_{850} - R_{1240})/(R_{850} + R_{1240})$] by Gao (1996). Khanna et al. (2007) and Palacio-Orueta et al. (2006) have proposed new angle indices to estimate soil and vegetation moisture based on NIR (858 nm) and SWIR (1240 and 1640 nm) bands of MODIS. The Shortwave Angle Slope Index (SASI) parameterizes the general shape of the NIR–SWIR part of the spectrum. SASI, originally called as SANI, is based on a combination of NIR, SWIR1 and SWIR2 bands of MODIS (Palacio-Orueta et al., 2006). ANIR (Angle at NIR), is a combination of reflectance values in the Red, NIR and SWIR1 (1240 nm) bands (Khanna et al., 2007).

Even in visible and near-infrared range, there is significant impact of water stress on canopy reflectance. Using handheld spectroradiometer, Ray et al. (2006) found that potato crop under three irrigations had highest reflectance in NIR range and lowest reflectance in red range compared to other two irrigation treatments (2 and 1 irrigations) (Figure 2).

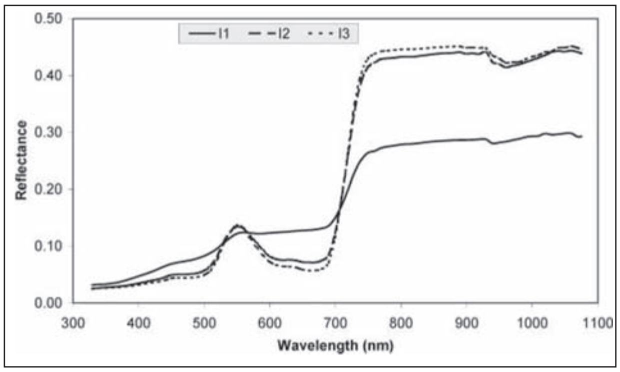


Fig. 2 : Average reflectance pattern of potato crop under three different irrigation treatments (I_1 – 1 irrigation, I_2 – 2 irrigations, I_3-3 irrigations) (Source: Ray *et al.*, 2006)

Disease Stress

Reflected light in specific visible, near- and middle-infrared regions of the electromagnetic spectrum have proved useful in detection of nutrient deficiencies, disease, and weed and insect infestations (Hatfield and Pinter, 1993). However, when disease and physiological stresses directly affect the reflectance properties of individual leaves, the most pronounced initial changes often occur in the visible spectral region rather than in the infrared because of the sensitivity of chlorophyll tophysiological disturbances (Knipling, 1970). Multi spectralremote sensing data available from space-based and airborne sensors have shown the feasibility of discriminating damaged crop fields from the healthy ones (Pozdnyakova*et al.* 2002; Apan *et al*., 2004; Qin and Zhang 2005). Ray et al. (2011) carried out a study to explore the role of hyperspectral (large number of contiguous narrow bands) remote sensing data for potato late blight assessment. Figure 3 shows the reflectance pattern of disease free plants vis-à-vis that of plants with different levels of disease infestation. Similar use of ground based hyperspectral remote sensing for detection of stress in cotton caused by leaf hopper was carried out by Prabhakar *et*

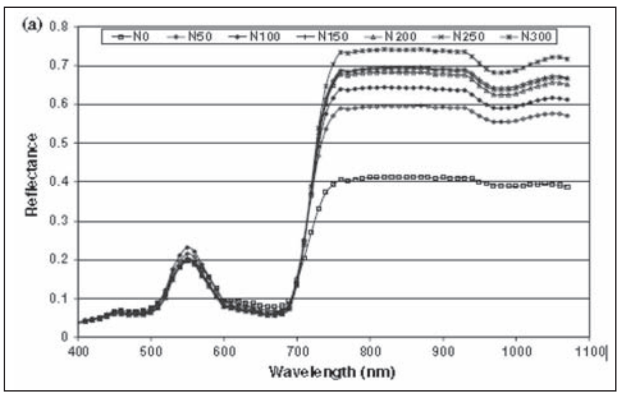


Fig. 3 : Average reflectance pattern of potato crop at different levels of late blight infestation (Source: Ray *et al.*, 2011)

al., (2011). Bhattacharya and Chattopadhyay (2013) developed a multi-stage tracking method for mustard rot disease, combining surface meteorology and satellite remote sensing.

Nutrient Stress: Nitrogen

Plant nutrients are among the most important and readily manageable variables for producing a profitable crop (Stevenson, 1982). There has been limited research on detection of the N, P and K status of crop plants through remote sensing techniques. Excessive N application, causes lodging and also results in contamination of groundwater (Jaynes *et al.,* 2001). Therefore, efficient monitoring of plant N status and appropriate N fertilizer management are essential to balance the factors of increasing cost of N fertilizer, the demand by the crop, and the need to minimize environmental pollution, especially water quality (Jaynes *et al.,* 2001). One of the goals of the site-specific farming is to accurately detect plant N status and provide N fertilizer in a timely manner to improve yield, increase N use efficiency and profit and minimize N losses to the environments (Zhao *et al.,* 2005a). Estimating nitrogen content of the plant, through laboratory methods, is cumbersome and time-consuming, thereby making difficult for the nitrogen management during crop growth. Studies have documented that N status of field crops can be assessed using leaf or canopy spectral reflectance data (Blackmer *et al.,* 1994). Zhao *et al.,* (2005b) showed that leaf N concentrations were linearly correlated with not only the reflectance ratio of R405/R715, but also the first derivatives of the reflectance in red edge centered at 730 or 740 nm. Jain et al. (2007) conducted a study, using hand-held spectro-radiometer, to explore the role of hyperspectral data to discriminate between the effects of different rates of nitrogen application to a potato crop. Figure 4 shows the reflectance spectra of potato crop at different levels of nitrogen application.

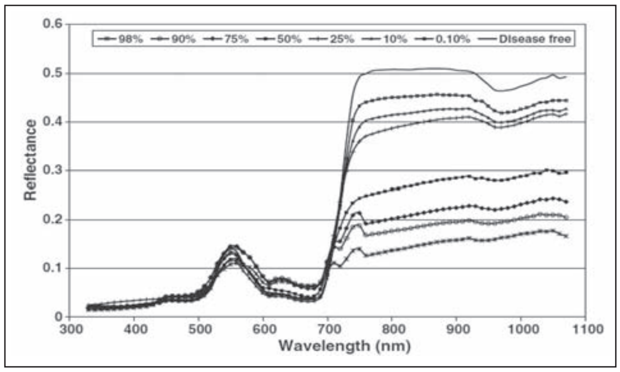


Fig. 4 : Reflectance spectra of potato crop at different levels of nitrogen application (Source: Jain et al., 2007)

Drought Assessment using Remote Sensing: NADAMS

The above discussions showed the principles and research activities related to the use of remote sensing data for crop stress assessment. One of the major operational projects of the country, which regularly carries out crop condition assessment, especially related to water stress is the 'National Agricultural Drought Assessment and Monitoring System (NADAMS)' project conceptualized and developed by National Remote Sensing Centre (NRSC) of ISRO. It provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/ district/sub-district level. Currently, it covers 13 states of India, which are predominantly agriculture based and prone to drought situation. Agricultural conditions are monitored at state/district level using daily NOAA AVHRR and MODIS data for all these states. However, for four states AWiFS (Advanced Wide Field Sensor, 56 m resolution) of Resourcesat is used for detailed assessment of agricultural drought at district and sub district level. Fortnightly/monthly report of drought condition is provided to the Government under NADAMS. From the year 2012, the NADAMS project is being implemented by the Mahalanobis National Crop Forecast Centre (MNCFC), Ministry of Agriculture. Agricultural drought assessment is carried out using multiple indices derived from remote sensing and meteorological data; such as Shortwave Angle Slope Index (SASI), Normalized Difference Wetness Index (NDWI), Normalized Difference Vegetation Index (NDVI), Soil Moisture Index (derived from soil water balance approach) and IMD Rainfall data (rainfall deviation, number of dry weeks, etc.). Figure 5 shows the district level drought assessment map for Kharif season of 2012.

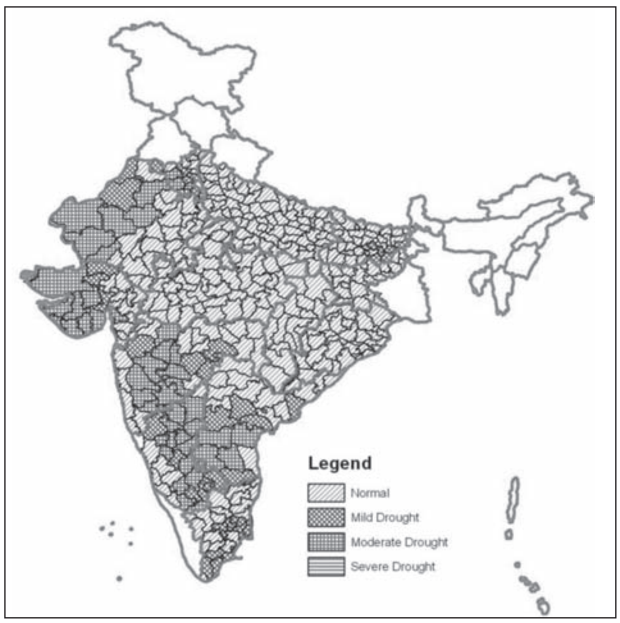


Fig. 5 : District-level agricultural drought assessment for Kharif season of 2012 (Source: MNCFC)

CHARACTERISTICS OF WET AND DRY SPELLS AND THEIR EXTREMES ACROSS INDIA

Nityanand Singh

Rainfall is a seasonal phenomenon in tropical monsoonal climates and occurs in spells. The start and end of the rainy season; frequency, rainfall amount, rainfall intensity and duration of wet spells; and duration and severity of intervening (between two rain spells) dry spells are characterized by large spatial and temporal variations. Climatology and variability of the parameters of the rainy season and the wet and dry spells are valuable information for scientists, engineers, planners and managers working in water-related sectors (agriculture, ecology, hydrology and water resources). Determination of year-wise starting and ending dates of the rainy season and identification of wet and dry spells during the season is important. In this study, we attempted to demarcation of the start and end of the rainy season, and identification of wet/dry spells.

In the country, the terms monsoon and wet season are used synonymously. During World War II, normal onset and withdrawal dates at 180 stations over the Indian subcontinent (present day India, Pakistan, Bangladesh, Myanmar and Sri Lanka) were determined by the India Meteorological Department (IMD) by applying a subjective approach 'characteristic monsoon rise/fall in 5-day period (pentad)'. For particular station, the first normal pentad rainfall for a full calendar year (73 pentads) was obtained. The middle date of the pentad that showed characteristic monsoon rise (fall) in rainfall from the previous pentad was taken as the normal onset (withdrawal) date. Similarly, the dates were obtained for other stations. The dates were charted and isolines of normal onset (withdrawal) dates drawn (IMD, 1943). Ananthakrishnan and Soman (1988) suggested an objective criterion to determine onset date of the summer monsoon over Kerala State 'when rainfall on the day and mean rainfall in the following 5 day period exceeded 10 mm'. Earlier Ananthakrishnan et al. (1967) suggested a criterion for declaring onset over Kerala, 'beginning from 10^{th} May, if at least five out of the seven stations report 24-hourly rainfall 1 mm or more for two consecutive days, the forecaster should declare on the second day that the monsoon has advanced over Kerala'.

Parts of India experience a rainy season of a considerably longer duration than the summer monsoon period as they also receive considerable rainfall from other systems in the pre- and post-monsoon periods: Western Himalaya (Uttarakhand, Himachal Pradesh and Jammu & Kashmir States) get rainfall from western disturbances both in the pre- and post-monsoon periods, northeast India from thunderstorms both in the pre- and post-monsoon periods, and the south peninsula (south of 18°N) from thunderstorms in the pre-monsoon period and from northeast monsoons in the post-monsoon period. Singh (1986) has identified a climatological period of reliable rainfall (rainy season), irrespective of the system(s) that produced the rainfalls, at 466 stations across the country by applying a unified criterion, '*a continuous period with each of the monthly rainfall greater than 50mm*'. Recently, Ranade et al. (2008) applied this criterion to determine yearwise start and end of the hydrological wet season (HWS) over 11 major and 36 minor river basins as well as the West Coast Drainage System (WCDS) and studied variability of the HWS parameters (starting and ending dates and duration, seasonal rainfall/rainwater and surplus rainfall/rainwater potential) over the period of longest available instrumental records (1813-2006).

Cook and Heerdegen (2001) defined rainy season as that period when the probability of 10-day dry spells was less than 0.5, and the wet season (monsoonal influence) as that period within the rainy season when the probability of dry spells was less than 0.1. A dry-day was defined with rainfall less than 5 mm. This definition was essentially meant for ecological purposes. Stern et al. (1981) defined the start of the rainy season as the first occurrence of 20 mm of rain within 2 successive days.

Understanding climatic and hydroclimatic features of wet and dry spell is essential for effective agricultural and hydrological operations. In the face of global climate wet and dry spells assumed greater importance. Therefore, in recent decades attempts have been made world-wide to understand these features on regional/local scales. The main items discussed here are:

1) Development of dynamic objective criteria for identification of yearwise wet and dry spells in different rainfall regimes of India

2) Understanding detailed climatological and fluctuation features of the wet and dry spells across the country

3) Examination of important features of extremes of wet and dry spells.

The start of the first wet spell is expected to provide a reliable estimate of the starting date of seasonal (hydrological) rainfall and the ending date of the last wet spell of the season. The second objective is to provide important input to decision-making support system in water-related sectors such as agriculture, hydrology, water resources and terrestrial and freshwater aquatic ecosystems, as well as diagnostics and prediction of rainfall. And, the third objective is to understand the impact of global climate change on extreme rain events across the country.

Data Used and Sub-division of the Country

Daily rainfall data of the country on 1-degree latitude-longitude spatial resolution for the period 1951-2007 developed by the India Metrological Department (IMD) (Rajeevan et. al., 2006) is utilized in the present study.. Following physico-climatological factors are qualitatively considered in order to divide the country into an optimum number of subregions:

a) Topographic features

b) Spatial pattern of the mean annual and southwest monsoon rainfall

c) Physiographic characteristics- coast, plateau, plains, valley, desert, etc. (NATMO, 1986)

d) Drainage pattern (NATMO, 1996)

e) Normal onset and withdrawal dates of southwest monsoon across the country (IMD, 1943)

f) Daily rainfall data available as 1-degree raster.

Geographical area and some important climatological information about the 19 major subregions is given in Table 1.

Table 1 : Some important information about the 19 subregions (SRs): geographical area, mean annual rainfall, mean onset and withdrawal dates of the summer monsoon, total monsoonal rainfall and daily mean rainfall as well as daily mean potential evapotranspiration (PE) of the monsoon period.

Sub-region	Name of the subregion	Appro-ximate Area (sq. km)	Normal annual rainfall (mm)	Onset of SW monsoon (SD in days)	Withdrawal of SW monsoon (SD in days)	Rainfall of monsoon period (mm)	Daily mean rainfall of monsoon period (mm/day)	Daily mean PE of monsoon period (mm/day)
SR 1	Extreme southwest peninsula (ESWP)	60,000	2700.8	1 Jun (7)	19 Oct (6)	2061.2	14.6	3.8
SR 2	Extreme southeast peninsula (ESEP)	110,000	962.0	2 Jun (7)	19 Oct (6)	365.6	2.6	5.4
SR 3	Southern central West Coast (SCWC)	60,000	3131.9	5 Jun (7)	17 Oct (6)	2724.4	20.2	3.0
SR 4	Central southeast peninsula (CSEP)	150,000	859.4	6 Jun (7)	17 Oct (6)	464.4	3.5	4.5
SR 5	Northern central West Coast (NCWC)	60,000	2220.1	9 Jun (7)	13 Oct (5)	1990.3	15.7	3.6
SR 6	Southern central peninsula (SCP)	120,000	710.5	11 Jun (6)	14 Oct (6)	538.1	4.3	4.6
SR 7	Central East Coast (CEC)	110,000	1025.8	12 Jun (6)	15 Oct (7)	715.5	5.7	4.4
SR 8	Northern West Coast (NWC)	90,000	1794.5	13 Jun (6)	7 Oct (8)	1648.0	14.1	4.1
SR 9	Northern central peninsula (NCP)	180,000	1012.7	15 Jun (6)	8 Oct (7)	855.7	7.4	4.3
SR 10	Northern East Coast (NEC)	210,000	1423.9	16 Jun (6)	12 Oct (6)	1080.5	9.1	3.8
SR 11	Southern northwest India (SNWI)	190,000	616.9	23 Jun (9)	28 Sep (6)	534.7	5.5	4.6
SR 12	Western central India (WCI)	240,000	1077.2	21 Jun (8)	3 Oct (6)	928.3	8.8	3.9
SR 13	Eastern central India (ECI)	150,000	1240.7	20 Jun (7)	7 Oct (6)	1036.2	9.4	3.8
SR 14	Eastern Indo-Gangetic Plain (EIGP)	120,000	1422.9	13 Jun (6)	10 Oct (6)	1145.5	9.5	3.6
SR 15	Northern northwest India (NNWI)	280,000	323.9	8 Jul (8)	19 Sep (8)	230.4	3.1	5.4
SR 16	Western Indo-Gangetic Plains(WIGP)	240,000	755.4	30 Jun (8)	27 Sep (8)	598.2	6.6	4.4
SR 17	Central Indo-Gangetic Plain (CIGP)	150,000	1140.2	21 Jun (7)	3 Oct (6)	918.8	8.8	4.2
SR 18	Northeast India (NEI)	60,000	2089.2	6 Jun (6)	15 Oct (5)	1461.6	11.1	3.1
SR 19	Extreme northern India (ENI)	290,000	873.3	1 Jul (8)	23 Sep (9)	544.6	6.4	4.1

Objective Criterion for Identification of Wet and Dry Spells

A dynamic criterion has been developed and applied to identify yearwise wet and dry spells over the 19 subregions. Rainfall threshold used in the criterion is derived from local rainfall climatology that is '*daily mean rainfall (DMR) of the climatological (long term mean or normal) summer monsoon period over the area of interest*'. Computational steps of the schemes are as follows:

i. Computation of daily rainfall climatology of the full calendar year.

ii. Calculation of daily mean rainfall (DMR) of the normal summer monsoon period (mm/day).

iii. Normalization of yearwise daily rainfall amounts by dividing by the respective DMR.

iv. Application of the 9-point Gaussian low-pass filter with weights 0.244, ±0.201, ±0.117, ±0.047, ±0.013 on the normalized daily rainfall values.

v. Identification of a continuous period with normalized, smoothed daily rainfall values equal to or greater than 1.0 as wet spell (WS) and less than 1.0 as dry spell (DS).

The WS (DS) is identified as 'a *continuous period with daily rainfall equal to or greater than (less than) daily mean rainfall (DMR) of climatological monsoon period over the area of interest*'. Climatological onset and withdrawal dates of the southwest monsoon period over the subregions have been calculated (step no. ii) from yearly value of the respective parameters manually picked up from the charts showing yearwise '*Advance of Southwest Monsoon*' and '*Withdrawal of Southwest Monsoon*' routinely prepared by the operational wing (Weather Central) of the India Meteorological Department (IMD), Pune. Yearwise charts of the 'Advance of Southwest Monsoon' are available for the period 1960-2007, and those of the 'Withdrawal of Southwest Monsoon' for the period 1975-2007. For the 19 subregions, climatological onset and withdrawal dates and total monsoonal rainfall and daily mean rainfall of the monsoon period are given in Table 2. Climatological and fluctuation features of the following parameters of actual wet and dry spells have been studied.

i. Number of wet/dry spells

ii. Total rainfall of the wet/dry spells

iii. Total duration of the wet/dry spells

iv. Starting date of first wet/dry spell

v. Ending date of last wet/dry spell

vi. Rainfall amount of individual wet/dry spell

vii. Rainfall intensity of individual wet/day spell

viii. Duration of individual wet/dry spell

Besides these, characteristics of four important parameters (duration, rainfall amount, rainfall intensity and starting date) of the extremes of wet and dry spells in respect of (i.r.o.) rainfall amount (mm), rainfall intensity (mm/day) and duration (days) have been studied in order to understand if there is any change taking place in the hydrological cycle of the area. In total 40 parameters of the two attributes of the rainfall time-distribution of wet and dry spells have been examined in this study. Description of spatial variation of total rainfall due to wet/dry spells, and rainfall amount and rainfall intensity of an individual wet/dry spell is given in comparison with annual rainfall distribution across the country. Spatially-averaged subregional normal annual rainfall along the West Coast varies from 1795-3132mm; over central India from 1077-1241mm; northeast 2089mm; extreme north 873mm; peninsula (excluding West Coast) from 711-1424mm; Indo-Gangetic Plains from 755-1423mm; and northwest dry province from 324-617mm.

Table 2 : Mean and standard deviation (SD) of 9 parameters of the wet spells for the 19 subregions.

Sub regions	$\overline{WS}$ (SD)	$WS_{\overline{TRAIN}}$ (SD) in mm	$WS_{\overline{TDUR}}$ (SD) in days	$WS_{\overline{RI}}$ (SD) in mm	$WS_{\overline{RAIN}}$ (SD) in mm	$WS_{\overline{DUR}}$ (SD) in days	$WS_{\overline{START}}$ (SD in days)	$WS_{\overline{END}}$ (SD in days)	$WS_{\overline{\%AGE}}$ (SD)
ESWP	6.9 (2.0)	1817.7 (538.1)	65.5 (17.3)	27.6 (2.5)	263.4 (139.1)	9.5 (4.3)	21 May (17.5)	22 Oct (25.8)	66.1 (8.6)
ESEP	10.7 (2.1)	778.8 (275.5)	100.4 (20.0)	7.6 (1.5)	72.8 (35.8)	9.4 (2.5)	19 Mar (32.6)	16 Dec (11.6)	79.3 (8.4)
SCWC	5.0 (1.4)	2130.4 (503.1)	57.7 (12.7)	36.9 (3.5)	426.1 (201.6)	11.5 (5.1)	2 Jun (11.1)	17 Sep (27.7)	67.3 (7.9)
CSEP	9.0 (2.2)	663.0 (216.9)	80.5 (17.6)	8.2 (1.5)	73.7 (37.0)	8.9 (2.6)	3 May (31.0)	4 Dec (15.1)	75.9 (7.1)
NCWC	4.8 (1.2)	1567.3 (438.9)	51.8 (12.2)	30.1 (3.3)	326.5 (134.6)	10.9 (3.7)	7 Jun (8.7)	19 Sep (27.9)	69.6 (7.8)
SCP	7.3 (1.9)	508. 9 (168.2)	57.6 (17.7)	8.9 (1.0)	69.7 (31.1)	7.9 (2.9)	30 May (26.1)	25 Oct (20.5)	70.1 (9.2)
CEC	8.3 (1.9)	711.2 (202.0)	61.2 (15.5)	11.6 (1.6)	85.7(25.3)	7.4 (2.0)	23 May (34.6)	7 Nov (19.1)	68.3 (8.4)
NWC	4.7 (1.3)	1289.9 (386.3)	45.1 (11.8)	28.7 (3.6)	280.4 (98.9)	9.7 (3.0)	15 Jun (8.1)	15 Sep (18.7)	70.7 (8.4)
NCP	6.1 (1.7)	707.8 (216.8)	52.2 (14.6)	13.5 (1.5)	116.0 (59.2)	8.6 (3.9)	9 Jun (27.4)	6 Oct (24.4)	68.5 (11.0)
NEC	8.1 (1.7)	900.2 (235.9)	55.5 (13.8)	16.2 (1.3)	111.1 (31.2)	6.9 (1.8)	8 Jun (24.4)	19 Oct (21.4)	62.3 (9.1)
SNWI	4.1 (1.5)	494.6 (225.3)	35.9 (14.0)	13.5 (2.5)	120.6 (56.5)	8.8 (3.5)	21 Jun (15.8)	16 Sep (30.6)	77.2 (12.7)
WCI	4.8(1.3)	761.0 (194.3)	48.4 (12.4)	15.8 (1.6)	158.5 (69.0)	10.1 (4.3)	21 Jun (18.1)	21 Sep (28.2)	69.8 (8.1)
ECI	5.6(1.6)	820.0 (203.8)	51.4 (11.9)	15.9 (1.1)	146.4 (63.8)	9.2(3.8)	18 Jun (27.2)	24 Sep (18.6)	65.4 (7.8)
EIGP	6.8 (1.6)	879.9 (272.0)	52.1 (14.1)	16.8 (1.5)	129.4 (38.0)	7.7 (2.0)	7 Jun (20.5)	1 Oct (14.4)	60.6 (10.3)
NNWI	3.8 (1.5)	283.7 (173.7)	29.2 (12.8)	9.2 (3.1)	78.8 (53.2)	7.7 (4.2)	22 Jun (30.4)	12 Sep (34.9)	77.4 (14.8)
WIGP	4.7(1.5)	531.2 (160.1)	44.5 (12.9)	11.9 (1.0)	113.0 (46.2)	9.4 (3.7)	23 Jun (30.5)	19 Sep (19.9)	68.9 (10.9)
CIGP	6.5 (1.5)	776.6 (219.1)	45.8 (10.7)	16.8(1.9)	119.5 (35.7)	7.1 (1.9)	14 Jun (28.8)	25 Sep (14.4)	66.9 (8.7)
NEI	9.2 (2.2)	1261.6 (319.2)	69.2 (15.8)	18.2 (1.5)	137.1 (36.4)	7.5 (1.8)	23 Apr (25.0)	9 Oct (22.6)	59.5 (8.7)
ENI	5.7(1.6)	486.3 (166.7)	46.9 (14.5)	10.3 (0.9)	74.9 (28.9)	8.2 (2.4)	16 May (52.9)	20 Sep (23.1)	47.3 (11.5)
INDIA	6.4 (1.7)	914.2 (269.3)	55.0 (14.3)	16.7 (1.9)	152.8 (64.3)	8.8 (3.1)	31 May (24.8)	8 Oct (22.0)	68.0 (9.4)

$\overline{WS}$ indicates mean number, $WS_{\overline{TRAIN}}$ mean total rainfall and

$WS_{\overline{TDUR}}$ mean total duration of the WSs; $WS_{\overline{RI}}$ mean rainfall intensity,

$WS_{\overline{RAIN}}$ mean rainfall amount and $WS_{\overline{DUR}}$ mean duration of the individual WS;

$WS_{\overline{START}}$ mean starting date of the first WS; $WS_{\overline{END}}$ mean ending date of the last WS; and

$WS_{\overline{\%AGE}}$ mean percentage contribution of the WSs rainfall to the annual total.

Climatological Features of the Wet Spells

Normally, the ESEP (SR2) experiences the largest number (11) of WSs. The number decreases along the East Coast to 7 over EIGP (SR14), then decreases to 4 over northwestern India (SRs 11 and 15). The standard deviation (SD) of inter-annual variation of the number of WSs on a subregional scale across India (hereafter referred to as 'SD_{AI}') is about 2 (Table 2). Total duration of the WSs follows the similar pattern and decreases from 101 days (ESEP) to 29 days (NNWI) (SD_{AI} = 14.3 days). Total rainfall due to WSs is, however, highest along the West Coast with 1290-2130mm, followed by NEI with 1262mm, and lowest over northwestern India with 284mm. Over the remaining areas the total rainfall varies from 495mm to 900mm following annual rainfall pattern with low values over the central peninsula (NCP and SCP) and high values elsewhere. Features of individual WSs are different along the West Coast. Duration varies from 10-12 days, rainfall amount from 263-327mm and rainfall intensity from 29-37mm/day; over other parts the duration varies from 7-10 days, rainfall amount from 70-159 mm and rainfall intensity from 8-18mm/day. The SD_{AI} of duration of individual WS is 3.1 days, rainfall amount 67.7mm and rainfall intensity 2.0mm/day. Interannual variation in rainfall intensity is a weak determinant of interannual variation of the WS rainfall amount (correlation coefficient; CC= ~0.45) and the respective annual rainfall (CC= ~0.36). Total duration of all the WSs is however strongly correlated with total rainfall. The CC of total duration with total rainfall of the WSs is 0.72-0.98 across the 19 subregions and with the respective annual rainfall 0.70-0.93. The CC between total rainfall due to WSs and respective annual rainfall is 0.72-0.95.

Normally the first WS starts on 19 March over the ESEP (SR2), followed by 23 April over NEI (SR18), 3 May over CSEP (SR4), 16 May over ENI (SR19), 21 May over ESWP (SR1), 23 May over SEC (SR7) and 30 May over SCP (SR6). Over the peninsula, the northeast India and extreme northern India, thunderstorms associated with the first WS starts 11 to 55 days earlier than the onset of the monsoon. Most parts of the country experience the first WS between 2 June and 23 June i.e., about 5 days earlier than the onset of the monsoon. Over the NNWI the first WS starts on 22 June, 16 days earlier (8

July) than the monsoon onset. The SD of the start of the first WS is 8-11 days (smallest) over central and northern West Coast and 31-35 days over the southeast peninsula and 30-53 days over the extreme north/northwest. Hence, the time-invariant orographic effect reduces inter-annual variability of the start of rains on the windward side of large-scale moist air-flows from the surrounding oceans/seas. We believe that intense convection from elevated land mass and ample moisture supplied by the perennial moist air stream from neighboring seas towards inland from the beginning of the summer contribute to reducing inter-annual variation of the start of the first WS/season.

The cessation process for the last WS starts in NNWI (SR15) on 12 September, the date progressively shifts towards the east, southeast and south and ends on 16 December in ESEP. In general, over most regions, the last WS ends ~9 days earlier than the withdrawal of the monsoon. However, from the northeast, east coast and southeast peninsula the last WS ends after the withdrawal of the monsoon: 4 days later from NEI, 7 days from NEC, 11 days from SCP, 22 days from SEC, 48 days from CSEP and 58 days from ESEP. This is because withdrawal of the southwest monsoon is followed by onset of the northeast monsoon over these subregions. The SD of ending date is 12-15 days (lowest) over the southeast peninsula, 28 days along central WC and 31-35 days over the northwest. Hence the time invariant orographic effect reduces variability of the ending date of the rains on the windward side. The contribution of rainfall due to WSs to the respective annual total varies from 60 to 79% over different regions except over the extreme north where it is only ~47% (Table 2). The last row of the table gives arithmetic mean of the subregions to provide an approximate value of the parameter for the whole country.

Climatological Features of the Dry Spells

Total duration of intervening DSs (3-10 in number) is shorter (45 days) over WCI and WIGP (SRs 12 and 16), increases to 59 days over NNWI, to 81 days over ENI, to 101 days over ENI and to 173 days over ESEP (Table-3). At subregional scale across the country, the interannual variation (SD) in total duration of DSs is 17-61 days; the SD is larger where rainfall occurrences are spread over long period of the year and rainfall intensity is relatively low. Total rainfall due to DSs is high over higher (annual) rainfall areas and low over lower rainfall areas- over NEI 553mm, along the West Coast 291-509mm and over CEC, NEC and EIGP 222-291mm and decreases to 28mm over NNWI. DS is shorter (11-12 days) over WCI, ECI, EIGP and CIGP (SRs 12, 13, 14 and 17), increases to 22 days over NNWI (SR15) and to 19 days over ESEP. The SD_{AI} is about 7.9 days suggesting large interannual variation in the duration on subregional scales. Mean rainfall amount of individual DS is 10mm over the northwest, increases to 14mm over ESEP, to 37mm over ENI, to 70mm over NEI, and to 116mm along the West Coast. The mean rainfall intensity during DS is 1-2mm/day over the northwest and eastern south peninsula, 3-6mm/day over almost all northern India and 6-10mm/day along the West Coast. The DSs rainfall contributes about 17% to the respective annual total.

The first dry spell starts around 24 March over ESEP (SR2), 28 April over the northeast (SR18), during May over ESWP (SR1), CSEP and CEC (SRs 4 and 7) and extreme north (SR19), and during June over most parts of the country except over WIGP (SR16) where it starts 4 July. The percentage contribution of rainfall due to DSs to respective annual total varies from 10% over NNWI (SR15) to 27% over NEI (SR18).

To comprehend broad spatial climatological features of the dry and wet spells across the country, a generalized description of the parameters in five categories is provided.

- Number and total duration of wet/dry spells and duration of actual and different extreme wet/dry spells- highest value in the extreme southeast peninsula and decreases towards north/northwest as the tropical and oceanic influences decrease.
- Total rainfall of wet/dry spells and rainfall amount and rainfall intensity of actual and extreme wet/dry spells- high value in the orographic regions (West Coast and central, northeast and extreme north India, and lowest over plains (peninsula, Indo-Gangetic Plains and northwest dry provinces.
- Start of the first wet spell- earliest in extreme southeast peninsula and latest in northwestern India.
- End of the last wet spell- earliest from northwestern India and latest from extreme southeast peninsula.
- Occurrence of different extreme wet/dry spells- during June through August over most parts of northern India and during September through December over south peninsula.

Table 2 : Mean and standard deviation (SD) of 9 parameters of the dry spells for the 19 subregions

Sub regions	$\overline{DS}$ (SD)	$DS_{\overline{TRAIN}}$ (SD) in mm	$DS_{\overline{TDUR}}$ (SD) in days	$DS_{\overline{RI}}$ (SD) in mm	$DS_{\overline{RAIN}}$ (SD) in mm	$DS_{\overline{DUR}}$ (SD) in days	$DS_{\overline{START}}$ (SD in days)	$DS_{\overline{END}}$ (SD in days)	$DS_{\overline{\%AGE}}$ (SD)
ESWP	5.9 (1.9)	509.1 (172.4)	89.5 (31.6)	5.8 (1.0)	86.3 (32.3)	15.2 (6.3)	30 May (21.5)	15 Oct (28.1)	19.4 (7.5)
ESEP	9.7 (2.1)	130.9 (29.5)	172.5 (41.4)	0.8 (0.1)	13.5 (4.7)	17.8 (7.2)	24 Mar (33.2)	6 Dec (17.2)	14.9 (6.7)
SCWC	4.0 (1.4)	459.4 (219.5)	50.7 (31.5)	9.8 (2.1)	114.9 (48.0)	12.7 (6.1)	13 Jun (16.9)	11 Sep (30.5)	15.1 (8.1)
CSEP	8.0 (2.2)	144.8 (32.5)	135.5 (34.6)	1.1 (0.2)	18.1 (5.9)	16.9 (6.9)	8 May (32.3)	26 Nov (17.6)	17.8 (6.0)
NCWC	3.8 (1.2)	358.7 (149.8)	53.3 (29.6)	7.2 (1.5)	94.4 (48.2)	14.0 (8.3)	20 Jun (14.8)	13 Sep (30.0)	16.6 (7.6)
SCP	6.3 (1.9)	119.1 (40.4)	92.1 (31.5)	1.3 (0.3)	18.9 (9.2)	14.6 (7.0)	3 Jun (27.5)	17 Oct (24.6)	17.5 (6.8)
CEC	7.3 (1.9)	221.8 (77.1)	108.1 (44.4)	2.2 (0.5)	30.4 (12.3)	14.8 (7.8)	28 May (36.3)	31 Oct (21.3)	22.3 (8.2)
NWC	3.6 (1.3)	291.0 (104.7)	47.6 (17.3)	6.2 (1.2)	80.8 (38.2)	13.2 (6.5)	26 Jun (12.9)	8 Sep (20.8)	16.7 (6.6)
NCP	5.1 (1.7)	175.6 (60.1)	67.7 (35.3)	2.9 (0.9)	34.4 (15.8)	13.3 (7.1)	17 Jun (30.1)	30 Sep (27.3)	18.1 (7.5)
NEC	7.1 (1.7)	302.7 (103.0)	78.7 (33.7)	4.0 (0.8)	42.6 (17.7)	11.1 (4.7)	14 Jun (25.4)	14 Oct (22.4)	21.6 (7.6)
SNWI	3.1 (1.5)	69.3 (36.6)	53.4 (29.0)	1.5 (0.7)	22.4 (11.7)	17.2 (11.5)	29 Jun (17.8)	10 Sep (32.4)	11.7 (6.3)
WCI	3.8 (1.3)	143.7 (62.9)	44.9 (32.3)	3.8 (1.3)	37.8 (17.7)	11.8 (8.9)	1 Jul (21.9)	13 Sep (32.5)	13.7 (6.3)
ECI	4.6 (1.6)	191.3 (82.6)	47.6 (30.7)	4.4 (1.1)	41.6 (21.5)	10.3 (5.6)	28 Jun (30.6)	17 Sep (22.8)	15.8 (7.2)
EIGP	5.8 (1.6)	291.2 (84.2)	65.6 (21.4)	4.5 (0.8)	50.2 (18.6)	11.3 (4.0)	14 Jun (23.9)	25 Sep (15.8)	21.0 (7.1)
NNWI	3.1 (1.4)	27.5 (18.6)	58.8 (40.8)	0.6 (0.3)	8.9 (8.8)	19.0 (25.0)	27 Jun (32.4)	7 Sep (34.8)	9.5 (7.5)
WIGP	3.7 (1.5)	102.0 (55.9)	44.5 (33.9)	2.6 (0.9)	27.6 (12.9)	12.0 (6.6)	4 Jul (34.7)	12 Sep (21.7)	14.0 (8.2)
CIGP	5.5 (1.5)	185.1 (66.6)	57.8 (31.9)	3.4 (0.7)	33.7 (11.2)	10.5 (4.3)	21 Jun (31.4)	20 Sep (15.4)	16.5 (6.1)
NEI	8.2 (2.1)	553.1 (129.6)	101.0 (30.2)	5.6 (0.8)	67.5 (20.8)	12.3 (4.3)	28 Apr (26.9)	5 Oct (23.3)	26.8 (6.8)
ENI	4.7 (1.6)	173.7 (86.8)	80.9 (61.3)	2.8 (1.1)	37.0 (15.1)	17.2 (11.3)	23 May (61.4)	13 Sep (31.1)	20.3 (10.0)
INDIA	5.4 (1.6)	234.2 (84.9)	76 (33.8)	3.7 (0.9)	45.3 (19.5)	14 (7.9)	8 Jun (28)	2 Oct (25)	17.0 (7.3)

$\overline{DS}$ indicates mean number, $DS_{\overline{TRAIN}}$ mean total rainfall and

$DS_{\overline{TDUR}}$ mean total duration of the DSs; $DS_{\overline{RI}}$ mean rainfall intensity,

$DS_{\overline{RAIN}}$ mean rainfall amount and $DS_{\overline{DUR}}$ mean duration of the individual DS;

$DS_{\overline{START}}$ mean starting date of the first DS; $DS_{\overline{END}}$ mean ending date of the last DS; and

$DS_{\overline{\%AGE}}$ mean percentage contribution of the DSs rainfall to the annual total.

It is interesting to note that normally 68% of the annual rainfall occurs during WSs and 17% during DSs (intervening period of subdued and/or no rainfall activities) identified by the present objective criteria. So, 85% of the annual rainfall occurs between first WS and last WS and only 15% as isolated random convection spread over remaining parts of the year. It is consistent with the known rainfall climatology that about 80% of the annual rainfall over the country is seasonal. Spatial variation of this seasonal contribution over most subregions is between ~80% and ~90%, which is relatively small. Hence, identification of the wet and dry spells can be regarded as robust. To get these robust results it is essential to use a variable rainfall threshold for different subregions. Arbitrarily, fixed choice of the threshold and its uniform application (Ananthakrishanan and Soman, 1988; Ananthakrishanan et al., 1967; Aviad et al., 2004; Bai et al., 2007; Cook and Heerdegen, 2001; Deni et al., 2008; Raman, 1974; Stern et al., 1981) will produce unrealistic results for the subregions. If rainfall threshold is larger than the daily mean rainfall (DMR) of the subregion, in low rainfall areas there will be fewer and shorter WS, broad and longer DSs, some or most years without any WS, late start of the first WS and early end of the last WS while opposite will be the features of rainfall occurrences in high rainfall areas. And if the rainfall threshold is smaller than the DMR, in high rainfall areas there will be broad and longer WSs, fewer and shorter DSs, some or most years without any DS, early start of the first WS and late end of the last WS while opposite will be the rainfall features in low rainfall areas.

Summary and Conclusions

A summary of the main results is as follows:

1) Climatologically, the number of WSs (DSs) decreases from 11 (10) over south/south southeast peninsula to 4 (3) over northwest India; total duration of the WSs (DSs) decreases from 100.4 (172.5) days to 29.2 (44.5) days; and duration of individual WS (DS) from 13 (19) to 8(11) days- the values of the parameters decrease as the tropical and oceanic influences decrease.

2) Total rainfall of the WSs/DSs, and rainfall amount and rainfall intensity of actual and extreme WS/DS are high over orographic regions (West Coast, central India and northeast India) and low over the peninsula, Indo-Gangetic plains and northwest dry province.

3) The country as a whole gets more than 6 WSs from 31 May through 8 October each with a duration of 8.8 days and rainfall amount of 152.8mm. The duration of the intervening DS is 14 days and the rainfall amount 45.3mm. The total rainfall and the total duration of the WSs (DSs) and the respective annual rainfall are highly correlated; the CC between total rainfall and total duration is ~0.91 (~0.77), between total rainfall and annual rainfall ~0.87 (~0.86) and between total duration and annual rainfall ~0.84 (~0.70). The WSs contribute ~68% and the DSs ~17% to the respective annual rainfall.

4) The first WS starts the earliest over the ESEP on 19 March and the latest over the NNWI on 22 June. Over most parts the first WS starts about 5 days earlier than the onset of the monsoon, and over the peninsula, northeast, extreme north and northwest, the first WS starts 11 to 55 days earlier.

5) The last WS ends the earliest (12 September) over NNWI and the latest (16 December) over ESEP. Over the CMRR the last WS ends ~9days earlier than withdrawal of the monsoon, and over the northeast, east coast and south peninsula about 4-58 days later.

6) Mean starting date of different extreme WSs/DSs is June through August over most parts of northern India and September through November over the northeast, east coast and south peninsula.

7) In recent years/decades the WSs are slightly shorter and rainfall intensity higher and DSs are slightly longer and rainfall intensity weaker over a majority of the subregions.

8) There is a weak tendency (not significant) for the first WS to start ~6 days earlier and the last WS to end ~2 days earlier; consequently the period of rainfall activities is ~4 days longer in recent years over most of the subregions.

Chapter - IV

Extreme Weather Events

EXTREME METEOROLOGICAL EVENTS - DEFINITION, CATEGORIZATION AND APPROACH OF ANALYSIS

Arvind Kumar Srivastava

What is Extreme Weather ?

Extreme weather, in the most obvious sense, is weather that lies outside a locale's normal range of weather intensity. It is therefore, by definition, infrequent or rare. Extreme weather is also potentially destructive, although not all extreme weather events end in disasters. For some weather events, the idea of what constitutes an extreme could vary from place to place. It often depends on what a region is used to experiencing and what it is prepared for. A 20-cm snowfall would be an extreme event for Washington, D.C., for example, but not for Montreal. In Washington such an event would come close to an emergency. In Montreal it would be merely an inconvenience. Extreme events such as hurricanes, tornadoes, and ice storms often require the presence of a number of special circumstances before they could take place. Many extreme events also come about as a result of a combination of factors, such as the merging of two weather systems or the occurrence of a severe weather event in tandem with some other factor that intensifies its impact. Hurricane Hazel, for example, was a weakening tropical storm when it merged with a deep low pressure system northwest of Toronto in October 1954, producing torrential rains and the deadliest flood in Canadian history. In the case of the Saguenay flood, water levels in the Saguenay basin were already at unusually high levels when the largest rainstorm in the region's recorded weather history struck on July 19, 1996. Some flooding would still have occurred if water levels had been normal, but the results might not have been as catastrophic.

WMO Definition:

"Dangerous meteorological or hydro-meteorological phenomenon, of varying duration, with risk of causing major damage, serious social disruption and loss of human life, requiring measures for minimizing loss, mitigation and avoidance, and requiring detailed information about the phenomenon (location, area or region affected, time, duration, intensity and evolution) to be distributed as soon as possible to the public and responsible authorities."

Costs

According to IPCC (2011) estimates of annual losses have ranged since 1980 from a few billion to above 200 billion USD (in 2010 dollars), with the highest value for 2005 (the year of Hurricane Katrina). The global weather- and climate-related disaster losses reported over the last few decades reflect mainly monetized direct damages to assets, and are unequally distributed. Loss estimates are lower bound estimates because many impacts, such as loss of human lives, cultural heritage, and ecosystem services, are difficult to value and monetize, and thus they are poorly reflected in estimates of losses.

Severe weather events may be classified into following two categories:

1) Geophysical **2) Meteorological**

General severe weather includes events like (category 1):

Heavy rain, *Tornadoes,*

Strong wind/ wind gusts, *Flash floodsand*

Hail, *Extreme temperature*

Lightning,

The more localized events are suggested as (category 2):

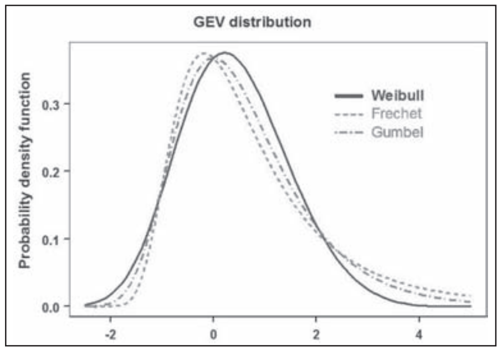
Snow storm, *Sea swell/ tsunamis/ storm surge,*

Dust/sand storms, *Extended area of fog for transport (aviation especially)*

Statistical theory of extreme values

(1) Block Maxima

This theory has been well developed for quite a while. One important theorem states that the maximum of a sequence of observations, under very general conditions, is approximately distributed as the generalized extreme value (GEV) distribution. This distribution has three forms



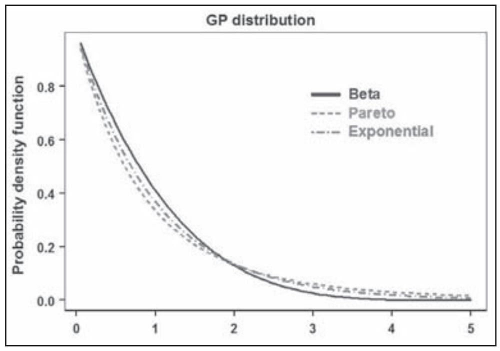
(i) Gumbel: A distribution with a light upper tail and positively skewed.

(ii) Frechet: A distribution with a heavy upper tail and infinite higher order moments.

(iii) Weibull: A distribution with a bounded upper tail.

(2) Peaks Over Threshold

In terms of the tail of a distribution, the corresponding theorem states that the observations exceeding a high threshold, under very general conditions, are approximately distributed as the Generalized Pareto (GP) distribution. This distribution has three forms



(i) Exponential: A light-tailed distribution with a "memory less" property.

(ii) Pareto : A heavy-tailed distribution (sometimes called "power law").

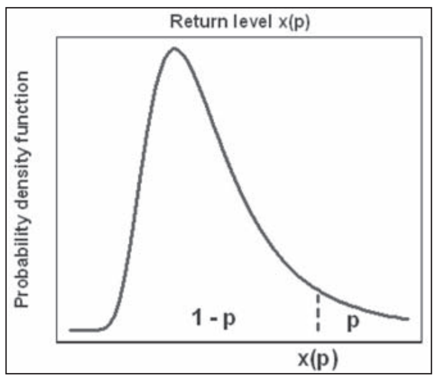
(iii) ***Beta*** **A bounded distribution:** The modern approach to extreme value analysis is based on a point process representation, equivalent to: (i) a Poisson process governing the rate of occurrence of exceedance of a high threshold; and (ii) a generalized Pareto distribution for the excess over the threshold. Through a reflection principle, the above theory can be converted into an equivalent form when the maximum is replaced by the minimum or an upper tail by a lower tail.

Weather and Climate Extremes

With the computational advances and software developed in recent years, the application of the statistical theory of extreme values to weather and climate has become relatively straightforward. Annual and diurnal cycles, trends (e.g., reflecting climate change), and physically-based covariates (e.g., El Nino events) all can be incorporated in a straightforward manner. Consistent with the point process representation, the "peaks over threshold" (or "partial duration series") approach enables the use of more of the information available about the upper tail of the distribution (e.g., not just the annual maxima).

Return Levels and Return Period

The concepts of return level and return period are commonly used to convey information about the likelihood of rare events such as floods. A return level with a return period of $T = 1/p$ years is a high threshold $x(p)$ (e.g., annual peak flow of a river) whose probability of exceedance is p. For example, if $p = 0.01$, then the return period is $T = 100$ years.



Two common interpretations of a return level with a return period of T years are:

(i) *Waiting time*: Average waiting time until next occurrence of event is T years

(ii) *Number of events*: Average number of events occurring within a T-year time period is one (as the concept of return period is of probabilistic nature, likely ear of occurrence cannot be give. But one can say with n $\longrightarrow \alpha$, n events may occur in nT years).

Categorization based on Mean and standard deviation:

In general, 'normal' refers to near absence of significant deviation from the average. The word normal is used in a more narrow sense in mathematics, where a normal distribution describes a population whose characteristics center around the average or the norm. When looking at a specific behaviour, such as the frequency of lying, a researcher may use a Gaussian bell curve to plot all reactions, and a normal reaction would be within one standard deviation, or the most average 68.3%. However, this mathematical model only holds for one particular trait at a time, since, for example, the probability of a single individual being within one standard deviation for 36 independent variables would be one in a million.

Analysis of meteorological events based on multi variant indices:

ID Indicator Name Indicator Definitions Units

TXx Max Tmax Monthly maximum value of daily max temperature °C

TNx Max Tmin Monthly maximum value of daily min temperature °C

TXn Min Tmax Monthly minimum value of daily max temperature °C

TNn Min Tmin Monthly minimum value of daily min temperature °C

TN10p Cool nights Percentage of time when daily min temperature < 10^{th} percentile %

TX10p Cool days Percentage of time when daily max temperature e <10^{th} percentile %

TN90p Warm nights Percentage of time when daily min temperature > 90^{th} percentile %

TX90p Warm days Percentage of time when daily max temperature > 90^{th} percentile %

DTR Diurnal temperature range Monthly mean difference between daily max and min temperature °C

GSL (Growing season length) Annual (1^{st} Jan to 31^{st} Dec in Northern Hemisphere, 1^{st} July to 30^{th} June in Southern Hemisphere) count between first span of at least 6 days with TG > 5 °C and first span after July 1 (January 1 in SH) of 6 days with TG < 5 °C days

FD0 Frost days	:	Annual count when daily minimum temperature < 0 °C days
SU25 Summer days	:	Annual count when daily max temperature >25 °C days
TR20 Tropical nights	:	Annual count when daily min temperature > 20 °C days
WSDI Warm spell duration indicator	:	Annual count when at least six consecutive days of max temperature > 90^{th} percentile days
CSDI Cold spell duration indicator	:	Annual count when at least six consecutive days of min temperature < 10^{th} percentile days
RX1day	:	Max 1-day precipitation amount Monthly maximum 1-day precipitation mm
RX5day	:	Monthly maximum consecutive 5-day precipitation mm
SDII Simple daily intensity index	:	the ratio of annual total precipitation to the number of wet days (=1 mm) mm day
R10 Number of heavy precipitation days	:	Annual count when precipitation = 10 mm in days
R20 Number of very heavy precipitation days	:	Annual count when precipitation = 20 mm in days
CDD Consecutive dry days	:	Maximum number when precipitation < 1mm in days
CWD Consecutive wet days	:	Maximum number when precipitation = 1mm in days
R95p Very wet days	:	Annual total precipitation from days > 95^{th} percentile mm
R99p Extremely wet days	:	Annual total precipitation from days > 99^{th} percentile mm
PRCPTOT Annual total wet-day precipitation	:	Annual total precipitation from days = 1mm mm

THUNDERSTORMS, HAILSTORMS AND CLOUDBURSTS

Someshwar Das

Thunderstorms occur almost everywhere in the world due to atmospheric instability associated with convection and strong moisture convergence. It is estimated that at any given instant more than 2000 thunderstorms are taking place around the world (WMO, 1953). Convection is initiated due to strong heating of the land mass during the day time, or by mixing of different types of air masses. Presence of atmospheric instability coupled with moisture convergence results in the formation of deep cumulonimbus clouds and thunderstorms.

While thunderstorm has also many beneficial effects on human society, it is dreaded for the hazardous weather elements associated with it. These include (i) lightning, (ii) hail, (ii) strong horizontal winds with shear, and (iv) heavy rain. Thunderstorms are mesoscale phenomena with horizontal dimension of 1-10 km and with a life span of a few hours. However, the characteristics of thunderstorm vary from place to place as land surface processes play a dominant role apart from synoptic and thermodynamic processes.

The climatology of thunderstorms depends on definition of thunderstorm and observation tools. It may change appreciably, if the definition of thunderstorm at a station changes i.e. (i) when a cumulonimbus cloud is detected by the radar and (ii) if severe convective cells are seen on radar and satellite imageries. However, with the present state of art, observation by the observer with/without support from satellite and radar observations is considered in reporting thunderstorm at a station.

During the pre-monsoon season (March-May) lot of thunderstorms occur over NE India, Bangladesh, Nepal and Bhutan (Das et al., 2013). They are called Nor'westers as they propagate usually from Northwest to southeast direction. Strong heating of landmass during mid-day initiates convection, which gets intensified by mixing with the low level warm moist air mass from the Bay of Bengal, and triggers violent storms. Nor'westers develop from a variety of mesoscale convective structures as they mature to meso scale (200-1000 km and 6 hours) systems. Earliest studies on Nor'westers date back to late 1920's to early 1940's. During the years 1928, 1941 and 1944, the India Meteorological Department (IMD) conducted three field experiments to understand their formation and to facilitate for their better prediction. In the 1944 experiment, IMD had established a special network of meteor-sonde and pilot balloons. It is note worthy that all these experiments were conducted to understand severe thunderstorms in India much before the famous thunderstorm project in USA in 1949. Several important features about time of development, movement and distribution of thunderstorms were determined in these very early campaigns. With the establishment of weather radar in Kolkata during 1950's the phenomenon was critically monitored and investigated by using available radar data.

Types of Thunderstorms and their Life Cycle

In this section, we shall present a brief review of the basic characteristics of different types of thunderstorms. A typical thunderstorm is made up of a single cumulonimbus (CB) cloud. The CB cloud consists of strong vertical updrafts and downdrafts. Depending upon their intensity (wind speed), they are classified as Gust wind, Squall wind, Light Nor'wester, Moderate Nor'wester, Severe Nor'wester, or a Tornado (Table 1).

Table 1: Classification of Nor'westers

Wind Speed Km/hr	Types	Wind SpeedKm/hr	Types
30-40	Gust Wind	91-120	Moderate Nor'wester
41-60	Squally Wind	121-149	Severe Nor'wester
61-90	Light Nor'wester	>150	Tornado

A downburst is defined as an area of strong winds produced by a downdraft. When it comes in contact with the earth, it spreads out laterally and causes damage at ground. There are two types of downbursts, a macroburst and a microburst. The macroburst covers an area larger than 4 kilometers in diameter, and the microburst is smaller than 4 kilometers in diameter (Fujita, 1985). Both are a serious threat to structures on the ground and to planes in the air. Damage caused by downbursts is frequently mistaken for tornado damage. By definition a tornado is "a violently rotating column of air, in contact with the ground, either pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud". In practice, for a vortex to be classified as a tornado, it must be in contact with both the ground and the cloud base. "Tornado" refers to the vortex of wind, not the condensation cloud. Most tornadoes have wind speeds between 40 mph (64 km hr^{-1}) and 110 mph (177 km hr^{-1}), are approximately 250 feet (75 m) across, and travel a few miles (several kilometers) before dissipating. Some attain wind speeds of more than 300 mph (480 km hr^{-1}), stretch more than a mile (1.6 km) across, and stay on the ground for dozens of miles (more than 100 km).

The thunderstorms are divided into 4 categories (Cotton and Anthes, 1989). They are the (i) single cell (ordinary), (ii) multicell line (squall line), (iii) multicell cluster, and (iv) supercell. Each one is characterized by different lifetimes, structures, and necessary environmental parameters, which are briefly described below.

The Single Cell Thunderstorm:

The ordinary or single cell thunderstorm is an ephemeral bursts of convection. Each burst creates a towering cumulus or "cell" of convection. When the cell gets large (and tall) enough, it is classified as a cumulonimbus, or thunderstorm. These often form in a more slightly unstable environment, and tend to have a more intense updraft. There may be lightning, marginally severe hail and brief microbursts in such thunderstorm. Because of the poor organization of these storms it is very difficult to forecast when and where they may occur.

The Multicell Cluster:

Thunderstorms often form in clusters with numerous cells in various stages of their life cycle. While each individual cell behaves as a single cell, the prevailing conditions are such that as the first cell matures, it is carried downstream by the upper level winds and new cell forms upwind of the previous cell. Fig. 1 illustrates a multi cell cluster.

This is the most common type of thunderstorm. In this type, there are many cells that grow to form a group of cells that move together as one unit. In this case, an ordinary thunderstorm creates neighboring storms via the downdraft and gust front. If the surrounding atmosphere is unstable and moist enough (and with adequate low-level vertical shear), new cells are created around the old one, giving birth to a cluster of active thunderstorms. Each cell is in a different phase of the life cycle. Each individual cell has its turn to be the dominant one.

The multicell cluster storms last a bit longer than ordinary or single cell storms, and cover a larger area. Each cell in a multicell cluster storm usually lasts about 20 minutes, but the cluster of storms itself can persist for several hours. An MCC, or mesoscale convective complex, is a multicell thunderstorm. It lasts at least 6 hours (sometimes much longer) and cover over 100,000 square kilometers (Bluestein, 1993). An MCC is large enough to actually alter the mesoscale or even synoptic scale environment. By far, the greatest threat posed by an MCC is the rain. Areas under the MCC typically experience both volume and flash flooding.

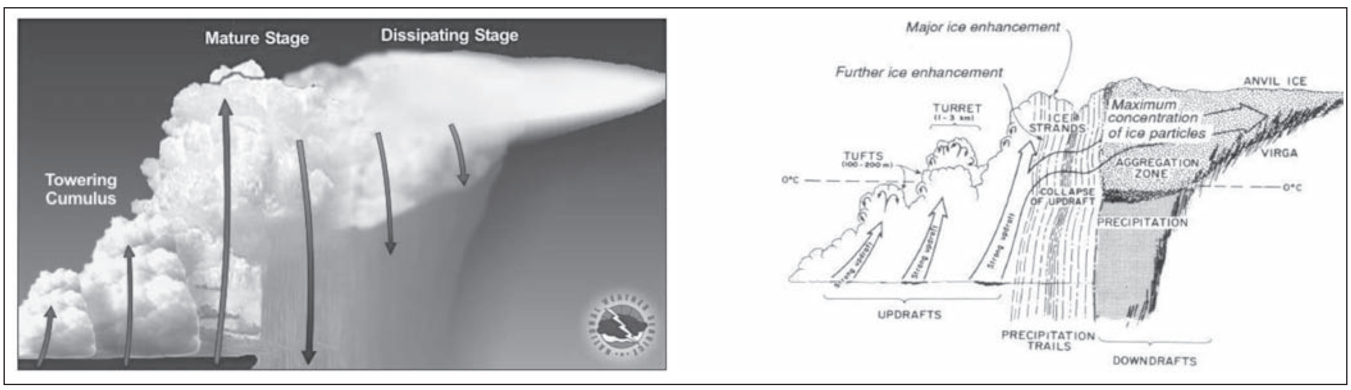


Fig. 1 : Illustration of a typical multi cell storm. Upper panel from National Weather Service (NOAA), and lower panel from Houze (1993)

Because of the storm-storm interaction, it is rare to get extreme weather (large hail, tornadoes) from a multicell cluster, but heavy rain, strong winds, and small to medium sized hail are still threats. They can also produce flooding rains if they mature over the same area. Winds of 70 knots are common, and hail up to the size of golf balls may occur.

The multicell line or squall line:

Sometimes thunderstorms form in a line which can extend laterally for hundreds of kilometers. These “squall lines” can persist for many hours and produce damaging winds and hail. Updrafts, and therefore new cells, continually re-form at leading edge of system with rain and hail following behind. Typical lines of thunderstorms tend to have the strongest, mature storms in the south or southwest end of the line. Moderate storms still not fully mature typically are found in the middle of the line and the dying variety is found in the north or northeast section of the line. As the gust front moves forward, the cold outflow forces warm unstable air into the leading edge (usually on the eastern side) into the updraft edge of the storm, with the heaviest rain and largest hail just behind (west) the updraft. As these cells die they produce lighter rains behind the main squall line, so one often sees a broad region of stratiform rain behind it. Cells that form on the southern ends of squall lines tend to inherit supercell characteristics since there is nothing to the south of them to disrupt air flow being entrained into them.

Squall lines are prolific downburst producers. If squall lines form over arid regions, a duststorm known as a *haboob* may result from the high winds in their wake picking up dust from the desert floor. Fig. 2 illustrates a multi cell squall line.

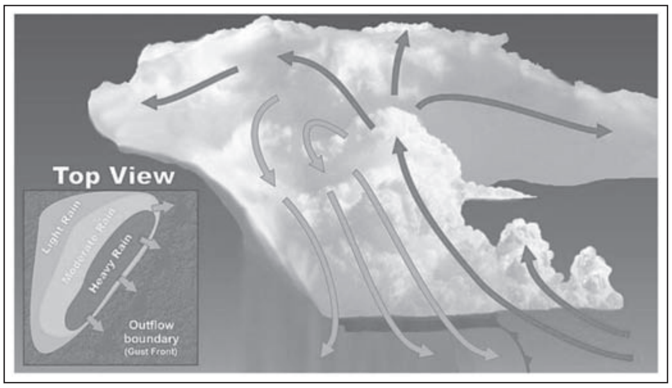


Fig. 2 : Illustration of a multi cell squall line (from National Weather Service, NOAA).

The supercell:

Finally, the epitome of thunderstorms is the supercell (Fig. 3). This type of storm is the classic cumulonimbus tower with the anvil top and on occasion the overshooting updraft tower. These storms are notorious for producing damaging straight-line winds, frequent lightning, flash floods, large hail, and violent tornadoes. This is a relatively small stand-alone entity that is so well organized it actually supports itself and enhances its own growth. The base of the storm may be only 20-50 km across, but the anvil aloft can stretch for many hundreds of kilometers. Conditions have to be just right in the atmosphere in order for supercells to form.

The supercell is unique because the updraft actually rotates; this rotating updraft is called a mesocyclone. The updraft and downdraft regions do not interfere with each other like in the ordinary thunderstorm; instead, they collaborate to prolong the life of the storm. The inflow, outflow, updrafts, and downdrafts all work together like a living, breathing creature. A supercell can exist in a quasi-steady state for hours, advecting along the ground with the ambient wind (unlike an ordinary storm that was a result of regenerating cells). In order to form a supercell, three ingredients are necessary: high thermal instability, strong winds in the middle and upper troposphere, and veering of the wind with height in the lowest kilometer. As precipitation is produced in the updraft, the strong upper-level winds blow the precipitation away from the updraft, allowing little or none of it to fall back down through the updraft core. Light rain begins as the supercell approaches. As the updraft area comes closer, the areas to the north and east see an increase in rain and hail, then near the updraft itself (typically toward the rear) is where most severe weather (tornadoes) occurs.

Life Cycle of Thunderstorm

All thunderstorms, regardless of type, go through three stages: (1) the **developing stage**, (2) the **mature stage**, and (3) the **dissipation stage**. The average thunderstorm has a 24 km diameter. Depending on the conditions present in the atmosphere, these three stages take an average of 30 minutes to go through.

Cumulus stage or developing stage:

The first stage of a thunderstorm is the cumulus stage, or developing stage. In this stage, masses of moisture are lifted upwards into the atmosphere. The trigger for this lift can be insolation heating the ground producing thermals, areas where two winds converge forcing air upwards, or where winds blow over terrain of increasing elevation. The moisture rapidly cools into liquid drops of water due to the cooler temperatures at high altitude, which appears as *cumulus* clouds. As the water vapor condenses into liquid, latent heat is released, which warms the air, causing it to become less dense than the surrounding dry air. The air tends to rise in an *updraft* through the process of convection. This creates a low-pressure zone beneath the forming thunderstorm.

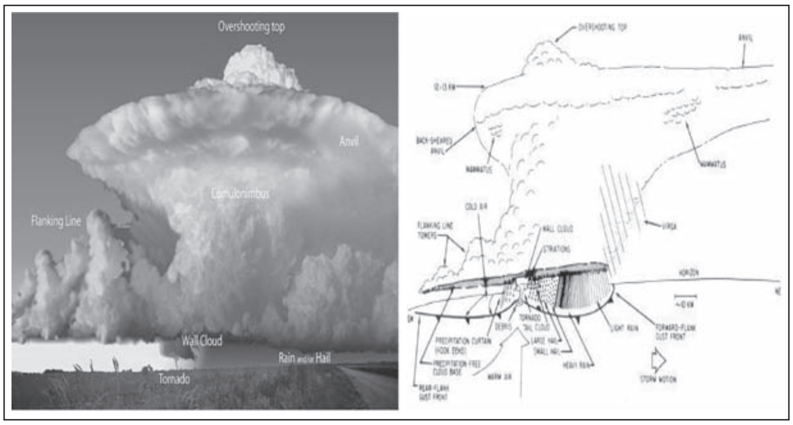


Fig. 3 : Illustration of a super cell storm. Upper panel from National Weather Service (NOAA), and lower panel from Houze (1993).

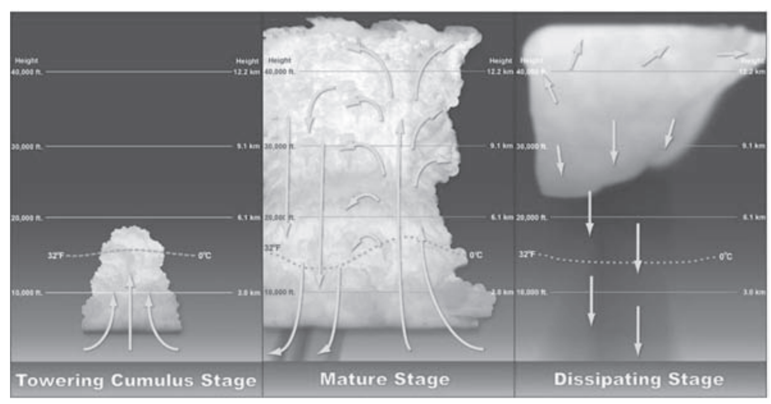


Fig.4 : Life cycle of a thunderstorm.

Mature stage:

In the mature stage of a thunderstorm, the warmed air continues to rise until it reaches tropopause (warmer air) and can rise no further. The air is instead forced to spread out, giving the storm a characteristic anvil shape. The resulting cloud is called *cumulonimbus incus*. The simultaneous presence of both an updraft and downdrafts marks the mature stage of the storm. During this stage, considerable internal turbulence can occur in the storm system, which manifests as strong winds, severe lightning, and even tornadoes. The mature stage can sustain itself for several hours

Dissipating stage:

In the dissipation stage, the thunderstorm is dominated by the downdraft. The downdraft will push down out of the thunderstorm, hit the ground and spread out. This phenomenon is known as a downburst. The cool air carried to the ground by the downdraft cuts off the inflow of the thunderstorm, the updraft disappears and the thunderstorm will dissipate. Thunderstorms in an atmosphere with virtually no vertical wind shear weaken as soon as they send out an outflow boundary in all directions, which then quickly cuts off its inflow of relatively warm, moist air and kills the thunderstorm.

Hailstorms

Any thunderstorm which produces hail that reaches the ground is known as a hailstorm. Hail has a diameter of 5 millimetres (0.20 in) or more. Hailstones can grow to 15 centimetres (6 in) and weigh more than 0.5 kilograms. Hail forms in strong thunderstorm clouds, particularly those with intense updrafts, high liquid water content, great vertical extent, large water droplets, and where a good portion of the cloud layer is below freezing 0 °C. These types of strong updrafts can also indicate the presence of a tornado. The growth rate is maximized where air is near a temperature of -13 °C. The storm's updraft, with upwardly directed wind speeds as high as 110 miles per hour (180 km/h), blow the forming hailstones up the cloud. The hailstone will keep rising in the thunderstorm until its mass can no longer be supported by the updraft. This may take at least 30 minutes based on the force of the updrafts in the hail-producing thunderstorm, whose top is usually greater than 10 km high. It then falls toward the ground while continuing to grow, based on the same processes, until it leaves the cloud. It will later begin to melt as it passes into air above freezing temperature.

Unlike ice pellets, hailstones are layered and can be irregular and clumped together. Hail is composed of transparent ice or alternating layers of transparent and translucent ice at least 1 millimetre thick.

India is among the countries in the world having large frequency of hail. There are about 29 hail days per year of moderate to severe intensity (Nizamuddin, 1993). Hail sizes comparable to mangoes, lemons and tennis balls have been observed. Eliot (1899) found that out of 597 hailstorms in India 153 yielded hailstones of diameter 3 cm or more. India and Bangladesh are different from other northern hemisphere tropical stations in that hail is observed in the winter and pre-monsoon seasons with virtually no events after the onset of the southwest monsoon. Chaudhury and Banerjee (1983) showed that the percentage of hailstorm days out of thunderstorm days decreases from 5% to less than 2% from March to May for NE India and Bangladesh.

Cloudburst

A cloudburst, also known as a rain gush or rain gust is a sudden heavy downpour over a small region, is among the well-known and least understood type of mesoscale system. An unofficial criterion specifies a rate of rainfall equal to or greater than 100 mm per hour featuring high-intensity rainfall over a short period, strong winds and lightning. A remarkably localized phenomenon affecting an area not exceeding 20-30 km 2 (Das *et al.*, 2006), cloudbursts in India occur when monsoon clouds associated with low-pressure area travel northward from the Bay of Bengal across the Ganges plains onto the Himalayas and “burst” in heavy downpours (75-100 mm per hour). It represents cumulonimbus convection in conditions of marked moist thermodynamic instability and deep, rapid dynamic lifting by steep orography. Cloudburst events occur at the meso-gamma (2-20 km) scale and may be difficult to distinguish from thunderstorm.

The states of Himachal Pradesh and Uttaranchal are the most affected due to steep topography. Most of the damage to property, communication systems and human casualities result from the flash floods that accompany clouburssts. Prediction of cloudbursts is challenging and requires high-resolution numerical models and mesoscale observations, high-performance computers and Doppler weather radar. Societal impact could be markedly reduced if high-resolution measurement (~10 km) of atmospheric parameters and vertical profiles are provided through a mesonet observations such as Automatic Weather Station (AWS), Radiosonde/ Rowinsonde (RS/RW), and Doppler weather radar.

Thunderstorm Electrification and Lightning

There is always free electricity in the air and in the clouds. Whatever may be the origin of free electricity in the atmosphere the electricity of enormous voltages that disrupts the air and produces lightning is due to the condensation of the water vapour forming the clouds. If the quantity of water that is condensed in and subsequently precipitated from a cloud is known, then the total energy of a thunderstorm can be calculated. In an average thunderstorm, the energy released amounts to about 10,000,000 kilowatt-hours (3.6 × 1013 joule), which is equivalent to a 20-kiloton nuclear warhead.

Ice inside a cloud is thought to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning. Fig. 5 illustrates the distribution of charges in a typical thunderstorm.

Lightning is an electrical discharge that occurs in a thunderstorm. It can be seen in the form of a bright streak (or bolt) from the sky. Lightning occurs when an electrical charge is built up within a cloud, due to static electricity generated by supercooled water droplets colliding with ice crystals near the freezing level. When a large enough charge is built up, a large discharge will occur and can be seen as lightning.

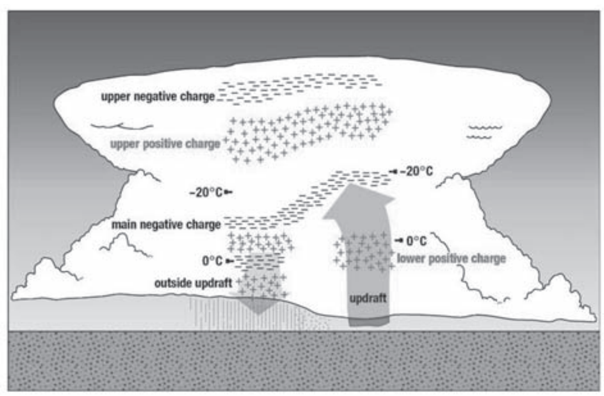


Fig. 5 : Schematic of the basic charge structure in the convective region of a thunderstorm. Four charge layers are seen in the updraft region, and six charge layers are seen outside the updraft region (to the left of the updraft in the diagram).

There are several types of lightning:

I. In-cloud or intra-cloud lightning is the most common.

II. Cloud to ground lightning

III. Ground to cloud lightning

IV. Cloud to cloud lightning

V. Ball lightning is extremely rare. It is seen in the form of a 15 to 50 cm radius ball.

VI. Cloud to air lightning seen is when lightning from a cloud hits air of a different charge.

VII. Dry lightning is a misnomer which can refer to a thunderstorm whose precipitation does not reach the ground.

VIII. Heat Lightning refers to a lightning flash that is seen from the horizon that does not have accompanying thunder.

Figure 6 illustrates different types of lightning mentioned above.

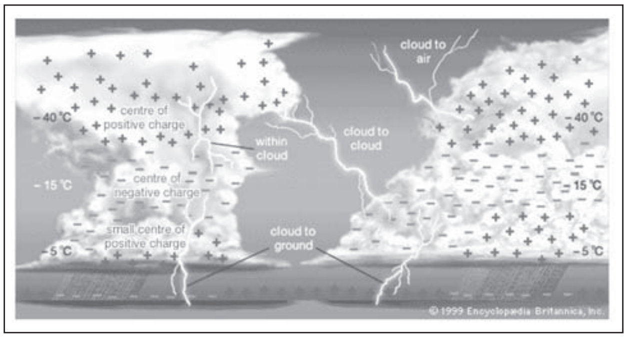


Fig. 6 : Schematic illustration of the different types of lightning.

Although the lightning is extremely hot, the duration is short and 90% of strike victims survive. The loud bang that is heard is the super heated air around the lightning bolt expanding at the speed of sound. Because sound travels much more slowly than light the flash is seen before the bang, although both occur at the same moment. It is estimated that there are more than 2,000 thunderstorms taking place around the world at any given instant. Observations indicate that the number of lightning strikes over the earth per second is about 100 of which 80% are in-cloud flashes and 20% are cloud-to-ground flashes. This implies that there are about 8,640,000 lightning strikes over the earth per day. Each year, lightning flashes about 1.4 billion times over Earth. An average bolt of lightning carries a current of 30 kiloamperes, transfers a charge of 5 coulombs, has a potential difference of about 100 megavolts and dissipates 500 megajoules (enough to light a 100 watt lightbulb for 2 months).

Forecasting Thunderstorms

To forecast thunderstorms, meteorologists use a variety of data. Surface and upper air observations are studied to find areas of low level moisture and instability, and to determine how winds aloft might influence storm development. Satellite imagery is used to help track the movement of weather systems that might generate thunderstorms. Forecasters scan computer model data to help determine where favorable areas for thunderstorm formation might be located. Radar and satellites are used to track the storms once they form.

Twice daily, at 0 Z and 12 Z (Z stands for Greenwich Mean Time) weather balloons are launched from locations all over the globe. These balloons carry with them an instrument package called a radiosonde that measures temperature, pressure, moisture, and windspeed and direction at multiple levels throughout the atmosphere. As these balloons ascend through the atmosphere they transmit this information back to computers at the surface. Meteorologist then plot this information on special diagrams called skew-t log-p diagrams (or just skew-t for short). From these few variables we can gain an enormous amount of information about the state of the atmosphere including, stability, vertical velocity, cloud base height, cloud top height etc. This information can also be used to help forecast whether or not thunderstorms will happen in the afternoon.

Synoptic Method:

- Use a Skew-T diagram (fig. 7)
- Find the cloud layer with a Skew-T (Where dew point and temperature are the same)
- Identify inversions with a Skew-T (strong drop off in dew point and strong increase in temperature)
- Find the Lifted Condensation Level (expected cloud base height)

- Find the Level of Free Convection (the height at which a parcel of air becomes positively buoyant)
- CINE - Convective Inhibition
- CAPE - Convective Available Potential Energy

The Skew-T Log-P diagram (Fig. 7) offers a way to look at the measurements made with a Radiosonde.

Convective Indices:

Convective indices such as CAPE, CINE, Lifted Index, Showalter index, Total Total index, SWEAT index, Bulk Richardson Number, etc. are generally used for operational forecasting. These convective indices are calculated based on observed soundings.

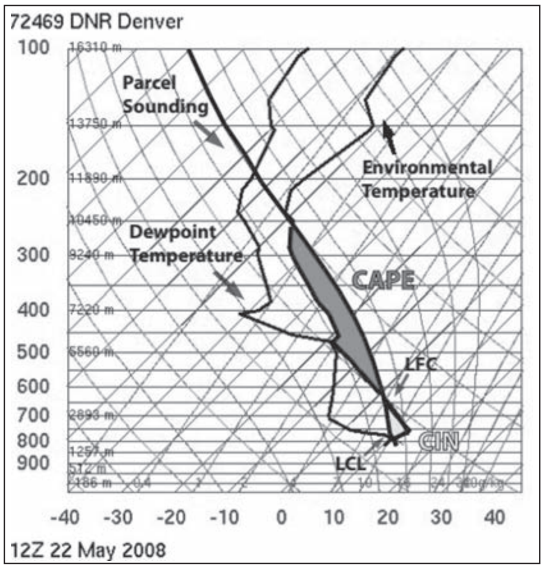


Fig. 7 : Illustration of a typical sounding on Skew-T Log-P diagram.

Convective Available Potential Energy (CAPE):

The Convective Available Potential Energy (CAPE) is the positive buoyancy of an air parcel. It is the amount of energy a parcel of air would have if lifted a certain distance vertically through the atmosphere. It is an indicator of atmospheric instability. It is defined as

$$CAPE=\int_{Zf}^{Zn} g\frac{(Tvp - Tve)}{Tve}dz$$

where, Zf and Zn are the levels of free convection and neutral buoyancy respectively. Tvp and Tve are the virtual temperatures of the air parcel and environment respectively. The threshold values of CAPE for different stability regimes are given below.

CAPE < 1000 : Instability is weak

CAPE > 1000 < 2500 : Moderate instability

CAPE > 2500 : Strong instability

Convective Inhibition Energy (CINE):

CINE is a negative energy which prevents the CAPE to be spontaneously released. The negative bouncy typically arises from the presence of a lid. If CINE is large, deep convection will not form even if other factors may be favourable. It is expressed as follows.

$$CINE=\int_{Zo}^{Zf} g\frac{(Tvp - Tve)}{Tve}dz$$

where, Zo and Zf are the levels at which parcel originates and free convection respectively.

Lifted Index (LI):

The Lifted index (LI) is the temperature difference between an air parcel lifted adiabatically to a given pressure (height) in the atmosphere (usually 500 hPa) and the temperature of the environment at that level. When the value is positive (negative), the atmosphere is stable (unstable).

Showalter Index (SI):

The Showalter Index is defined as SI = T_{500} - Tp_{500};

where Tp_{500} is the temperature of a parcel lifted dry adiabatically from 850 mb to its condensation level and moist adiabatically to 500 mb.

SI values = +3 indicate possible showers or thunderstorms. SI values = -3 indicate possible severe convective activity.

Note that the LI differs from the SI by the initial location of the lifted parcel.

Total Total Index (TTI):

It is defined as TTI = T_{850} + Td_{850} - $2T_{850}$

TTI = 40 indicator of occurrence of Nor'westers

TTI = 47 indicator of severe Nor'westers with tornado intensity.

The total totals index is actually a combination of the vertical totals, VT = T_{850} - T_{850}, and the cross totals, CT = Td_{850}- T_{500}, so that the sum of the two products is the total totals.

SWEAT (Severe Weather Threat) Index:

It is defined as, SWEAT = $12Td_{850}$+ 20(TT - 49) + $2f_{850}$ + f_{850} + 125(s + 0.2);

where the first term is set to zero if the 850 mb Td (°C) is negative; TT is the Total Totals Index (if TT < 49, the term is set to zero); f is the wind speed in knots; and s = sin (500 mb wind direction - 850 mb wind direction). The last term is set to zero if any of the following is not met:

1) the 850 mb wind is between 130°-250°;
2) the 500 mb wind is between 210°-310°;
3) (the 500 mb wind direction - the 850 mb wind direction) is greater than zero; or, both the wind speeds are greater than or equal to 15 kts.

SWEAT values +250 indicate a potential for strong convection. SWEAT values +300 indicate the threshold for severe thunderstorms. SWEAT values +400 indicate the threshold for tornadoes.

These empirical indices are used by meteorologists to give a quick estimate of the atmospheric condition.

Bulk Richardson Number (BRN):

The Bulk Richardson Number (BRN) is a dimensionless number relating vertical stability and vertical shear (generally, stability divided by shear). It represents the ratio of thermally produced turbulence and turbulence generated by vertical shear.

Practically, its value determines whether convection is free or forced. High values indicate unstable and/or weakly-sheared environments; low values indicate weak instability and/or strong vertical shear. Generally, values in the range of around 10 to 45 suggest environmental conditions favorable for supercell development. For mesoscale forecasting purposes, the Bulk Richardson Number (BRN) is simply defined as:

$$BRN = CAPE / (0.5 * (u6km - u500m)^2)$$

Where, u6km is the wind speed at 6km above ground level (AGL) and u500m is the wind speed at 500m AGL. In summary, BRN < 10 : Probably too much shear for thunderstorms, BRN > 10 < 45 : Supercells possible

BRN > 45 : Storms more likely to be multicells rather than supercells

Radar detection of thunderstorms:

Doppler RADAR can detect the location and intensity of storms (reflectivity), the speed and direction of wind (velocity), and the total accumulation of rainfall (storm total). RADAR systems generate a different image for each. A reflectivity image shows the location where rain, snow, or other precipitation is falling and how intensely. Velocity images reveal the speed and direction of winds. The color keys are not standard, but on some images warm colors, like red and orange, indicate that winds are blowing away from the RADAR site. Cool colors, like green and blue, indicate that winds are blowing towards the RADAR site.

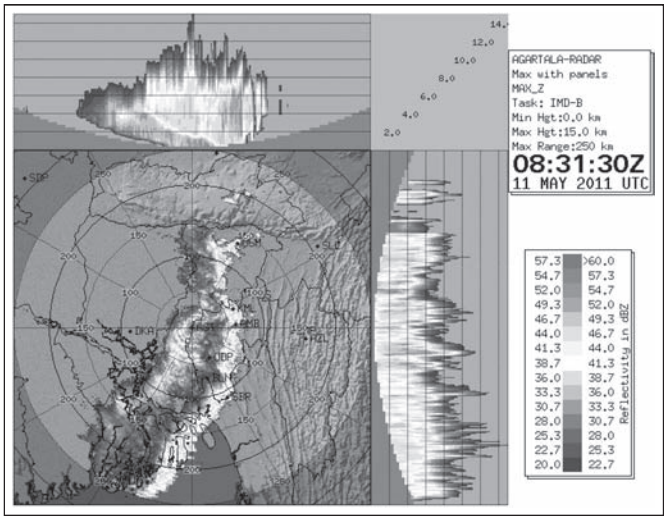


Fig. 8 : A Squall line observed by Doppler radar at Agartala on 11 May 2011.

Doppler radars are used to monitor convergence lines even in the absence of clouds. It has been demonstrated (Wilson et al., 1998) that forecasters could often anticipate thunderstorm initiation by monitoring Doppler radar-detected boundary layer convergence lines (boundaries) together with visual monitoring of cloud development in the vicinity of the convergence line. Figure 8 illustrates a squall line observed by radar at Agartala. Squall lines typically bow out due to the formation of a mesoscale high pressure system which forms within the stratiform rain area behind the initial line.

Numerical prediction of thunderstorms:

Numerical models have the ability to simulate all the phases of thunderstorm evolution.

The mesoscale models can be configured to run from global to cloud resolving scale for simulation of thunderstorms and cloud cluster properties.

Presently, mesoscale models have been developed with a wide varieties of flexibilities in terms of changing horizontal and vertical resolutions, nesting domains, and choosing options for different physical parameterization schemes, i.e. MM5, WRF, RAMS, ETA, ARPS, HIRLAM, etc (Anthes, 1990; Dudhia, 1993; Cotton et al, 1994; Mesinger, 1996; Toth, 2001, Case et al., 2002). These models require initial and boundary conditions from a large-scale/ global model and may be used for forecasting up to 72 hours. Such models can be run at cloud resolving scale for simulation of thunderstorms and cloud cluster properties. Fig. 9 illustrates nowcasting of thunderstorms by the India Meteorological Department (IMD).

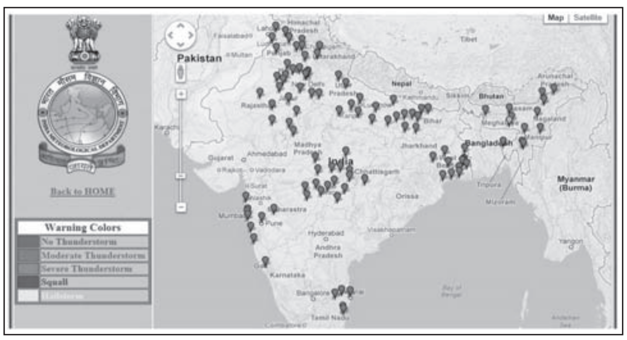


Fig. 9 : All India now casting of thunderstorms

CLOUD BURST AND HAILSTORMS- IMPACT ON AGRICULTURE AND PROTECTIVE MEASURES

Rajendra Prasad

Thunderstorms

During late winter and in the hot months preceding the arrival of the monsoon, conditions become favourable for the growth of clouds to altitudes of 10 kilometres or even higher. Such clouds of great vertical extent are called cumulonimbus clouds and a cluster of such clouds have a horizontal dimension of 20 to 30 kilometres. The cluster causes moderate to heavy rain, 2 to 10 cm in an hour or so and thereafter dissipate.

As rain falls, it cools the air around it and drags down the cooled air along with it. The falling cooled air on striking the ground fans out as a strong wind squall lasting a few minutes. The wind speed in the squall varies; it can be anything between 50 kmph per hour and 150 kmph. This whole phenomenon of lightning, thunder, wind squalls, towering cloud and the sharp rain shower, together is called a *Thunderstorm.* Thunderstorms move in a direction and with a speed determined by the mean motion of the atmosphere layer extending from the ground up to heights of 15-20 kilometres. An average thundercloud is 20 to 30 kilometres per hour. Consequently, it takes about an hour or an hour and a half for an average thunderstorm to pass over a station. The electric discharges produce oxides of nitrogen which are washed down to earth by the rain, where they become a nitrogenous fertilizer. It is estimated that each thunderstorm lasting an hour or so produces about ten tons of nitric acid. Thunderstorm is therefore, a valuable friend of farmer.

In some thunderstorms of great vertical extent, hailstorms form. They are tossed up and down in the clouds before they finally fall down as hail stones. They are simply rain water frozen hard. Their equivalent diameters can be a centimeter and occasionally even 10-15 cm and their fall velocities naturally vary with size. Those with an equivalent diameter of 1 cm have a fall velocity of about 40 kilometres per hour (12 metres per second) and those with 5 cm a fall velocity of 30 metres per second or 100 kilometres per hour.

Southern India experiences 30 to 60 thunderstorms during the year and very few during the period when the monsoon is in full swing. In the extreme south, each station in Kerala, experiences 60-100 thunderstorms during a whole year but, most of them are not associated with any significantly strong squall. Northeast India experiences 80-100 thunderstorms over each place during the whole year; two or three of them during the period February to May are accompanied by hail stones. The number of hailstorms over the hills of West Uttar Pradesh and neighborhood can be three to four. No accurate enumeration of the number of hailstones that fall during an average hailstorm even is available. However, several years ago, an estimate has been made at Pune in Maharashtra, in the case of a severe hailstorm. Hailstones fell over an area of 60 square kilometres.

Generally, before and after the monsoon (during monsoon hail storms are practically absent), thunderstorms with associated shower of rain and hail are the predominant weather phenomena. When sufficient moisture is not present in the air, as over North West India (excluding large part of Himachal Pradesh) only a dust storm may result. These dust storms or *andhis* are quite frequent over North West India. Thunderstorms with associated squalls are of short duration but, some are very violent and destructive like the *Kalbaisakhis/ mongo showers* of Bengal. Some violent thunderstorms are accompanied with hail, especially in northern and central India and occasionally in the interior of peninsular India. The frequency of hail storm is small in winter but, increases generally as the season advances to summer due to higher frequency of convective activity.

The number of days with hail is about 6-7 per year (highest) over Himachal Pradesh and its neighborhood but, decrease to one in two years over adjoining plains. Over Bengal, Bihar, Uttar Pradesh and Madhya Pradesh, hail storm occurs once a year. Hailstorms are comparatively rare over the costal tracts of the Peninsula. The hailstorm in Himachal Pradesh has peculiar clear line of demarcation due to Dhauladhar range perhaps due to associated orographic ascent and this can be used as highly valuable landmark for hailstorm study. Hailing in the state is frequent at the time of flowering of horticultural crops viz., apple, mango, peach, plum etc. (during March and April) and at the time of maturity of wheat and *brassica* crops (April and May) and maturity of rice crop (October). Lot of damage to young seedlings and foliage of crops and trees, flowering, fruit set, fruits and mature crops is caused.

Himachal Pradesh is high risk zone of hailstorm damage in India (Kumar, 2010). Each year more than five hundred crores of crop/horticulture & floriculture plants/trees and livestock get perished by hailstorm lashing the state. According to Horticulture department estimates, hailstorms damage 20-30 percent of vegetable and fruit crops in the state every year. The economy of the state is highly dependent on horticulture, apart from hydroelectric power and tourism, with the annual fruit industry worth about Rs.2, 000 crores.

As a principle, protection against violent hail storms is possible by adopting artificial hail suppression methods. During recent years, the state government undertook a pilot project on anti hail cannon/guns. The experience on trials of anti hail cannons/guns in the state has really not been found encouraging. The project has since then been discontinued and anti hail nets have been recommended. Hail storm event, occurrence is sporadic and limited to small areas being a highly localized phenomenon. IMD is also proposing a new initiative to install Doppler Radars to give boost to weather forecasting at two locations viz., Shimla for Shimla district and Dharamshala for Kangra district.

Hail Suppression is a problem of importance to farmers in Himachal Pradesh, Punjab, Haryana and adjoining parts of Uttar Pradesh. USSR scientists claim that they are able to suppress artificially more than 50% of the hailstorms. Their method prevents the formation of large hailstones by injecting a large number of artificial hail embryos into the region of hail formation within a cloud. This is done by firing small rockets carrying silver iodide pyrotechnic sticks into the sensitive part of the cloud. The small rockets are self destroying so that their fall should not produce any damage. Now the state-of-the-art acetylene-fired anti-hail gun covers an aerial distance of around 80 to 100 hectares and the coverage area of the weather radar is 25 km. The guns send shock waves into the pressure areas where hail clouds are formed and puncture them resulting in rain instead of the damaging hail.

Containing the Impact of Disasters

The Disaster Management Act, 2005 stipulates every state in India to prepare its own disaster management plan aimed at reducing potential loss of life and property in disasters as well as ensuring strong preparedness, response, relief and rehabilitation measures for effective and efficient response management in case any disaster strikes. The Plan for the Himachal Pradesh has been prepared as per the guidance provided by the National Disaster Management Authority.

Reliefs for disasters in Himachal Pradesh:

In Himachal Pradesh, Disaster Management and Relief Manual, 2012 was prepared. The hazard profile of Himachal Pradesh is presented in Table 1. All of the weather/climate hazards belong to hydro meteorological or geological categories and they have also capacity to promote other three categories of hazards viz., industrial, manmade and biological.

Table 1: Profile of different types of hazards in Himachal Pradesh

Hydro meteorological	Geological	Industrial	Manmade	Biological
Flash floods, cloud bursts, hailstorms, drought, wind storms, lightning, avalanche and forest fires	Earthquakes, landslides and soil erosion	Chemical and industrial	Accidents, building collapse, terrorism, boat-capsizing, stampede and domestic fires	Epidemics, pandemics, CBNR emergencies and pest attack

The state of Himachal Pradesh is basically not prone to floods but, is mainly prone to riverine and flash floods induced by heavy rains, cloud burst and thunderstorms. Ravi, Beas and Satluj are three main rivers which cut across the state besides, many rivulets/streams flow in different parts of the state. These rivers and streams carry huge load of water during rainy season and many a times, loss of life and property results. Cloud burst, glacial lake outburst (2005, Parecho) and flash floods have been causing huge loss of life and property in the state. Floods are intimately connected to monsoon season and heavy rains cause wide spread damage to infrastructure, loss of life and cattle heads. Damage to agricultural land, crops, agriculture and horticulture in general is also wide spread. This relief manual gives action plan to deal with these disasters.

Pre-disaster activities:

i. It is mandatory to catalogue the incidents of cloud burst, flash floods and losses caused over the years.
ii. Vulnerable areas of each district should be identified and all preventive and precautionary measures should be taken.
iii. People located along the river beds and nullahs should be alerted and warned.
iv. Contingency plans along with SOPs to deal with emergency should be drawn and made part of the DDMP.
v. A meeting sometimes in the month of May / June should be held at the district and sub division head quarters to review the preparedness measures.
vi. Special attention is to be made to clean and keep drainage system free from obstructions so that the rain water flows smoothly.
vii. DDMP should be activated on the on-set of monsoon.

Flood warning system:

The Meteorological Centre, Shimla of IMD issues weather forecasts and warnings for heavy rainfall. The daily bulletin is e-mailed to all Deputy Commissioners, Superintendents of Police, Divisional Commissioners, Department of Revenue and electronic and print media and all Agromet Field Units (AMFUs). Similarly, the office of Central Water Commission located at Shimla, also sends regular bulletins about the flow of rivers and water level in the reservoirs/dams in the state during monsoon season. The District Control Rooms process the information received and issue alerts through electronic means etc. All pre-emptive steps are taken to minimize loss and search and rescue parties should be put on high alerts.

During the cloud burst/flash flood - some guidelines:

i. It is mandatory for the local Patwaris and other field officers of the departments to report the incidents to the concerned Tehsildars/Sub Divisional Officer (Civil)/Deputy Commissioner.
ii. The SDO (Civil)/Deputy Commissioner on hearing the occurrence would immediately activate the Disaster Management Plan and organize the coordinated search and rescue and relief operation.
iii. Shelter for victims be arranged wherever needed.
iv. The loss to dwelling house includes loss to the buildings and loss to the belongings inside buildings.
v. In the collapsing house due to rain /cloud burst, the first attempt be made to move the occupants and their belongings to safe places.
vi. Effort be made to prepare a realistic estimate of the loss on the basis of the statement of the victim, plinth area (in case of a building), seeing his status and inspecting the remnants.
vii. Immediate assistance be given in the form of clothes (quilts), food articles out of the existing stock of the district administration which could be later replenished. Safe drinking water also be insured.
viii. Arrangement for the supply of medicines or shifting affected persons to the hospitals is made for which ambulances are pressed into service.
ix. Necessary arrangements for shifting of orphans/widows to special homes should be made immediately.
x. Necessary assistance to evacuate the injured persons and air dropping of the essential supplies including food articles through air routes in difficult areas of the state may be requisitioned from the Army authorities.
xi. Efforts should also be made for supply of timber for reconstruction of houses as well as deferring of loan recoveries and suspension of collection of land revenue.

Rescue and evacuation operations:

i. Before hitting the area by flood, the likely victims should be evacuated by road and at/after the commencement of the floods, the boats/rafts and divers should be pressed into action.

ii. The security of the belongings left behind by the evacuated people should be ensured by involving patrolling of local residents at night.

iii. Ensure that the members of a family are evacuated together to the same safe site and any human deaths should be promptly reported to the authorities.

Post flash flood phase: General observations:

i. Repair of damaged roads/bridges is the foremost requirements to make them suitable for vehicular traffic after the flood water recedes.

ii. During flash floods, many a time, good agricultural land is washed away resulting in heavy loss to farmers. In such cases, immediate steps are needed to formulate the land development schemes for all affected farmers. Department of rural development and soil conservation wing of Department of Agriculture should take up soil conservation activities under Employment Generation Scheme.

iii. Losses caused due to flash floods should be assessed and reported to the Deputy Commissioners by the all concerned departments.

iv. In flash flood prone areas, the check dams, live hedges should be planted by the Forest Department and they should ensure good plantation in catchment area, rivers and khads.

v. As a long term measure, the Public Works Department should provide cross drainage to all katccha roads so that during rains these roads remain good for vehicular movement. The Public Works Department should prepare a check-list of probable land- slide prone locations and remedial/actions required to be taken so that landslides can be prevented in future.

Long term measures:

Structural: Water shed management, reservoir, natural water detention basins and safe disposal of surplus runoff.

Non structural measures: Flood plain zoning, flood forecasting and warning, flood proofing and establishment of rain gauges in all the sub divisional and tehsil HQs.

Structural measures are the physical measures that help in modifying the floods where in the water is kept away from the people with the help of these structures. The non structural measures are the planning that helps in modifying the losses due to floods wherein people are kept way from the water.

Contingency plans for the floods:

Check-list needed before commencement of floods:

i. Whether a meeting of district level committee on natural calamities/DDMA convened, control room started functioning before monsoon, high flood level marking done in vulnerable locations, drainage lines cleaned and obstructions /congestions removed, past breaches in river embankments closed, rain recording and rain gauge readings submitted, arrangements made for dissemination of weather reports and flood bulletins, deployment of rescue material at strategic points done, installation of temporary police wireless stations and temporary phones in flood prone areas done and their orderliness ensured, arrangement for dry food stuff and other necessities of life made, drainage system desilted a month before monsoon, agricultural requirements of crop insurance/seed availability ensured, action plans for people and animal health measures kept ready, selection of flood relief shelters done and kept ready, advance arrangement for army assistance made, officials trained in flood relief work, organization and arrangement for bringing of relief parties done and whether alternative drinking water supply arrangements have been made?

ii. **Arrangements during and after flood: Checklist**

Shelter arrangement for people in distress made, if the efforts of the civil authorities are inadequate, should army assistance be sought immediately? Relief measures by voluntary organizations enlisted, provision of basic amenities like drinking water, sanitation and public health care and arrangements of cooked food in relief camps made, necessary arrangements of air-dropping of food packets in marooned village through helicopter made, number of relief parties for the rescue of the marooned people sufficient, alternative communication link for effective communication in marooned areas done, need for organizing cattle/veterinary care camps to affected animals assessed, emergency relief to the affected people disbursed, action for daily reports and arrangements to disseminate correct information through mass media made, action plan for rehabilitation of homeless people done, commencement of agricultural activities-desiltation, resowing has taken place, action taken to repair and reconstruct infrastructural facilities such as roads, embankments and resettlement of flood prone areas done and what arrangements are planned for economic reconstruction in the district?

First information report on occurrence of natural calamity:

The report is sent to SEOC and NEOC, Government of India within 24 hours of occurrence of calamity. This report includes information on nature of calamity, date and time of occurrence, affected area (number and names of affected districts), population affected, number of persons, dead, missing, injured, number of animals affected, lost, covering area of crops affected, number of houses damaged, damage to public property, relief measures undertaken in brief, immediate response and assistance required and the best logical means of delivering that relief, forecast of possible future developments including new risks and any other relevant information.

Situation report

This report includes information on calamity categories viz., rainfall and damage/loss position, fire incidents, accidents, snowfall, hailstorm, other incidents of loss of life and property and any other relevant information.

Rapid assessment format (for big disasters):

This information is required to determine the immediate response of the locality. Type of disaster, date and time, name of location, administrative unit and geographical location, local authorities interview (with name, address and designation), estimated total population, worst affected areas/population, number of blocks, Gram Panchayats, villages, areas currently inaccessible, type of area affected, distance from the HQ, accessibility of an area, effect on population- primary affected population, children below one year, between 1-5 years, women-pregnant and lactating, elderly (above 60 years), disabled, death/report on starvation, orphans, injured, missing, homeless-number of people, number of families, displaced/migrated, evacuated, destitute, need for counseling for traumatized population, number of buildings -collapsed/washed away, partially collapsed/washed away, with minor damage (can be retrofitted), schools, government building, any other building affected, gravity of damage in each case with scale 1 to 5 where 1 is no damage and 5 is completely destroyed/washed away. Infrastructure- roads, railways damaged/destroyed, their location and distance from HQ, Is railway still working, bridges damaged/collapsed-locality and villages isolated, damages to electric/telecommunication network and gravity of damage in each case with scale 1 to 5 where 1 is no damage and 5 is completely destroyed. Health services-number of hospitals, health centres and vaccination centres destroyed, availability of doctors and paramedical staff- in area, in district, number of doctors, paramedical staff affected with scale 1 to 5 where 1 is no damage and 5 is completely destroyed. Condition of hospital equipments, in Yes/No, about availability of medicine/drugs, any immunization campaign undertaken before the disaster, possibility of disease break out and list of any other health problems. In Yes/No, about availability of safe drinking water, sanitation facilities, disinfectant and potable water and damages to water supply and sewage system.

Crop/agriculture damage:

Crops damage in hectares of upland, medium or low land paddy or other cereals, irrigated or non- irrigated, assessment of actual rainfall compared to normal, livestock loss, availability of health services for livestock, cattle feed/fodder availability and damage to agriculture infrastructure with scale 1 to 5 where 1 is no damage and 5 is completely destroyed.

Revised Norms of Assistance for Loss in Agriculture

Following assistance is provided to small and marginal farmers;

A.	**Assistance for land and other loss**	**To be given to individual beneficiaries**
	Loss to agriculture/horticulture crops	i)Loss between 50-75%= Rs 300/- per bigha ii)Loss above 75%= Rs 500/- per bigha
B.	**Input subsidy (where crop loss is 50% and above)**	**For allotment to agriculture and horticulture only**
	a) For agricultural crops, horticultural crops and plantation crops	Rs 3,000/- per ha in rainfed areas Rs 6,000/- per ha in assured irrigation, subject to minimum assistance not less than Rs 500/- and restricted to sown areas
	b) Perennial crops	Rs 8,000/- per ha for all types of perennial crops, subject to area sown and subject to minimum assistance not less than Rs 1000/-
	c) Sericulture	Rs 3,200/- per ha for Eri, Mullberry, Tussar Rs 4,000/- per ha for Muga

Assistance other than to small and marginal farmers

i)	Input subsidy to farmers other than small and marginal (for agriculture and horticulture only)	Rs 3,000/- per ha in rainfed areas Rs 6,000/- per ha in assured irrigation, subject to minimum assistance not less than Rs 500/- and restricted to sown areas Rs 8,000/- per ha for all types of perennial crops may be provided where crop loss is 50% and above, subject to ceiling of 1 ha per farmer and up to 2 ha per farmer in case of successive calamities irrespective of size of holding

Animal husbandry-Assistance to small and marginal farmers

i)	Replacement of milch animals or animals used for haulage	• Buffalo, ox, yak, mule, camel=Rs 16,000/- per cattle • Cow (cross bred) and churu/churi=Rs 11,000/- per cattle • Cow (local bred), donkey, pashmina goat=Rs 6,000/- per head • Sheep/goat=Rs 1,650 per head Maximum relief on livestock for each family to be Rs. 50,000/- • Poultry: Poultry @Rs 37/- per bird subject to ceiling of assistance of Rs 400/- per beneficiary household. The death of the poultry birds should be on account of a natural calamity.
ii)	Cost of fodder and transportation	Rs 500/- per family having livestock
iii)	Additional cost of medicine and vaccine	Allocation to Animal Husbandry Department as per actual cost incurred by the Department of Animal Husbandry and assessed at local level and recommendation of the central team consistent with estimates of cattle as per Livestock Census and subject to the certificate by the competent authority about the requirement of medicine and vaccine being calamity related.

Specific hazards and nodal departments in Himachal Pradesh

Sr. No.	Name of Hazard	Nodal Department	Supporting agencies/departments for early warning systems
1	Flood/flash floods/ cloud burst	Irrigation and Public Health	India Meteorological Department, Central Water Commission
2.	Hailstorm	Agriculture and horticulture	India Meteorological Department, Insurance

Role and responsibilities of Nodal Agencies

Department of Agriculture	Primary agency for hailstorm, droughts and pest attacks. Their main role is to provide seeds and necessary planting material and other inputs to assist in early recovery.
Department of Horticulture	Primary agency for hailstorm and pest attacks on horticulture sector. Their main role is to support in crop damage assessment due to disasters.

STRONG WINDS AND DUST STORMS - DAMAGES AND COUNTER MEASURES

A.S. Rao

Strong winds associated with dry conditions results in wind erosion, a serious problem in many parts of the world. Strong winds under dry soil conditions physically remove the most fertile portion of the soil from the field, pollutes the air, fills road ditches, reduces seedling survival and growth, lowers the marketability of many vegetable crops, and creates new landforms and landscapes. Wind erosion is worst in arid and semi-arid areas, where these conditions frequently occur: (1) loose, dry, finely divided soil; (2) smooth soil surface devoid of vegetative cover; (3) large fields; and (4) strong winds (FAO, 1960). Arid lands comprise about one-third of the world's total land area and are the home of one sixth of the world's population (Dregne, 1976; Gore, 1979). Areas most susceptible to wind erosion on agricultural land are much of North Africa and the Near East, parts of southern and eastern Asia, Siberian Plain, Australia and southern South America, and the semi-arid and arid portions of North America (FAO, 1960). In pastoral rangelands, composition of pastures subjected to excessive grazing in dry periods deteriorates, the proportion of edible perennial plants decreases, and the proportion of annuals increases. The grazers also trample vegetation and pulverize soil aggregates. In rainfed farming, removal of the original vegetation and fallow expose the soil to accelerated wind and water erosion.

Part of the soil from damaged lands enters suspension and becomes part of the atmospheric dust load. Hagen and Woodruff (1973) estimated that eroding lands of the Great Plains contributed 244 and **77** million tons of dust per year to the atmosphere in the 1950s and 1960s, respectively. Jaenicke (1979) estimated the source strength of mineral dust from the Sahara at 260 million tons per year. Blowing soil fills road ditches; reduces seedling survival and growth; lowers the marketability of vegetable crops, increases the susceptibility of plants to certain types of stress including diseases; and contributes to transmission of some plant pathogens (Hayes, 1965, 1966; Claflin *et al.*, 1973).

Mechanics of Wind Erosion, Sand and Dust Storms

Wind erosion is possible when the wind velocity at the soil surface exceeds the threshold velocity required to move the least stable soil particle. The detached particle may move a few millimetres before finding a more protected site on the landscape. The wind velocity required to move this least stable particle is called the "static threshold". If the wind velocity increases, soil movement begins and if the velocity is sufficient, soil movement is sustained. This velocity is called the "dynamic threshold". When the wind force reaches the threshold value a number of particles will begin to vibrate, Increasing the wind speed still further, and a number of particles will be ejected from the surface into the airflow. When these injected particles impact back on the surface, more particles are ejected, thus starting a chain reaction. Once ejected, these particles move in one of three modes of transport depending on particle size, shape and density of the particle. These three modes are designated ***suspension, saltation and creep***. Their size and density determine movement pattern of sand-dust particles. The suspension mode involves dust particles of less than 0.1 mm in diameter and clay particles of 0.002 mm in diameter i.e. small in size and light in density. These fine dust particles may be transported at altitudes of upto 6 km and move over distances of up to 6,000 km. Saltation particles (i.e. those between 0.01-0.5 mm in diameter) leave the surface, but are too large to be suspended. The remaining particles (i.e above 0.5 mm) are transported in the creep mode. These particles are too large to be ejected from the surface and are therefore rolled along by the wind and impacting particles. Due to the nature of this mode, the heights carried are rarely more than 30 cm and the distance travelled rarely exceeds a few metres. During a storm, creep can move particles over distances from a few centimetres to several metres, saltation particles travel from a few metres to a few hundred metres, and suspension transport ranges from several tens of metres to thousands of kilometres.

Estimation of wind erosion and control principles:

Principles for controlling wind erosion include- stabilizing with various materials; producing a rough, cloddy surface; reducing effective field width with barriers; and establishing and maintaining sufficient vegetative cover (Woodruff *et al.*, 1972). Those principles for controlling wind erosion are summarized by the general functional relationship given by Woodruff and Siddoway (1965) as a wind erosion equation in the form $E = f(1, K, C, L, V)$, where E is potential average annual soil loss per unit area, I is a soil erodibility index based on fraction of non-erodible soil aggregates (particles > 0.84 mm) in the erodible size range, K is a soil ridge roughness factor, C is a climatic factor, L is the unsheltered median travel distance of wind across a field and V is equivalent quantity of vegetative cover. The equation was developed as a result of many years of studying the factors influencing wind erosion. It has been used widely for its intended purposes to determine both the potential erosion from a particular field and the field conditions (soil cloddiness, roughness, vegetative cover, sheltering by barrier, or width and orientation of field) necessary to reduce potential erosion to a tolerable amount.

Status of wind erosion/ land degradation:

Globally, it has been estimated that out of 5169 million hectare (Mha) area of the drylands (constituting 40% of the global land surface), about 1035 Mha (or 20% of the total area; 17% slight to moderately affected; 3% strongly affected) is affected by land degradation/desertification. While 467 Mha area is estimated to be susceptible to water erosion, 432 Mha is assessed to be under wind erosion. The global estimates are based on a Global Assessment of Human-Induced Soil Degradation (GLASOD) (Oldman, 1988), and its modified version, Assessment of the Status of Human-induced Soil Degradation in South and Southeast Asia (ASSOD) (UNEP, 1977), both commissioned by the UNEP.

In India, drylands cover about 228 M ha area (69% of the total geographical area of the country). The Indian Council of Agricultural Research (ICAR) and the Department of Space (DoS) estimated the area under land degradation in India as follows.

Degradation category	Arid	Semi-arid	Dry sub-humid	Total
Water erosion	3.67	17.67	4.87	26.21
Ravines				
Flooding				
Wind erosion	16.16	1.60	0.01	17.77
Water logging	0.00	0.07	0.59	0.66
Salinity/alkalinity	3.03	0.71	0.23	3.97
Vegetation degradation	1.97	8.43	7.23	17.63
Total(Mha)	34.89	31.99	14.57	81.45

(Source: Majhi *et al.*, 2010)

Biophysical processes mainly contribute to land degradation in western Rajasthan, which contains the Indian segment of the Thar Desert and accounts for ~62% of the country's hot arid area. Studies at Central Arid Zone Research Institute (CAZRI) have revealed that the major physical manifestations of desertification in western Rajasthan is wind erosion/ deposition, followed by water erosion, as well as water logging and salinity. Degradation of natural vegetation is widespread, as most of the permanent pastures have been very severely exploited for fuel-wood and fodder. With time, industrial effluents and mining are also gradually becoming important factors of desertification.

Strong wind regime and dust storms:

In arid and semi-arid regions of India, winds are generally light and variable during winter, but they build up from April onwards and are strongest during pre-monsoon months of May and June. The wind directions are northeast to north in winter while during the rest of the year they are mostly south-westerlies or west-south westerlies. The maximum wind velocity that can be expected normally during peak summer months at about 2 to 4 meter height from the surface in the area of Jodhpur is about 25 to 40 *kmph* (Singh *et al*., 1992) but can occasionally reach as high as 60 to 80 *kmph* during a severe dust storm period. Strong wind regime during May and June cause much wind erosion as well as advection, increasing the evaporation losses from irrigated lands. Wind erosion primarily depends on soil texture and the prevailing wind velocity above the soil surface. Minimum threshold of wind velocity is 4 *kmph* to initiate wind erosion from loose soils of duny areas (Ramakrishna *et al*., 1990). Beyond 9 *kmph* sand movement increases rapidly, it is very high at wind speeds over 14 *kmph*. Quantum of wind erosion may have higher correlation with intensity and duration of turbulence winds rather than mean wind speed over a place. Also, the sandy and duny soils of Chandan and Bikaner were more erosive than the loamy sand soil of Jodhpur.

Long-term dust storm data (1967-98) have indicated significant decreasing trend in wind erosion/ dust storm activities in the Jodhpur region. The significant decrease in wind speed and apparent increase in annual rainfall resulted in decrease of wind erosion and dust storm activity over Jodhpur and surrounding region (Rao and Roy, 2012).

Control Measures for Wind Erosion and Crop Losses

A number of mechanical and chemical methods are available globally for the control of wind erosion, but looking to the fact that Indian region is highly populated and has a dominantly agricultural economy, many of the mechanical and chemical methods of control can not be implemented. So far, the large-scale wind erosion control measures in India have been sponsored by the Government. Farmers protect and manage their fields especially through crop residue management and fencing during critical periods. Two major activities of wind erosion control are sand dune stabilization and shelter belt plantation (Venkateswarlu and Kar, 1996).

National Programmes

As per the guidelines of UNCCD, India launched two specific programmes, the desert development programme (DDP) and the drought-prone area development programme (DPAP) and were undertaken from the 1980s. The DDP districts were chosen on the basis of their aridity index, and the irrigated area being less than 50% of the cultivated land for controlling land degradation and to conserve, develop and harness land, water and other natural resources through sand dune stabilization, afforestation, watershed development, soil and water conservation, etc., and to raise the level of production, income and employment through irrigation, afforestation and dryland farming. Areas under the non-arid drylands were covered under DPAP. An overview of the major land degradation/desertification control technologies in the country, with emphasis on the technologies developed by CAZRI are as follows;

(a) Sand dune stabilization:

In Thar Desert, vegetative methods for sand dune stabilization and shelterbelt plantation were found successful. Sand dune stabilization technology includes: (a) protection of the area from human and livestock encroachment; (b) creation of micro-wind breaks on the dune slopes, using locally available shrubs either in a checker board pattern or in parallel strips across the direction of wind; (c) direct seeding or transplantation of indigenous and exotic species; (d) plantation of grass slips or sowing of grass seeds on leeward side of micro-wind breaks; (e) management of re-vegetated sites. Approximately 300,000 ha area of sand dunes has been stabilized through CAZRI technologies, Shrubs and grasses are better sand binders than the trees.

Studies at CAZRI have revealed that the sand dunes in this desert can be categorized into the old and the new dunes (Pandey *et al*., 1964). The old dunes are usually more than 10m high. These were last formed about 10000 years back, and are naturally stabilized with potentials to support copious natural vegetation. These dunes have extremely low rates of movement, unless their ecology is disturbed by human action. The new dunes are mostly smaller than 10 m in height. These are forming now, are almost always bare of vegetation, and have a high rate of movement (Singh, 1982; Kar, 1993). Most sand dune stabilization programmes as listed above, (Muthana, 1982; Harsh and Tewari, 1993) are directed towards the old dunes, so that the production potentials of these lands can be restored. The tree, shrub and grass species, suitable for stabilization programme, are described in Table 1.

In the drier western part where large tracts of less accessible sand dunes occur, and where most of the dunes are not being held privately, with consequent very little grazing pressure, aerial broadcast of pelletized seeds of *Lasiurus sindicus* grass and suitable trees and shrubs have been tried successfully (Shankarnarayan and Kumar, 1986).

Table 1 : Plant species suitable for sand dune stabilization in arid region of India

Annual rainfall zone (mm)	Trees	Shrubs	Grasses
150-300	*Prosopis juliflora, Acacia tortilis, A. Senegal*	*Calligonum polygonoides, Ziziphus nummularia, Citrullus colosynthis*	*Lasiurus sindicus*
300-400	*A. tortilis, A. senegal, P. juliflora, P. cineraria, Tecomella undulata, Parkinsonia aculeata, Acacia nubica, Dichrostachys glomerata, Colophospermum mopane, Cordia rothii*	*Ziziphus mauritiana, Z. nummularia, C. polygonoides, Cenchrus ciliaris, C. setigerus,*	*Citrullus colosynthis L. sindicus, Saccharum munja*
400-550	*A.tortilis, P. cineraria, P. juliflora, A.senegal, Dalbargia sisoo, Ailanthus excelsa, Albizzia lebbek, P. aculeata, T. undulata, D. glomerata, C. mopane*	*Z. mauritiana, Cassia auriculata*	*C. ciliaris, C. setigerus, S. munja, Panicum antidotale*

(Source: Venkateswarlu, 1993)

(b) Shelterbelt plantation :

Erection of shelterbelts along the boundaries of crop fields helps to reduce wind velocity in the leeward of the shelter by ~76% at distance 2 to 10 times the height of the shelter belt. It also reduces injury to the tender seedlings due to sand blasting and hot desiccating wind. CAZRI has recommended a three row wind break of *Acacia tortilis*, *Cassia siamea* and *Prosopis juliflora* as the side rows and *Albizzia lebbek* as the central row. Studies have also shown that plantation across the wind of a 13 m wide tree belt, interspersed with 60 m wide grass belt, provided the best results. Shelterbelts also reduce the loss of moisture from fields in the leeward of shelters. About 14 per cent higher soil moisture and 70 per cent more grain yield of pearl millet were recorded in the lee of shelters, as compared to that in the areas without shelters (Gupta *et al*., 1997). Establishment of micro-shelterbelts in arable lands, by planting tall and fast growing plant species like castor bean on the windward side, and shorter plants like vegetable crops in the leeward side of tall plants helped to increase the yield of lady's finger by 41 per cent, and of cowpea by 21 per cent, over the control (Venkateswarlu, 1993; Venkateswarlu and Kar, 1996).

(c) soil and water conservation:

To counter crust formation of soil and its subsequent erosion from the agricultural fields a number of practices have been suggested. These include contour bunding (low rainfall area) or graded bunding (medium to high rainfall area), contour tillage, contour sowing, etc. (Singh, 1990; Dhruva Narayana, 1993). In the black soil areas, ridge and furrow system may help to reduce the problem of water logging, while in the hard pan soils deep ploughing at 3-4 years' interval will ensure better infiltration and root growth. Mixing crop residues and organic matter with light textured soils help to increase the soil moisture and crop yield. On the non-arable lands a grass cover ensures minimum soil loss, but not the cultivated fallow. Small and medium gullies can be reclaimed through clearing and leveling of gully bed, followed by construction of contour bunds and check dams, and providing of pipe outlets and ramps with suitable grasses. Deep and closely spaced gullies are not always easily accessible. Gully plugging, planting of grass species like *Dichanthium annulatum* on gully heads and sides, and plantation of tree species like *Prosopis chilensis*, *Acacia nilotica*, *Dendrocalamus strictus*, *P. juliflora*, etc. help to control erosion (Dhruva Narayana, 1993).

(d) Management of croplands:

A number of management practices are available for management of croplands in the drylands. Many of these practices counter land degradation and wind erosion. Few such practices are highlighted here.

(i) Minimum tillage:

Tillage of land at regular interval usually ensures healthy crop growth. In the sandy soils of arid region, farmers normally practice deep tillage after every 3-4 years. It reduces the clod percentage in the surface soils, but encourages wind erosion. Tillage can also cause hard pan development below the depth of tillage, and crusting due to loss of soil structure (Papendic and Parr, 1997). Reduced tillage is, therefore, recommended for such areas and summer tillage is discouraged, a limited tillage after the first monsoon showers has been found to be ideal in our desert (Gupta, 1993; Gupta *et al*., 1997). In experimental plots production of mung bean, clusterbean and cowpea increased with the limited tillage of one disking and sowing in a loamy sand soil under an average rainfall regime of 300 mm (Gupta, 1993).

(ii) Strip cropping:

Strip cropping (or lay farming), consisting mostly of a strip of crops, followed by another of grass or shrub with fodder value, has been found to be useful for wind and water erosion control. Plants for the strips are chosen so that they do not compete with each other for moisture, nutrients, etc. The width of strips depends on the types of soil and crop. In the sandy loam of arid areas the strips may vary from 6 to 30 m. At CAZRI Farm, Jodhpur, strips of *Lasiurus sindicus* grass and *Ricinus communis* (castor) between two rows of *kharif* crops helped to reduce wind erosion and increased the crop production, while at Bikaner 18-20 years old perennial grass strips of *Lasiurus sindicus*, *Cenchrus biflorus* and *Panicum turgidum* not only reduced wind erosion, but also helped to form surface crusting which bound the soil particles (Gupta *et al*., 1997). In the semi-arid areas, the system helps to arrest water erosion and stabilize the production system. A width of 7.8 m was found to be optimum. Sorghum and pearlmillet crops were found to be compatible with *Leucaena latisiliqua* as fodder crop rows (Singh, 1990).

HEAT AND COLD WAVES AND THEIR EFFECT ON AGRICULTURE AND ALLIED SECTORS

Y.S. Ramakrishna

Agricultural production systems are exposed to the vagaries of the climate and they often have to perform within the boundaries laid out by the climatic conditions prevailing in that region. Often the land use and crop production systems are drawn based on long term climatic conditions of the given region and hence perform at optimum level under average climatic conditions. However, the weather being variable from season to season these crop production systems often experience severe weather extremes that stress the plant system functioning. However, plants have some resilience mechanism and adjust to meet such stress conditions successfully, if they are of short duration in nature. In case such stress conditions prevail for longer periods or if the stress levels are severe, it can have an adverse effect on the plant performance and its ultimate productivity. Extreme weather conditions like High or low temperatures, or water logging or water stress (long period drought) conditions beyond the threshold values of a given crop can lead to a sharp drop in its productivity and at times to the mortality of such plants. This threshold limit is a plant characteristic and some plants (Xerophytic species) may have a higher tolerance and survive, while other plants may wilt and wither away at high atmospheric temperature levels, if exposed for long.

Over the past few decades, climate change has emerged as an issue of global concern. With increased levels of carbon dioxide and other green house gases, a perceptible increase in day and night temperatures and increased climatic variability on a sustained basis is playing havoc with the agricultural production systems and livelihoods of people across the globe. The climate change impacts are also being felt in the Indian sub-continent.

Since 1950 there has been a substantial increase in the number of heat waves worldwide and also, the heat waves have become longer in duration (Trenberth, *et al.*, 2007, 2012). The hottest days and nights have started to become hotter and more frequent (Gutowski, *et al.*, 2008). In the past several years, the global area hit by extremely unusual hot summer temperatures has increased fifty -folds (Hansen, *et al.*, 2012).

Assessing the predicted climate change scenarios and their impact on the Indian agriculture, Lal (2001) predicted the area averaged surface warming over the Indian sub continent to increase by 3.5 °C to 5.5 °C by 2080, with increased warming in the winter season, compared to summer season. The rise in surface temperatures is predicted to be more in north Indian region (3 °C by 2050).

Heat Waves and Cold Waves

Continuous periods experiencing above or below normal temperature conditions are called as heat wave and cold wave conditions, respectively. Certain limits or large departures from mean values of daily maximum and minimum temperatures have been used as the criteria for defining these periods.

Heat wave:

In India, Heat wave is defined as the period/ conditions over a prolonged period when the " departure of maximum temperature from normal is +4 ^{0}C to +5 ^{0}C or more for the regions where the normal maximum temperature is more than 40 ^{0}C and departure of maximum temperature from normal is +5 ^{0}C to +6 ^{0}C for regions where the normal maximum temperature is 40 ^{0}C or less" (Heat Wave is declared only when the maximum temperature of a station reaches at least 40 ^{0}C for plains and at least 30 ^{0}C for Hilly regions). When actual maximum temperature remains 45 ^{0}C or more irrespective of normal maximum temperature, heat wave is declared.

When the "departure of maximum temperature from normal is +6 ^{0}C or more for the regions were the normal maximum temperature is more than 40 ^{0}C and +7 ^{0}C or more for regions were the normal maximum temperature is 40 ^{0}C or less", it is defined as a severe heat wave condition.

Cold wave:

Wind chill factor is taken into account while declaring the cold wave situation. The wind chill effective minimum temperature (WCTn) is defined as the effective minimum temperature due to wind flow, e.g., when the minimum temperature is 15 ^{0}C and the wind speed is 10 mph, WCTn will be 10.5 ^{0}C. Departure of WCTn from normal minimum temperature is from –5 ^{0}C to –6 ^{0}C where normal minimum temperature >10 ^{0}C and from -4 ^{0}C to –5 ^{0}C elsewhere, Cold Wave is declared. For declaring cold wave etc. WCTn only is used and when it is <10 ^{0}C only, cold wave is considered (this criteria does not hold for coastal stations). Also cold wave is declared when WCTn is <0 ^{0}C irrespective of the normal minimum temperature for those stations

When departure of WCTn from normal minimum temperature is –7 ^{0}C or less for the regions where normal minimum temperature is > 10 ^{0}C and –6 ^{0}C or less elsewhere". (Departure of WCTn from normal minimum temperature is from –5 ^{0}C to –6 ^{0}C where normal minimum temperature > 10 ^{0}C and from –4 ^{0}C to –5 ^{0}C elsewhere), it is declared as a severe cold wave.

In recent years, severe heat waves have caused high mortality and morbidity in many parts of the world (Chicago1995, 1999; most part of Europe 2003). The impact of these changes can be devastating. The recent drought, heat wave conditions and associated record wildfires that hit Texas and the Southern plains of USA, in the summer of 2011 cost $12 billion. Often Extreme heat events in USA are responsible for more deaths annually, than hurricanes, lightning, tornadoes, floods, and Earthquakes combined (Lugber and McGeehin, 2008). Even in India such adverse impacts of heat waves were observed on human, livestock and poultry besides crops and horticulture (AP and Orissa in 1998, 2003 and 2004)

Temperature Variations Over India

Analysis of long term data on annual mean maximum, minimum and average temperature conditions over Indian sub-continent (Rao et al., 2009), indicated that the maximum temperatures are showing an increasing trend at more than 75% of the stations in south zone followed by central (67%), east (60%) and west zone (57%) regions. A larger change is observed in minimum temperatures. The Minimum temperatures showed increasing trend at large number (88%) of stations in central and east zones followed by north zone (80%), south zone (75%), and west zone (57%).

Case Studies:

The state of Orissa witnessed unprecedented heat waves in 1998, particularly in the coastal area. Causalities in 1998 were more compared to single digit casualties (range: 1 to 5) due to heat stroke, in previous years (Table.1). The death toll in 1998 rose to 2042 alarming the state administration (Saudamini Das, 2011). Many researchers have made attempts to examine the link between mortality and temperature anomaly by studying either the daily fluctuations in mortality or the aggregate annual death counts and have found a positive association between excess mortality and temperature, especially when temperature exceeds specified threshold level of tolerance(O'Neill et al. 2003; Ramon-Medina and Schwartz 2007; Ramon-Medina et.al 2006; Deschenes and Moretti 2007). Using cross over approach and pooled data, Michelle L Bell *et al.,* (2008) examined 754 291 heat related deaths witnessed in Mexico city, Sao Paulo and Santiago in between 1998 to 2002 and found same and previous day temperature, and high age to be significantly related to deaths. These categories of studies clearly indicate the existence of socio-economic gradients for heat related deaths along with factors like age, health history and the weather.

For many heat waves, there are also important feedbacks that come into play that amplify drought and heat and set the stage for adverse impacts. The Local weather conditions directly contribute to the drying and high temperatures in the absence of evaporative cooling. While heat waves with high humidity (especially in the monsoon season) are oppressive and give no relief at night, heat waves often form in association with drought. In these cases, the prevailing dry conditions set the stage for the heat since the land is dried out and the vegetation is wilted, all the heat from the sun be utilized for raising soil and air temperatures, whereas, in the process of evaporative cooling, surface water or wetness acts as an evaporative cooler.

Table 1: The number of heat wave days and the number of human casualties in the state of Orissa

Year	Heat wave days	Deaths in the state	Deaths in DRM districts	Deaths in non-DRM districts
1983	1	3	NA	NA
1987	2	1	NA	NA
1988	1	22	NA	NA
1989	1	1	NA	NA
1995	1	9	NA	NA
1996	2	3	NA	NA
1998	28	2042	1124	918
1999	25	91	57	34
2000	18	29	8	21
2001	12	25	21	4
2002	21	41	29	12
2003	28	67	48	20
2004	8	41	35	10
2005	29	234	161	75
2006	4	21	17	4
2007	8	47	28	19
2008	12	69	41	27
2009	29	85	63	22
2010	38	61	25	35

Source: Indian Meteorological Department, Bhubaneswar and Orissa State Disaster Mitigation Authority, 2010

Heat Waves in South and North India

The southern east coast region experienced unusual heat wave conditions during May 2003. These heat wave conditions were associated with the formation of a low pressure system in the Bay of Bengal region which induced flow of hot air from the normal summer heat low region over North west India and Baluchistan. As a result very high temperature regime (above normal temperatures of 5 to 7 ^{0}C prevailed in Bihar, West Bengal and Coastal Orissa and Andhra regions, for a considerable time till the low pressure system weakened and the heat flow from the summer heat low in NW India reduced (Fig.1).

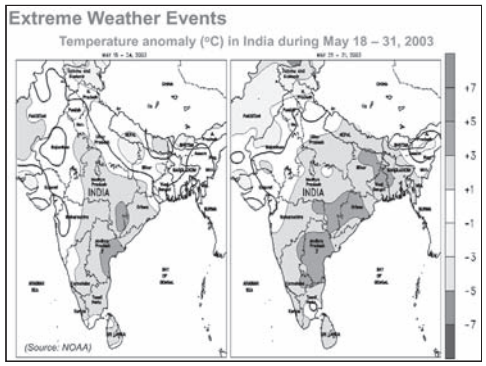


Fig. 1 : Heat wave conditions over eastern India during May, 2003

Similarly, a major part of north western region of India witnessed intense heat wave conditions during March, 2004. These heat wave conditions produced an adverse impact on the productivity of major crops in the NW region. Analyzing the cause and impacts of this heat wave conditions Samra and Singh, (2004) on the winter crops including wheat, mustard and vegetables, observed highest rise in the daily maximum temperature at Srinagar (Fig.2) to be (8-12 ^{0}C) followed by Palampur (8-10 ^{0}C); Hisar (2-10 ^{0}C); Ludhiana (3-6 ^{0}C); Jammu (1-6 ^{0}C), Uttaranchal (1-5 ^{0}C) and Jaipur (1-5 ^{0}C). This impact was seen even on the minimum temperatures during this period, which remained substantially higher than normal across the region. The impact of this abnormal temperature conditions on the winter crops was significant. The wheat crop, experienced terminal heat stress, which led to a significant drop in its productivity in the Northern region by 4.6 million ton. Also the high thermal regime led to early

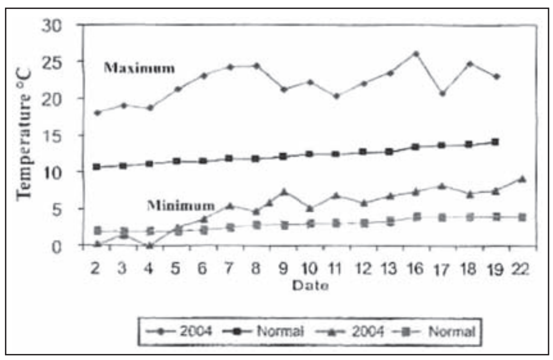


Fig. 2 : Maximum and minimum temperature variations at Srinagar during March,2004

(Source: Samra and Singh, 2004)

maturity (by 10 to 20 days) leading to smaller grain and lower 1000 grain weight. Simulation studies by Aggarwal and Singh (2004) using Infocrop model could show that the thermal conditions were mainly responsible for this large reduction in wheat production from North India during 2004.

Some of the earlier studies on impact of above normal temperatures and thermal conditions on crop phenology and productivity have clearly brought out that: Higher temperatures and reduced radiation associated with increased cloudiness caused spikelet sterility and reduced yield in wheat. As a result of these above normal temperatures, any increase in dry-matter production as a result of CO_2 fertilization proved to be of no advantage to grain productivity. Further, some of the conclusions from similar studies indicated that: In north India, a 1 ^{0}C rise in the mean temperature may have no significant effect on potential yields, but an increase of 2 ^{0}C reduced potential grain yields of rabi crops at most places (Aggarwal and Sinha, 1993).

- Wheat yield reductions in *rabi* season were mainly influenced by the shortening of the wheat-growing season (faster accumulation of growing degree days), resulting from increasing temperature scenario. (Hundal and Kaur, 2007)
- In Rajasthan, a 2 ^{0}C rise in temperature was found to reduce production of pearl millet by 10-15 per cent (Ramakrishna *et al*., 2004, 2007).
- According to Climate Change some scenario studies, soybean yields in MP could increase considerably under elevated CO_2 conditions. However, if this increase in carbon dioxide is accompanied by an increase in temperature, by more than 2 ^{0}C, it can reverse the gain and in fact may start reducing yields. For an increase in the maximum and minimum temperatures by 1.5 ^{0}C, the gain in yield can come down to 35 per cent.
- Simulating the impacts of high temperatures on irrigated wheat in north India, Aggarwal and Mall, (2002), indicated that grain yields of wheat can decrease by 17% if the temperatures increased by 2 ^{0}C. Beyond this limit, the decrease will be very high. These decreases can be compensated to a certain extent by increasing levels of CO_2 due to its positive influence on crop growth. For example, CO_2 concentrate at 450 ppm can nullify the negative effect of 1 ^{0}C increase in temperature. Similarly to nullify the 2 ^{0}C increase the CO_2 concentration should be at 550 ppm.

Cold Wave Conditions Over North India

Similar to increased thermal regime conditions affecting crop productivity and human and livestock comfort, the occurrence of below normal temperature conditions associated with cold wave conditions also adversely impact crop growth and productivity. Most of these cold wave conditions in North India are often associated with the passing western Disturbances over this region which brings cool air in its wake.

These Western Disturbances though help the winter crops by providing some rainfall, could occasionally cause severe cold and frost conditions affecting plant growth and survival and at times leading to sudden plant mortality. Except the southern Peninsula, most parts of the country, particularly the Indo-Gangetic Plains will be widely affected by freezing and cold days, causing severe impact on crops, fruit trees, fishery, livestock and even human beings (Gurbachan Singh, 2009).

Analysing the Cold Wave conditions over North India during December 2002 to January, 2003, Samra *et al*., (2002 and 2003) observed that the daily maximum and minimum temperatures at several places in north India remained un-usually below the normal conditions, continuously for 3-4 weeks (Fig. 3). As a result of these adverse conditions, over 600 ha of

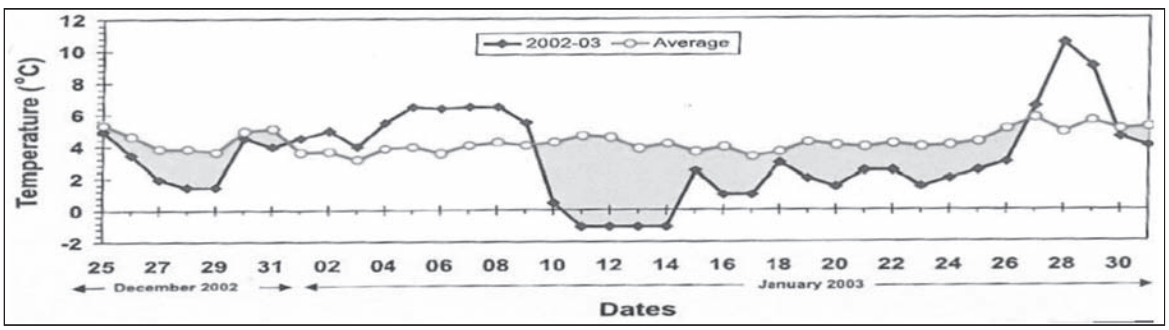


Fig. 3 : Daily minimum temperature of 2002-03 and average at Dehradun (Source: Gurbachan, 2009)

orchards of mango and litchi were severely damaged in the Shiwalik belt of Punjab (Table 2). The extent of damage varied from 40 to100 per cent in mango, and to 50-80 per cent in litchi. Crops like guava, ber and kinnow suffered with reduced fruit size and poor quality. Similarly, during 2002-2003 cold wave associated mortality rate in papaya ranged from 40-83 per cent in the lower shiwalik regions. Early sown winter maize in more than 36,000 ha was adversely affected by cold waves with about 70-80 per cent loss in seed setting in Bihar. Similar damage was also reported during 2005-2006 and 2007-2008 due to cold waves in northern states of India. Excellent crops of tomato, potato, peas, marigold were severely affected. There was 100% loss of tomato crop, 72-80% in potato, 30-50% in winter maize and peas, 50% in brinjal, 100% loss to marigold due to the severe cold wave conditions.

Table 2 : Effect of cold wave on fruit orchards in selected villages of Hoshiarpur region, Punjab (Source: Samra *et al.*, 2003)

Name of the farmer and village	Fruit species and age (years)	Area in acres	Yield damage (%)	Damage to plants (%)
Sh. U.S. Chatha Village Mehlawali	Litchi (12)	8	100	30-60
Sh J.S. Lali Bajwa Village Mehlawali	Litchi (15)	2	100	30-60
Sh. K.S. Gill Village Kharkan	Mango (15) Litchi (12)	10 5	100 100	60-80 60-80
Sh. Ranjit Singh Village Kantia	Mango (10) Aonla (15)	45 10	100 100	80-100 80-100
Mr. Ramji Das Village Dholwaha	Mango (8-10)	30	100	40-60
Sh. J.S. Dhaliwal Village Dholwaha	Mango (8-10)	60	100	40-60
Mr. Deepak Puri Village Chohal	Mango (30)	5	100	100
Sh. Jaspal Singh Village Mehmowal	Mango (10)	6	100	60-80
Village Salimpur	Mango (2-3)	5	100	100

Conclusions

Extreme weather events induce stress on plant growth and performance. When these extremes exceed the tolerance limits the impacts can be severe on plant performance and even its survival capacity, often leading to plant damage and mortality. Heat waves and cold waves are such climatic aberrations of a short period that can cause severe stress on plant survival and performance. Significant losses have been experienced year after year due to increased occurrence of weather extremes which could be a significant part of the Climate Change impacts. Both the extremes of maximum and minimum temperatures cause stress to plant productivity. Some options that can be tried to reduce the severity of the impact of heat and cold waves are:

- Developing improved weather forewarning mechanisms for undertaking timely preventive measures to reduce production risks. There is a strong case now to go for developing and upgrading medium and extended forecasting systems (15-20 days in advance) so that farmers have reasonable time to respond to risks.
- Manipulation of crop micro climate by means of Cropping systems, Crop geometry and use of wind breaks, shelter belts to reduce the effects of severe weather conditions.
- Develop knowledge based decision support systems for translating weather information into operational management practices at district, block and village Panchayat level.
- There is a need to develop crop insurance and early warning systems to reduce/negate the impact of climate change and provide monetary support for achieving stability in production.

FOG - ITS TYPES, AND IMPACTS ON AGRICULTURE AND ALLIED SECTORS

Diwan Singh

Fog is essentially a dense cloud of water droplets, or cloud, that is close to the ground. When night conditions are cool, clear, and calm, the ground looses the heat it absorbed during the day. As the temperature of the ground decreases, it cools the air above it to the dew point (the point at which water vapor condenses into droplets of liquid water), forming a cloud of water droplets known as **radiation fog**. Fog also forms when warm, moist air travels over a cold surface. While fog is a type of stratus cloud, the term ‘fog’ is typically distinguished from the more generic term ‘cloud’ in that fog is low-lying, and the moisture in the fog is often generated locally (such as from a nearby body of water, like a lake or the ocean, or from nearby moist ground or fields).

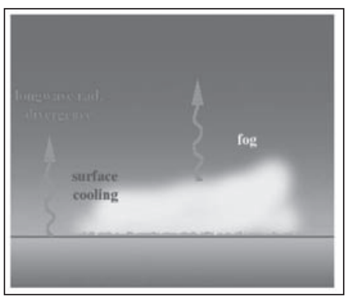
Mist and fog usually form at night when the air is too cold to hold all its moisture. Under clear sky conditions the ground gets cooled and it then cools the air close to it. This cool air causes condensation and water droplets form in the air. Fog is distinguished from mist only by its density, as expressed in the resulting decrease in visibility. Fog reduces visibility to less than 1 km, whereas mist reduces visibility to no less than 1 km. Fogs are thickest when the air can hold a lot of moisture. Although mist is not as thick as fog, they are both formed in the same way. Mist, however, usually stays closer to the ground and you can see over the top of it. Water droplets are only about 0.01 millimeter in diameter. A dense fog contains about 1200 visible drops per cubic centimeter of empty space - barely enough water to wet an object’s surface.

In India, during recent years, occurrences of large-scale intense fog conditions over Indo-Gangetic Plains in winter have been causing very low visibility over most parts of the region. Study shows that its development, intensification and persistence are so unique that it may be rare in any other part of the world. During some seasons, it extends from Pakistan to Bangladesh across plains of North India roughly covering 1500 thousand sq km. It affects various sectors of the region severely, as noted below and hence been classified as very high impact weather event.

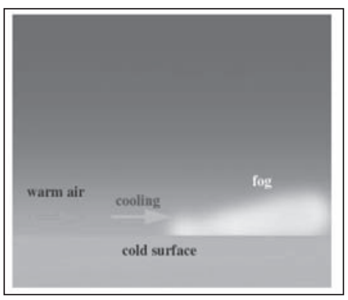
Fog Characteristics: Fog forms when the difference between air temperature and dew point is generally less than 2.5 ^{0}C. The main ways water vapor is added to the air - wind convergence into areas of upward motion, precipitation or *virga* falling from above, daytime heating evaporating water from the surface of oceans, water bodies or wet land, transpiration from plants, cool or dry air moving over warmer water, and lifting air over mountains. Water vapor normally begins to condense on condensation nuclei such as dust, ice, and salt in order to form clouds. Fog, like cloud, is a stable cloud deck which tends to form when a cool, stable air mass is trapped underneath a warm air mass. Fog normally occurs at a relative humidity near 100%. This can be achieved by either adding moisture to the air or dropping the ambient air temperature.

Types of Fog: Fog can form in a number of ways, depending on how the cooling that caused the condensation occurred.

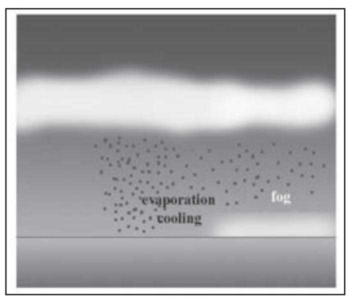
1. **Radiation Fog** is formed at night under clear skies with calm winds when heat absorbed by the earth’s surface during the day is radiated into space. As the earth’s surface continues to cool, provided a deep enough layer of moist air is present near the ground, the humidity will reach 100% and fog will form. Radiation fog varies in depth from 3 to 1,000 feet and is always found at ground level and usually remains stationary. This type of fog can reduce



Radiation Fog



Advection Fog



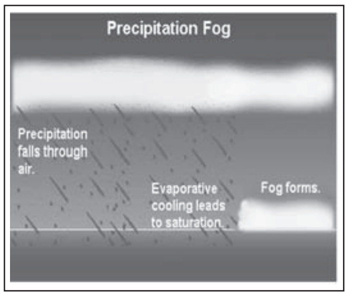
Evaporation Fog

visibility to near zero at times. Radiation fogs occur at night, and usually do not last long after sunrise, though can persist all day in the winter months especially in areas bounded by high ground.

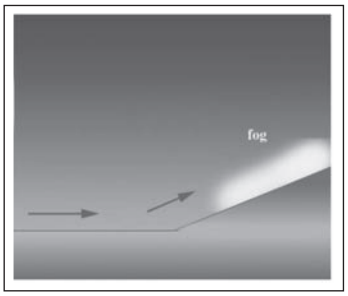
2. **Advection Fog** occurs when moist air passes over a cool surface by advection (wind) and is cooled. Advection fog often looks like radiation fog and is also the result of condensation. However, the condensation in this case is caused not by a reduction in surface temperature, but rather by the horizontal movement of warm moist air over a cold surface. This means that advection fog can sometimes be distinguished from radiation fog by its horizontal motion along the ground. Sea fogs are always advection fogs, because the oceans don't radiate heat in the same way as land and so never cool sufficiently to produce radiation fog.

3. **Evaporation fog, sea smoke, steam fog or mixing fog** is the most localized form and is created by cold air passing over warmer water or moist land. It often causes freezing fog, or sometimes hoar frost. Instead of condensing into water droplets, the evaporating water sublimates into ice crystals.

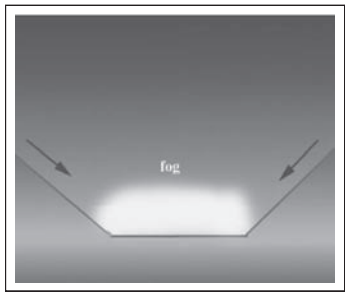
4. **Precipitation fog or frontal fog** forms as precipitation falls into drier air below the cloud, the liquid droplets evaporate into water vapor. The water vapor cools and at the dewpoint it condenses and fog forms.



Precipitation fog



Upslope fog



Valley fog

5. **Upslope fog** or **hill fog** forms when winds blow air up a slope (orographic lift), adiabatically cooling it as it rises, and causing the moisture in it to condense. This often causes freezing fog on mountain tops, where the cloud ceiling would not otherwise be low enough.

6. **Valley fog** forms in mountain valleys, often during winter. It is the result of a temperature inversion caused by heavier cold air settling into a valley, with warmer air passing over the mountains above. It is essentially radiation fog confined by local topography, and can last for several days in calm conditions.

7. **Freezing fog** occurs when liquid fog droplets freeze to surfaces, forming white soft or hard rime. This is very common on mountain tops which are exposed to low clouds. It is equivalent to freezing rain, and essentially the same as the ice that forms inside a freezer which is not of the 'frostless' or 'frost-free' type. The term 'freezing fog' may also refer to fog where water vapor is super-cooled, filling the air with small ice crystals similar to very light snow.

8. **Frozen fog or ice fog** is any kind of fog where the droplets have frozen into extremely tiny crystals of ice in mid air. Generally, this requires temperatures at or below -35°C, making it common only in and near the Arctic and Antarctic regions.

Freezing fog

Frozen fog

Hail fog

9. **Hail fog** sometimes occurs in the vicinity of significant hail accumulations due to decreased temperature and increased moisture leading to saturation in a very shallow layer near the surface. It most often occurs when there is a warm, humid layer atop the hail and when wind is light. This ground fog tends to be localized but can be extremely dense

and abrupt. It may form shortly after the hail falls; when the hail has had time to cool the air and as it absorbs heat when melting and evaporating.

10. **Smog** is described as the conditions of fog that had soot or smoke in it. Smog is a combination of various gases with water vapor and dust. A large part of the gases that form smog is produced when fuels are burnt. Smog forms when heat and sunlight react with these gases and fine particles in the air. Its occurrences are often linked to heavy traffic, high temperatures, and calm winds.

Smog

Artificial fog

Types of fog according to Bruijnzeel et al., (2005). Terms in upright font are process-based types, those in italics are geographic types. Additionally, the terms "ice fog" and "urban fog" are used for very local types of fogs.

Impact of Fog on Agriculture and Allied Sectors

The effect of fog on human life was recognized in the early ages of mankind but its impact has significantly increased during recent decades due to increasing air, marine, and road traffic. Several facets of fog illustrate how its significance extends beyond a simple reduction in visibility. In fact, the financial and human losses related to fog and low visibility became comparable to the losses from other weather events, e.g., tornadoes or, in some situations, even hurricanes.

Our ability to accurately forecast/nowcast fog remains limited due to our incomplete understanding of the fog processes over various time and space scales. Fog processes involve droplet microphysics, aerosol chemistry, radiation, turbulence, large/small-scale dynamics, and surface conditions (e.g., pertaining to the presence of ice, snow, liquid, plants, and various types of soil).

Fog plays a major role not only in the hydrological cycle but also for many human activities, such as agriculture and land, sea and air transport. Like most hydrometeorological phenomena, fog occurrence strongly varies with geographical location at both the local and the regional scale. In addition, fog observation and recording methods are still very dependent on direct human presence and perception, since its detection by automated instrumentation is not a widespread practice in standard weather stations. These characteristics make it difficult to develop detailed fog climatologies that cover the whole world.

Fog climatology based on satellite remote sensing using time series data is important because long term knowledge of regional changes in fog frequency and fog properties are of importance for Global Circulation Model simulations dealing with global climate change. Fog plays an important role in the earth's ecosystem, being a medium for the exchange of water and pollutants between the atmosphere and the biosphere.

The feasibility of a fog water collection system depends on the availability of a site where relatively large amounts of water can be collected and fog may be measured on top of canopy to estimate its impact on the crop beneath. In the absence of significant rainfall, many regions still have surprising amounts of water available from fog. Fog collection has been shown as viable source of good quality water in many arid parts of the world *e.g.* Scemenauer and Cereceda (1994), Cereceda *et al.,* (2000) and Cereceda and Scemenauer (2001). The water droplets in high-elevation fog can be collected in enormous numbers by appropriate meshes and used to provide water to agriculture use. Suitable fog conditions are found both in extremely arid parts of the world and in seasonally arid regions. Fog which often occurs in the winter time during stable weather situations plays an important role in tropics. Knowing the climatological distribution of fog and low stratus would allow for regional risk assessments and to estimate the radiative effect of these clouds.

Because fog occurs near the ground, it affects people's life in many ways. Both positive and negative interrelations with the biotic and abiotic environment are obvious. If fog is accompanied by a temperature inversion, its clearance by solar heating can be delayed or even inhibited and smog (SMoke in combination with fOG) formation might be fostered (refer e.g. to

Bendix 1998) in areas of high anthropogenic emissions and less-established emission control policies. In these areas, smog is well-known as a trigger of pulmonary diseases (Sunyer 2001) and reduced daylight length can lead to depression (Benedetti *et al.* 2001). Direct contact with acid fog water might also harm the vegetation surface (e.g. Cape 1993).

Main negative and positive consequences of fog occurrence

Bane	Boon

1) Reduction of surface visibility -
• Obstacle for traffic
  • Accidents (land, sea)
  • Financial losses (all)
	1) Water harvesting –
	• Financial benefit

2) Reduced solar irradiance -
• Delayed clearance of temperature inversions
• Might support smog formation
  • Pulmonary diseases
  • Mood
	2) Reduced solar irradiance –
	• Reduction of heat and water stress for vegetation

3) Dissolution of air pollutants –
• Occult deposition
• Might harm vegetation
	3) Reduced IR-radiation losses –
	• Lower risk of nocturnal ground frost
	  • benefit for winter crops
	4) Occult deposition
	• Water source of vegetation
	  • in cloud forests
	  • in fog deserts (e.g. Loma)
	  • for epiphytes
	• Water source for desert animals
	  • for fog harvesting beetles

Study also indicates that fog may play a significant role in the physical interactions within plant canopies and their physiological and growth conditions. These are also related to fog water pH and the production of acid fogs. These and other issues are being explored through various studies around the world.

Frequency and duration of foggy events have increased in winter season in India compared to the long term normals. Such type of continued and varied climatic situations in the region, affect the agricultural productivity adversely and symbolized the shift in local climates due to global climatic change. Continued foggy conditions for days especially more than a week causes considerable damage to various agricultural crops. The growth and development of crops is adversely affected due to the reduction in PAR available for photosynthesis, cold stress and congenial conditions for diseases and insect-pest development. Fog has also yielded some beneficial effects in terms of aesthetic and agricultural application in moisture deficit regions. Non-irrigated winter crops positively benefit from the amount of moisture supplied by fog. It affects plant growth through the higher air humidity, through wetting of aerial parts of plants and through humidification of surface of the soil.

Thus, the meteorological variables need to be monitored carefully for better predicting of ensuing foggy conditions and to negotiate these conditions up to some extent particularly for crop production operations for sustainable agricultural development. Strategies are needed to predict the sustenance of foggy conditions over the region using remotes sensing technology viz., satellite monitoring which may provide a better approach in getting useful information essential for fog forecasting and fog collection for water trapping/collection in continued foggy weather for sustainable crop production in otherwise moisture deficit regions.

There also exist programs and methods for the dispersion, or enhancement, of fog – particularly at airport locations – and the reduction of acid fogs. The basic methods tend to focus on heating of the fog layer (to evaporate droplets), downwash mixing (to entrain drier air), hygroscopic treatment (e.g., ice seeding) to precipitate out, and the use of fog breaks (passive control) to prevent formation or movement into an area. The most effective methods tend to be those that match the natural dissipative factors (i.e., mixing and evaporation) and that promote improved visibility within an hour.

FROST - CAUSES, IMPACTS AND PROTECTION MEASURES

Diwan Singh

Frost is a meteorological phenomenon that occurs when the air temperature near the earth's surface drops to 0 ^{0}C or below. It is the solid deposition of water vapor from saturated air and formed when solid surfaces are cooled to below the dew point of the adjacent air as well as below the freezing point of water. Technically, the word **'frost'** refers to the formation of ice crystals on surfaces, either by freezing of dew or a phase change from vapor to ice (Blanc *et al.*, 1963). The most appropriate definition of frost is a **'frost'** is the occurrence of an air temperature of 0 ^{0}C or lower, measured at a height of between 1.25 and 2.0 m above soil level, inside an appropriate weather shelter. Water within plants may or may not freeze during a frost event, depending on several avoidance factors (e.g. supercooling and concentration of ice nucleating bacteria). A 'freeze' occurs when extracellular water within the plant freezes (*i.e.* changes from liquid to ice). Freeze injury occurs when the plant tissue temperature falls below a critical value where there is an irreversible physiological condition that is conducive to death or malfunction of the plant cells. This damaging plant tissue temperature is correlated with air temperatures called **'critical temperatures'** measured in standard instrument shelters.

Causes of frost: The sub-zero air temperatures are caused by reductions in sensible heat content of the air near the surface, mainly resulting from (1) a net energy loss through radiation from the surface to the sky (*i.e.* radiation frost); (2) wind blowing in subzero air to replace warmer air (*i.e.* advection frost); or (3) some combination of the two processes. Frost forms in much the same way as dew forms. Frost usually forms when a surface cools through loss of longwave radiation to a temperature which is colder than the dewpoint of the air next to the surface, and the temperature of that surface is below freezing (0 ^{0}C). The source of this moisture is water vapour contained in the air.

The heaviest coatings of frost usually do not occur at the coldest temperatures because very cold air can't hold very much water vapour. Instead, thick deposits of frost usually occur when the air temperature is close to 0 ^{0}C.

In general, for frost to form the deposition surface must be colder than the surrounding air. For instance frost may be observed around cracks in cold wooden sidewalks when moist air escapes from the ground below. Other objects on which frost tends to form are those with low specific heat or high thermal emissivity, such as blackened metals. It is also affected by differences in absorptivity and specific heat of the ground which in the absence of wind greatly influences the temperature attained by the superincumbent air.

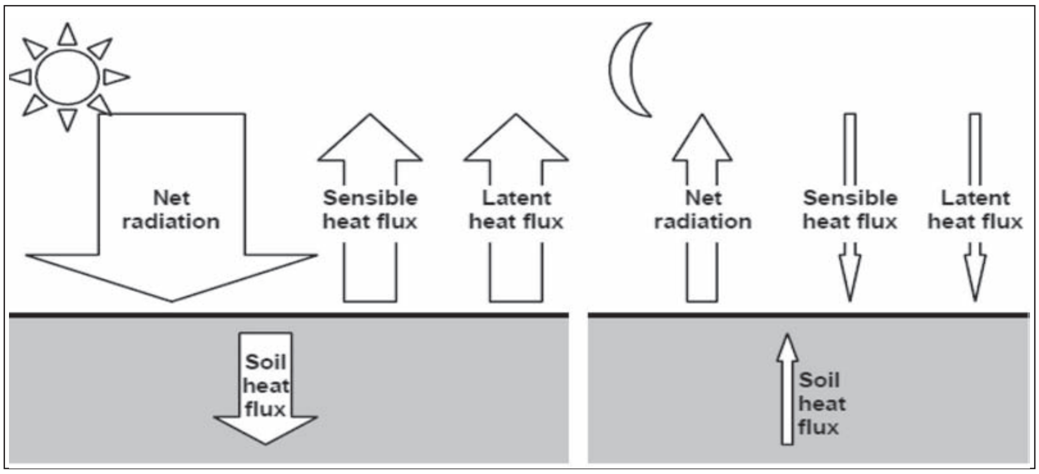


Fig. 1 : Energy balance of a clear-cut surface during sunny days (left) and clear and calm nights (right) (Oke, 1990)

Types of Frost

1. **Radiation frost** is very common in occurrence. It is characterized by a clear sky, calm or very little wind, temperature inversion, low dew-point temperatures and air temperatures that typically fall below 0 ^{0}C during the night but are above 0 ^{0}C during the day. The dew-point temperature is the temperature reached when the air is cooled until it reaches 100 per cent relative humidity, and it is a measure of the water vapour content of the air.

   Radiation frost also called 'hoar frost' or '***pruina'*** refers to the white ice crystals, loosely deposited on the ground or exposed objects that form on cold clear nights when heat losses into the open skies cause objects to become colder than the surrounding air. A related effect is flood frost which occurs when air cooled by ground-level radiation losses travels downhill to form pockets of very cold air in depressions, valleys, and hollows. Hoar frost can form in these areas even when the air temperature a few feet above ground is well above freezing.

2. **Advection frost** occurs when cold air blows into an area to replace warmer air that was present before the weather change. It is associated with cloudy conditions, moderate to strong winds, no temperature inversion and low humidity. Often temperatures will drop below the melting point and will stay there all day. The advection frost is also called wind frost, refers to tiny ice spikes forming when there is a very cold wind blowing over branches of trees, poles and other surfaces. It looks like rimming the edge of flowers and leaves and usually it forms against the direction of the wind. It can occur at any hour of day and night.

3. **Window frost** also called fern frost or ice flowers forms when a glass pane is exposed to very cold air on the outside and moderately moist air on the inside. If the pane is not a good insulator (such as a single pane window), water vapour condenses on the glass forming patterns.

4. **White frost** is a solid deposition of ice, which forms directly from water vapour contained in air. White frost forms when there is a relative humidity of above 90% and a temperature below - 8 ^{0}C and it grows against the wind direction, since arriving windward air has a higher humidity than leeward air, but the wind must not be very strong in order not to damage the delicately built icy structures. These structures resemble a heavy coating of hoar frost with big and interlocking crystals, usually needle-shaped.

5. **Rime** is an ice formed when a damp, icy wind blows over flowers, branches and other surfaces. Rime frost looks like icing around the edge of petals and leaves, and only occurs when the temperatures are very low. It is a type of ice deposition that occurs quickly, often under conditions of heavily saturated air and windy conditions. Unlike hoar frost, which has a feathery appearance, rime generally has an icy solid appearance.

Frost impact on plants: Frost damage occurs when ice forms inside the plant tissue and injures the plant cells. It can occur in annuals, multi-annuals and perennials. Frost damage may have a drastic effect on entire plant or affect only a small part of plant tissue, which reduces yield, or merely product quality. The extent of damage caused by frost depends on the temperature, length of exposure time, humidity levels, and the speed with which the freezing temperature was reached. However, it is very hard to give a definite temperature to which crops can tolerate frost as there are so many other factors that affect it. Even if the air temperature reaches 0 ^{0}C the crop itself can be 4 or 5 degrees cooler, because the plants lose heat faster than the surrounding air temperatures.

In order to understand the effects of frost one must understand plant cells. Plant cells contain not only water but also many substances such as proteins, sugars, amino acids and other solutes that can lower the freezing temperature and protect the cells against intracellular ice formation (similar to antifreeze in vehicles). What this means is that even though water freezes at 0 ^{0}C, a plant cell may need temperatures down to minus 4 ^{0}C or lower before the cells will freeze and damage occurs. Different parts of the plant, different stages of development of the plant, and different types of plants can have varying levels of these 'antifreeze' compounds that result in a range of susceptibility to frost. Environmental conditions such as drought, cold temperatures, heat, etc., can also influence the levels of these compounds, and thus affect the tolerance to freezing temperatures. Typically, when a plant is exposed to stress they become more hardened which can moderately increase the tolerance to frost.

Mechanism of frost damage: Direct frost damage occurs when ice crystals form inside the protoplasm of cells (intracellular freezing), whereas indirect damage can occur when ice forms inside the plants but outside of the cells (*i.e.* extracellular freezing). It is not cold temperature but ice formation that actually injures the plants (Westwood, 1978). It is believed that intracellular ice formation causes a “mechanical disruption of the protoplasmic structure” (Levitt, 1980). The extent of damage due to intracellular freezing depends mainly on how fast the temperature drops and to what level it supercools before freezing. There is little evidence that the duration of the freezing affects injury.

Direct intracellular freeze injury is associated with rapid cooling. For example, Siminovitch *et al.*, (1978) observed intracellular freezing and cell death when winter rye plants were cooled at 8 ^{0}C per minute to -12 ^{0}C when the supercooled water froze inside the cells. When plants were cooled to -12 ^{0}C over 23 minutes, ice formation was extracellular and the plants fully recovered after thawing. In climate chamber studies to determine critical temperatures, plant cuttings are typically cooled at a rate of 1.0 to 2.0 ^{0}C h^{-1}. This is a slower rate than in the rye plant experiment and a slower rate than some of the rates that often occur in nature. Indeed, Levitt (1980) reports that, in nature, freeze injury results from extracellular ice crystal formation and there is no evidence of intracellular freezing.

Although the evidence is not strong, it seems that the rate of thawing after a freeze is also partially related to the amount of damage. Citrus growers in southern California commonly believe that slowing the warming process after a freeze night can reduce frost damage. In fact, growers justify operating wind machines longer into the morning following a freeze night in order to slow the thawing process. Yoshida and Sakai (1968) suggested that thawing rate will slowdown the rehydration of cells in plants that experience extracellular freezing and that might reduce the damage due to fast thawing.

Levitt (1980) proposed that cells were gradually killed as a result of growth of the extracellular ice mass. The saturation vapour pressure is lower over ice than over liquid water, and as a result of extracellular ice formation, water will evaporate from the liquid water inside the cells and will pass through the semipermeable cell membranes and deposit on the ice crystals outside of the cells. As water is removed from the cells, the solute concentration increases and reduces the chances of freezing. However, as ice continues to grow, the cells become more desiccated. The main cause of frost damage to plants in nature is extracellular ice crystal formation that causes secondary water stress to the surrounding cells.

Antitranspirants are often promoted as a method of freeze protection. It is argued that the frost damage occurs because of cell dehydration and the antitranspirants are purported to reduce water loss from the plants and provide freeze protection. However, the cell desiccation results from evaporation of cellular water in response to a vapour pressure gradient caused by extracellular ice formation and not because of transpiration. There is no evidence that antitranspirants reduce desiccation due to extracellular ice crystal formation.

Frost damage occurs as moisture within the plant crystallizes and expands. This causes cells to rupture and fluid to leak out thus, the watery appearance of plant tissue or seed after a damaging frost. Freezing-induced cellular dehydration is the most wide-spread cause of damage. Frost cracks in trees are a good example of structural damage as an indirect result of freezing. This involves sudden radial splitting of a tree trunk from its centre through to the bark, said to make a sound like a gunshot. Frost cracks do not directly kill the tree; the cracks can persist for years, opening again each winter, and can cause economic loss.

Many plants can be damaged or killed by freezing temperatures or frost. This varies with the type of plant and tissue exposed to low temperatures. Tender plants, like tomatoes, die when they are exposed to frost. Hardy plants, like radish, tolerate lower temperatures. Hardy perennials, such as *Hosta*, become dormant after the first frost and regrow when spring arrives. The entire visible plant may turn completely brown until the spring warmth, or may drop all of its leaves and flowers, leaving the stem and stalk only. Evergreen plants, such as pine trees, withstand frost although all or most growth stops. Vegetation is not necessarily damaged when leaf temperatures drop below the freezing point of their cell contents. In the absence of a site nucleating the formation of ice crystals, the leaves remain in a supercooled liquid state, safely reaching temperatures of -4 ^{0}C to -12 ^{0}C. However, once frost forms, the leaf cells may be damaged by sharp ice crystals. Hardening is the process by which a plant becomes tolerant to low temperatures. Certain bacteria, notably *Pseudomonas syringae*, are particularly effective in triggering frost formation, raising the nucleation temperature to about -2 ^{0}C. Bacteria lacking ice nucleation-active proteins (ice-minus bacteria) result in greatly reduced frost damage. More economic losses are caused by freezing of crops all over than by any other weather hazard.

Type	Crop Examples	Critical temperature for freeze damage
Very tender crops	Strawberries and raspberries (blossom and fruit), tomatoes, cucumbers, melons, peppers, squash and pumpkins (plants), beans, tobacco	0 to -1 ^{0}C
Tender crops	Potatoes, corn, apples (blossoms), pears (blossoms and fruit), plums (blossom), cherries (blossom and fruit), beans	-l to -2 ^{0}C
Half hardy crops	Apples (fruit, buds), blueberries, alfalfa, pears	-2 to -4 ^{0}C

Frost protection measures: The cost-effectiveness of frost protection depends on the frequency of occurrence, cost of the protection method and the value of the crop. Generally, passive frost protection is easily justified. Frost protection is required in certain areas or small isolated locations to lengthen the growing season making it possible to grow horticultural crops which otherwise would not be feasible or economical. This is important, especially with kiwifruit, cranberries, tree fruits, grapes and other crops requiring high capital investments. In numerous cases, the frost protection method used is passive, and is taken long before the danger of frost actually occurs. The main passive methods are:

i) Site selection and management: Farmers are usually aware that some spots are more prone to frost damage than others. The first step in selecting a site for a new planting is to talk with local people about what crops and varieties are appropriate for the area. Local growers and extension advisors often have a good feeling for which locations might be problematic. Typically, low spots in the local topography have colder temperatures and hence more damage. However, damage can sometimes occur in one section of a cropped area and not in another, without apparent topographical differences. In some cases, this might be due to differences in soil type, which can affect the conduction and storage of heat in the soil.

Dry sandy soils transfer heat better than dry heavy clay soils, and both transfer and store heat better than organic (peat) soils. When the water content is near field capacity (i.e. a day or two after thoroughly wetting the soil), soils have conditions that are most favorable for heat transfer and storage. However, organic soils have poor heat transfer and storage regardless of the water content. When selecting a site in a region prone to frost, avoid planting on organic soils. Planting deciduous crops on slopes facing away from the sun delays springtime bloom and often provides protection. Subtropical trees are best planted on slopes facing the sun where the soil and crop can receive and store more direct energy from sunlight.

Trees, bushes, mounds of soil, stacks of hay, and fences are sometimes used to control air flow around agricultural areas and the proper placement can affect the potential for frost damage. A careful study of topographical maps can often prevent major frost damage problems. Once the cold air drainage flow pattern is known, then proper placement of diversion obstacles can provide a high degree of protection.

a) Plant selection: It is important to choose plants that bloom late to reduce the probability of damage due to freezing, and to select plants that are more tolerant to freezing. For example, deciduous fruit trees and vines typically do not suffer frost damage to the trunk, branches or dormant buds, but they do experience damage as the flowers and small fruits or nuts develop. Selecting deciduous plants that have a later bud break and flowering provides good protection because the probability and risk of frost damage decreases rapidly in the spring. In citrus, more resistant varieties are selected. For example, lemons are least tolerant to frost damage, followed by limes, grapefruit, tangelos and oranges, which are most tolerant. Also, trifoliate orange rootstock is known to improve frost tolerance of citrus compared with other rootstocks. For annual field and row crops, determining the planting date that minimizes potential for subzero temperature is important. If freezing temperatures cannot be avoided then select crops to plant based on their tolerance of subzero temperatures.

b) Intercropping: In Southern California, growers intercrop plantings of citrus and date palms, partly because the date palms give some frost protection to the citrus trees. In Alabama, some growers interplant pine trees with small Satsuma mandarin plantings and the pine trees enhance long-wave downward radiation and provide protection to the mandarins. Shade trees are used to protect coffee plants from frost damage in Brazil.

c) Plant nutrition management: Unhealthy trees are more susceptible to frost damage and fertilization improves plant health. Also, trees that are not properly fertilized tend to lose their leaves earlier in the autumn and bloom earlier in the spring, which increases susceptibility to frost damage. In general, nitrogen and phosphorus fertilization before a frost encourages growth and increases susceptibility to frost damage. To enhance hardening of plants, avoid applications of nitrogen fertilizer in late summer or early autumn. However, phosphorus is also important for cell division and therefore is important for recovery of tissue after freezing. Potassium has a favorable effect on water regulation and photosynthesis in plants.

d) **Pest management:** The application of pesticide oils to citrus is known to increase frost damage and application should be avoided shortly before the frost season.

e) **Proper pruning:** Late pruning is recommended for grapevines to delay growth and blooming. Pruning grapevines to raise the fruit higher above the ground provides protection because temperature during frost nights typically increases with height. Late-autumn pruning of citrus leads to more physiological activity during the winter frost season. Citrus pruning should be completed well before frost season.

f) **Plant covers:** Plant row covers are warmer than the clear sky and hence, increase downward long-wave radiation at night, in addition to reducing convectional heat losses to the air. Removable straw coverings and synthetic materials are commonly used. Woven and spun-bonded polypropylene plastics are sometimes used to protect high value crops. The degree of protection varies from about 1 ^{0}C to 5 ^{0}C, depending on plastic thickness. White plastic is sometimes used for nursery stock but not for fruit and vegetable crops. Partially covering grapevines with black polyethylene has been observed to increase air temperature next to the foliage by as much as 1.5 ^{0}C. However, clear plastic is generally more effective.

g) **Avoiding soil cultivation:** Soil cultivation creates air spaces in the soil and it should be avoided during frost-prone periods. Air is a poor heat conductor and has a low specific heat, so soils with more and larger air spaces will tend to transfer and store less heat. If a soil is cultivated, compacting and irrigating the soil will improve heat transfer and storage.

h) **Irrigation:** When soils are dry, there are more air spaces, which inhibit heat transfer and storage. Therefore, in dry years, frost protection is improved by wetting dry soils. It is unnecessary to wet the soil deeply because most of the daily heat-transfer and storage occurs in the top 30 cm. Wetting the soil will often make it darker, and increases absorption of solar radiation. It is best to wet dry soils well in advance of the frost event, so that the sun can warm the soil.

i) **Removing cover crops:** For passive frost protection, it is better to remove all vegetation (cover crops) from orchards and vineyards. Removal of cover crops will enhance radiation absorption by the soil, which improves energy transfer and storage.

j) **Soil covers:** Plastic covers are often used to warm the soil and increase protection. Clear plastic warms the soil more than black plastic, and wetting the soil before applying the plastic further improves effectiveness. Sometimes vegetative mulches are used during dormancy of tree crops to help prevent damage to roots due to freezing and soil heaving; however, vegetative mulches reduce the transfer of heat into the soil and hence make orchard crops more frost prone after bud break. In general, vegetative mulches are only recommended for locations where soil freezing and heaving are a problem.

k) **Trunk painting and wraps:** The bark of deciduous trees sometimes splits when there are large fluctuations in temperature from a warm day into a frost night. Painting the trunks with an interior water-based latex white paint diluted with 50% water in late autumn when the air temperature is above 10 ^{0}C will reduce this problem. White paint, insulation and other wraps are known to improve hardiness against frost damage in peach trees.

l) **Bacteria control**: For freezing to occur, the ice formation process is mostly initiated by presence of INA bacteria. The higher the concentration of the INA bacteria, the more likely that ice will form. After forming, it then propagates inside the plants through openings on the surface into the plant tissues. Commonly, pesticides (copper compounds) are used to kill the bacteria or competitive non-ice-nucleation active (NINA) bacteria are applied to compete with and reduce concentrations of INA bacteria.

The active methods of frost protection are applied immediately, prior to and during the occurrence of frost. **Active protection measures** include:

i) **Heaters:** Heaters provide supplemental heat to help replace energy losses. Generally, heaters either raise the temperature of metal objects (e.g. stack heaters) or operate as open fires. If sufficient heat is added to the crop volume so that all of the energy losses are replaced, the temperature will not fall to damaging levels.

ii) **Wind machines:** Most wind machines (or fans) blow air almost horizontally to mix warmer air aloft in a temperature inversion with cooler air near the surface. They also break up microscale boundary layers over plant surface, which improves sensible heat transfer from the air to the plants.

iii) **Helicopters:** Helicopters move warm air from aloft in a temperature inversion to the colder surface. Estimated coverage area by a single helicopter varies between 22 and 44 ha depending on helicopter size and weight and on the weather conditions. The optimal flying height is commonly between 20 and 30 m and the flight speeds are 8 to 40 km $h^{-1.}$

iv) **Sprinklers:** The secret to protection with conventional over-plant sprinklers is to re-apply water frequently at a sufficient application rate to prevent the plant tissue temperature from falling too low between pulses of water. For non-rotating, targeted over-plant sprinklers, the idea is to continuously apply water at a lower application rate but targeted to a smaller surface area. For conventional under-plant sprinklers, the idea is to apply water at a frequency and application rate that maintains the ground surface temperature near 0 ^{0}C. This increases long-wave radiation and sensible heat transfer to the plants relative to an unprotected crop.

v) **Surface irrigation:** Surface (flood and furrow) irrigation is commonly used for freeze protection where irrigation is practiced. Protection is provided by the conversion of latent to sensible heat from the cooling water. Both convection of air warmed by the water and upward radiation are enhanced.

Furrow irrigation: Furrow irrigation is commonly used for frost protection and the basic concepts are similar to flood irrigation. Furrows work best when formed along the drip-line of citrus tree rows where air warmed by the furrow water transfers upwards into the foliage that needs protection, rather than under the trees where the air is typically warmer, or in the middle between rows, where the air rises without intercepting the trees. The furrows should be on the order of 0.5 m wide with about half the width exposed to the sky and half under the tree skirts.

vi) **Foam insulation:** Application of foam insulation has been shown to increase the minimum temperature on leaf surfaces of low growing crops by as much as 10 ^{0}C over unprotected crops. However, the method has not been widely adopted by growers because of the cost and labour as well as problems with covering large areas in short times due to inaccuracy of frost forecasts. When applied, the foam prevents radiation losses from the plants and traps energy conducted upwards from the soil.

Combination of methods: Under-plant sprinklers and wind machines: Under-plant sprinklers with low trajectory angles can be used in conjunction with wind machines for frost protection. The addition of wind machines could potentially increase protection by up to 2 ^{0}C over the under-plant sprinklers alone, depending on system design and weather conditions. In addition to heat supplied by the water droplets as they fly from the sprinkler heads to the ground, freezing water on the ground releases latent heat and warms air near the surface. While this warmed air will naturally transfer throughout the crop, operating wind machines with the sprinklers will enhance heat and water vapour transfer within the mixed layer to the air and plants.

Surface irrigation and wind machines: Combination of wind machines and surface irrigation is widely practiced in the USA, especially in citrus orchards. Growers typically start with the surface water and turn on the wind machines later to supplement protection when needed. As with under-plant sprinklers, the wind machines facilitate the transfer to the air and trees of heat and water vapour released from the water within the mixed layer. Combination of heaters and wind machines improves frost protection over either of the methods alone.

FLOODS, IMPACT ASSESSMENT AND THEIR MONITORING FOR PLANNING AND MITIGATION

M. Satya Kumar

Flood

The inundation of a normally dry area caused by overflow of rising water in an existing waterway, such as a river, stream, lakes, tanks etc. is called flooding. Among all the natural disasters afflicting the country, river floods are the most devastating, which cause maximum damages to life and property in India. Total flood prone areas in India are 40 million hectares. As per the Geological Survey of India (GSI), the major flood prone areas of India cover almost 12.5% area of the country. Besides drought, about 90% damages are caused only due to flood. Flooding is a long-term event that may last for days or weeks.

India is the most flood-affected nation in the world after Bangladesh. Floods account for 1/5th of the global deaths every year and on an average 30 million people are evacuated every year. The average area affected by floods is 8 million hectare. Unprecedented floods take place every year at one place or the other. Over that past few years the rise in population is forcing large settlements along the riverbanks, making the country highly vulnerable to floods. The most vulnerable states of India for floods are: Uttar Pradesh, Bihar, Assam, West Bengal, Gujarat, Orissa, Andhra Pradesh, Madhya Pradesh, Maharashtra, Punjab and Jammu & Kashmir. Flooding in rivers like Brahmaputra, Ganges, Godavari, Krishna, Yamuna and Narmada etc is a usual occurrence in this country. Over the past few decades, central India has become familiar with precipitation events like torrential rains and flash floods. The major flood prone areas in India are the riverbanks and deltas of Ravi, Yamuna-Sahibi, Gandak, Sutlej, Ganga, Ghaggar, Kosi, Teesta, Brahmaputra, Mahanadi, Mahananda, Damodar, Godavari, Mayurakshi, Sabarmati and their tributaries.

Flooding in river basins is a natural part of the river's processes, serving to improve water quality and provide essential habitat to species, and other benefits like increase in soil fertility due to fertile fresh soil on top of the existing soil layer once the floodwater recede completely.

Floods vary in degree of sensitivity in terms of areas in extent or magnitude in depth. They are, thus, classified as minor or major floods.

Minor floods:

Inundation may or may not be due to over flowing the banks of the water bodies. Flooding may be due to the accumulation of excessive surface run-off in low lying flat areas or topographically depressed terrains.

Major floods:

They are caused by overflowing of rivers and lakes, serious breaks in dikes, levees, dams and other protective structures; by uncontrollable releases of impounded water in reservoirs and by the accumulation of excessive runoff. Floodwaters cover much larger areas and spread rapidly to adjoining areas relatively lower in elevation

Impact of the Flood

The after effects of flooding cause more damages than the flood itself. If the Floodwaters take long time to recede then the water logging causes civic and health problems. If water gets contaminated during the flood then wide spread diseases prevail especially diahorrea, cholera, fever etc. If the area is flooded with saline water like seawater then the soil salinity will increase there by making the land uncultivable. If the agricultural fields get inundated then the productivity and quality of the produce decrease and the farmers incur heavy losses. If the floodwaters cause inundation of the villages, colonies etc cause hardships to the inhabitants disrupting the daily routine, transportation and economic activities. The floods may cause physical damage to rail, road, bridges, buildings, canals and any other structure that comes in its way.

Types of Floods

1) Coastal flooding **2) River flooding** **3) Flash flooding**
4) Urban flooding **5) Groundwater flooding** **6) Sewer flooding**

Coastal flooding

In India, the coastal flooding occurs mostly in the port cities or towns. These places lie in the delta regions and at low elevations therefore have high risk of flood. Due to increased density of population in the coastal regions, already large number of people are exposed to coastal flooding in large port cities. Across all cities, about 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population) are exposed to a one in 100 years coastal flood event. Coastal flooding occurs when normally dry, low-lying land is flooded by seawater. The extent of coastal flooding is a function of the elevation inland floodwaters penetrate which is controlled by the topography of the coastal land exposed to flooding. The seawater can inundate the land in different ways and through several different paths; these are:

a) Direct inundation b) Overtopping of a barrier c) Breaching of a barrier

Coastal flooding is largely a natural event; however human influence on the coastal environment can influence and increase coastal flooding. By the 2070s, total population exposed could grow more than threefold to around 150 million people due to the combined effects of climate change (sea-level rise and increased storminess), subsidence, population growth and urbanization.

Causes: Coastal flooding can result from a variety of different causes. They are: i) Storm surges from tsunami ii) Storm surges from tropical cyclone landfall iii) Rising sea levels due to climate change iv) Subsidence of coastal areas

I. Coastal flood mitigation measures

Some of the mitigation measures adopted are: i) Improvement and up gradation of existing protection ii) Identification of susceptible places for subsidence and managing subsidence iii) Land Use Planning iv) Development away from the flood plains v) Defense repair pumping of excess waters vi) Effective Early Flood warning systems vii) Speedy Evacuation viii) Lying out the effective drainage system ix) Renovating the existing drainage system to meet the requirement.

II. Flash flood

A flash flood can be defined as a flood that occur and recede quite rapidly with little or no advance warning, usually as a result of intense rainfall over a relatively small area. Flash flooding is a result of heavy localized rainfall generally seen in the hilly or mountainous areas. Flash floods often result from run-off due to saturated soils or dry soils with low absorbing capacities. The run off makes small creeks and streams overflow and the joining of these streams lead to flash flood. Flash flooding usually occurs within 6 to 8 hours of heavy rainfall events (short duration) with a relatively high peak discharge. What makes flash floods most dangerous is their sudden occurrence with fast moving water. Poor drainage system also contributes to flooding during this situation. Flash floods may be seen anywhere downstream from the source of the precipitation in the up stream of the river (or upper catchment's area), even far away from the source.

In deserts, flash floods can be particularly deadly for several reasons. First, storms in arid regions are infrequent, but they can deliver an enormous amount of water in a very short time. Second, these rains often fall on poorly absorbent and often clay-like soil, which greatly increase the amount of runoff that rivers and other water channels have to handle. These regions tend not to have the infrastructure that wetter regions have to divert water from structures and roads, such as storm drain, culverts etc. Short notice, large depths, and high velocities of flash floods make the particularly dangerous.

Causes of Flash Flood

i) Slow moving thunderstorms ii) Sudden cloud burst iii) Stagnant cyclonic storms iv) Melting of snow/glaciers v) Breaking of man-made dams or natural ice dams

Flash flood mitigation

- **I. Structural:** Planting of trees for protection, other civil works such as floodwalls, transversal protection works, embankments, conduits and reservoirs.
- **II. Non-Structural:** Land Use planning, developmental activities, soil conservation and management, awareness and public information, emergency warning systems and recovery measures. Flood plains and flood prone areas regulation.

III. River flooding

The dynamics of river flooding vary with terrain. This type of flooding, where a river bursts or overtops (much above danger mark) its banks and floods the areas around it, is more common flooding than coastal flooding. Sometimes, overflowing streams or tributaries meeting with main river stream can cause river flooding. Flooding can also occur if the free flow of a river gets blocked by fallen trees, natural overgrowth or rubbish, occupation of the catchment areas by human settlers, Along major rivers with very large drainage basins, the timing and elevations of flood peaks can be predicted far in advance and with considerable accuracy. In very small basins, flooding may be more difficult to predict to provide useful warning time. Generally, the smaller the drainage basin, the more difficult it is to forecast the flood. This type of flood occurs generally in the Southwest Monsoon months from June to September.

Causes of river flooding

i) Occurrence of heavy or exceptional rainfall in the river's catchment over an extended area for an extended period of time. ii) Poor drainage iii) Changes in the course of the river due to earthquakes iv) Encroachment of flood areas or flood plains v) Obstruction to the course of the river that blocks free flow of water.

Mitigation of river flooding

1) Effective forecasting and warning systems 2) Emergency evacuation response system 3) Flood plain or Flood areas regulation for development 4) Embankment of rivers 5) Accurate forecasts of heavy to very heavy rainfall 6) Construction of flood waterways or channels to carry excess floodwaters and 7) A forestation of riverbanks are some of the mitigation measures.

IV. Urban flooding

At present more than 40 million people live in major cities and recurring flooding of major cities in India is major problem faced by the civic authorities. The main cause for urban flooding is lack of drainage/sewage or poor drainage/ sewage system in an urban area. As there is little open soil that can be used for storage of water nearly all the precipitation is transported as surface water or into the sewage system. Sudden high intensity of precipitation can cause flooding when the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets.

Causes of flooding

a) Flooding is normally caused by natural weather events such as cloud burst or heavy thunderstorms that produce heavy to very heavy rainfall over a very short period of time.
b) Prolonged extensive rainfall over urban areas.
c) Astronomical tides combined with the storm surges.
d) The urban flooding can be a result of coastal floods or river floods because many urban areas may lie in the coastal areas or flood areas or flood plains.
e) Lack of maintenance of existing infrastructure.
f) Insufficient drainage/sewage networks
g) Lack of mechanism to divert excess rainwater in to drainage/sewage systems.
h) Poor maintenance of sewage/drainage systems.
i) Inappropriate development in flood plains.
j) Lack of good flood defense systems.
k) Hapazardous growth of urban areas.

Urban flood mitigation

To mitigate the urban flooding an integrated approach is required that includes public administration and community based strategies. The efforts of mitigation can both be structural or non structural. Development of adequate drainage systems in view of the growing population in urban areas, reducing the encroachment of water bodies and encouraging the rainfall harvesting to reduce runoff.

V. Groundwater flooding

Groundwater flooding can occur when water levels underneath the ground rise above normal levels approaching the surface. It is usually caused by prolonged periods of rainfall. Groundwater flooding can last for weeks and months. If the probability of a major flood is high and the consequences are severe, i.e "high" risk. If the probability of a flood is small and the consequences are too small then the risk is also "small". These situations are clear.

Floods that can happen often with small consequences or floods can happen rarely, but with very serious consequences. The risk can be calculated by using various methods. Some methods are practical while the others are of scientific interest.

Flood forecasting

The flood forecasting begins with data collection and transmission and an effective estimation methodology. The mechanism to transmit precipitation, level and flow data on daily basis. Estimates are made using mathematical models that represent various components of the water cycle.

Generally the flood forecasts are made by (a) precipitation forecast (b) real time precipitation data, (c) upstream flow. In this case, India Meteorological Department collects daily rainfall data from manual rain gauge stations on real-time basis for all the stations falling within the river basins of the country and computes the realized areal average rainfall for each of the sub basins. It provides sub basin-wise quantitative precipitation forecasts to each river basin in the country on daily basis throughout the flood season to the Central Water Commission. The department uses equipment such as radar or remote sensing through satellites for estimation of average areal rainfall over sub basins of the river catchments. The model-derived and satellite and radar-derived sub basin quantitative precipitation forecasts are also available. The central water commission regularly collects the guage level data from guage sites within the river basin. Both the information enters the hydrological model to estimate the flood. Next, with data on the precipitation over the watershed, it is possible to estimate the flow and level using a mathematical model simulating the conversion of precipitation into flow. When the precipitation in the watershed is known, the forecast uses a computerized data collection and transmission network (in the previous case such a network is indispensable) and the mathematical model for converting the precipitation into flow. This gives a short-range forecast that is limited to the average time the floodwater takes to arrive.

Measures to reduce the *probability* of flooding

The risk of a flow or precipitation means the probability (p) of the occurrence of an equal or higher value in any year. The return time (T) is the inverse of probability (p) and represents the mean time at which this event is likely to recur.

$$T = 1/P$$

If the probability of occurrence of event (say rainfall of given magnitude) is "P" then risk (R) of this rainfall at least once in next 'N' years is given by

$$R = 1 - (1 - p)^{N}$$

Flooding estimates for a particular place can be made on the basis of

(i) An observed series of flows, (ii) Regionalization of flows, (iii) Precipitation and use of a rainfall-flow model.

These methodologies estimate the risk of flooding at the place on the basis of the historical data.

Along the seacoast the probability of flooding can be reduced, for example, by making the dunes or dikes by the sea or the dike along the river mouths higher and/or stronger. A higher dike is also wider at the base, to facilitate rise the mangroves.etc.

1) For river floods the options are to create more room for the river water by way of widening the riverbed, make it deeper or remove obstacles and develop thick vegetation etc. That way the river water gets extra space.
2) The river water level is kept low; it facilitates the transport of large amount of water in case of flood situation.
3) Another option is to create a new channel on the side of the present river that is only used when the water is higher than a certain height, creating water storage facilities(like ponds or lakes) or even linking the river systems where the water level are flexible so that the flood water can be diverted and stored.

Measures to reduce the *consequences* of flooding

1) A measure to reduce the *consequences* of a flood, for example, is to build houses on mounds or higher ground.
2) A well-defined warning system can help to reduce the damage due to flooding. Implementing mitigation measures after the event also important. People in threatened areas need to be warned in time for a flood so that they can move along with their livestock and valuables to safety.

Measures to Mitigate the Flooding

Flood Mitigation Measures may be divided mainly into three areas: 1) Control over the river 2) Control over the land 3) Other measures

Control over the river:

Mainly depends on the physical alteration to the channel, flood plain or watershed to control the river.

Measures include

- Dams and reservoirs built on mainstreams or tributaries that store excessive water and release it gradually after the threat has passed.
- Levees or floodwalls confine floodwaters to a floodway, thereby reducing flood damage.
- Channel improvements which include: 1. Straightening to remove undesirable bend ways, 2. Deepening and widening to increase size of waterways, 3. Clearing to remove brush, trees and other obstructions, 4. Lining with concrete to increase efficiency
- Watershed treatment that renders the soil more absorbent of excessive rainfall until flood heights have receded.

Control over the land: Measures are embodied in the following Land Use Policies:

1) Designated floodways and encroachment lines 2) Zoning 3) Subdivision Regulations 4) Building Codes

Other Measures: These include flood proofing, flood forecasting, and warning and evacuation systems.

- Flood Proofing is a combination of structural changes and adjustment to properties that can be used in new or existing construction. Action includes, Seepage control, protective coverings, elevation or raising anchorage and under pinning.
- Reliable accurate and timely forecasting of floods coupled with timely evacuation to save lives and reduce property losses.
- Temporary evacuation removes persons and property from the path of flood waters.
- Permanent evacuation removes an affected population from areas prone to inundation. This involves the acquisition of lands. The acquired lands can be used for agriculture, parks or other purposes that would not interfere with flood flows or result in material damage.
- Flood insurance

Flood Risk Analysis

In recent years, through the availability of remotely sensed data, river gauge data, data on hydrological parameters etc, it has become possible to conduct national-scale flood risk assessment. The results of this type of risk analysis can be used to brief policy-makers and prioritization of resources for flood management. It can form the starting point for more detailed strategic and local-scale or area based flood risk assessments. The national-scale risk assessment methodology makes use of information on the location, standard of protection and condition of flood defenses, together with datasets of floodplain extent, topography, population occupancy of the area and asset/property values. The flood management methodology when applied to flood risk assessment, the expected annual damage from flooding can be estimated and also the effects of climate and socio-economic change may be estimated for the future. The analysis predicts increasing flood risk and impact factor over flood prone areas. The increase in the risk factor is attributable primarily to a combination of climate change (in particular sea level rise, increase in extreme weather events and increasing precipitation) and increasing economic vulnerability.

Flood Mitigation

GIS is an effective tool for developing flood emergency response as a part of disaster preparedness for decision makers and analyze the risk of disaster effects. Immediately after flood recedes, it is important to contain the spread of communicable diseases like cholera, dysentry etc. Fresh water supply is to be restored at the earliest, so as to stop the spread of water borne disease. Later, a team of experts from various fields should visit the affected areas and assess the damage by sector wise on housing, health, agriculture, livestock, transport and communication, energy sector, social and gender impact, infrastructure etc and submit the summary of damage in detail to respective authorities to take-up rehabilitation programs.

Heavy rain is the most frequent cause of floods, but there are many other natural triggers, viz. tidal surges and snowmelt etc. Flood is basically a natural hydrological phenomenon. Its occurrence is usually the aftermath of meteorological events. These included

- Intense and prolonged rainfall spells;
- Unusually high coastal and estuarine waters due to storm surges, seiches, etc.

Floods are also caused, indirectly, by seismic activities. Coastal areas are particularly susceptible to flooding due to tsunamis (seismic sea waves). To a certain extent, astronomically influenced phenomenon such as high tides coinciding with the occurrence of heavy rainfall is also a cause of flooding. Occasionally, floods occur unnaturally. These are usually the result of human activities. Such activities include:

Blasting, Construction of temporary dams, Failure of hydraulic and other control structures and Mismanagement of hydraulic structures. Other factors that can also cause or contribute to flooding. Human activities (not frequent) that tend to alter the ecological system in a river basin will have an impact on the hydrology of the catchment. This could, in the future, result in frequent floods. Among such activities are the raging of forest areas, and watershed areas. River floods sometimes can also be reduced by human intervention such as dredging the riverbeds and linking the rivers.

CLIMATIC RISK MANAGEMENT TOOLS FOR EXTREME WEATHER EVENTS IN AGRICULTURE

K.K. Singh

Agricultural activities are very sensitive to climate and weather conditions. Although, occurrences of erratic weather are beyond human control, it is possible to adapt to or mitigate the effects of adverse weather if a forecast of the expected weather can be had in time. The drought of 2002 brought to the forefront an extreme situation of the adverse impacts of the active and break cycles of sub-seasonal time scales in the Indian summer monsoon. The agricultural community in India felt, post 2002 drought episode, that one of the major constraints in implementing their designed contingency crop planning was the lack of advance weather information during the monsoon season with sufficient lead time and accuracy to enable farmers to modify their usual cropping patterns before and during the crop season.

The 2002 drought event threw up an urgent requirement for developing methodologies for providing advance weather and climate information in extended range from weeks (intra-seasonal) to months (inter-seasonal) to years on the one hand and, on the other, for refining and improving the approaches to anticipate and manage the weather associated crop production losses by treating monsoon aberrations as an intrinsic risk to agriculture. However, the critical period over which knowledge of future weather, seamless weather forecast, is needed is the main growing season.

IMD has been providing long range forecast of south west monsoon rainfall for India as a whole to various stakeholders but it is not sufficient for crop planning at local level. Besides, its Agrometeorological Advisory Services based on medium range weather forecast at district level enables the farmers to mend their intercultural operations/ tactical decisions up to a week. Due to modernization and improvement of computational power, weather observations and forecasting in the country during 11th five year plan, it led to improved understanding to examine the possibility of integrating longer term variations in El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and the Madden Julian Oscillation (MJO) into the ensemble forecast information on rainfall and temperature at week to fortnight to month scale for different states/ meteorological subdivisions.

A research project entitled "Development and Application of Extended Range Forecast System (ERFS) for Climate Risk Management in Agriculture" supported by the DAC, Ministry of Agriculture, Government of India, had the key objectives to develop the experimental extended range test forecast from monthly to seasonal scale for Indian region and its application for the **development of climate risk management tools** to address these risks with the involvement of agricultural scientists, farmers and service support agencies at field levels. This project integrates risk management and climate science research, involving leading institutions of India and abroad. These include IIT Delhi (project nodal institution), IMD, NCMRWF, ICAR, SAUs, International Research Institute for Climate and Society and others. The project adopts a very strong demonstration approach, focusing on select districts in nine states that face significant livelihood impacts due to variability in the southwest monsoon: Andhra Pradesh, Gujarat, Maharashtra, Madhya Pradesh, Orissa, Himachal Pradesh, Rajasthan, Tamil Nadu, and Uttarkhand. Being the lead organization, IIT Delhi is involved in the generation of the experimental test forecast, which is being transferred to IMD for further dissemination at selected demonstration sites for its use in agriculture risk management.

Climate Related Risks at the Selected Demonstration Sites

The nine organizations including 8 agricultural universities and one ICAR research organization were identified for verification and application of experimental test forecast on pilot basis. All of these demonstration sites are located in the different part of the country with variable climatic conditions and these represents nine separate meteorological subdivisions along with the districts and crops selected:

Vidarbha: Akola- Cotton, soybean, sorghum: Selected village comes under rainfed based agriculture. Uncertainty of rainfall and moisture stress during development phase of cotton and pod development in soybean crop is the common in the region during *Kharif* season. In the *Rabi* season soil moisture is the major menace to the pulse crops and also the cultivation of wheat crop is totally dependent upon the moisture status and availability of water source. The Village has suffered scarcity conditions on a few occasions. But this village cannot be regarded as having a permanent feature of scarcity.

Gujarat: Anand and Kheda - Tobacco, potato, paddy, castor: There is higher risk of large-scale drought, flooding and loss of topsoil due to erosion. In summer, the most remarkable trend is a decrease in the frequency of wet days, and shorter return times of heat waves and droughts. This increases the risk of losses of crop yield and forage quality. The more frequent occurrence of dry years may accelerate.

Reduced water availability may lead to insufficient water available for irrigation, crops suffering from heat and drought stress, and increased competition for water resources may result in higher prices and regulatory pressure. Crop area changes due to decrease in optimal farming conditions, increased risk of agricultural pests, diseases, weeds as well as increased irrigation requirements.

Tamil Nadu: Coimbatore Nagapattinum **-** Maize, Cotton: In Coimbatore district, major risks are early or late onset of monsoon, drought due to reduction in quantum of rainfall in the season, untimely rainfall, intermittent dry spell, problems in rainfall distribution as well as low air and water temperatures during November and December months. Similarly for Nagapattinum district, Cyclonic storms are a major risk. Between 1891 and 2000, nearly 26% of cyclones that formed in the Bay of Bengal struck the coast of Tamil Nadu; of which 55 severe cyclones crossed the region, mostly during the months of October and November. Besides this, other risks are high wind speed, early or delayed monsoon onset, mid season drought, early withdrawal of monsoon, floods in the growing season, less rainy days and more intense rainfall during NEM.

Telangana (AP): Mahabubnagar – Cotton, Maize: The onset and distribution of southwest monsoon rainfall is most crucial for sowing of rainfed crops and their growth and development. Any deviation in the onset and distribution of southwest monsoon rainfall causes huge impact on agriculture and its dependent activities. The major levels are large variations in the dates of commencement of rainy season, variation in total seasonal rainfall received, prolonged dry spell within the rainy season, high intensity rainfall due to cyclonic activities, depression etc. that results in flood damage to crops and variation in cessation date of rainy season.

Eastern M.P.: Jabalpur- Rice, Chickpea: Selected village comes under rainfed based agriculture. Uncertainty of rainfall and moisture stress during reproductive phase of rice is the common in the region during *Kharif* season. In the *Rabi* season frost is the major menace to the pulse crops.

Western Rajasthan:Jodhpur - Pearl millet, cluster bean, cumin, mustard, wheat and livestock: Drought is the most frequent climatic hazard in Jodhpur and occurs once in 2-3 years. During winter, passing western disturbances in northern latitudes, cause severe cold wave conditions causing frost injury in mustard, cumin, vegetable crops like tomato, brinjal, chillies, horticultural crops like ber, anar. etc. During summer, heat wave conditions lead to thermal injury in vegetable crops.

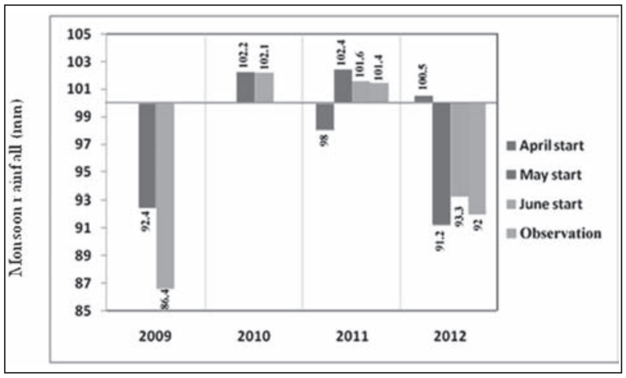
Himachal Pradesh: Kangra and Kullu - Wheat & Apple: The major risks for wheat crop are failure of rains during planting/sowing time and reduction in rabi season rainfall, the delayed rainfall during harvesting time. On the other hand, the most prominent risks for apple are decreasing trends of chill unit hours during winter season, failure of rains during bloom period. Frost, that occurs at still night and clear skies and heat damage that causes yellow lesion which are attacked by fungal diseases.

Uttarakhand: U.S. Nagar - Rice and Wheat: Rice-wheat cropping system is a major system in which complete recommended set of agronomic practices are followed including timely control of pests and diseases, proper integrated nutrient management, application of balanced fertilizers and crop residue management, recommended tillage practices after harvesting of rice and control of weed flora over a time period under different conditions and crop stages. In-spite of these the yield of wheat after rice in the area has declined after the green revolution. This decline in trend may be due to over irrigation or irrigation followed by medium to heavy rainfall.

Orissa: Angul, Khorda - Rainfed rice and groundnut: Agriculture in the state is prone to several hazards and vulnerable to multiple risks that include climatic (seasonal weather), social, economic and predatorial. *Kharif* being the principal crop season and rainfed agriculture being the most dominant, gamble of monsoon is the greatest climatic risk. Both the districts experience extreme weather events such as exremly heavy rain, cyclones, flood, drought, heat wave, etc. Summer temperature touches nearly 50 ^{0}C in Angul and above 45 ^{0}C in Khorda. Even in the same year both drought and flood may occur. In 2002, which was a severe drought year in the country, crop damage occurred in all the blocks of both the districts.

Forecast Products

These forecast products include both type of forecasts *viz.*, deterministic as well as probabilistic forecasts. Methods used to generate the deterministic rainfall and mean temperature forecast include SVD Based Regression, Supervised Principal Component Regression, Canonical Correlation Analyses. All these above stated forecasts were combined using some statistical techniques and has been converted in probabilistic forecast to see the chance of occurrence of particular event. Probabilistic forecast is made in three categories viz. Below Normal, Near Normal and above normal. These categories are based on the previous year's observed data set (IMD's gridded data). The experimental forecast products thus generated since monsoon 2009 were disseminated to all the selected demonstration sites through IMD for its verification and application purposes. The performance of experimental test forecast products were evaluated at each selected pilot demonstration sites with the observed data of temperature and rainfall during the month. Performance of real time experimental forecast for summer monsoon seasonal rainfall (JJAS) is shown in the figure:



Climatic Risk Management Tools

Crop simulation models and DSS are being increasingly used in decision making for risk minimization in agriculture. The idea of informed decision making gains more reality if integrated with reliable seamless weather forecast during crop season. These models need daily weather data for crop season. The major challenge in linking seasonal forecast to crop model is mismatch between spatio-temporal scale of forecast and crop model. On the one hand, these forecasts are available at bigger spatial domain for a month or season and on the other, crop simulation models can be run at point scale or smaller grid space. Forecast needs to be downscaled spatially and temporally. Crop model based generated viable management options against a given forecast require frequent validation through farmers participatory meetings. In order to make use of extended range forecast for decision making on strategic agriculture planning and risk management and integrate with ongoing advisory service system, a range of climatic risk management tools were developed.

1. Extended/ seasonal climate forecast*:* as explained above.
2. Climatic risk matrices: Climate risk analysis for crop under various farming situations showing the impact of soil, time of planting and weather requirement and extremes at various phenopahese. Abiotic stresses are quantified.
3. Stochastic Weather generator: Downscaling can be achieved by linking a seasonal forecast with a weather generator. Nonhomogeneous hidden Markov model (NHMM) or HMM are used as a promising approach to constructing multi-station weather generators. A number of weather realizations is made.
4. Crop simulation model and Decision support system: Crop models embedded in Decision Support System for Agro-technology Transfer (DSSAT) are a process-oriented, management-level model of crop growth and development **and** developed to predict the duration of growth, the average growth rates, and the amount of assimilate partitioned to the economic yield components of the plant along with impact of water and nitrogen on crop. The simulation processes of model are dynamic and are affected by environmental and cultivar specific factors. The duration of growth for a particular cultivar, however, is highly dependent on its thermal environment and to some extent the photoperiod during floral induction DSSAT also includes a basic set of tools to prepare the input data, as well as application programs for seasonal, crop rotation and spatial analysis.
5. Farmers participatory meetings.

Pilot study demonstrated use of monthly forecast on rainfall and temperature by establishing an end-to-end information generation and application. This was implemented with participation of agricultural universities/research centers, service support agencies at field levels and farmers for better crop planning and management in the following areas:

- Land preparation
- Nursery raising
- Irrigation scheduling
- Urea application to rainfed crops in normal rain forecast
- Frequent intercultural operation to conserve soil moisture
- Contingency plan under delayed monsoon onset rains
- Temperate apple crops- Chilling hours to help skip hormonal spray for bud breaking/ flower setting
- Nomadic farming hills- sheep, goat
- Livestock- malnutrition and disease infection under deficit rainfall

Future plan includes the integration of ERFS experimental system in IMD for its operationalization, generation of seamless weather forecast for agriculture risk management, expand to all parts of the country and R&D for continuous improvement in weather forecast products at fortnightly to monthly scale.

ASSESSING THE VULNERABILITY TO AND IMPACT OF EXTREME EVENTS ON AGRICULTURE

C A Rama Rao

There is now adequate evidence about the impending climate change and the consequences thereof. The fourth assessment report of IPCC observed that 'warming of climate system is now unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (IPCC, 2007). Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse consequences. Globally, climate change is seen as a failure of market mechanisms wherein the polluters did not have to pay for the negative externalities (Stern, 2007).

Climate change projections made upto 2100 for India indicate an overall increase in temperature by 2-4 ^{0}C with no substantial change in precipitation quantity (Kavikumar, 2010). However, different regions are expected to experience differential change in the amount of rainfall that is likely to be received in the coming decades. The Western Ghats, the Central Indian and North Eastern parts of the country are projected to receive higher amount of rainfall. Another significant aspect of climate change is the increase in the frequency of occurrence of extreme events such as droughts, floods and cyclones. All of these expected changes will have adverse impacts on climate sensitive sectors such as agriculture, forest and coastal ecosystems and also on availability of water for different uses and on human health.

Considerable attention was paid towards understanding the impact of changing climate on agriculture as it most intricately related to climate. A wide range of approaches starting from physical simulations of climate, simulation modelling to statistical and econometric modelling have been followed for understanding the impact of climate change on agriculture. Each method and approach has its own advantages and disadvantages. But all have the potential to contribute to enhance the understanding.

'Vulnerability' has emerged as a cross-cutting multidisciplinary theme of research in the current context characterized by rapid changes in the environmental, economic and social systems. Accordingly, vulnerability is viewed differently by different individuals and organizations depending on the context in which they operate. Vulnerability is essentially an *ex ante* concept and refers to the possibility of being hit or propensity to be harmed by a stress or shock.

The IPCC defined vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is **exposed, its sensitivity, and its adaptive capacity**" (McCarthy *et al.*, 2001). According to IPCC, vulnerability has three components – adaptive capacity, sensitivity and exposure.

The term vulnerability in other contexts is used to refer to susceptibility, proneness or frequency or intensity of occurrence of a shock on a particular entity. Assessment of vulnerability is thus determined by the context, purpose and the scale of analysis.

Extreme events generally refer to the occurrence of weather events that are considerably deviant from the long term average or normal. Incidence of drought, flood, heat and cold waves are some of the examples of extreme events.

Occurrence of Extreme Events in Rainfed Districts

The analysis is done for 220 districts where rainfed agriculture is predominant. These districts are selected based on the following criteria: (a) Included in the centrally sponsored Drought Prone Area Programme (DPAP) or in the Desert Development Programme (DDP) or the net irrigated area is less than 30 per cent and (b) The average annual rainfall is less than 1500 mm. In addition, all the districts in the North Eastern States and states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand were not included in the analysis. Climatically, these districts represent arid, semi-arid, dry and moist sub-humid regions in the country.

There are a number of global circulation models and the corresponding versions of downscaled projections at a relatively smaller spatial resolution and these projections vary with the parent GCM. Here, the projections obtained at a resolution of grid of 50 x 50 km using the PRECIS were chosen where the daily data on maximum temperature, minimum temperature and rainfall is available for the period 1961-2098. Though these estimates are available for different scenarios, we used the output for the A1B emission scenario as this showed ‘reasonable skill in simulating the monsoon climate over India’ (Krishna Kumar *et al.,* 2011) and was considered as ‘the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory’ (MoEF, 2012). Using the daily data on these variables, the following parameters are estimated.

Parameter	**Description**
Incidence of drought	A year is considered as a moderately drought year if the annual rainfall is less than 80 per cent and above 50 per cent of the normal rainfall and a year with rainfall less than half of the normal is considered as severely drought year (Gore *et al.,* (2010). Each severe drought year was considered equivalent to two moderate drought years. An index was then calculated as (number of moderate drought years + 2* number of severe drought years) / total number of years * 100.
Dry spells	Number of events of rainless period of at least 14 consecutive days during the monsoon (June to September). A day is considered as a rainless day if the rainfall is less than 2.5 mm
Extreme rainfall events	Number of events when cumulative rainfall in three consecutive days is more than 100mm

All the values at grid level were converted into district level estimates by obtaining the weighted average, with the area under a given grid falling into a particular district as weight, in case of rainfall-related parameters and by obtaining the simple average of all the grid values passing through a district in case of temperature related parameters. The above parameters were computed for the three periods – 1961-90 (baseline), 2021-2050 (mid-century) and 2071-2098 (end-century) and the results are presented in terms of change relative to baseline in order to account for the model bias in the estimates.

Occurrence of dry spells of at least two weeks is observed to increase by 0.25 spells per year in a few districts in Tamilnadu and southern Maharashtra and Chittoor in Andhra Pradesh during the mid-century and in south Karnataka, Tamilnadu, Chhattisgarh and Madhya Pradesh during the end-century (Fig. 1). Some decrease in the incidence of dryspells is also observed in 24 districts Rajasthan, Gujarat and Andhra Pradesh during mid-century and in 25 districts in Rajasthan, Gujarat and Madhya Pradesh during the end-century.

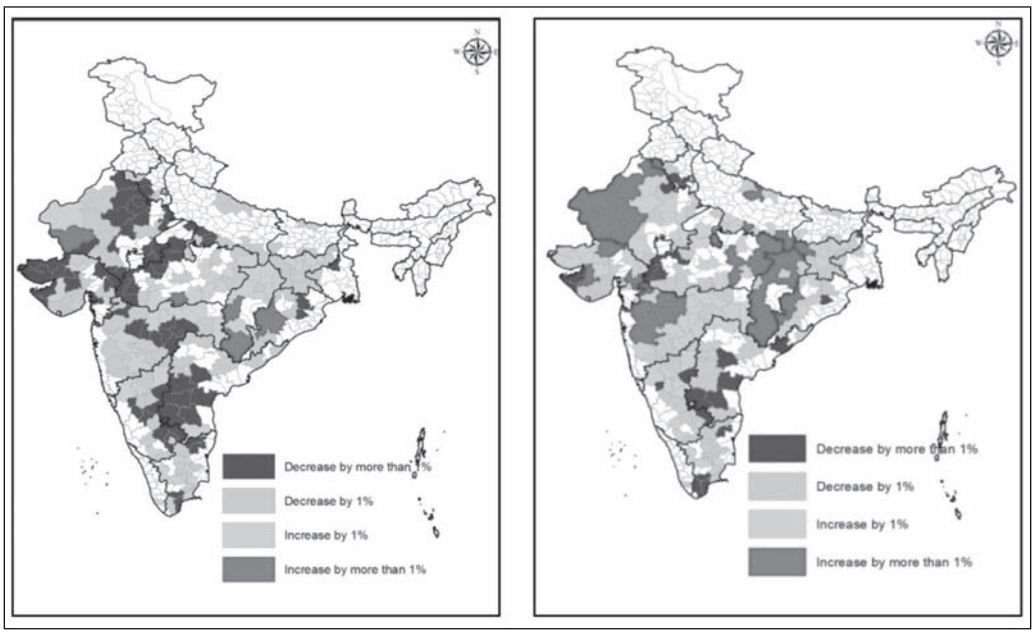


Fig. 1 : Projected changes in incidence of drought during (a) mid-century and (b) end-century relative to baseline in rainfed districts of India (%)

During the mid-century, thirteen districts are likely to be worse off with incidence of drought projected to increase by more than one per cent and these are located in Rajasthan Chhattisgarh and Orissa (Fig. 2). However, the increase in drought incidence is reported in a larger number of districts during the end-century. In all, incidence of drought is observed to increase in 62 districts during mid-century and in 134 districts during the end-century.

Fig. 2 : Projected changes in incidence of dry spells during (a) mid-century and (b) end-century relative to baseline in rainfed districts of India (No/year)

Occurrence of extreme rainfall events is another threat to agriculture. These events, defined as occurrence of rainfall of more than 100 mm in three consecutive days, are projected to happen more frequently in four districts during the mid-century and in 24 districts during the end-century (Fig. 3). In the rest of the districts, the frequency is not likely to change by more than five per cent with respect to the baseline situation.

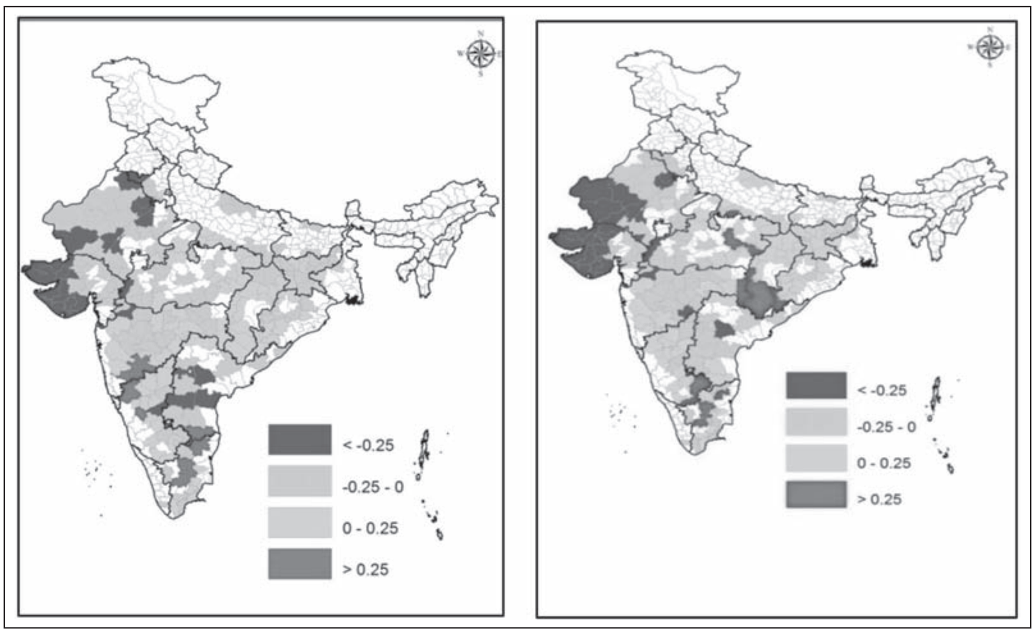


Fig. 3 : Projected changes in incidence of events of extreme rainfall during (a) mid-century and (b) end-century relative to baseline in rainfed districts of India

Impact of Drought on Production of Major Dryland Crops in India

Incidence of droughts has been and continues to be one of the key threats to country's food security at the macro-level and livelihoods of farmers at the micro-level. While technological advances might have been helpful in ameliorating effects on crop productivity to some extent, the adverse impacts of drought on crop yields and livelihoods of farmers are still a formidable challenge. An analysis of the impact of incidence of drought, which is considered as an extreme event, on production of major dryland crops and how the impact has changed over time is illustrated here.

Methodology:

In order to examine the impact of drought on crop performance, a linear regression equation of the following form (Haffis *et al.*, 1994) was fitted to the data:

$Y = a_0 + a_1 t + a_2 D + e$

where Y = Area, production or yield

t = year (1 to n)

D = dummy variable if it is a drought year and 0 otherwise

e = random error which is iid $(0, s^2)$

a_i s are regression coefficients estimated by ordinary least squares method. The coefficients with respect to time and drought indicate the rate of annual change and the impact of drought on the dependent variable concerned. In case of yield, the annual rate of change can be considered as the impact of technological change.

The equation was fitted for the period 1970-2011 and for three different periods, 1970-85, 1986-2000 and 2001-2011 separately to examine the sensitivity to drought. The data were collected from the Department of Economics and Statistics, Ministry of Agriculture and Cooperation, Government of India. Data on incidence of drought is taken from Fertilizer Statistics published by Fertilizer Association of India. The rate of annual change and the extent of impact of drought were then divided by the mean value of the dependent variable to get the relative impact.

Results and discussion:

Any year that receives less than 80 per cent of the normal rainfall is considered as a drought year. Incidence of drought can impact productivity of crops by limiting the availability of water to crop plants. The irregular behavior of monsoon, especially in term of its arrival, can cause changes in the cropping pattern as crop yields are sensitive to when they are sown in relation to the progress of monsoon. Thus, area sown to different crops can be affected by the incidence of drought. These changes in area and in productivity as affected by drought together result in changes in production of different crops. The changes observed in area, production and yield of major dryland crops during different period are presented in tables 1-3.

It is observed that area sown to sorghum was not affected much by incidence of drought as can be seen from the coefficients (Table 1). For the period 1970-2011, the area sown to sorghum was found to increase by about 2.88 per cent during a drought year. Such a positive area response was found to be stronger during 1985-2000 whereas it tended to be negative during 1970-85 and 2001-11. In case of pearl millet, less area was found to be sown during the years of drought. The area sown to this crop declined by as much as about 23 per cent during 2001-11 compared to about 8.31 per cent during 1970-2011. In case of finger millet, the area response to drought was most significant during the period 2001-11 compared to the other periods. The decline was not significant for the period 1970-2011 as well as for the period 1986-2000. In case of maize, which is found to be expanding at significant rate during the recent years, the impact of drought on acreage allocated was not found to be significant during any period though it tended to decline by about 4.23 per cent during 2001-11. In case of pulses, pigeonpea found to lose area by about 9.42 per cent during a drought year for the period 1986-2000. For the long term, it was about 3.57 per cent. Significant decline in area was observed in case of chickpea (9.59% during 2001-11), green gram (9.03% during 2001-11) and black gram (12.84% during 1986-2000). The long term area impacts of drought in the pulse crops ranged from about -0.36 % in black gram to -5.8 per cent in chickpea. The area response of oilseed crops for the long term period of 1970-2011 was found to vary between 5 to 7 per cent. However, the shrinkage in area during a drought year was found to be the highest in case of groundnut (-28.5%) during 1986-2000 followed by castor (-18.04% during 2001-11). Cotton is another important crop largely grown on drylands. Though the response in terms of reduction in area sown was not very high, it increased over time. The change in area was actually not found to be significant during 1970-85. However, the crop lost about 6 per cent of area during 2001-11 during a drought year compared to 4.17 per cent during 1986-2000 and 2.67 per cent for the period 1970-2011.

Table 1: Impact of drought on area sown to major dryland crops (%)

Crop	1970-85	1986-2000	2001-11	1970-2011
Sorghum	-0.21	5.27	-3.69	2.88
Pearlmillet	-5.58	-13.77	-22.97	-8.31
Ragi	-3.68	-0.64	-15.75	-2.22
Maize	-2.19	0.57	-4.23	-1.56
Pigeonpea	-3.09	-9.42	-0.25	-3.57
Chickpea	-3.66	-6.36	-9.59	-5.8
Green Gram	-5.37	-6.62	-9.03	-3.1
Black Gram	-3.96	-12.84	8.1	-0.36
Groundnut	-0.45	-28.5	-1.3	-7.06
Castor	4.78	-15.07	-18.04	-7.75
Sesamum	-2.43		-14.9	-6.07
Soybean	25.25	5.25	-9.24	-5.25
Cotton	1.57	-4.17	-5.89	-2.67

Compared to area effects, yield effects were found to be more conspicuous (Table 2). The yield effect in case of sorghum was most significant (-15.82%) during 1986-2000 which was about 9% during the initial period (1970-85) and during the long term (1970-2011). The impact of drought on yield was not found to be significant during 2001-11. Of all the crops, the impact on yield of drought was found to be highest (27.43 to 33.95%) in case of pearl millet. Rapid spread of high

Table 2 : Impact of drought on yield of major dryland crops (%)

Crop	1970-85	1986-2000	2001-11	1970-2011
Sorghum	-8.97	-15.82	0.66	-9.54
Pearlmillet	-31.82	-32.8	-33.95	-27.43
Ragi	-7.5	1.29	-33.89	-11.96
Maize	-11.83	-15.62	-11.84	-11.86
Pigeonpea	0.48	-1.05	-7.19	-0.7
Chickpea	-3.38	-7.48	-13.2	-6.37
Green Gram	-8.94	-12.89	-23.92	-9.57
Black Gram	-6.85	-16.83	-4.67	-7.36
Groundnut	-15.58	-13.35	-37.55	-19.05
Castor	-7.99	-37.44	-22.88	-22.86
Sesamum	-11.83	-18.49	-29.55	-11.72
Soybean	-18.69	-29.88	-12.8	-19.04
Cotton	6.82	-32.47	-16.7	0.45

yielding varieties in this crop might have contributed to the observed high sensitivity as these varieties are responsive to input use which tends to be affected in the moisture scarce conditions that the drought leads to. Further, the yield of pearl millet was found to be more sensitive to water stress during flowering and before the crop establishment. In case of finger millet, the yield response to drought was most significant during the period 2001-11 compared to the other periods. The decline was relatively considerable at about 11.96 per cent for the period 1970-2011and 7.5 per cent for the period 1970-85. In case of maize, which also witnessed rapid tehnological change in terms of spread of improved crop varieties, the yield impact was significant and ranged between 12 and 16 per cent. In case of pulses, sensitivity of yields to incidence of drought was found to be increasing over time as is evident from the yield effects of pigeonpea, chick pea and green gram. The negative impact was relatively more in case of green gram and chick pea compared to that in pigeon pea. Chick pea and green gram were largely grown on residual moisture during rabi and poor rainfall during a drought year means reduced availability of moisture which is why the yield impacts are conspicuous. In case of black gram, highest yield effect was observed during 1986-2000. As far as oil seed crops are concerned, incidence of drought affected the yield of groundnut most during 2001-11. In fact, the impact doubled compared to the previous two fifteen year periods. Yields of castor and soybean were found to be most sensitive to drought during 1986-2000 compared to other time periods. The sensitivity of yield of sesamum increased from 11.83 during 1970-85 to 29.55 per cent during 2001-11. Yield of cotton was found to be most sensitive (-32.47%) during 1986-2000. However, during the the long term 1970-2011, the impact was not found to be significant.

The observed changes in area and yield were together responsible for the changes in production induced by drought. For the long term, production was found to be more sensitive in case of pearlmillet (36.02%), castor (29.11%) and groundnut (25.28%) (Table 3). In most of the crops, production was more sensitive during 1986-2000. Production of sorghum was found to be more resilient during 2001-11 compared to earlier periods and that of pearl millet, finger millet, chickpea and green gram was found to be more sensitive during this period.

Table 3 : Impact of drought on production of major dryland crops (%)

Crop	1970-85	1986-2000	2001-11	1970-2011
Sorghum	-8.85	-14.94	-3.18	-7.73
Pearlmillet	-37.1	-46.64	-52.02	-36.02
Ragi	-11.27	-0.84	-48.27	-13.25
Maize	-13.87	-13.03	-13.88	-11.93
Pigeonpea	-3.17	-10.67	-7.62	-4.77
Chickpea	-6.59	-13.01	-20.56	-11.45
Green Gram	-12.69	-19.4	-32.45	-11.6
Black Gram	-10.96	-30.38	2.94	-7.58
Groundnut	-15.99	-40.18	-38.41	-25.28
Castor	-4.71	-39.44	-33.17	-29.11
Sesamum	-14.33	-46.06	-41.08	-18.6
Soybean	11.95	-1.73	-18.61	-11.18
Cotton	8.18	-32.65	-19.3	-0.34

Incidence of extreme events continues to be an important cause of production risk in Indian agriculture. Droughts, floods, heat waves have caused considerable yield, production, income and welfare losses to the farmers and to the society. The incidence of such extreme events is projected to increase further. There is therefore a need for better preparedness to deal with these events and to develop various technological, policy and institutional options that enhance the capacity of all concerned to adapt to and cope with the extreme events.

INDEX BASED INSURANCE FOR RISK MANAGEMENT IN AGRICULTURE

Kolli N Rao

Crop Insurance

Crop Insurance is a tool for protection against loss or damage to crops due to natural calamities and other specified non-preventable risks. It is a financial mechanism in which the uncertainty of loss in crop yields is minimized by pooling large number of uncertainties that impact on crop yields so that the burden of loss can be distributed.

Benjamin Franklin likely the first person to have thought about Crop Insurance. Based on a severe storm of 24th October 1788 in French countryside which destroyed crops, he observed – *'I have sometimes thought that it might be well to establish an office of insurance for farms against the damage that may occur to them by storms, blight, insects etc. A small sum paid by a number of farms would repair such losses and prevent much distress'*. However, the first crop insurance programme in the form of hail insurance started in 1820s in France and Germany for Grapes, while it started in USA in 1883 for tobacco crop. The earliest Multi-Peril Crop Insurance (MPCI) started in USA in 1939, with formation of Federal Crop Insurance Corporation (FCIC).

Agriculture Risks

Agriculture in India despite its relatively diminishing contribution to Gross Domestic Product (GDP), accounts for over 50 percent of employment, and sustains close to 70 percent of the population. In addition to satisfying all the food and nutritional requirements of the nation, agriculture also provides important raw materials to some major industries and accounts for significant share of total exports.

Because of the dominance of the monsoon, India's climate and weather risk exhibit the heaviest seasonal concentration of precipitation in the world. Nearly 2/3rd of the land is rain-fed, and almost 20 percent of India's total land area is perennially drought prone. The Ganges-Brahmaputra and Indus river systems are highly prone to flooding. The magnitude of flooding has increased in recent decades, from approximately 19 million hectares affected 50 years ago to 40 million hectares in 2003, about 12 percent of India's geographic area. Agriculture though faces risks including price risks, financial risks, institutional risks, personal risks etc., **production risk** however is the most important one. Indian agriculture is often and rightly termed as **'gamble in monsoon'** and is characterized by high variability of production outcomes. Many external and internal factors during crop cycle make it almost impossible for farmers to predict with certainty the amount of output that the production process will yield.

Agriculture sector is, thus subject to a great many uncertainties. Uncertainty of crop yield is thus one of the fundamental risks, which every farmer has to face. These risks are particularly high in India as the overwhelming majority of farmers are poor, with extremely limited means and resources. Given these limitations, they cannot bear the risks of crop failure of a disastrous nature.

A serious crop failure has cascading affect leading to serious repercussions for entire society. Various methods have been adopted for helping farmers to compensate, at least partially, for loss of their crops. Reduction or suspension of land rent, taxes, cancellation of accumulated agricultural debts, and relief from Calamity Relief Fund (CRF) / National Calamity Contingency Fund (NCCF) are the more usual of the methods applied so far. Useful though these means have been, the farmers cannot expect them as a right. Secondly, the continued prospects of relief are liable to 'soften' its recipients and are also likely to be questioned by the non-farming community. The basic difference between 'Relief' and 'Crop Insurance' is outlined in table-1 below. An important measure that is largely free from the above complications is crop insurance against all natural and unavoidable hazards. Thus Crop insurance spans crop failure gap.

Table 1 : Crop Insurance and Relief

S.No	Crop Insurance	Agriculture Relief
1	Financial instrument with or without social welfare dimension	Mainly social welfare instrument of the Government
2	Normally administered by the insurance company, which quite often promoted by the Government. However, it's not uncommon to see insurers from private sector	Handled by the Government, mostly by departments like Revenue, Agriculture, Relief etc. For example, Calamity Relief Fund (CRF), National Calamity Contingency Fund (NCCF) are administered by Ministry of Home Affairs
3	Fairly scientific and based on established principles of insurance	Mostly welfare oriented and based on administrative assessment of losses, and not devoid of political dimension
4	Largely based on 'indemnity principle'	Mainly ad-hoc and depends on the Government's ability and charity in providing the quantum of relief
5	Farmers availing insurance have to pay the consideration (premium), which may or not subsidized	Farmers don't pay consideration to be eligible for relief benefit
6	Farmers who suffer losses has a right to demand compensation	Farmers have no right to demand compensation

Crop Insurance Evolution:

Agriculture, particularly prone to systemic and co-variant risk doesn't easily lend itself to insurance. Lack of historical yield data, small sized farm holdings, low value crops and the relatively high cost of insurance, have further made it more difficult to design, a workable crop insurance scheme (Rao, 2007).

A brief evolution and present status of Indian crop insurance is presented below:

In India although a few concrete ideas were documented between 1912 and 1920, the crop insurance programme, albeit as a pilot become a reality only during 1972.

(i) **Program based on 'individual' approach (1972-1978):** The first ever crop insurance program started in 1972 on H-4 cotton in Gujarat, and was extended later, to a few other crops & states. The program by the time its wound up in 1978, covered merely 3,110 farmers for a premium of Rs. 454,000 and paid claims of Rs. 37.90 lakhs.

(ii) **Pilot Crop Insurance Scheme – PCIS (1979-1984):** PCIS was introduced on the basis of report of Prof. V.M. Dandekar and was based on the 'Homogeneous Area' approach. The scheme covered food crops (cereals, millets & pulses), oilseeds, cotton, & potato; and was confined to borrowing farmers on a voluntary basis. The scheme was implemented in 13 states and covered about 627,000 farmers, for a premium of Rs. 197 lakhs and paid indemnities of Rs. 157 lakhs.

(iii) **Comprehensive Crop Insurance Scheme – CCIS (1985-1999):** The scheme was an expansion of PCIS, and was made compulsory for borrowing farmers. Sum insured which was initially 150 percent of the loan amount, was lowered to a maximum of Rs.10,000 per farmer. Premium rates were 2 percent of the sum insured for cereals & millets and 1 percent for pulses & oilseeds, with premium and claims, shared between the Centre & States, in 2:1 ratio. The scheme when wound up in 1999, was implemented in 16 States & 2 Union Territories and cumulatively covered about 763 lakh farmers, for a premium of Rs. 403.56 crore and paid indemnities of Rs.2319 crore.

National Agriculture Insurance Scheme –NAIS (1999)

NAIS replaced CCIS starting from Rabi 1999-2000 season, presently administered by Agriculture Insurance Company of India Limited (AICI), which provides coverage to approximately 35 different types of crops during the Kharif season and 30 during the Rabi season. Till Rabi 2011-12, NAIS cumulatively covered 291.56 million hectares of crops grown by 193 million farmers covering a risk of Rs. 2,55,576 crore for a premium of Rs. 7606.40 crore and paid or finalized indemnities of Rs. 24,530 crore. The overall loss cost (indemnities to sum insured) stands at 10.55 percent. NAIS is the **world's largest area yield index insurance programme**, which during 2011-12 insured 23 million hectares cultivated by about 17 million farmers for a sum insured of approx. Rs. 34,000 crore (Source: Agriculture Insurance Company of India Limited). The basic working of NAIS is illustrated through an example given in table-2 below:

Table 2 : NAIS illustration of claims at different Indemnity levels

Crop: Groundnut		**Sum Insured (Rs.): 10000**				
Year	**Yield (Kg/Ha.)**					
2004	350					
2005	950					
2006	1200	**Claim Formula:**				
2007	875					
2008	250					
2009	950					
2010	1200	$\text{Indemnity} = \text{Max}\left(0, \frac{\text{Threshold Yield} - \text{Actual Yield}}{\text{Threshold Yield}}\right) \times \text{Sum Insured}$				
Current Yield - 2011 (Kg/Ha.):	650	**(Below given is claim calculation at various indemnity levels)**				
Average Yield of latest 5 years: (Kg/Ha.):	895.00					
	Risk category	**Indemnity level**	**TY (Kg/Ha.)**	**Shortfall (Kg/Ha.)**	**shortfall %**	**claim (Rs.)**
	high risk	60%	537	0	0.00%	0.00
	medium risk	80%	716	66	10.15%	1015.38
	low risk	90%	805.5	155.5	23.92%	2392.31

NAIS and Challenges

NAIS despite best suited for Indian conditions, has some shortcomings. Key shortcomings from farmers' view point are briefly discussed below:

i) The basic premise of yield index insurance is 'homogeneity' of insurance unit (tehsil / block /mandal / hobli etc.) wherein the yield levels and loss experience is by and large similar. However, knowing that these units are primarily 'administrative units', and not created on 'homogeneity', the fundamental problem is 'varied' experience of farmers as against 'similar' experience. This, in other words mean that the yield estimated at insurance unit by sample crop cutting experiments across villages, is unlikely to be representative of majority of the insured farmers' experience (called basis risk in insurance parlance).

ii) Since the indemnity levels vary across crops and regions, in high risk crops unless the yield losses exceed about 40 percent on a sample basis, an insured farmer doesn't become eligible for compensation, though he may have severe crop loss on his farm.

iii) The Threshold yield is calculated taking preceding three years average for rice and wheat and 5 years average for other crops. Since it's a moving average if there happens to be two or three bad years in the average, the threshold yield gets drastically reduced, making it nearly impossible for farmers to get compensation unless the crop losses are severe.

iv) Claims settlement process is very tedious and lengthy. On one hand, it begins only after receipt of final yield estimates from the State government (which could be 3 to 4 months from harvest), on the other, claims can be settled only when the necessary funds are received from Central and State governments as claims exceeding the premium amount shall be borne by the government. There are instances of inordinate delays in claims settlement as the State government could not provide necessary funds timely.

v) Non-loanee farmers' participation is dismal, and one key reason for that is the non-loanee farmer has to avail insurance only through the bank, which many of these farmers are finding inconvenient.

Despite these shortcomings, area yield index is still considered important insurance programme in Indian conditions.

Modified National Agricultural Insurance Scheme (MNAIS)

The government announced a pilot on improved version Modified NAIS (MNAIS) w.e.f. Rabi 2010-11 season for experimentation in 50 districts. The new version has to a large extent taken care of the irritants in the existing NAIS. Some salient features of MNAIS are as follows:

(i) Insurance Unit for major crops is village panchayat or other equivalent unit;

(ii) In case of prevented / failed sowing, claims upto 25 percent of the sum insured is payable, while insurance cover for subsequent period gets terminated;

(iii) Post-harvest losses caused by cyclonic rains are assessed at farm level for the crop harvested and left in 'cut & spread' condition upto a period of two weeks;

(iv) Individual farm level assessment of losses in case of localized calamities, like hailstorm and landslide;

(v) On-account payment up to 25 percent of likely claim as advance, for providing immediate relief to farmers in case of severe calamities;

(vi) Threshold yield is based on average yield of past seven years, excluding upto two years of declared natural calamities;

(vii) Minimum indemnity level of 70 percent is available (instead of 60 percent as in NAIS);

(viii) Premium rates are actuarial supported by up-front subsidy in premium, which ranges from 25 percent to 75 percent, equally shared by Centre and States. Insurer is responsible for the claims liabilities, and

(ix) Non-loanee farmers can also be serviced by insurance intermediaries, including micro insurance agents

As can be seen from the features, MNAIS seem to have resolved some of the key shortcomings of NAIS. The basic working of MNAIS is illustrated through an example using the same dataset (assumptions) of NAIS, given in table-3 below:

Table-3: MNAIS illustration of claims at different Indemnity levels

Crop: Groundnut		**Sum Insured (Rs.):10000**				
Year	**Yield**					
2004	350	calamity year1				
2005	950					
2006	1200					
2007	875					
2008	250	calamity year2	Claim Formula:			
2009	950					
2010	1200					
Current Yield - 2011 (Kg/Ha.):	650	$\text{Indemnity} = \text{Max}\left(0, \frac{\text{Threshold Yield} - \text{Actual Yield}}{\text{Threshold Yield}}\right) \times \text{Sum Insured}$				
Average Yield of latest 7 years: (Kg/Ha.):	825.00					
Average Yield of latest 7 years less 2 calamity years (Kg/Ha.):	1035	**(Below given is claim calculation at various indemnity levels)**				
	Risk category	**Indemnity level**	**TY (Kg/Ha.)**	**Shortfall (Kg/Ha.)**	**Shortfall %**	**claim (Rs.)**
	high risk	70%	724.5	74.5	11.46%	1146.15
	medium risk	80%	828	178	27.38%	2738.46
	low risk	90%	931.5	281.5	43.31%	4330.77

As can be seen, besides qualitative improvements like reduction of insurance unit size, prevented / failed sowing benefits, 'on-account' payment of claims, individual farm assessment of hailstorm & landslide losses, coverage of post-harvest losses, MNAIS is quantitatively much better than NAIS. At the same time MNAIS is not free from challenges, and a few of them are discussed below:

(i) Insurance unit for major crops has been lowered to village / village panchayat which is good for the farmers, but exponentially increases the work load required for crop cutting experiments (CCEs). Many States are shying away from the pilot because of the enormity of the workload. Some states are requesting GoI to share part of the cost of CCEs. From the insurer's point of view, timely and quality data is needed to price the product accurately and to make timely pay-outs. Since the yield estimation is done by the State agencies, insurers may have a lurking fear that the yield estimation process is prone to subjectivity as well as local interferences. It's, therefore, worthwhile in the long run to deploy technologies like satellite imagery for estimating the yield, which is largely free from human interference.

(ii) Present premium subsidy structure does not provide much support for lower to medium risk layers. For example for Rabi 2010-11 season farmers' share of premium was Rs. 23.23 crore (out of total Rs. 47.30 crore). In other words, farmers paid 50 percent of the cost of the insurance under MNAIS compared to only about 30 percent under NAIS & WBCIS. There is a strong need for increasing the premium subsidy for lower and middle tiers

Weather Index Insurance

Weather index based insurance caught the imagination of the policy makers at the beginning of 21st century, and international financial institutions like the World Bank encouraging the pilots in low income countries where traditional crop insurance could not take off for various reasons, including lack of historical yield or loss data. The basic purpose of 'weather index' insurance is to estimate the percentage deviation in crop output due to adverse deviations in weather conditions. There are crop modeling and statistical techniques to precisely workout the relationships between crop output and weather parameters. This gives the linkage between the financial losses suffered by farmers due to weather variations and also estimate the payouts that will be payable to them.

Its worth mentioning that the pioneering work on weather index insurance commenced as far back as 1912 by J S Chakravarthi, as a mechanism to compensate crop losses. It was between 1912 and 1920, Chakravarthi of Mysore State (India) published technical papers on the subject of 'Rainfall Insurance' and a book entitled **'Agricultural Insurance: A Practical Scheme Suited to Indian Conditions'**, in 1920, describing how rainfall index could be used to guarantee payouts to farmers due to adverse deviations. He used rainfall data from 1870 to 1914 from India Meteorological Department (IMD) to demonstrate the utility of the index. Surprisingly, this piece of pioneering work, which is probably one of the earliest monographs on the subject, does not appear to have been taken into account in the analytical literature on agricultural insurance (Mishra P K). It was some 85 years later that the policy makers of the modern world started advocating the very same index for low income countries.

Weather Index – Key Advantages

One key advantage of the weather index based crop insurance is that the payouts could be made faster, besides the fact that the insurance contract is more transparent and the transaction costs are lower. Because index insurance uses objective, publicly available data it is less susceptible to moral hazard (IRI, 2009). Most importantly there are many low income countries where no historical data whatsoever is available, except weather data, affording an opportunity to try out some sort of index insurance.

Thanks to the advocacy role played by the World Bank, many countries are piloting the weather index based crop insurance. Countries like Mexico, India, Ukraine, Malawi, Ethiopia and China have been piloting weather index based crop insurance for some years, while others like Tanzania, Nicaragua, Thailand, Kazkhastan, Senegal, Morocco, Bangladesh, Vietnam, Caribbean Islands the weather index products are in development stage (Barry and Olivier, 2007).

Pilot weather risk based crop insurance:

In order to address some of the shortcomings of NAIS, Agriculture Insurance Company of India (AICI) developed a pilot weather risk index-based insurance product in 2004. Building on the existing weather risk insurance products, the Government asked AICI in 2007 to design the Weather risk-Based Crop Insurance Scheme (WBCIS) as a pilot.

Insurers are using various attributes of the weather, an illustration of it is shown in table-4 below:

Table 4 : Weather parameters indexed under WBCIS

Table: Weather Index Parameters		
S.No	**Weather Parameter**	**Components**
1	Rainfall	Deficit rainfall, Consecutive Dry Days (CDD), Number of Rainy Days, Excess rainfall, Consecutive Wet Days (CWD)
2	Temperature	Max. Temperature (heat), Min. Temperature (frost), Mean Temperature, Hourly Chilling units
3	Relative Humidity	High Humidity
4	Wind Speed	High Wind Speed
5	Disease proxy	Combination of Weather parameters like rainfall, temperature & humidity

AICI developed parametric weather risk based crop insurance for a variety of crops ranging from seasonal to perennial crops and low value to high value crops. An example of the product for deficit rainfall is presented in table-5, below:

Table 5 : WBCIS illustration

Crop: Groundnut	**Season: *Kharif***			
		PHASE-I	**PHASE - II**	**PHASE – III**
1 A. Rainfall Volume	**PERIOD**	**21st June to 15th July**	**16th July to 15th Aug**	**16th Aug to 30th Sept**
	TRIGGER I (<)	**80 mm**	**160 mm**	**80 mm**
	TRIGGER II (<)	**40 mm**	**80 mm**	**40 mm**
	EXIT	**20**	**30**	**20**
	RATE I (Rs./ mm)	**25**	**25**	**25**
	RATE II (Rs./ mm)	**75**	**60**	**75**
	Max. Payout (Rs.)	**2500**	**5000**	**2500**
	TOTAL PAYOUT (Rs.)	**10000**		
1 B. Rainfall Distribution (Consecutive Dry Days)	**PERIOD**		**1st July to 31st August**	
	TRIGGER DAYS (>=)	**20**	**25**	**30**
	PAYOUT (Rs.)	**1500**	**3000**	**5000**
	TOTAL PAYOUT (Rs.)	**5000**		
Rainfall of less than 2.5 mm in a day shall not be considered as a rainy day; and multiple payouts considered				
Max. Payout (Rs.) 15000				

During 2011-12 as many as 15 States have combinedly implemented the pilot programme in over 150 districts covering more than 1000 Blocks / tehsils. Most importantly the State of Rajasthan implemented the pilot in all areas of the State, while Bihar in all but three districts of the State. The weather insurance market as a whole in the country insured during 2011-12 over 11.60 million farmers for an acreage of over 15.63 million hectares covering a risk valued at Rs.20,900 crore with a premium of Rs. 1850 crore.

Going by the fantastic growth witnessed in the past four years, there appears greater awareness and acceptance at least by the States, though not all farmers seem to be convinced.

Weather Index Insurance: Key Challenges

Weather index insurance though considered more transparent and enables quick settlement of claims, has a few grey areas as insurance tool as well as in comparison to yield index insurance. These key areas are briefly discussed below:

(i) Substantial premium subsidies and the market demand for regular payouts rendered weather index insurance more like a 'money-back' policy that pays small amounts of payouts every second or third year, rather than working as insurance product that compensates medium and large losses once in five to ten years.

(ii) If one analyzes a typical kharif weather index insurance product covering 'deficit rainfall', the sum insured (maximum payout) is distributed across different crop stages (primarily to meet the market demand for regular payouts). This renders the product often unsuitable for severe losses as the product may not be able to pay more than half of the sum insured because of its a distribution across the crop phases.

(iii) Another grey area is the likely difference in rainfall and weather experience between the weather station location and the farmer's field. With a weather station being referenced to a radius of more than 10 KM, in the present circumstances there are bound to be differences in weather, particularly the rainfall between the location of weather station and the farmer's field. The result may either lead to undeserved payouts and vice versa. This problem in index insurance is known as 'basis risk'. Ideally every village should have a weather station to reasonably minimize the basis risk, which would require almost 50 fold increase in the existing weather station network.

(iv) Yet another grey area is the difficulty in designing a proxy weather risk index with predictive capability to realistically measure crop losses. Weather –Yield relationship is not as simple and straight forward as it looks. With different soil types, planting dates, management practices, the relationship weather – yield could be quite complex. The result often could be payout without a crop loss and vice versa.

One solution at least to partially minimize the shortcomings and enhance the strengths of yield insurance and weather insurance is to create a hybrid of them as 'double-trigger' insurance products wherein weather index insurance provides a trigger against indexable weather deviations as also release early payout, while yield index provides protection against crop losses due to other than indexable weather events like pests & diseases, as also residual weather deviations not captured by weather index.

Crop Health Index:

Another index with potential to provide reasonably sound platform for extending insurance, is satellite imagery based Normalized Difference Vegetative Index (NDVI), which is a reflection of crop health. A few pilots have been conducted by AICI in Haryana & Punjab for wheat crop, but the results are not very encouraging.

The comparison of insurance products based on yield index, weather index and crop health index are presented in table-6:

Crop Insurance as Safety-net in Drought Mitigation Tool: Key Policy Directions

Crop insurance like any other insurance cannot prevent economic losses, but can certainly help the farming community in reducing its financial losses. Crop insurance given the context of increasing uncertainties of climate has to play an important role as an integral part of overall risk management of agricultural risks. Some key policy directions are outlined below towards making crop insurance effective and meaningful:

(i) **Agriculture risk protection act:** Agriculture insurance is specialty insurance, and different from traditional general insurance in many respects. As an illustration, agriculture insurance, particularly crop insurance programme is conceived as a 'multiple-agency' approach in which Rural Financial Institutions (RFIs), State government, Central government etc. are actively involved, with the government providing significant financial support. Moreover the programme is compulsory for loanee farmers. A programme of this nature and magnitude is unlikely to be effectively administered unless backed by a statute. It may be worthwhile to note that the countries like United States of America, Canada, Spain, Japan, Philippines etc. where crop insurance is being used as an integral part of 'agriculture risk management' a separate statute is in force, and facilitating smooth implementation of the programme.

Table 6 : Index Insurance Comparison of Yield, Weather & Crop Health

Yield Index Insurance	Weather Index Insurance	Crop Health Index Insurance
Characteristics 1. Practically 'all-risk' insurance 2. Can work well for field crops having historical yield data of at least 10 – 15 years 3. Works efficiently when the insurance unit is largely homogenous ***Strengths*** 4. Very important program in developing countries like India where large number of small sized farm holdings exist 5. It's a good solution where historical farm-level yield data do not exist 6. Can minimize problems associated with 'asymmetric information', like adverse selection & moral hazard 7. Credit-linkage can help in reducing administrative cost ***Weaknesses*** 8. Delay in indemnity payment of almost 6 - 9 months as indemnity processing is linked to availability of final yield estimates 9. Basis risk is another serious problem as the insurance unit is rarely homogenous 10. Huge administrative cost in conduct of yield estimation surveys, and also the possibility of interference at grass root level in yield estimation	***Characteristics*** 1. Payouts are linked to level of the weather index 2. Can be designed for field crops and horticultural crops having weather data of 25 – 30 years ***Strengths*** 3. Has almost all the advantages of 'Area Yield' Insurance, plus many other positive features 4. It can work even for areas / crops, which do not have historical yield data 5. Provides timely indemnity payment 6. All communities whose incomes are dependent on weather could buy the insurance 7. Indemnity payments are made on the basis of weather data, which is both tamper-proof & accurate and transparent ***Weaknesses*** 8. Basis risk due to poor density of weather station network 9. Scope limited to parametric weather exigencies 10. Challenges in contract design 11. Challenges in actuarial modeling 12. Changing weather patterns	***Characteristics*** 1. Practically 'all-risk' insurance 2. Can work well for field crops and forage crops 3. Best captures crop stress (drought and pest / disease affected) 4. About 10 years' historical satellite imageries is must ***Strengths*** 5. Provides for reasonably accurate loss assessment 6. Faster and rapid loss assessment 7. Provides for reasonably timely indemnity payments 8. Can assess losses of areas unapproachable by normal means ***Weaknesses*** 9. Unsuited for tree crops; and seasonal crops where the economic product grows below the surface 10. Quality scientific information is required in designing the insurance product 11. Requires all-weather satellite and good resolution images at key crop stages, which is a challenge 12. Could be expensive in the initial stage

A number of countries also have clearly articulated their policy commitment through specific legislations for agricultural protection. It may be interesting to note that many countries in European Union have specific guidelines delineating the role of agriculture insurance vis-à-vis ad-hoc and disaster relief. The status w.r.t. a few countries in European Union is provided in the table-7 below:

Table 7 : European Union: Agriculture Risk Protection

- **Austria, Spain, Portugal, Greece and Sweden**: There are no payments from a public fund if there is insurance available.
- **France**: Payments include those damages for which there is no insurance at all or that insurance has not reached yet a significant diffusion level.
- **Italy**: Only subsidized risks are excluded from public ad-hoc payments after natural disasters.
- **Romania**: Only payments from the public budget are given to farmers in the case of natural disasters if they have insured risks called "standard risks" like hail.

Source: Agriculture Insurance Schemes by European Union (Modified Report of February 2008)

(ii) Catastrophic insurance and universal coverage of farmers: Despite over 25 years' of existence of country-wide crop insurance programme, only about 1/5th of the farmers or cropped area could be brought under insurance. Only a minority of non-loanee (institutional non-borrowers) who constitute about 60 percent of the total farmers participate in crop insurance despite high level of premium or claim subsidies. Moreover, there are many crops particularly vegetables & fruits etc. for which insurance products are not available. At present, though there are provisions to extend relief to such farmers in case of catastrophic weather events or crop disasters, but the quantum of such relief is largely ad-hoc, limited and subject to availability of funds. In order to protect the non-borrowing farmers from extreme financial distress and provide basic economic security, and other farmers cultivating crops which do not have insurance products the Government can introduce 'Catastrophe Protection' or 'Non Insured Crop Loss Assistance' for farmers. Such protection can also become an effective conduit for channelizing calamity and disaster relief funds from central and state governments. By linking relief funds to Catastrophe Protection or Crop Disaster Assistance, the benefit of such relief can be passed on to the targeted groups with greater efficiencies and transparency.

(iii) Defining the role of agriculture insurance: Agriculture insurance has been used by the government as a tool of risk management though since 1985, its role vis-à-vis other risk management tools, particularly (ad-hoc) 'relief' is not very clearly delineated. Consequently there are many government programmes operating almost with similar objectives, leading to duplicity and lack of accountability. It's time the role of agriculture insurance is clearly defined, and possibly channelize a portion of the funds going into agriculture sector using other programmes through agriculture insurance, This would on one hand, avoid duplication and maximize value of the government's funds, and on the other, will also help in minimizing the competition between agriculture insurance and government's (ad-hoc) relief. **It would be an important policy initiative if eligibility or access to the government's subsidies and extension services in this sector is linked to participation in agriculture insurance.**

(iv) Financial literacy: Despite Agriculture insurance existing in the country for over 25 years, its awareness levels are poor not only among the farmers, but also among the policy makers and key government functionaries. Only a sustained capacity building for stakeholders and financial literacy programme aimed at the farming community could help in understanding the merits of agriculture insurance, which in-turn could help in increase in adoption rate of agriculture insurance.

(v) Appropriate mix of insurance models: Experience of index based insurance products in India suggest that the various index products are not substitutes for each other, but largely complementary in nature. For example, between yield and weather index products, each have their strengths and weaknesses. Yield index insurance provides nearly all-risk cover, where as weather index insurance quick and timely payouts. A combination of these indices like '**double trigger**' or '**multiple trigger**' insurance products can bridge the 'gap' in indemnity and lower the basis risk.

(vi) Weather station density: India Meteorological Department (IMD) though rapidly increasing its network of other stations, it would not be adequate to meet the growing demands of weather insurance. For weather insurance to be effective and realistic, a rain gauge should be placed for every 5 KM radius. Similarly a weather station for every 10 KM radius. This would require about 35,000 rain gauges and 10,000 weather stations to cover the country. Given the enormity of task, it may be good idea to bring all public and private weather stations on a 'weather grid'. However its equally important to ensure that the equipment is sound and required levels of security and accuracy of data is maintained before allowing a particular weather station on to a 'weather grid'. This would help in public-private investment in the sector while meeting the requirements.

(vii) Technology: Technology is expected to play a crucial role in creating a robust decision support system to increase the adaptability of agriculture insurance and to mitigate the risk. The main technologies centre on weather data and yield data generation. For example, it's quite possible to create 'virtual weather station' network at 1 KM grid level using Terrestrial Observation and Prediction Systems (TOPS) with capabilities to provide medium range weather forecast. Similarly, finer resolution satellite imagery can estimate yields, provide early warning on crop loss minimization measures, etc. In other words, these technologies have to play an important role in increasing the adaptability of agriculture to the changing profile of agricultural risks.

(viii) Incentives for sustainable agriculture practices: While subsidies are must in agriculture insurance, it would be equally important to build risk management stipulations and incentives into the programme for sustainable agricultural practices, like integrated pest management, low Green House Gases (GH) crops, etc.

PREDICTION OF EXTREME WEATHER EVENTS USING MESOSCALE MODELS

U C Mohanty

The coastal region of India is one of the most disaster-prone areas in the world. The extreme weather events like severe thunderstorms, tornadoes, tropical cyclones, monsoon depressions and systems associated with heavy rainfall evolve through different scales of processes. The genesis, intensification and movement of these weather events involve complex interaction mechanism of mesoscale convective systems embedded in large-scale circulation. Timely and reasonably accurate prediction of these high impact weather systems can significantly reduce loss of lives and damage to property. With the advancement of high resolution mesoscale models and sophisticated data assimilation techniques, it became possible to generate more accurate prediction of such extreme weather events. Also, the demand for deterministic prediction of such high impact weather events has increased worldwide. The foundation of short and medium range Numerical Weather Prediction (NWP) efforts based on complex atmospheric models is key component in studies of global weather and climate processes. Better understanding of the physical processes involved in different atmospheric phenomena often rests upon diagnostic studies of output from numerical models, since observations with sufficient density or quality are not always available. This ubiquitous use of numerical models suggests that all aspects of numerical models need to be understood properly by those who use the models or examine their outputs.

The high impact weather events are short lived and localized mesoscale intense convective processes. Although, there have been significant improvements in NWP in last few decades, the prediction of high-impact tropical extreme weather events is still a difficult and challenging task for the operational forecasters. Since inception of operational NWP in mid sixties of last century, it has been constant endeavor to simulate high impact tropical weather events such as tropical cyclone, thunderstorm and tornado (Kasahara, 1957). In this study, advancements in the prediction of some of the extreme weather events using NWP models are discussed and a few results are illustrated.

High Resolution Mesoscale Models

The Weather Research and Forecasting (WRF) system, a state-of-the-art mesoscale model, is used to advance the understanding and prediction of mesoscale convective systems. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. The WRF model is used for a wide range of applications, from idealized research to operational forecasting, across scales ranging from meters to thousands of kilometers.

The Weather Research and Forecasting (WRF) model contains two dynamic cores: the Non-hydrostatic Mesoscale Model (NMM – Janjic 2003) core, developed at the National Centers for Environmental Prediction (NCEP) and the Advanced Research WRF (ARW –Skamarock *et al.* 2005) core, developed at the National Center for Atmospheric Research (NCAR). Table 1 gives a brief illustration of the two WRF dynamic systems.

Table 1: A brief illustration of the two WRF dynamic systems

ARW	**NMM**
Terrain following sigma vertical coordinate	Hybrid sigma to pressure vertical coordinate
Arakawa C-grid	Arakawa E-grid
3rd order Runge-Kutta time-split differencing	Adams-Bashforth time differencing with time splitting
Conserves mass, entropy and scalars using up to 6th order spatial differencing equation for fluxes (5th order upwind diff. is default)	Conserves kinetic energy, enstrophy and momentum using 2nd order differencing equation
NCAR physics package	Eta/NAM physics
Noah unified land-surface model	Noah unified land-surface model

Initial and boundary conditions for all the following cases are derived from 6-hourly global final analysis (FNL) at 1.0° x 1.0° grids generated by National Center for Environmental Prediction (NCEP)'s global forecast system (GFS). Table 2 briefly describes the model configuration used for different convective activities.

Table 2: Model configuration of different convective activity

Physics options	Thunderstorm	Tropical Cyclone	Heavy Rainfall/ Monsoon Depression
Radiation parameterization	GFDL/GFDL	GFDL/GFDL	Rrtm/dudhia
Surface layer parameterization	Janjic similarity scheme	NCEP GFS scheme	Janjic similarity scheme
Land surface parameterization	NMM Land surface scheme	NMM Land surface scheme	Noah Land surface scheme
Cumulus parameterization	Grell-Devenyi ensemble scheme	Simplified – Arakawa- Schubert	Grell-Devenyi ensemble scheme
PBL parameterization	Mellor-Yamada-Janjic	YSU	YSU
Microphysics	Ferrier scheme	Ferrier scheme	Ferrier scheme

Simulation of Extreme Weather Events

The skill of prediction has been demonstrated here through the numerical simulations with the mesoscale modeling as well as assimilation systems. Mohanty *et al* (2009a) demonstrated the prediction of extreme weather events using high resolution mesoscale models.

a. Simulation of severe thunderstorms:

Thunderstorm is a mesoscale system of space scale - a few kilometers to a couple of 100 kilometers and time scale of less than an hour to several hours. During pre-monsoon season (April-May), very severe thunderstorms form and move from northwest to southeast over the Eastern and Northeastern states of India (i.e., Gangetic West Bengal, Jharkhand, Orissa, Assam and parts of Bihar). They are locally called "Kal-baishakhi" or "Nor'westers". Strong heating of landmass during mid-day initiates convection over Chhotanagpur Plateau, which moves southeast and gets intensified by mixing with warm moist air mass from head Bay of Bengal (BoB). It produces heavy rain showers, lightning, thunder, hail-storms, dust-storms, surface wind squalls, down-bursts and tornadoes. The northwest India gets convective dust-storms called locally as Andhi, in this season. These severe thunderstorms associated with thunder, squall lines, lightning, torrential rain and hail cause loss of life and damage to property. The high resolution non-hydrostatic mesoscale models with sophisticated physical parameterization schemes would be very useful tools for reasonably accurate prediction of these severe thunderstorms (Weiss *et al.*, 2007). Several studies related to the simulation of severe thunderstorm events using WRF-NMM model have been performed (Kain *et al.*, 2006; Litta and mohanty, 2008; Litta *et al.*, 2009; 2012).

In the present study, an attempt has been made to simulate a severe squall line that occurred over Kolkata (22.65 °N, 88.45 °E) on 03 May 2009, using NMM model and the results are validated with observational data. This intense convective event produced 31.4 mm rainfall over Kolkata. The weather situation started with a squall passing Dum Dum airport on 03 May 2009 at 11 UTC with a maximum speed of 17 ms^{-1} lasting for a few minutes. A few places recorded moderate rainfall over Gangetic West Bengal (GWB) and isolated rainfall over Orissa, Chattisgarh and Bihar. The details of the system are explained in Mohanty *et al.* (2009b). In this study, the model was integrated for a period of 24 hours, starting from 03 May 2009 at 00 UTC as initial values. A single domain with 3 km horizontal spatial resolution was configured.

Figure 1a shows the inter-comparison of observed and NMM model simulated diurnal variation of accumulated rainfall (mm) over Kolkata valid from 03 May 2009 at 00 UTC to 04 May 2009 at 00 UTC. The model is able to simulate 29 mm of rainfall at 12 UTC, which is close to the actual observation (31.4 mm). The model simulated thunderstorm is one hour after the actual occurrence (11 UTC).

The model has well captured the rainfall intensity and the time of occurrence. Figure 1b shows the inter-comparison of observed and model simulated relative humidity (%) using NMM model over Kolkata valid for 03 May 2009 at 00 UTC to 04 May 2009 at 00 UTC. The observed relative humidity values peaked from 54% to 100% at 11 UTC whereas model showed a sharp rise from around 46% to 80% at 12 UTC, which is one hour after the thunderstorm occurrence.

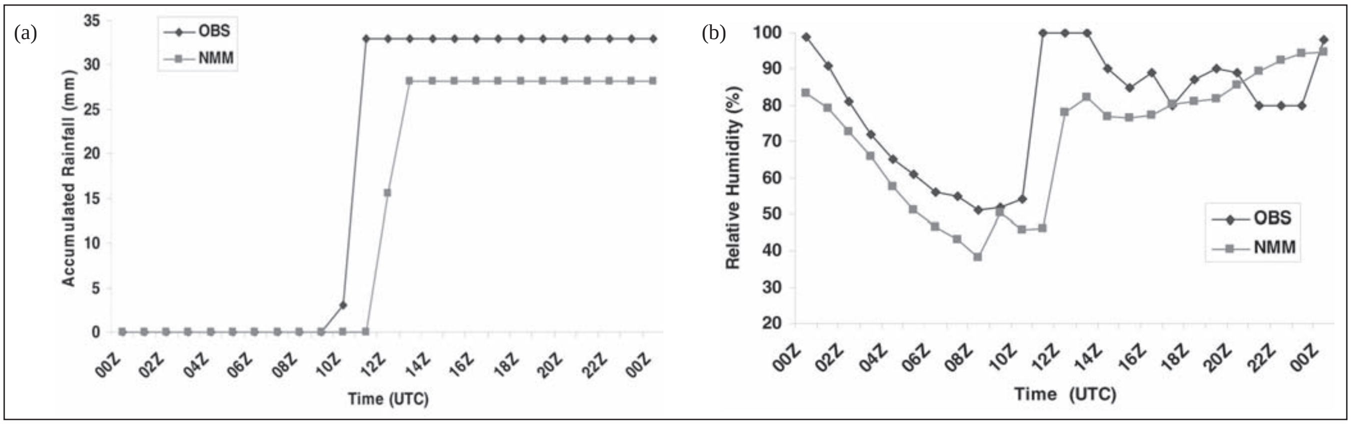


Fig. 1 : Inter-comparison of observed and NMM model simulated diurnal variation of (a) accumulated rainfall (mm) (b) relative humidity (%) over Kolkata valid from 03 May 2009 at 00 UTC to 4 May 2009 at 00 UTC.

The spatial plots of NMM model simulated surface wind speed from 10 UTC to 13 UTC (Fig. 2) shows that a squall line is initiated at 10 UTC from the north-west of Kolkata, gradually moved towards Kolkata and intensified at 12 UTC as in DWR analysis. The squall line passed over Kolkata with a maximum speed of 18 ms^{-1}, which is consistent with the weather report that a squall line passed over Kolkata at 11 UTC from northwesterly direction with maximum speed of 17 ms^{-1}. The prediction of the dominant convective mode is based on the assessment of magnitude of vertical motion, which is needed to initiate convection (May and Rajopadhyaya, 1999). Figure 3 shows the time-height cross section of model simulated pressure vertical velocity over Kolkata valid from 03 May 2009 at 00 UTC to 04 May 2009 at 00 UTC. The figure shows a strong upward velocity with a magnitude of -14 Pas^{-1} existed during the model simulated thunderstorm hour, which is an important phenomenon related to thunderstorm life cycle. The trends shown by various meteorological fields of NMM model are in good agreement with each other and very much consistent with dynamic and thermo-dynamic properties of the atmosphere for the occurrence of a severe thunderstorm on 03 May 2009.

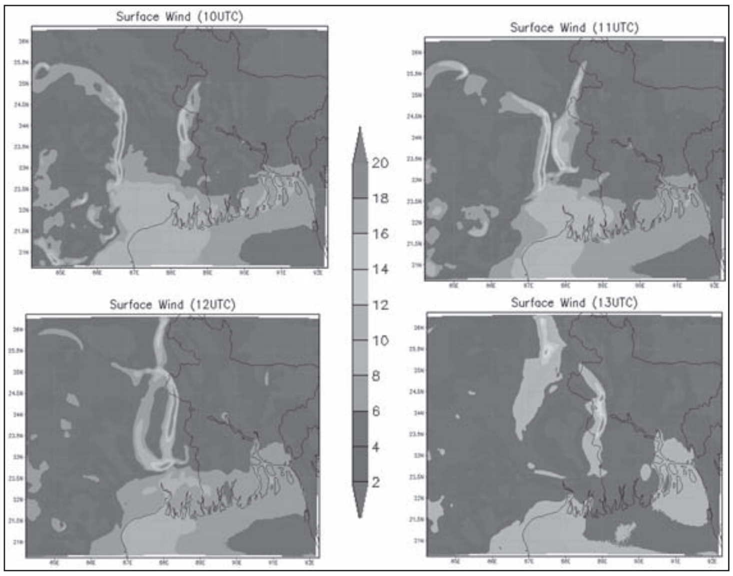


Fig. 2 : Spatial distribution of surface wind speed (ms^{-1}) on 03 May 2009 at (a) 10 UTC (b) 11 UTC (c) 12 UTC (d) 13 UTC.

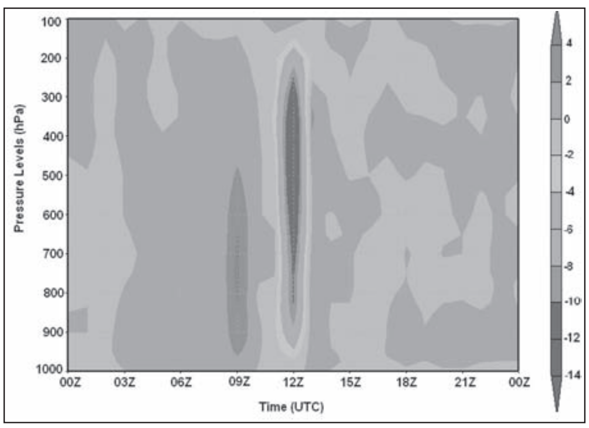


Fig. 3 : Model simulated time-height cross section of pressure vertical velocity (Pas^{-1}) over Kolkata valid from 03 May 2009 at 00 UTC to 04 May 2009 at 00 UTC.

b. Simulation of tropical cyclone:

Tropical cyclones are among nature's most violent manifestations and potentially a deadly meteorological phenomenon worldwide. The Indian seas comprising of Bay of Bengal (BoB) and Arabian Sea (AS) contributes about 7% of the global annual tropical storms of relatively moderate intensity as compared to typhoons and hurricanes. Though the frequency is relatively less over Indian seas, out of 10 recorded deadliest cases with very heavy loss of life (ranging from about 40,000 to well over 200,000) over the world, 8 cases formed in the BoB and AS in the past 300 years. Moreover, the Bay of Bengal storms are exceptionally devastating, especially when they cross the land (Mohanty, 1994). Thus the Bay of Bengal tropical cyclone is the deadliest natural hazard in the Indian sub-continent. It has significant socio-economic impact on countries bordering the Bay of Bengal, especially India, Bangladesh and Myanmar. At the same time, Arabian Sea contributes 2% of the global annual tropical storms. Therefore, reasonably accurate prediction of these storms is important to avoid the loss of lives. There are a number of studies (Mohanty *et al.*, 2010; 2013; Pattanayak and Mohanty, 2008; Pattanayak *et al.*, 2012; Osuri *et al.*, 2011) encompassing the use of high resolution WRF modeling system in prediction of tropical cyclones over North Indian Ocean.

The tropical storm Gonu has developed as a depression over the east central Arabian Sea with center near lat 15.0 ºN, long 68.0 ºE at 18 UTC 01 June 2007. It moved westwards and intensified into a cyclonic storm at 09 UTC 02 June 2007 near lat 15.0 ºN, long 67.0 ºE. It remained in that stage for 15 hours i.e. up to 00 UTC 03 June 2007. By 00 UTC 03 June 2007, it intensified into a severe cyclonic storm with the central pressure of 988 hPa and centered at lat 15.5 ºN, long 66.5 ºE and the storm remained in that stage for next 18 hours i.e. up to 15 UTC 03 June 2007. Continuing its northwestward movement, it further intensified into a very severe cyclonic storm by 18 UTC 03 June 2007 and lay centered at lat 18.0 ºN, long 66.0 ºE with the central pressure of 980 hPa. It sustained in that stage for next 18 hours i.e. up to 15 UTC 04 June 2007. By 15 UTC 04 June 2007, the system moved west-northwestwards and further intensified as a super cyclonic storm.

Figure 4a and b represents the day-3 forecast of mean sea level pressure and wind at 850 hPa valid at 00 UTC 06 June 2007. The model simulation shows that the storm moved northwestward with the minimum central pressure of 981 hPa. The observed central pressure at that time was 970 hPa. The observed maximum sustained surface wind at that time was 77 kts, whereas the model could simulate the maximum wind of 66 kts. Figure 5 represents the 24 hrs accumulated precipitation valid at 03 UTC of 06 June 2007. Figure 5a represents 24hrs TRMM accumulated precipitation valid at 03 UTC of 06 June 2007. Figure 5b represents the Day-3 forecast of accumulated precipitation valid at 03 UTC 06 June 2007 from WRF-NMM. The observed precipitation is about 16 cm in Day-3 whereas the model could simulate on precipitation of 14 cm. The track of the cyclone as obtained with both the model

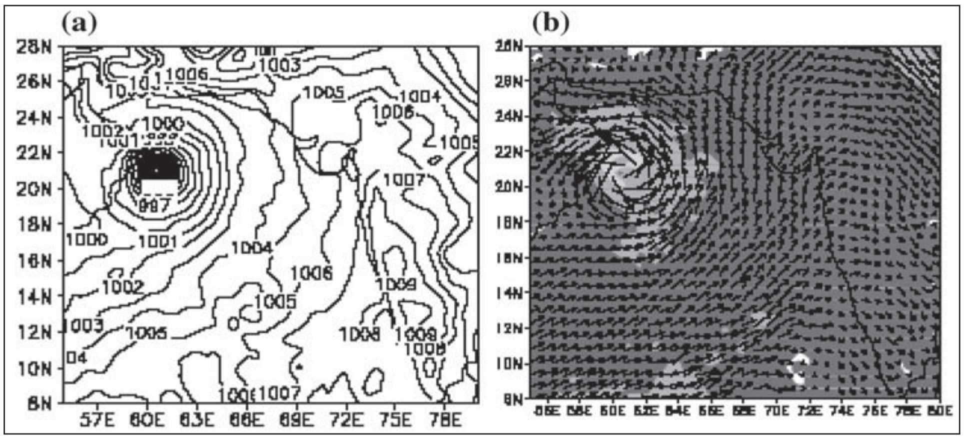


Fig.4 : Simulation of mean sea level pressure & wind at 850 hPa for case-II (Gonu), (a) MSLP for Day-3 and (b) wind for Day-3.

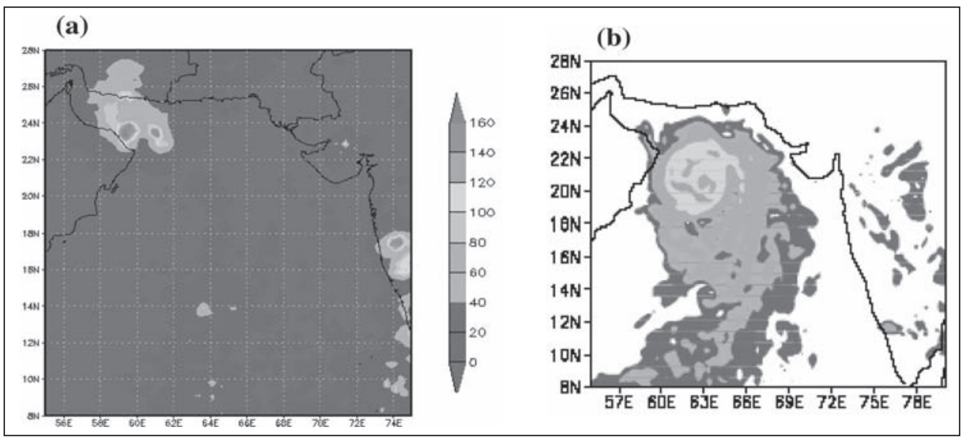


Fig. 5 : 24 hours accumulated precipitation valid at 03 UTC 06 June 2007. (a) Observed from TRMM and (b) simulated with WRF-NMM (Day – 3).

simulations from different initial conditions are evaluated and compared with the best-fit track obtained from IMD. Figure 6 represents the track of the cyclone Gonu as obtained with model simulations from different initial conditions.

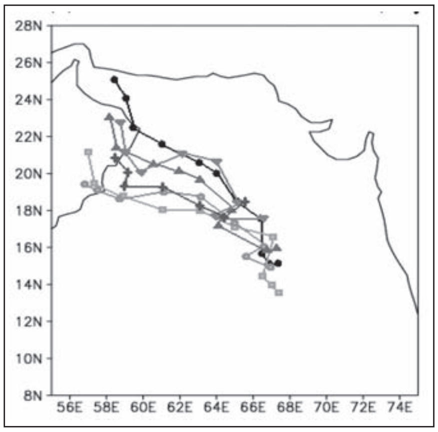


Fig. 6 : Track of the cyclone Gonu.

c. Simulation of heavy rainfall events:

South west (SW) monsoon is the main feature in the climate of India as well as the principal denominator of the prosperity of the country and the agro-economy. Most of the country as a whole receives 70% of the total annual rainfall except southern parts of peninsula, especially Tamil Nadu (Parthasarathy, 1984) during this SW monsoon season. Hence, it not only nourishes the kharif crops but enriches all sources of irrigation to enable cultivation of a wide variety of crops during rabi and pre-kharif season.

Over the Indian monsoon region in particular, the better simulation of weather events like heavy rainfall and monsoon depressions are important which routinely have resulted in flooding and significant loss to agriculture, life and property during the Indian monsoon. But the current mesoscale models have limited success in simulating these events over the region (Routray *et al.*, 2005). The forecast performance of the mesoscale models critically depends on the quality of initial conditions (Pielke, 2006). Typically, large scale global analyses which provide the initial condition to the mesoscale models have limitations such as coarse resolution and inadequate representation of localized mesoscale features. Therefore, assimilation approaches like 3-dimensional variational data assimilation (3DVAR) that ingest local observations are important to develop improved analyses (Daley, 1991) and hence the forecast. Routray et al (2009) simulated the heavy rainfall events over Indian monsoon region using WRF-3DVAR data assimilation system. Vinod Kumar *et al.* (2007) adopted four dimensional data assimilation (FDDA) and surface data assimilation to study tropical depressions over Bay of Bengal. The results suggested that improvement of monsoon depression simulations over Bay of Bengal were equivalent or better than that of increasing the model resolution from 30 km to 10 km grid spacing. The main purpose of this study is to demonstrate the ability of the WRF-ARW mesoscale model in simulating the heavy rainfall events like Mumbai heavy rainfall (26-27 July 2005) with and without assimilation of Indian conventional and non-conventional observations using 3DVAR assimilation system.

The Mumbai heavy rainfall was a record-breaking rain event, Santacruz received 94.4 cm within 24hrs and the study by Jenamani et al. (2006) described details of the event. To simulate this localized and intense rainfall event, two numerical experiments with (3DV) and without (CNTL) data assimilation are carried out. For both the experiments, the model integrated 36 hrs from 00 UTC of 26 July 2005 up to 12 UTC of 27 July 2005. Figure 7 shows the temporal evolution of model and observed cumulative rainfall over Santacruz and

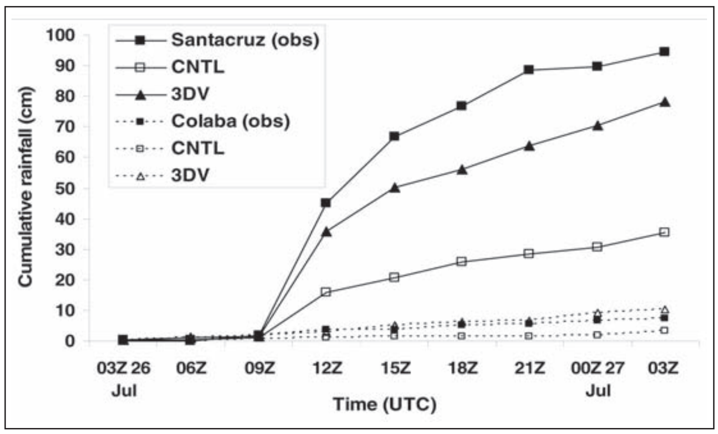


Fig.7 : Observed and simulated 3-hourly interval cumulative rainfall (cm) over Santacruz and Colaba on 26-27 July 2005.

Colaba IMD recording stations along 72.5 ^{0}E. It is clearly observed that the record-breaking rainfall at Santacruz is significantly improved in the 3DV simulation (more than 78 cm) compared with the CNTL simulation (36 cm). At the same time, the 3DV experiment also simulated well low rainfall amount over Colaba as compared to the CNTL simulation and trend matched well with the observations. Figure 8 shows the 24hrs accumulated precipitation as obtained from CNTL and 3DV experiments and satellite estimates rainfall (TRMM) along with the IMD ground based rain gauge observations at and around Mumbai. The orientation and distribution of rainfall is well simulated in the 3DV experiment (Figure 8d) and feature matched very much with the satellite estimated rainfall pattern (Figure 8b). However, the CNTL experiment (Figure 8c) shows the patch of maximum rain (50-60 cm) very much away from the observed location with a location error 120 km northeast of Santacruz, Mumbai.

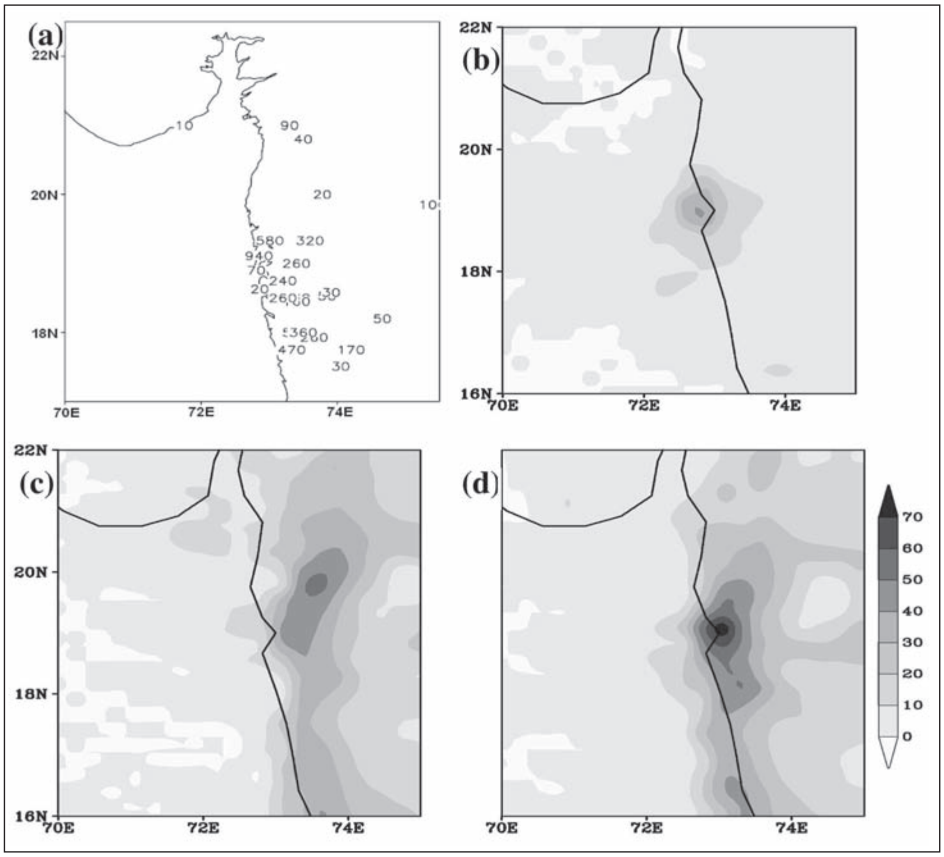


Fig. 8 : (a) IMD observed rainfall (mm) and 24 hrs accumulated rainfall (cm) for (b) TRMM (c) CNTL and (d) 3DV valid at 0300 UTC of 27 July 2005.

Conclusions

The model simulation studies of severe thunderstorm, tropical cyclone, heavy rainfall and monsoon depression lead to the following broad conclusions:

The WRF-NMM model simulated meteorological parameters such as relative humidity and rainfall are consistent with each other and in good agreement with the observation values with one hour time lag. From the model simulated spatial plots of composite radar reflectivity, the squall line movement is clearly noticeable.

The WRF-NMM model also could simulate most of the features of the cyclones Mala and Gonu with reasonable accuracy. The intensity of the tropical cyclones in terms of MSLP and maximum sustainable wind illustrates that the model underestimates the intensity of the storm. The pattern of distribution of precipitation is reasonably well predicted for both the cyclone cases. The mean vector displacement error clearly demonstrates the forecast skill of the WRF-NMM in terms of track prediction. However, intensity of cyclone need further research for better performance.

The WRF-ARW model with improved initial condition is able to simulate with reasonably good accuracy the amount, intensity, timing and spatial distribution of this unusual rain event as compared to CNTL simulation. From the 3DV simulation, the analyses of the dynamical parameters at the location of heavy precipitation revealed that the maximum convergence and vorticity precede the mature stage, however the maximum vertical velocity follows it. The CNTL simulation failed to represent these types of features during the simulation period.

Overall, WRF modeling systems are able to broadly reproduce several features of these intense convective activities leading to extreme weather events and heavy rainfall in tropics. However, more realistic initial conditions with advanced data assimilation techniques of observational data from various platforms is required for better prediction of these extreme weather events with state-of –the-art mesoscale models.

Chapter - V

Adaptation Strategies

ADAPTATION STRATEGIES IN AGRICULTURE FOR EXTREME WEATHER EVENTS

V.U.M. Rao

In meteorological or climatological terms, wide departures from a mean climate state that occur on time scales i.e. from days to millennia are called extreme events. The most important for human activities, however, are perhaps the short-term extreme (weather related) and the medium-term (climate related) events, given their potential and significant impact. Extreme weather and climate events are also an integral aspect of climate variability, and their frequency and intensity may vary with the prospects of climate change. One of the most important questions regarding short term extreme events is whether their occurrence is increasing or decreasing over time; that is, whether there is a trend for the envelopes within which these events preferentially occur. The most difficult trend analysis is that of extreme precipitation, The year 1999 witnessed a super cyclone striking the eastern coast of India (Odisha State). It was a major natural disaster affecting the subcontinent in recent years. The Bangladesh Cyclone of 1971, droughts of 1972 and 1987, the heat wave in 1995 and 1998 and cold wave in 2003 killing several hundred people are still fresh in public memory. The drought and failed monsoon of 2002, in particular, an unusually dry July, was a matter of concern for scientists and planners. The worst Drought in India during the last century occurred in 1918. Changes in precipitation have implications for the hydrological cycle and water resources in a future warmer climate. Occurrences of large-scale precipitation deficits often have severe effects on activities such as agriculture, forestry, hydroelectricity production, wetlands and wildlife. Their surpluses are often beneficial to the aforementioned activities. However, a persistence of anomalously wet conditions can also have severe effects, such as flooding and delays in harvesting, amongst others. Because of this, the economic and social costs of increasing extreme events will also be higher, and the impacts will be substantial in the areas and sectors most directly affected, such as agriculture, hydroelectricity generation, large cities and biodiversity. A few extreme events in India and their effect on agriculture sector and adaption measures to these extreme events are reviewed here.

Agriculture, being a vital source of livelihood, was essentially dependent on the natural seasons. Disasters are an inseparable part of nature and a series of undesirable fluctuations in climate could endanger food security. People have seen disasters as a part of rural-agrarian life and they tried to cope with undesirable climate by offering sacrifices to gods, and by inventing various small-scale devices to ensure the security and their lives, lands and livelihoods. They made their own disaster mitigation policy, with which they were able to manage the risk, damage and stress of disasters. In spite of recent technological developments that have helped to increase agricultural production in many countries, growth of plants and animals continue to depend to a large extent on the weather conditions. Each plant has its own climatic requirements for growth and development and any large-scale deviation from it exerts negative influence. Growth of plants is most sensitive to temperature just above a threshold value and near the maximum value, where growth normally stops. Therefore, periods of extreme temperature are hazardous to plant development and growth. Extreme temperature conditions during cold spells cause stress and frost; high temperatures lead to heat stress, and both affect agricultural production. Snow and ice storms in late spring or early autumn are very hazardous to many temperate crops. Similarly, extremes of moisture conditions caused by dry desiccating winds, drought episodes and low moisture conditions as well as very humid atmospheric conditions including wet spells adversely affect agriculture. Water logging and flooding associated with heavy rainfall and tropical storms have adverse effect on plant growth and development since they influence the rate of transpiration, leaf area expansion and ultimately plant productivity. Drastic changes in rainfall variability can have very significant impact, particularly in climatically marginal zones such as arid, semi-arid and sub-humid areas where incidence of widespread drought is frequent. Dry, desiccating and strong winds reduce agricultural production as a result of very high evapotranspiration rates. It also causes mechanical damage to such plants as sugarcane and bananas with weak stems caused by lodging.

Agro Meteorological Impact of Extreme Events

Basically, the climate of India is dominated by the summer monsoon (June to September). The entire year is however, divided into four seasons (1) Winter (January and February) (2) Pre-monsoon or Hot Weather season (March-May) (3)

Southwest or Summer Monsoon season (June - September) (4) Post monsoon season (October-December). Year to year deviations in the weather and occurrence of climatic anomalies / extremes in respect of these four seasons are

(i) Cold wave, Fog, Snow storms
(ii) Hailstorm, Thunderstorm and Dust storms
(iii) Heat wave
(iv) Tropical cyclones and Tidal waves
(v) Floods, Heavy rain and Landslides, and
(vi) Droughts

In the past, earthquakes, volcanic eruptions, landslides, floods, tropical storms, droughts and other natural calamities have killed over three million people and inflicted injury, disease, homelessness and misery on one billion others, and caused billions of dollars of material damage. Currently, annual global economic costs related to disaster events average US$880 billion per year. These figures provide a grim picture. By the year 2025, 80 % of the world's population will reside in developing countries, and it has been estimated that up to 60 percent of the people will be highly vulnerable to floods, severe storms and earthquakes. Nearly 90 percent of the natural disasters and 95 percent of the total disaster-related deaths worldwide, occur in the developing countries. Since the 1960s, economic losses caused by disasters have increased at least fivefold. These losses are growing largely because of the increasing concentration of population and investments in vulnerable locations coupled with inadequate investment in measures to reduce risk. Droughts have led to famines. Famines have led to migrations. When the people ceased to cultivate the areas that were left behind, creeping deserts swallowed the arable land and made it untenable. The CAgM (Commission for Agricultural Meteorology) working group of WMO on "Agro meteorology related to extreme events", recently developed a survey of countries regarding extreme weather events and their agricultural impacts. The survey identified a number of extreme events including drought, desertification, cold/frost, floods and heavy rainfall, high winds and severe storms, tropical storms, forest and range fires etc. throughout the globe. Fig.1 provides a graphical representation of these results. Impacts of extreme events on the agricultural sector can be positive or negative.

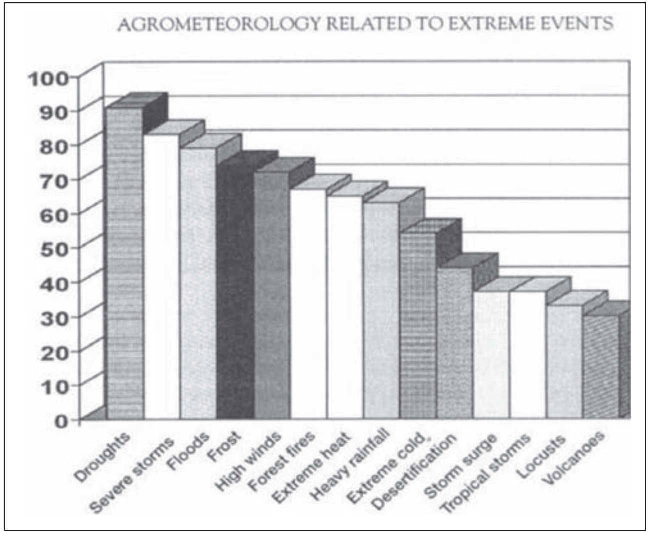


Fig. 1 : Percentage of countries reporting agricultural impacts from extreme agro meteorological events.

Positive effect on agriculture of extreme events:

It is easier to explain or contemplate negative impacts of extreme events such as droughts, tropical cyclones and floods but there are several positive impacts or benefits of extreme events. Increased rainfall in coastal areas from tropical cyclones, fixing of atmospheric nitrogen due to thunderstorms, the germination of many native plant species resulting from bushfires and the maintenance of the fertility of the basin soils due to river flooding are some of the positive impact of extreme meteorological events. There are some advantages of drought at certain times in the development of some crops such as the sugarcane where a brief dry spell is essential during the pre-harvest stage that helps to increase the sucrose content of the cane. A lower incidence of pests and diseases is observed in periods of drought.

Negative effect of extreme events on agriculture:

The negative or adverse impacts of extreme events referred to as damages or losses which have significantly pronounced affect on agricultural operations. Impacts of extreme events can be direct or indirect. Direct impacts arise from direct physical contact of the events with people, their animals and property. Indirect impacts of extreme agro meteorological events are those induced by the events. Indirect impacts often occur away from the scene of the extreme event or after the occurrence of the event. Indirect impacts include evacuation of people in the event of cyclone landfall, disruption to household and leisure activities, stress induced sickness, and apprehension and anxiety of future extreme events like floods or bush fires. In order to assess the impact of weather disaster on agriculture, one must link two fundamental aspects: the disaster proper (i.e., the destructive power of the event) and, the characteristics of the agricultural system which has been hit. Weather disaster interactions with agriculture are complex and, of course, are likely to involve non-agricultural factors as well. As stated earlier, two broad categories of effects on the agricultural sector are direct and indirect effects. Direct effects to a farmer could be, for example, the loss of his current crop and damage to his irrigation facilities. Indirect effects on agriculture appear progressively, as a result of low income. These are given below:

Rainfall: Direct damage to fragile plant organs, like flowers; soil erosion; water logging; drought and floods, landslides, impeded drying of produce; conditions favorable to crop and livestock pest development and negative effect on pollination and pollinators.

Wind : Physical damage to plant organs or whole plants (e.g. defoliation, particularly of shrubs and trees); soil erosion; excessive evaporation. Wind is an aggravating factor in the event of bush or forest fires.

High temperatures: Increased evapotranspiration; induced sterility in certain crops; poor vernalization; survival of pests during winter. High temperatures at night are associated with increased respiration loss. “Heat waves”, lengthy spells of abnormally high temperatures are particularly harmful.

Low temperatures: Destruction of cell structure (frost); desiccation; slow growth, particularly during cold waves; cold dews.

High cloudiness: Increased incidence of diseases; poor growth. Hail impact is usually rather localized, but the damage to crops particularly at critical phenological stages- and infrastructure may be significant. Even light hail tends to be followed by pest and disease attacks.

Lightning: Lightning causes damage to buildings and the loss of farm animals. It is also one of the causes of wildfire. Snow Heavy snowfall damages woody plants. Unseasonable occurrence particularly affects reproductive organs of plants.

Volcanic eruptions, avalanches and earthquakes: The events listed may disrupt infrastructure and cause the loss of crops and farmland, sometimes permanently. A recent example of carbon dioxide and hydrogen sulphide emissions from a volcanic lake in Cameroon caused significant loss of human life and farm animals.

Air and water pollution: Air pollutants affect life in the immediate surroundings of point sources. Some pollutants, like ozone, are however known to have significant effects on crop yields over wide areas. In combination with fog, some pollutants have a more marked effect on plants and animals. Occurrences of irrigation water pollution have been reported.

Strategies Adopted in Areas with High Weather Risk

The agro meteorological impacts of natural disasters have a persistent societal effect particularly in developing countries. A disastrous event does not pose much of the threat and ceases to be a disaster, if suitable and adequate mitigation measures are adopted well in advance. Prevention of the formation of tropical cyclones is not in the realm of possibility, but much of their disastrous potential can be reduced, restricting thereby the loss of human life and loss of property, by adopting appropriate strategies and taking timely precautions on the receipt of weather warnings. Climatological data helps in the advance preparation of long-range policies and programme for disaster prevention. The following are the agricultural strategies to be adopted in the events of some major natural disasters.

Drought management

In arid, semi-arid, and marginal areas with a probability of drought incidence at least once in ten years, it is important for those responsible for planning of land-use, including agricultural programme, to seek expert climatological advice regarding rainfall expectations. Drought is the result of the interaction of human pattern of land use and the rainfall regimes. Thus, there is urgent need for a detailed examination of rainfall records of these regions. In this regards, the development of methods of predicting many weeks or months in advance the occurrence of rainfall deserves high priority. More emphasis should be placed on drought management policies, especially in dry land farming areas. Agricultural planning and practices need to be worked out with consideration to the overall water requirements within an individual agro climatic zone. Short duration crops with relatively low water need to be encouraged in drought prone areas. Irrigation, through canals and groundwater resources, need to be monitored with optimum utilization, avoiding soil salinity and excessive evaporation loss. A food reserve is needed to meet the emergency requirements of upto two consecutive droughts. Sustainable strategies must be developed to alleviate the impact of drought on crop productivity. In areas of recurring drought, one of the best strategies for alleviating drought is varietal manipulation, through which drought can be avoided or its effects can be minimized by adopting varieties that are drought resistant at different growth stages. If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilization or weed management. In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as life saving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for a second crop with a lower water requirement, such as chickpea. However, no one strategy can be adopted universally. In fact, all such strategies are location, time, crop, crop stage and (to some extent) socio-economic condition specific. Developing such strategies for each specific factor can help to make agriculture sustainable. Participate in watershed planning. Implement water conservation initiatives. Establish secure water supplies that will be available during drought (develop new sources, new infrastructure). Adopt dry-land farming techniques (zero till, perennial forage), seed drought-resistant crops and varieties.

Cyclone preparedness in agriculture system:

Disaster preparedness for impending cyclones, refers to the plan of action needed to minimize loss to human lives, damage to property and agriculture. Preparedness for cyclones in the agriculture system can include early harvesting of crops, if matured, safe storage of the harvest etc. Irrigation canals and embankment of rivers in the risk zone should be repaired to avoid breaching. Beyond this, as the storm approaches the area, nothing can be done, but to secure as much of the property as possible and find safety. An example of crop diversification may be cited here as a long-term measure to reduce the crop damage during the period of cyclone. The cyclone struck at the worst possible time of crop growth, just after the grain had set but before the harvest had commenced. In the cyclone hit areas, the high impact of wind caused majority of the grains to blow away, leaving behind only the stalks. Two reasons could be attributed for the loss of grains. One the traditional varieties are heavy shredders by nature and are susceptible to lodging easily on impact. Secondly, the high winds caused friction among the ear-heads resulting in grain shed again. As a long-term measure, the farmers should be advised to take up the cultivation of those short-duration variety crops which are not easy grain shredders. With eight to ten typhoon storms striking the coast of Vietnam annually, tidal flooding often breaches sea dykes causing economic losses to the local population engaged in aquaculture. The planting of mangroves served two important purposes: (a) It acts as a buffer zone in front of the sea dyke system and reduces the water velocity, wave strength and wind energy to protect coastal land, human life and assets invested in development, and (b) It contributes to the production of valuable export products such as shrimps and crabs, high-value marine fish species in cages, mollusk farming and seaweed culture for agar and alginate extraction. By helping to protect the sea dykes, the mangroves were contributing to the economic stability of the communes. The benefits of the mangroves planted would be to:

- Lessen the frequency of storms, protect flooding of sea dykes and ponds, and protect property and the coastal inhabitants
- Improve aquatic production and the environment, and prevent saline intrusion into agricultural land
- Expand the land area for the national benefit.

Adaptation of Damage on Agricultural Sector due to Flood and Heavy Rainfall

Damage caused by flood is based on the Preconditioning of an area *i.e.* conditions are like soil, vegetation and water supply factors. Soils that are saturated prior to an extreme weather event are more likely to result in a damaging flood than soils that are relatively dry. Fields that have recently been tilled and are devoid of vegetation are much more susceptible to soil erosion.

- Vegetation that is able to use much of the water and that can act as a barrier to moving water (horizontally and vertically) can reduce flood severity and impacts.
- Water storage systems (rivers, lakes, reservoirs, etc.) that are able to capture and hold most of the incoming water will be effective in reducing flood damage.
- In rain-fed agricultural systems, managers typically anticipate rainfall during the growing season sufficient to naturally or artificially irrigate crops.
- Here, analysis of past weather and water data are critical for estimating average conditions and inherent variability.
- Crops like rice that can function effectively in saturated and even submerged conditions are appropriate for locations that flood regularly and the system becomes dependent upon regular flooding.
- Many other crops (e.g. corn) may not be adaptable to such conditions and would not be appropriate alternatives to rice.

- Geographical Information System (GIS) can be extremely useful tools in the analysis of flood-prone areas. A GIS in conjunction with digital elevation model (DEM) data can quickly determine slope and aspect of region and can be used to provide geospatial analyses of multiple spatial layers (elevation, slope and aspect-all at various scales or resolutions along with soil characteristics, precipitation, temperature, vegetation, and other factors).
- GIS are being used to develop new floodplain maps (at various frequency and severity levels) and delineate wetlands in many regions and countries, using these types of spatial layers as well as others, including aerial photos. Such information will certainly assist in the best design of agricultural systems, while accounting for reasonable risk.
- Floodplain maps with appropriate information about probabilities (return periods) of certain amounts of precipitation and/or depth of flooding water should be developed and used in risk assessments and agricultural planning.
- Prudent planning would ensure that structure and other items that would be damaged or destroyed by these frequent floods need not be built in the flooded area
- It is also important that future flood planning looks not only to structural solutions but also to land use planning, zoning and other solutions that encourage agricultural production in less vulnerable areas.
- Improved drainage is desirable. It needs to be balanced with environmental considerations, such as wetland protection, and downstream residents. It must also meet regulatory requirements
- Address on-farm excess water issues through Environmental Farm Planning Improve/upgrade farm equipment to handle excessive moisture.
- Participate in watershed planning.
- It is necessary to promote ecologically appropriate policies for human settlements and agriculture in the floodplains. Suitable short duration strains of paddy and other crops, which can withstand flooding for a few days, have to be developed.
- The living style, habitations, and crops grown are all evolved taking into consideration the climate and the flood-proneness of the area.
- Prolonged flooding of soils causes several physical, chemical and biological changes, some of which are not reversible. The application of Nitrogen, Phosphorous and Potassium in appropriate amounts could be especially important to build up soil nutrients for plants weakened by prolonged flooding and especially prone to development of disease problems and provides a perspective on the development of flood mitigation strategies in the future.

Adaptation measures against wind:

- Crop damage by winds may be minimized or prevented by the use of windbreaks (shelterbelts). These are natural (e.g. trees, shrubs, or hedges) or artificial (e.g. walls, fences) barriers to wind flow to shelter animal or crops.
- Properly oriented and designed shelterbelts are very effective in stabilizing agriculture in regions where strong wind cause mechanical damage and impose severe moisture stress on growing crops.
- Windbreaks save the loose soil from erosion and increase the supply of moisture to the soil in spring.
- Crop varieties that are resistant to lodging may with-stand strong winds during the sensitive stage of crop growth.
- In addition, improve crop management through crop rotations and intercropping,

Adaption of Crops from Dust Storm/Sand Storm

- Afforestation is the main measure to protect the soil from dust storm.
- Improving soil resistance to erosion can be achieved by careful selection of cultivation methods, applying mineral and organic fertilizers, sowing grass and spraying various substances that enhance soil structure.
- One major protection strategy is to establish well-developed plant cover before the dust storms period.
- This can encourage a reduction in the wind speed in the layer next to the ground by forming an effective buffer.
- When looking at the conditions in which dust storms developed and data on storm-induced damage, it is evident

that measures to reduce the wind speed at the soil surface and to increase the hooking of soil particles are both crucial.

- Such measures include the establishments of tree belts and wind breaks.
- Leaving stubble in fields, non-mould board ploughing, application of chemical substances promoting the hooking of soil particles, soil-protective crop rotation using perennial grasses and seeding of annual crops are also important.
- In regions with intensive wind erosion, especially on wind shock slopes or on light soils, stripe cultivation may be used. On fallow lands bare fallow stripes of 50-100 mcan be alternated with stripes of grain crops or perennial grasses; spring crops can be alternated with winter crops.

Protection of Crops from Cold Injury and Frost

Frost is a climatic hazard that causes serious damage to standing crops in temperate and subtropical climates. Crop damages can be avoided by properly understanding the characteristics of the frost. Frost protection methods may be divided into passive and active forms (Powell and Himelrick., 1998; Mavi, 2000). Passive protection involves methods such as site selection and variety selection and several cultural practices such as brushing and soil surface preparation. These methods do not require expenditure of outside energy sources. Active protection systems replace radiant energy loss by using methods such as irrigation, heaters, and wind machines. Active methods require outside energy to operate. The proper choice of a protection method depends on many factors, such as site, crop, advantages and disadvantages of the protection methods, relative costs, and operating principles of the method.

Site Selection: Many factors are involved to creation of pockets of very low temperatures. Before planning a crop or an orchard, the best method of frost protection is careful selection of the site. The site should be selected taking into account the climatic conditions prevailing in that location, its slope, and the soil characteristics. There is a possibility of cold air buildup in low paddocks or behind barriers such as fences, hedges, and wooded areas (Hutton, 1998). Such paddocks are not the best locations for planting orchards and frost sensitive crops. Removal or thinning of trees that create cold air dams is desirable. If a site has good cold air drainage, then it is likely to be a good production site as far as frost damage is concerned. Frost-sensitive fruit trees are usually planted on hillside slopes from which the cold air drains rapidly to the bottom of the valley. Such sites are usually 2 to 4^0C warmer during radiational frost.

Frost-Resistant Cultivars: Planting frost-resistant cultivars and crop varieties is one approach to avoid frost damage to fruit trees and field crops. Oats are more tolerant to frost damage than barley, and barley is slightly more tolerant than wheat. The varieties could be those in which genetic resistance to freezing stress has been incorporated. Growers should refer to available extension publications on varieties that could withstand the low temperatures.

Optimizing Sowing Dates: The best and most cost-effective strategy to save field crops from frost is the choice of the optimum sowing dates. As crops enter the flowering and grain-forming stage, their tolerance to frost is drastically reduced. If the sowing dates of crops are adjusted in such a way that these stages do not fall in the period of heavy frost, then its damaging action is avoided. In the case of wheat, it is necessary for anthesis to occur after the high-risk frost period is over. Results of experiments in New South Wales have shown that a wheat crop can be saved from frost damage to a great extent if the crop flowers in mid-September in areas around Trangie, in late September around Narrabri, and in early October around Tamworth. A late date of anthesis, however, needs to be balanced against the damage that can occur if grain filling takes place during the period of high temperatures or moisture stress. Each week's delay after these dates in anthesis can reduce yields dramatically (Boer *et al.,* 1993).

Storing Heat in the Soil: Frost frequency and intensity is greater in orchards in which the soil is cultivated, dry, and covered with weeds or mulch as compared to orchards in which the soil is moist, compact, and weed free (Johns, 1986). This is because soil that is bare or weed free, compact, and moist stores more heat during the daytime than soil that is covered with shade and is dry. At night this heat is released to the lower layers of the air surrounding the crop plants and fruit trees, minimizing the damage from frost. Standing weeds increase the incidence of frost in three ways: by shading the soil, which hampers the heat flow to the soil; by drying the soil; and by raising the cold radiating surface which comes close to the fruit level. Thick mulches also increase the incidence of frost through hampering the heat flow to the soil during the day and retarding the heat flow to the top of the straw during the night. A dry cultivated soil increases the incidence of frost, because cultivation creates more air pockets in the soil which act as insulating layers and hamper the flow of heat to the soil, lowering its heat storage during the day. Therefore, keeping the soil moist with frequent light irrigation, maintaining it weed free, and making it compact with rollers is the best technique to minimize frost damage in orchards, vineyards, and wide-row crops.

Plant Cover: Planting large canopy trees with orchard plants provides some freeze protection. Date palms in California and pine trees in southern Alabama are used as canopy cover for citrus plantings (Perry, 1994) “Brushing” is commonly used for protecting vegetable crops from frost damage. Shields of coarse brown paper are attached to arrowhead stems on the pole ward side of the east-west rows of plants. The fields present a brushy look. During the day the shields act as windbreaks against cold wind, while at night they reduce radiation loss to the sky. Woven or spun-bonded polypropylene covers of varying thickness are among the latest forms of protection used on fruit crops. Depending on the material used, several degrees of protection are achieved. Copolymer white plastic has provided protection to nursery stock but is not used on fruit and vegetable crops. Light and medium-weight covers provide excellent protection for low-growing crops such as strawberries.

Nutrition: Deciduous fruit plants, such as peach, that are not nutritionally sound, especially in regard to nitrogen, are more subject to frost damage. Fruit buds of such trees are less healthy and more easily damaged by frost. Using mid-summer or postharvest application of nitrogen can induce vigor for strong fruit bud development and some delay in flowering in stone fruits such as peaches. However, tree fruits with low fertility requirements, such as apples and pears, do not normally require mid- to late-summer fertilization, whereas such applications do benefit blueberries (Perry, 1994).

Chemicals: Some inexpensive materials which could be stored easily until needed and are portable and easily applied to provide frost protection have been tested. The possibilities of using cryoprotectants, antitranspirants, and growth regulators are encouraging. A number of materials that could change the freezing point of plant tissue, reduce the ice nucleating bacteria on the crop and thereby inhibit frost formation, or affect growth, i.e., delay de-hardening, have been examined. Several products are advertised as frost protection materials; however, none of the commercially available materials has successfully withstood the scrutiny of scientific testing. Growers should be very careful about accepting the promotional claims of these materials (Ullio, 1986; Powell and Himelrick, 1998). Growth regulator applications that could increase the cold hardiness of the buds and flowers, delay flowering, or both seem to hold the most promise at this time. Among the growth regulators tested, only the ethylene-releasing compound ethephon has shown promise (Gallasch, 1992; Powell and Himelrick, 1998). Ethephon increases winter fruit bud hardiness and delays flowering of peaches by four to seven days. It provides the same effects on cherries. In the United States, ethephon has been federally labeled for use on cherries, and it is on several state labels for use on peaches.

Irrigation: Irrigation is the oldest, most popular, and most effective method of protection from frost. Irrigation is done with sprinklers mounted above or below the crop canopy. Sprinkling the canopy with water releases the latent heat of fusion when water turns from liquid to ice. As long as ice is being formed, latent heat released by water efficiently compensates for the heat lost from the crops to the environment. For most situations, sprinkler rotating once each minute and an application rate of 2 to 4 mm of water per hour is sufficient. A backup power source is essential, as power failure can be devastating. Once started, irrigation must continue until the morning sun hits the trees (Wickson, 1990). During the other seasons the sprinklers can be used for evaporative cooling, artificial chilling, delayed flowering, fruit drop prevention, sunburn injury, and color improvement of fruits (Spieler, 1994).

Heaters: Heating of orchards for protection against frost has been relied upon for centuries. The high cost of fuel has now provided an incentive to look at other methods. There are several advantages to using heaters. Most heaters are designed to burn oil and can be placed as freestanding units or connected by a pipeline network throughout the crop area. The advantage of connected heaters is the ability to control the rate of burning and shut all heaters down from a central pumping station simply by adjusting the pump pressure. A pipeline system can also be designed to use natural gas. Propane, liquid petroleum, and natural gas systems have been used for citrus. Heaters provide protection by three mechanisms. The hot gases emitted from the top of the stack initiate convective mixing in the crop area and break the inversion. The bulk of a heater’s energy is released in this form. The remaining energy is released by radiation from the hot metal stack. A relatively insignificant amount of heat is also conducted from the heater to the soil. Around the periphery, more heaters are required, because the ascending plumes of hot air allow an inflow of cold air. Heaters provide the option of delaying protection measures if the temperature unexpectedly levels off or drops more slowly than predicted. The initial installation costs are lower than those of other systems, although the expensive fuels required increase operating costs. There is no added risk to the crop. Whatever heat is provided will be beneficial.

Wind Machines: The purpose behind using wind machines is to circulate warmer air down to the crop level. Wind machines are effective only under radiation frost conditions. They should be installed and operated after a thorough understanding of how frost affects a particular area or orchard (Lipman and Duddy, 1999). A typical wind machine with fans about 5 m in diameter and mounted on a 10 m steel tower can protect approximately four hectares of area, if the area is relatively flat and round. The fan is powered by an engine delivering 85 to 100 HP. Wind machines used in conjunction with heaters provide the best protection. When these two methods are combined, the required number of heaters per hectare is reduced by about half. Wind machines provide noteworthy advantages in frost protection by minimizing labor requirements, reducing refuelling and storage of heating supplies, and requiring a low operational cost per hectare. Wind machines use only 5 to 10 percent of the energy per hour when compared to heaters. The original installation cost is quite similar to that for a pipeline heater system, making wind machines an attractive alternative to heaters for frost protection. They are also more environmentally friendly (except for noise) because they do not produce smoke or air pollution. Each grower must choose the proper method of frost protection for the particular site considered. Once the decision has been made, and if frost protection is to be practiced successfully, three guidelines apply to all systems:

1. Operation for protection against frost must be handled with the same care and attention as spraying, fertilizing, pruning, and other cultural practices.
2. Frost protection equipment must be used correctly with sound judgment and attention to detail and commitment.
3. Operation should not be delegated to someone with no direct interest in the result.

Fire Prevention Measures

Wildfire is a natural regenerative force within the boreal forest and native grassland. Lightning accounts for just under 50% of all fires while the remainder are caused by humans. Wildfire must be effectively managed to protect life and property.The use of periodic seasonal data of certain specific forest areas prone to forest fires could be used by the forest managers to enable taking certain fire prevention measures or mounting fire operation measures in advance to mitigate possible damages. On the basis of the weather fire relationship, a systems of fire danger rating has been evolved to guide the fire management people in their day to day activity and also to provide a basis for comparing weather and fire behavior throughout the nation or region. Such system usually include book-keeping schemes for keeping track of the moisture contents from one to three size classes of forest fuels, plus indices of spread rate, fuel quantity consumed and energy output rate of the fire front. Forest fire danger rating system in Canada and universal system of fire danger rating along with fire weather forecasting in USA are providing valuable information to mitigate possible damage due to forest fire.

- Improve predictions and warning capability.
- Ensure insurance and disaster support is in place.
- Continue fire suppression efforts with implementation of the Wildfire Management Strategy.

ADAPTATION STRATEGIES IN MARINE FISHERIES FOR EXTREME WEATHER EVENTS

E. Vivekanandan

Fishermen, fish farmers and their communities are vulnerable to extreme climatic events and disasters. This is because of their location, the characteristics of their livelihood activities, and their overall high levels of exposure to natural hazards, livelihood shocks and climate change impacts. Exposure and vulnerability to these hazards is increasing. For example, in the past century, there has been an increasing trend in the number of natural disasters reported around the world and in India as well. The increasing extreme weather events are often associated with increasing climate variability and change (FAO, 2012). The impacts of disasters on coastal communities are particularly pronounced in the case of subsea events resulting in tsunamis (geological), storm surges and coastal flooding (hydrological), and coastal and lakeshore storms (meteorological). Droughts and floods can also affect river flows, wetland areas, and lacustrine and riparian communities. The types of extreme weather events that affect the fisheries and aquaculture sector include storms, cyclones/hurricanes with associated flooding and tidal surges, droughts, floods and landslides. The associated climate change events are sea erosion, sea level rise and changing wave and tide patterns.

Cyclones

There are 13 coastal states and union territories in the country, with about 84 coastal districts affected by tropical cyclones. Although cyclones affect the entire coast of India, the east coast is more prone to cyclones compared to the west coast.

Table 1 : Cyclones that hit Indian coasts since 1990

Name	State	Lowest pressure (mbar)	Year
BOB 01	Andhra Pradesh	920	1990
BOB 08	Tamil Nadu	998	1991
BOB 06	Tamil Nadu, Kerala, Karnataka	994	1992
BOB 03	Tamil Nadu, Karnataka	968	1993
ARB 02	Maharashtra	994	1994
ARB 01	Gujarat	976	1996
08B	Tamil Nadu	967	1996
BOB 05	Andhra Pradesh	982	1998
ARB 05	Gujarat	996	1998
BOB 05	Odisha	968	1999
BOB 06	Odisha	912	1999
BOB 05	Tamil Nadu	958	2000
ARB 01	Gujarat	932	2001
O3B	Andhra Pradesh	992	2003
Onil	Gujarat	990	2004
Fanoos	Tamil Nadu	998	2005
Yemyin	Andhra Pradesh, Gujarat	986	2007
Nisha	Tamil Nadu	996	2008
Khai Muk	Andhra Pradesh	996	2008
Phyan	Maharashtra	988	2009
Aila	West Bengal	988	2009
Laila	Andhra Pradesh, Odisha	986	2010
Jal	Andhra Pradesh, Maharashtra	988	2010
Thane	Tamil Nadu, Andhra Pradesh	972	2011
Nilam	Tamil Nadu	992	2012

An analysis of the frequencies of cyclones on the east and west coasts of India during 1891-2012 shows that nearly 320 cyclones (out of which 110 were severe) affected the east coast. During the same period, 52 tropical cyclones crossed the west coast, of which 26 were severe cyclonic storms. Four states (Tamil Nadu, Andhra Pradesh, Orissa and West Bengal) and one UT (Puducherry) on the east coast and one state (Gujarat) on the west coast are the states that are more vulnerable to cyclone disasters. Within the last 23 years, 25 cyclones hit the Indian coasts with the super cyclone of Odisha in the year 1999 as the most severe (lowest pressure: 912 mbar) (Table 1). Many cyclones that have hit the coast during the last 15 years have been far more catastrophic than the previous ones. The cyclone of 1998 in Andhra Pradesh, the 'super cyclone' of Orissa in 1999, Cyclone Aila of 2009 in West Bengal and cyclone of Thane in Tamil Nadu in 2011 are considered to be the most grievous of their kind to have hit the respective coasts. These cyclones were not only more intense, but also covered more extensive area further inshore than ever before. Thousands of houses were partially or fully destroyed, and millions left homeless. In all these cases, the influx of seawater deep into the inland led to salinisation of land and groundwater resources, making them unfit for agriculture for long periods, and creating drinking-water scarcity.

Special nature of the problem of cyclones:

The frequency of number of tropical cyclones in the north Indian Ocean are the least in the world (7% of the global total), but their impact on the coasts bordering the north Bay of Bengal (north of 15^0 N latitude) in India is extremely disastrous. The problem can be fathomed from the fact that during the past two and a half centuries, 20 out of 23 major cyclone disasters (with human loss of life 10,000 or more and not considering the damages) in the world have occurred over the Indian subcontinent (India and Bangladesh). One of the major reasons for this is the serious storm tide problem in these coasts. A tropical cyclone of specific intensity, when it strikes the east coast of India and Bangladesh, usually produces a higher storm surge compared to that when such a cyclone strikes elsewhere in the world. This is because of the special nature of the coastline, the shallow coastal ocean topography and the characteristics of tide in the north Bay of Bengal region. Further the high density of population, low awareness of the community about cyclones and their risks, inadequate response and preparedness add to the severity of the problem.

Predicted increase in cyclones:

The simulation results (Anon., 2000) of HadRM2 for the CTRL run (the 1990s) and for the increased GHG run (2050s; IS92a scenario) showed no significant change in the number of total tropical disturbances in the increased GHG simulation from that in the control run (Anon., 2010). However, there is an increase in the number of intense cyclone events in the Bay of Bengal, particularly during the post-monsoon period. The frequency of cyclones having maximum wind speed, particularly in the range of 30–35 m/sec, is much higher in the increased GHG run than in the control run. This indicates that the intense cyclones may be more frequent in the increased GHG scenario than in the control scenario, consistent with the finding based on the trends from past observations.

Sea Level Rise

Sea level changes can be of two types: (i) changes in the mean sea level, and (ii) changes in the extreme sea level. The former is a global phenomenon while the latter is a regional phenomenon. Estimates of mean sea level rise made from past tide gauge data at selected stations along the coast of India indicate a rise of slightly less than 1 mm/year; however these estimates need to be corrected by including the rates of vertical land movements, whose measurements are not available at present.

Although the rise in sea level is gradual and predictable, the effects of storms on coastal shorelines and structures are often stochastic and uncertain, in part because of of effects the sea-level rise. Sea-level rise will cause progressive flooding followed by inundation of low-lying shoreline areas. Sea-level rise can increase the damage caused by storms because mean water level (the base level for storm effects) is higher, waves can attack higher on the shore profile, and coastal erosion often is accelerated, bringing structures nearer the shoreline and potentially removing protection offered by dunes and other protective features.

Sea Erosion

The landward displacement of the shoreline caused by the forces of waves and currents is termed as coastal erosion. While the effects of waves, currents, tides and wind are primary natural factors that influence the erosion coast, the other aspects eroding the coastline include the sand sources and sinks, changes in relative sea level, geomorphological characteristics of the shore and sand, etc. Other anthropological effects that trigger beach erosion are construction of artificial structures, mining of beach sand, offshore dredging, or building of dams or rivers.

Coastal erosion threatens property and businesses and puts people living near cliffs and shorelines at risk. The Indian coastline is about 8129 km, in length of which, 17% is affected by erosion (Table 2).

Table 2 : Areas affected by erosion along the Indian coast (modified from Sanil Kumar *et al*., 2006)

States/UT	Coast length (km)	Erosion (km)	Extent of erosion (%)
Gujarat	1600	36	2.3
Maharashtra	720	263	36.5
Daman & Diu	27	-	
Goa	104	11	10.6
Karnataka	300	250	83.3
Kerala	590	480	81.4
Tamil Nadu	1000	36	3.6
Puducherry	45	6	13.3
Andhra Pradesh	974	9	0.9
Orissa	480	108	22.5
West Bengal	157	49	31.2
Andaman & Nicobar Islands	2000	-	
Lakshadweep	132	132	100.0
Total	8129	1380	17.0

Erosion leads to total loss of beaches in a few locations, wiping out the local beach-seine fisheries, reducing space for local fish landing, boat berthing, net mending and fish trade. Erosion of beaches has led to increased inundation of fishers' houses during the high-tide period in Maharashtra and Andhra Pradesh. Islands like Gosaba in the Sundarbans also suffer periodical inundation of the *bund*s and incursion of waters into the village as a result of higher tidal amplitude in the area.

Some adaptation options of sea erosion are dune grass planting, dune thatching, dune fencing, beach recycling and re-profiling, beach nourishment, beach drainage, deployment of sand bag structures, gabion revetments, groynes, rock and timber rivetments, impermeable rivetments, developing artificial headlands, artificial reefs, nearshore backwaters and construction of sea wall.

Waves and Currents

In most places, the intensification of waves in one area is complemented by a weakening of the same in the neighbourhood. The cyclical pattern that characterized the movement of waves to the coast appears to be broken; rogue waves keep intruding into the cycle. The wave action in the coastal waters has become weaker as a result of weakening nearshore winds and increased siltation around river mouths (Salagrama, 2012). There is a perception that there has been a reduction in wave height, frequency and intensity. At the same time, wave action is much stronger in places where (i) beaches have been eroded and/or built over extensively; (ii) reclamation of land has taken place in the neighbourhood; (iii) natural barriers like mangroves have declined; and (iv) new barriers to water movement (like jetties and harbours) have come up.

The stronger wave action in these areas is reported to (i) destroy homes and other structures closer to the coast, and (ii) capsize boats as they near the coast and occasionally destroy them by dashing them against the shore. In the offshore or deep-sea waters, where the mechanized boats of Maharashtra, Kerala and West Bengal are increasingly operating, the waves are reported to have become stronger, leading to more pitching and rolling than previously. In West Bengal, the problem of increased pitching and rolling has emerged as a major issue (Salagrama, 2012).

Extreme Seawater Temperature Events

Fishing is an activity determined and affected by local ecological and socioeconomic conditions. Ecological conditions include phenology of different species to the functionality of ecosystems, whereas socioeconomic conditions include a wide range of variables that may consider fishing craft and gear, processing, distribution, trade and consumption of fisheries products (Vivekanandan, 2011). Most of fisheries yield is affected by regional climate variability that impacts oceanographic variables at a temporal and spatial scale. Changes on key physical factors during events like *El Nino* and decadal oscillations affect fish populations and fisheries yields. Extreme events influence fisheries through modification of habitat characteristics, affecting organisms and their productivity, development, nourishment, reproduction and distribution. Subtle changes in key environmental variables like temperature, salinity, wind velocity and direction, currents, upwelling intensity, as well as the ones that affect prey-predator populations, can drastically modify the abundance, distribution and availability of fish populations. Among the most relevant physical impacts of climate change on marine and coastal ecosystems on which fisheries and fish yields depend are: (i) increase in sea surface temperature, (ii) sea level rise, (iii) increased intensity of storms, (iv) changes in precipitation pattern and runoff, (v) changes in sea surface currents, (vi) increase in CO_2 concentration, and (vii) habitat changes (Easterling *et al*., 2007; Nicholls *et al*., 2007).

Extreme temperature events in the El Nino years have serious effect on marine ecosystems. Coral reefs are the most diverse marine habitat, which support an estimated one million species globally. They are highly sensitive to extreme thermal events in the sea, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. Reef-building corals are highly dependent on a symbiotic relationship with microscopic algae (type of dinoflagellate known as zooxanthellae), which live within the coral tissues. The corals are dependent on the algae for nutrition and colouration. The bleaching results from the ejection of zooxanthellae by the coral polyps and/or by the loss of chlorophyll by the zooxanthellae themselves. Corals usually recover from bleaching, but die in extreme cases.

In the Indian Seas, coral reefs are found in Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Seas and Lakshadweep Seas. Coral bleaching occurred in these reefs in the El Nino year 1998. The coral bleaching event in the Gulf of Mannar (GoM, southeast coast of India) in 1998 is given as an example here. In the summer of extreme *El Nino* year 1998, the SST increased to 31.3°C on 5th April, peaked at 32.0°C on 3rd May, and remained at around 31.0°C until 14th June (Fig. 1), which was 2.0 to 2.5°C above the annual average of 29.3°C. High incidence of coral bleaching affecting 85% of the reefs in the GoM was reported during May 1998 (www.reefbase.org). With warming of seawater, it is expected that coral bleaching will be a regular phenomenon in the future.

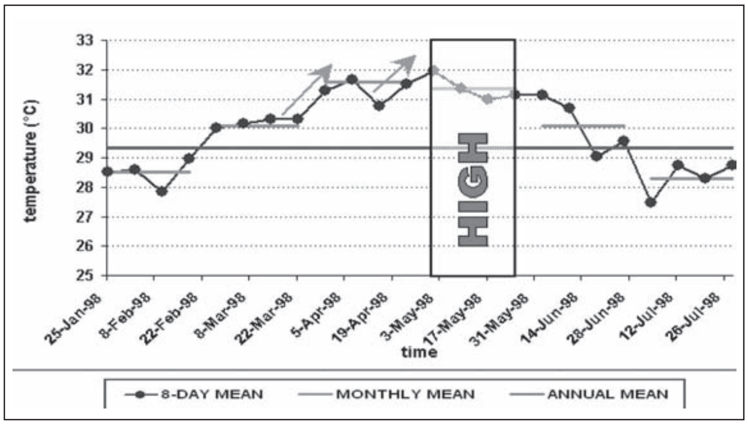


Fig. 1. SST profile prior to, during and after the "high" coral bleaching event of 1998 in the Gulf of Mannar (source: AVHRR data)

On a simple first inspection of SRES A2 scenario, corals will be soon exposed to regular summer temperatures that will exceed the thermal thresholds observed over the last 20 years. The outcome of this analysis suggests that if the projected increase in sea temperature follows the trajectory suggested by the HadCM3 for an SRES A2 scenario, reefs should soon start to decline in terms of coral cover and appearance (Vivekanandan et al., 2009). Given the implication that reefs will not be able to sustain extreme thermal events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep region and between 2050 and 2060 in the Andaman and Nicobar regions (Vivekanandan et al., 2009). This will have great impact on fisheries as coral reefs are important ecosystems in the sea, harbouring and nurturing hundreds of commercially important fish species.

Vulnerability to Extreme Events

The extreme events like the cyclones cause loss of life and properties such as houses, craft and gear, and infrastructure such as landing sites, markets, fish storage sites. The livelihood is also affected as the fishermen are unable to venture into the sea on the days of cyclones. For fish farmers, the loss is in the form of aquaculture farms, escape of broodstocks and outbreak of disease to farmed fish. As per Marine Fisheries Census 2010, about 38% of fishermen live in *kutcha* houses. It is questionable whether the remaining 62% of the *pucca* or semi-*pucca* can withstand cyclones. In addition, about 20% of marine fishing villages have no road connection.

Apart from cyclones, the other serious natural disaster that the fishers face are the annual floods of the major river systems like the Ganges and Godavari. However, they also had a positive impact in terms of allowing a good mix of fresh and saline waters, cleaning up the rivers and creeks, flushing out siltation from river mouths, rejuvenating the coastal freshwater aquifers, and helping in the survival of mangroves. With uncertain rainfall, and with the construction of dams across the major rivers, the annual floods have given way to more irregular, frequently man-made events, which are far more catastrophic. Moreover, the steps taken to control floods have had their own implications. The *bund*s built in the Sundarbans to protect the human habitation from flooding have been counterproductive on at least two counts: (i) the process of flooding would help in depositing silt outside. (With the construction of *bund*s, this process has been disrupted—the silt remains in the river, elevating the river bed. Thus, the river is often seen to be flowing much above the land lying on the other side of the *bund*. This makes the *bund*s very prone to bursting and spilling.); (ii) the soft, unsettled soil makes the base of the *bund*s very unstable, putting them at risk of being swept away by the pressure of tidal or flood waters.

The vulnerability of countries and communities to extreme events is determined, on the one hand, by their exposure to such hazards and, on the other, by their ability to withstand (sensitivity), respond to and recover from (adaptive capacity) the effects of such hazards. Thus, susceptibility is directly affected by underlying issues such as food and nutrition insecurity, weak institutions, conflict and poor access to markets. However, the way each of these issues affects people varies considerably. Men and women, the old and the young, the rich and the poor, and small-scale and large-scale undertakings are all affected differently and have different ways of responding to hazards that affect them.

Extreme weather events, such as storms, are likely to increase in frequency and affect fishing operations, and coastal and wetland flooding is likely to become more frequent. Even in normal sea conditions, marine fishing is one of the riskiest occupations known to human civilization. An International Labour Organization (ILO) report shows that compared to other professions, the fatality rate (number of incidents per 1,00,000 employees per year) is very high in sea fishing. The global fatality rate in fishing is estimated as 24,000 per year (ICAR, 2011). The fatality rates are much higher during storms and cyclones. In India, the mechanism for collecting fishing related accidents is yet to be established. A study carried out by the South Indian Federation of Fishermen Societies (SIFFS) estimated about 1210 accidents during 2000-07 in Tamil Nadu excluding deaths due to tsunami in 2004.

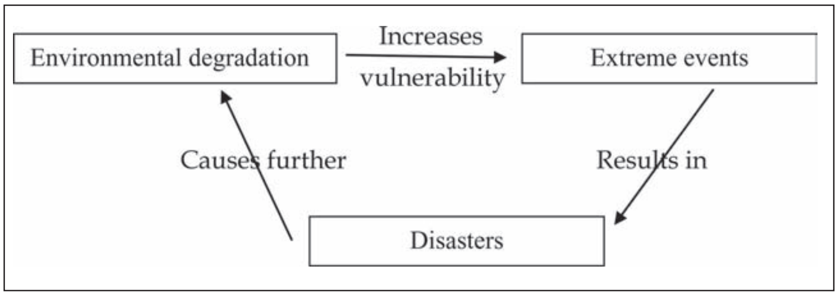


Fig. 2. Linkage between the environment, extreme events and disaster risks

Increased precipitation in some areas will lead to the erosion of riparian lands and to greater sedimentation in coastal areas, affecting seagrass and reef production. Sea-level rise is likely to increase coastal flooding, and the incursion of saltwater into coastal areas will affect agricultural production and fish farming. Temperature changes will also affect fish physiology, with implications for both capture fisheries and fish farming. Increased ambient air temperatures could have very significant effects on the types of fish that can be cultured.

The lessons learnt from extreme events is that pre-existing environmental degradation, as a result of inadequate land use and poor resource management, increases the vulnerability of communities, turning the extreme events into a major disaster and resulting in additional environmental damage (Fig. 2).

Possible Adaptation Options

Reducing the effects of disasters on fisheries and aquaculture sectors can be achieved through measures for prevention, mitigation, and preparedness [Disaster risk reduction (DRR)] (FAO, 2010). In the fisheries and aquaculture sector, this includes preparedness to respond rapidly and effectively before extreme events occur, and early warning to provide information before potentially disastrous events occur. Managing the effects of hazards and disasters [Disaster risk management (DRM)] goes beyond DRR to incorporate emergency response, recovery and rehabilitation within a management framework (Baas et al., 2008). DRR involves three phases: (i) reducing vulnerability; (ii) responding to emergencies when they arise; and (iii) rehabilitating communities after the emergency has passed.

Many studies have highlighted that mangroves, along with beach and dune forests, help protect the coastline from erosion, storm damage and wave action, by acting as buffers and trapping alluvial sediments. The degree of protection offered by coastal forests depends on many factors related to the characteristics of the hazard, the site and the state of the forest. Mangrove forests have proven to be the most effective barriers to natural hazards resulting from storms and [smaller-scale] tsunamis.

Key actions in the DRM cycle may include (Sperling and Szekeley, 2005):

- Assessment of damage and need (with respect to fisheries and aquaculture);
- Rehabilitation of livelihoods (to reduce dependence on food aid);
- Long-term development and planning and preparedness;
- Relief or emergency response to address immediate humanitarian needs and to protect livelihoods following a disaster;
- Rehabilitation to initialize the restoration and rebuilding of livelihoods;
- Reconstruction for replacing destroyed infrastructure;
- Sustainable recovery for longer-term re-establishment and enhancement of livelihoods and livelihood support structures.

Emergency response should comply with best practices, national policies and agreed recovery plans (FAO, 2012):

- Sustainable rehabilitation of fishing and fish farming;
- Fish preservation and processing practices compatible with the state of fishery resources
- Rehabilitation and conservation of the environment and fisheries resources;
- Strengthened governance and community-based planning;
- Strengthening and diversification of sustainable livelihoods of traditional fishing and fish-farming communities.

Resilience to the effects of disasters can be achieved by working with communities and multilevel stakeholders to reduce their sensitivity to disasters (through preventive actions or by reducing levels of dependence) and/or by strengthening coping and adaptive strategies that respond to those hazards. In so doing, the differences between different stakeholder groups within a given community need to be carefully considered.

As the effects of climate change will be to alter the magnitude and frequency of extreme events, it is important to recognize that existing coping and response mechanisms to disasters - based on past vulnerabilities – may no longer be appropriate for future events. Indeed, on many occasions, the existing mechanisms are insufficient for the current level of vulnerability.

Climate change and more rapid-onset of hazards such as cyclones, floods and earthquakes are related in a number of ways (FAO, 2012):

- They both directly affect the livelihoods of fishers and fish farmers and invariably reduce the quality of their livelihoods.
- They interact to compound the adverse effects of both – most noticeable will be the increased frequency and impact of extreme events as a result of climate change.
- Climate change will interact with extreme events to change their location and, thus, the communities affected.
- Adaptation to both forms of hazard at the community level tends to have many aspects in common.

Adaptation to extreme events should be inclusive of not only means addressing changes in the intensity and frequency of extreme events, but also more subtle changes in climate conditions as well as emerging risks that have not been experienced in a region before. This is because the susceptibility of fishers, fish farmers and their communities to rapid-onset disasters is also being affected by climate change (Cochrane et al., 2009). This growing inter relationship of climate change and extreme events suggests a need for a convergence of DRM and CCA (Climate Change Adaptation) preparedness and response approaches, particularly at the land–water interface where the effects are felt most strongly and particularly by fishers, fish farmers and their communities. This would suggest that DRM and CCA need to be fully incorporated into fisheries and fish-farming policies and plans, and that fisheries and fish farming should be fully considered in CCA and DRM approaches. In addition, the increasing vulnerability of the poor to both climate change and hazards would suggest that CCA and DRM need to link to livelihoods in a holistic and integrated way. Moreover, the implications of both extreme events and climate change for wider national and regional food security suggest that these elements also need to be integrated with each other.

The fisheries and aquaculture sector must be considered in a different way than other sectors (such as agriculture) in emergencies, in view of the many unique challenges related to management and the complex range of activities undertaken by fishers and fish farmers.

The key areas for action may include (FAO, 2012):

- Strengthening policy coherence and institutional structures to ensure explicit and adequate consideration of fisheries and aquaculture activities in disaster preparedness and CCA strategies;
- Integrating an understanding of the increasing vulnerability of fishers, fish farmers and their communities both to extreme events and to climate change, and developing and incorporating comprehensive preparedness and response strategies into fisheries and fish-farming sector plans and wider development frameworks;
- Building an increased understanding of the vulnerability of fishers, fish farmers and their communities into wider social, economic and environmental development plans;
- Working with communities, governments and civil society to help build their productive, coping and adaptive capacity and to ensure that the adaptive, coping and livelihood strategies of fishers, fish farmers and their communities are incorporated into wider disaster preparedness and response strategies;
- developing shared tools, guidance and approaches that combine DRM and CCA at a practical level and that link into fisheries and fish-farming development strategies to increase the resilience of communities and that of aquatic systems on which they depend;
- Building partnerships at the global, regional, national and state levels among international agencies, national agencies, local government, civil society and communities to learn lessons about, the preparedness and response for slow- and rapid-onset hazards in an integrated and informed way.

ADAPTATION STRATEGIES IN AGRICULTURE FOR EXTREME WEATHER EVENTS - POULTRY

M R Reddy

Poultry is the fastest growing animal production sector. The demand for poultry products eggs and meat is consistently increasing because of their nutritive value, wide consumer preference and cost effectiveness compared to other sources of animal protein. Poultry production will remain an important agricultural activity which probably will continue to grow. However, climatic change is going to be major challenge before the poultry sector. Poultry flocks are particularly vulnerable to climate change, which could adversely affect poultry health and production. Broilers and layers are susceptible to heat stress for the following reasons.

1. Their metabolic heat production is high as a result of rapid growth and high rate of egg production.
2. There is little heat dissipation by convection and radiation, because of the very effective insulation of the body surface by their feathers.
3. the chicken lack sweat glands, and their respiratory water evaporation rate is not high enough to maintain normal thermia at high ambient temperatures.

Poultry are naturally homeothermic and thus, they try to maintain a constant body temperature. Normally, body temperature of an adult chicken is in the range of 41 to 42 °C, while that of day old chick is slightly less. The ''thermoneutral zone'' or "zone of comfort" is a particular range of environmental temperature over which birds do not change their behaviour or show signs of discomfort and use the minimum amount of metabolic energy to maintain normal body temperature. In thermoneutral zone (19-25 °C), the metabolic rate of birds is kept constant either by non-evaporative heat loss through vasomotor control (peripheral vasoconstriction or vasodilatation, feather manipulation and postural changes) or water evaporation from the lungs (evaporative cooling), which keeps the birds comfortable. Within this zone, energy efficiency is maximized due to minimum energy needed for maintaining body temperature.

Thermoregulation

As ambient temperature increases, birds start to pant to lose heat by evaporation. Evaporative heat loss through panting is the most important mechanism to control body temperature under heat stress. However, panting is accompanied with increases in respiratory rates. The increased respiratory rate causes higher losses of CO_2 that result in increased blood pH and disruption of acid balance. When this balance is altered towards alkalosis or acidosis, metabolic pathways are diverted to homeostatic regulation rather than used for supporting growth. The acid base balance is further disrupted by the increased electrolyte excretion through urine and faeces

Under heat stress, birds lose more water through panting and urine than they do in their thermal comfort zone. A decrease in body water results in a reduced ability to dissipate heat via evaporation and or through increased peripheral blood flow. As a consequence, birds increase water consumption to compensate for water loss and to increase the heat dissipation capacity. However, water retention is reduced due to the increased electrolyte excretion in urine and faeces. Reduction in intracellular water adds further stress to the bird. Panting also requires increased muscle activity, which result in increased energy efficiency accompanying hot weather.

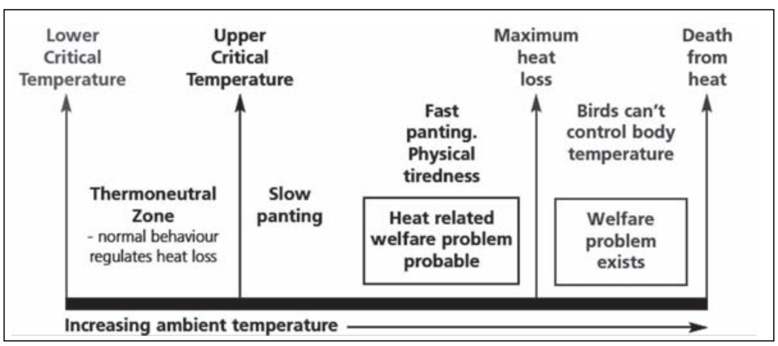


Fig : Diagram of Thermoneutral Zone

Optimum temperature range: The performance of partly under different temperature ranges (Table-1) revealed that 21-26°C temperature range is ideal for both feed efficiency and egg production. Beyond the temperature range 35-38°C emergency measures are requested to be take up.

Table 1 : A guide to the performance of poultry at various temperatures

Below 10°C	Reduction in egg production and weight gains are common with severe negative impact on feed efficiency.
10-21°C	Feed efficiency becomes poorer
21-26°C	Ideal temperature range
26-29°C	Slight reduction in feed consumption can be expected but nutrient intake is adequate. Production efficiency is good. Egg size may be smaller and shell quality may suffer as temperature reaches the top of this range.
29-32°C	Feed consumption falls further & weight gains are lower. Egg size and shell quality deteriorate. Egg production usually suffers. Cooling procedures should be started before reaching this temperature.
32-35°C	Feed consumption continues to drop. There is danger of heat prostration among layers, especially the heavier birds and those in full production. At these temperatures cooling procedures must be carried out.
35-38°C	Heat prostration is probable, Emergency measures may be needed. egg production and feed consumption are severely reduced. Water consumption is very high.
Above 38°C	Emergency measures are needed to cool birds. Survival is the concern at this temperature.

Economic Losses

High environmental temperature is one of the most serious factors affecting the production performance of broilers and layers in both tropical and subtropical countries. Large economic losses occur because of decreased production and increased mortality.

- Decreased growth rate and egg production as a result of reduced feed intake and nutrient, digestibility, especially amino acids.
- Decreased egg shell quality leading to egg breakage.
- Reduced broiler breast meat quality.
- Increased mortality and morbidity.
- Reduced immunity and disease resistance.
- Heat stressed broilers have higher abdominal fat and lower carcass protein

Strategies for Heat Stress Mitigation

Heat stress negatively affects chickens because their feather coverage hinders the dissipation of internal heat, leading to elevated body temperatures. To avoid a dangerous increase in body temperature, chickens minimize endogenous heat production by reducing feed intake, and consequently exhibit decreased growth and meat yield in broilers, and egg production in layers. Decreasing the feather coverage should enhance heat dissipation and consequently alleviate the heat stress on chickens reared in hot climates. In addition, reduced feathering saves valuable protein which is turned instead into meat tissues.

a. Breeding

There are a few options available for mitigating this inevitable adversity through breeding and evolving varieties better adapted to survive. At present, the commercial stocks used in tropical countries are evolved by the breeders doing selection programme in the temperate climate conditions. It would be more appropriate to produce suitable stocks for hot climatic conditions by breeding in tropical climates to reduce environment-genotype interaction. To make genetic improvement, heat tolerance can be incorporated in the selection indices. The research on selection in controlled high temperature has also resulted in developing heat tolerant lines (Yamada and Tanaka, 1992). The heritability of heat tolerance is quite high and rapid progress can be expected (Wilson, et al., 1996). The introgression of genes responsible for heat tolerance would be another strategy to develop heat resistant stocks. Naked neck (Na) gene is one such that reduce the feather cover by 30 to 40%, thereby improves heat dissipation (Meerat, 1990). The effects of this gene under adverse climatic condition in layers and broilers have been well established. The beneficial effect of Na gene in reducing heat stress in fast growing birds exposed to acute heat has been reported by Washbum et al. (1993). The frizzle gene (F) causes the contour feathers to curve outward away from the body. This has the advantage of easy heat dissipation through convection and radiation heat losses. Another major gene having such application is sex-linked slow feathering (K). The benefits of these feather reducing genes in birds exposed to hot climates have been established (Meerat, 1990). Also some other genes like silky (h), which affects the barbules on the feathers, may improve the effect to dissipate heat. The dominant gene for pea comb (P) also has the feather tract reduction action. The recessive, sex-linked, multiple allelic locus for dermal melanin (id) can improve radiation from skin. There are many reports to prove the individual and interaction effects of these major genes in coping with high environmental temperatures. The experiments with introgressing these genes in commercial lines revealed encouraging results. Therefore, one of the genetic strategies to develop competent lines for climatic change would be the inclusion of these genes in commercial stock. Recent studies (Cahaner and Druyan, 2007) revealed that featherless broilers bearing scaleless (sc) gene exhibited economically important advantages when reared under warm conditions.

b. Housing management

The design of poultry houses can greatly help in tiding over the adverse effects of climate change. The building site, orientation, insulation, roof overhang, and equipment design all affect the temperature inside the poultry house. Air movement is particularly important in houses that are ventilated by natural air currents. All poultry houses, but particularly curtain-sided houses, should be positioned so that the roof line runs from east to west. This orientation will keep direct summer sunlight coming from the sidewall and causing heat to build up within the house. Naturally ventilated houses should not exceed 10 m in width for effective cross ventilation. Adequate insulation in the ceiling and sidewalls will pay dividends by reducing the amount of the sun's radiant heat energy that reaches the interior. Installing insulation to the end of a 24-inch roof overhang will prevent solar radiation from penetrating the sidewalls. Insulation also reduces heating costs during winter months. A shiny surface can reflect twice as much solar radiation as a rusty or dark metal roof. Roofs should be kept free of dust and rust. Roof reflectivity can be increased by cleaning and painting the surface with metallic zinc paint by installing an aluminium roof. These practices are particularly effective for buildings that are under-insulated. Poultry house ventilation systems have a number of components. These include curtains, fans, fogging nozzles, evaporative cooling pads, timers, static pressure controllers, and thermostats. Curtain-sided houses rely extensively on natural air movement. These houses work best when they are located away from obstructions such as other buildings or trees that can block natural air currents. To avoid total reliance on natural air movement, most producers have added circulation fans in curtain houses to increase air movement and promote the loss of body heat from the birds. These fans should be spaced and positioned to maintain air movement between fans and to direct their flow in a way that will increase the turbulent air movement around the birds. Foggers reduce air temperature in the house on hot days (90° to 95 °F) when humidity is low, especially during midday when humidity levels are lowest and temperature is highest. The foggers inject fine water particles into the warm inside air. As the water vaporizes, heat is absorbed from the air, lowering its effectiveness to avoid excessive water flow into the environment. In forced ventilation systems, all air movement is produced by fans in the building walls. Houses that use this type of ventilation are also referred to as controlled environment systems.

c. Feeds and feeding

In addition to heat-stress mortality, economic losses associated with broiler heat stress also occur as a result of lowered growth rate and decreased feed efficiency. Therefore, it is natural for producers to stimulate feed consumption in hot weather. However, any management technique which promotes feed consumption or increased activity during the peak hot periods may be counterproductive. During the late afternoon there is a significant rise in body temperature, which, if severe, may kill the bird. The late afternoon may not be the hottest time in the day, but it is the peak of digestion in birds when they eat in the early-mid morning period. A good management strategy for layers to aid in reducing heat stress is to withdraw feed prior to the anticipated time of peak temperature so that it may take an unneeded heat load off the bird. For birds, a period of withdrawal program, can be beneficial to give supplemental lights during the period of natural darkness. Fasting reduces the heat production from digestion, absorption and metabolism of nutrients. Fasting also has a calming effect. Movement in animals occurs through muscle contraction which generates heat. In hot environments this heat production only adds to the heat load. Therefore, to lessen the heat load, birds should be kept as calm as possible. This is especially important during the hottest parts of the day. Once the hottest periods are over and ambient temperature starts to fall, the birds will usually begin consuming feed again.

Heat stress causes birds to decrease feed intake and consequently nutrient intake. Therefore, the dietary nutrient concentrations should be increased. Simply increasing the protein concentration is the wrong approach. The energy content of the diet, along with other nutrients, should be increased. Increasing fat calories should be considered. Dietary vitamin and mineral concentrations should be re-evaluated. The use of vitamin C, as an anti-stress agent, is often considered during periods of heat stress. Choosing the correct coccidiostat is very important as well as the use of antioxidants and mould inhibitors in stored feed. Protein contributes more to metabolic heat production than do carbohydrate and fat. Therefore, feeding imbalanced diets with regards to amino acids will result in increased metabolic heat production. Amino acid balance in the diet is especially important. Efforts should be made to formulate diets with slightly lower protein levels and to utilize synthetic amino acids, especially methionine and lysine. Birds under heat stress have to make critical life sustaining physiological adjustments. Feed intake is depressed and water intake is increased. Dietary adjustments can help reduce metabolic heat production and maintain nutrient intake. Energy intake and amino acid balance is of extreme importance in heat stress.

d. Watering

Panting is accompanied by an increase in water loss by the lungs. Therefore, more water has to be consumed by birds during hot weather in order to prevent dehydration. Cool drinking water stimulates both feed and water intake. Reducing the body temperature of heat stressed birds is beneficial. When the temperature of drinking water is lower than body temperature it will absorb body heat. Therefore, providing adequate and cool drinking water is extremely important to heat stressed birds. Usually, anything that results in increased water consumption during heat stress will benefit the survival rate. In fact, some researchers have attributed the increased survival rates of heat stressed birds receiving supplemental salts such as potassium bicarbonate, potassium chloride, sodium chloride and ammonium chloride.

e. Management

Providing adequate ventilation and stimulating water consumption is essential. Minimizing bird activity during the hottest parts of the day lessens the heat burden. Controlled fasting is beneficial and usually increases survival rate of birds during heat stress. In hot/humid environments, adequate air movement and water consumption are essential. Ventilation should be maximized. Air movement facilitates removal of build-up ammonia, carbon dioxide and moisture. Power ventilation houses can provide good, uniform airflow patterns under hot summer conditions if correct static pressure is maintained and airflow obstructions are avoided. Negative pressure systems use exhaust fans to provide air movement. Stale air is expelled from the house by fans at a slightly higher rate than air is allowed to enter through the vents. This creates a partial vacuum, causing the air to enter the house at a high velocity. Positive pressure systems use fans to blow fresh air into the building, creating a slightly higher pressure inside the house. Stale air is allowed to escape through strategically placed exhaust vents. Air movement is controlled by automatic environmental control mechanisms. A new arrangement for ventilating poultry houses in hot temperatures is tunnel ventilation. Simply put, this method involves moving air along the building axis from inlets to exhaust fans, providing high airflow velocities. This rapid air movement increases convective heat loss, reducing the effective temperature experienced by the birds. Fogging nozzles and evaporative cooling pads are options that can be used in combination with power ventilation systems and especially with tunnel ventilation. Evaporative cooling uses heat from the air to vaporize water, increasing humidity but lowering air temperatures. Evaporative cooling pads operate on the same cooling principle as foggers, except that the air is cooled when it passes through the wet pads as it enters the house. This method avoids the problem of wet litter sometimes encountered with foggers, allowing evaporative cooling pads to be used on a continuous basis. Aspen fibre and corrugated cellulose are two materials widely used as cooling pads. Regular maintenance is necessary to ensure long life of the pads. Fogging systems have also been used successfully in environmentally controlled poultry houses. A grass cover on the grounds surrounding the poultry house will reduce the reflection of sunlight into the house. Shade trees should be located where they do not restrict air movement. Fans used in aided air movements within and through the house should be routinely maintained.

EXTREME WEATHER EVENTS: IMPACTS ON LIVESTOCK PRODUCTIVE, REPRODUCTIVE PERFORMANCE AND AMELIORATION STRATEGIES

S.V. Singh

Cattle, buffalo, sheep, goat and birds are homeotherms and are sensitive to thermal stress. Studies showed that the negative effects of hotter summers will outweigh the positive effects of warmer winters on production efficiency of animals. Beyond a threshold optimum, higher the ambient temperature increases, the more the animal's production decreases. IPCC predicted an annual mean surface temperature rise by 3 to 5°C (A2 scenario) and by 2.5 to 4° C (B2 scenario) up to the end of century, with more pronounced warming in the northern parts of India (IMD, Pune), which would cause a drastic decline in livestock productivity. Temperature and humidity interact to cause stress in animals. Higher the temperature and humidity, the greater will be the stress and discomfort to animals and the more will be the reduction in the animal's ability to produce milk, gain weight and reproduce. The number of days it takes for cows to reach their target weight in dairy and meat animals and milk production and conception rate in cattle/ buffaloes decreases depending upon severity and duration of stress. As a result of rapid global warming, milk and meat production are projected to decline in a warmer world (Hatfield *et al*, 2008). The projected increases in air temperatures will negatively affect confined animal operations, increasing production costs as a result of reductions in performance associated with lower feed intake and increased requirements for energy to maintain healthy livestock. These costs do not account for the increased death of livestock associated with extreme weather events such as heat waves. Nighttime recovery in physiological functions is essential for survival, when animals are stressed by extreme heat. A feature of recent heat waves is the lack of nighttime relief and which causes the deaths of livestock species. (Hatfield *et al,* 2008). Warming also affects/ help in survival of parasites and disease pathogens. The earlier arrival of spring and warmer winters allow greater proliferation and survival of parasites and disease pathogens (Hatfield *et al,* 2008). Changes in rainfall distributions are likely to further lead to spread vector borne diseases due to higher humidity. Heat stress reduces animals' ability to cope with other stresses, such as diseases and parasites due to lower immunity status. Sustaining livestock production would require modification of shelter system to reduce thermal stress on animals, using the understanding of the chronic and acute stresses that livestock will encounter to determine the optimal modification strategy (Singh and Upadhyay, 2008 and Hatfield *et al*, 2008). Changing livestock species as an adaptation strategy is a much more extreme, high-risk, and in most cases, high-cost option than changing crop varieties. Accurate predictions of climate trends and development of the infrastructure and market for the new livestock products are essential for making this an effective response.

Climate and Climate Variability in India

The climate of India is mainly dominated by the high temperature (April to September). The whole year can be divided into four seasons based on the similar meteorological conditions viz. (i) Winter season (January and February) (ii) Hot weather season (March to May) (iii) hot humid season (June to September) (iv) Post monsoon season (October to December). Year to year deviations in the weather and occurrence of climatic anomalies / extremes in respect of these four seasons are:-

(i) Cold wave, fog, snow storms and avalanches
(ii) Hailstorm, thunderstorm and dust storms
(iii) Heat wave
(iv) Tropical cyclones and tidal waves
(v) Floods, heavy rain and landslides, and
(vi) Droughts

The cold and heat waves are the major threats to the livestock productivity in different parts of India. The occurrence of these events during different years of last hundred years (1901-1999) is given in tables 1 and 2. After 2000, heat waves further intensified in different parts of India. According to the Glossary of Meteorology (AMS, 1989) heat wave is "a period of abnormally uncomfortable hot and usually humid weather of at least one day duration, but conventionally lasting several days to several weeks". An operational definition often used for a heat wave is three to five successive days with maximum temperatures above a threshold.

Cold wave/wind chill are the apparent temperature felt on the exposed animal's body owing to the combination of temperature and wind speed. As wind velocity increases, heat is carried away from the animal's body at a faster rate, driving down both the skin temperature and eventually the internal body temperature below their normal temperature and to a state of hypothermia.

Table 1 : Number of cold waves recorded in different states of India

State	Years and number of extreme events				
	1901-10	**1911-67**	**1968-77**	**1978-99**	**1901-99**
West Bengal	2	14	3	28	47
Bihar	7	27	8	67	109
Uttar Pradesh	21	51	8	47	127
Rajasthan	11	124	7	53	195
Gujarat, Saurashtra & Kutch	2	85	6	6	99
Punjab	3	34	4	19	60
Himachal Pradesh	-	-	4	18	22
Jammu & Kashmir	1	189	6	15	211
Maharashtra	-	60	4	18	82
Madhya Pradesh	9	88	7	12	116
Orissa	4	5	-	-	9
Andhra Pradesh	2	**8**	**1**	-	11
Assam	1	1	-	-	2
Haryana, Delhi & Chandigarh	-	-	4	15	19
Tamil Nadu	-	-	-	-	-
Karnataka	-	10	-	-	10

Source: De et al; 2005

Table 2 : Number of heat waves recorded in different of India

State	Years and number of extreme events				
	1901-10	**1911-67**	**1968-77**	**1978-99**	**1901-99**
West Bengal		76	9	28	113
Bihar		105	6	23	134
Uttar Pradesh		27	3	42	72
Rajasthan		43	1	7	51
Gujarat, Saurashtra & Kutch		-	2	-	2
Punjab		-	1	-	1
Himachal Pradesh		-	-	-	-
Jammu & Kashmir		26	5	35	66
Maharashtra		82	4	13	99
Madhya Pradesh		32	4	15	51
Orissa		**25**	8	18	51
Andhra Pradesh		52	**2**	31	85
Assam		-	4	19	23
Haryana, Delhi & Chandigarh		-	1	2	3
Tamil Nadu		5	-	2	7
Karnataka		-	-	-	-

Source: De et al; 2005

Projections of Climate Change over India for the 21st Century

Based on modeling and other studies, the following changes due to increase in atmospheric GHG concentrations may arise from increased global anthropogenic emissions:

- As per IPCC, annual mean surface temperature rise by 3 to 5 °C (A2 scenario) and 2.5 to 4 °C (B2 scenario) by end of this century. The warming will be more pronounced in the northern parts of India as per the simulation studies carried by Indian Institute of Tropical Meteorology (IITM), Pune.
- Indian summer monsoon (ISM) is a manifestation of complex interactions between land, ocean and atmosphere. The simulation of ISM's means by IITM, Pune, have indicated that summer monsoon intensity may increase beginning from 2040 and by 10% by 2100 under A2 scenario of IPCC.
- Changes in frequency and/ or magnitude of extreme temperature and precipitation events. Some results show that fine-scale snow albedo influences the response of both hot and cold events and that peak increase in extreme hot events are amplified by surface moisture feedbacks.

Climate change and availability of feed resources:

As per the IPCC (2007) report, climate change will further negatively impact the Indian agriculture and would adversely affect livestock production in the India (Dinar *et al.* 1998). Due to poor availability of good quality of feed and fodders in India (3.4% area under pasture), animals are generally maintained on poor quality grasses available in the pastures or are stall-fed, mainly on crop residues. As per the Govt. of India (2002) estimate, India is already deficit in feed and fodder viz. dry fodder (22%), green fodder (62%) and concentrates (64%). These shortages would be further aggravated by the adverse effects of global warming/climate change on agricultural/ fodder crops.

Adverse consequences of climate change would be more visible on livestock species in areas where high ambient temperature could be associated with decline in rainfall, increased evapo-transpiration or increase in the incidence of droughts. A drought in 1987, affected over 168 million cattle in India, due to decline in feed and fodder availability and serious water shortages. In one of the worst draught affected state of Gujarat, 18 million cattle out of 34 million were reported to have died before it rained the next year. A 1999–2000 drought in the arid state of Rajasthan in

the north-western part of the country, which is highly drought-prone affected 34.5 million cattle; in the subsequent year about 40 million cattle were affected by drought (CSO, 2000). Drought damaged 7.8 million ha of cropped area in the state and fodder availability fell from 144 to 127 million tons. Any increase in the frequency and intensity of droughts in the arid and semi-arid regions in India would perhaps have the greatest impact on the pastoral families, as they have to migrate to arable areas to secure their livelihoods.

Effect of long term and extreme events on milk production and reproduction in India:

The impact of temperature rise/change was assessed on milk production of cattle and Murrah buffaloes and a decline in milk production was observed with a rise in THI and T_{max}. Analysis of the potential direct effects of climate change in 2020/2050 and global warming on summer season milk production of Murrah buffaloes indicated that a rise of 1.0 or 1.2 °C during March-August for India (Region 23- HADCM3 A2/B2 scenario) will marginally affect milk production but temperature rise of more than 2 °C over existing temperatures for time slices 2040-2069 and 2070-2099 will cause higher incidence of silent estrus, short estrus and decline in reproduction efficiency of buffaloes. Animals with limited water access will experience warming effect more than that of buffaloes dissipating heat by water wallowing (Upadhyay *et al.* 2009).

A sudden rise in T_{max} during summer and a fall in T_{min} cause a negative impact on milk yield of cattle (Fig.1). The increase in T_{max} (>4 °C) than normal during summer (Fig.1) and decline in T_{min} (>3 °C) during winter (Fig.2) was observed to impact the milk production negatively in crossbred cattle and buffaloes. The decline in yield varied from 10-30% in first lactation and 5-20% in second and/ or third lactation. The extent of decline in milk yield was less at mid lactation than either late or early stage. The negative impact of sudden temperature change i.e. cold wave or heat wave on milk yield of cattle/buffaloes were not only observed on next day of extreme event but also on the subsequent day (s) after extreme event, thereby indicating that T_{max} increase during summer and T_{min} decrease during winter cause short to long term cumulative effect on milk production of cattle and buffaloes. The return to normal milk yield took 2-5 days with a

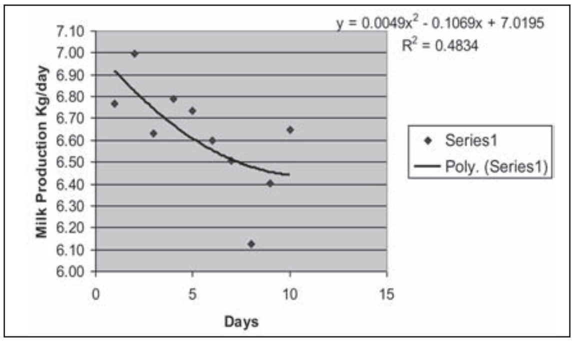


Fig. 1 : Impact of temperature change (+5°C) on milk production of Karan fries cows

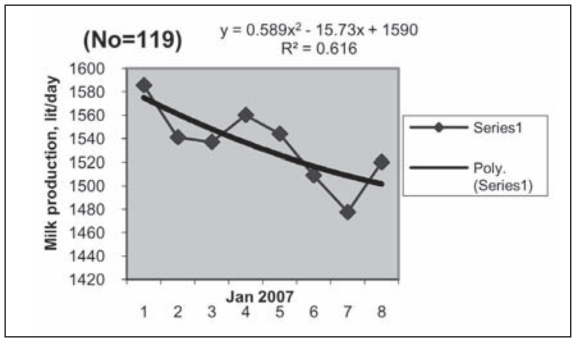


Fig. 2 : Impact of cold extreme event on milk production of Karan fries cows

variable response. The decline in milk yield and return to normal yield after and extreme event was also dependent on subsequent day (s) T_{max} and T_{min}. The R^2 was non significant and very low for cool period observed during Feb-April / Sept-Nov and actual affect on milk production was minimum. This indicated that low THI (<75) had a relatively small effect on milk production performance. The lactation period of buffaloes were shortened by several days (3-7) during extreme summer when THI was more than 80.The expressions of estrus and reproductive functions were also negatively impacted. Excessively distressed buffaloes with higher rectal temperature (more than 40 °C) did not exhibit estrus or exhibited estrus symptoms for short duration that often remained undetected (Upadhyay et al. 2009).

Global extreme events and their impact on animal performance and survival:

Extreme weather event that adversely impacted livestock includes the severe heat waves of 1995 and 1999 in the Midwestern states (USA) which caused nearly 5,000 animal deaths in each year (Busby and Loy, 1996; Hahn and Mader, 1997; Hahn *et al.*, 2001). Major death losses in the United States and elsewhere e.g. dairy cows in southern California, 1977 (Oliver *et al.*, 1979); feedlot cattle in Nebraska, 1992 (Hahn and Nienaber, 1993), and 1999 (Mader *et al.*, 2001). A 1995 (July 10-15) heat wave in the Midwestern United States resulted in more than 4000 feedlot cattle deaths in Iowa and Nebraska, as well as numerous human deaths in Chicago and elsewhere. During this heat wave event, there were extended periods during five days of the heat wave (July 10-14) when the THI values were 84 or above. One contributing factor to the cattle losses was the continuous exposure to THI values above critical threshold, so there was no opportunity for recovery in physiological functions at night (Scott et al., 1983). Accompanying higher solar radiation loads (clear to mostly clear skies) and low to moderate wind speeds were further contributing factors in the area of highest risk. For cattle in other locations with 20 or more daily THI-hrs in the "Emergency" category (THI 84) for only one or two days, the animal heat load was apparently dissipated with minimal or no mortality (Hahn, 1999). The economic toll from this heat wave event for cattle feeders in Iowa alone was estimated to be $28 million as a result of death and performance losses (Smiley, 1996). Retrospective analysis of hourly climatic records during the 1995 heat wave event was used to evaluate characteristics of heat waves (e.g., intensity, duration, recovery time) that cause feedlot cattle deaths; the results, in terms of daily THI-hrs at or above the Livestock Weather Safety Index (LWSI) thresholds for the Alert, Danger, and Emergency categories, provide a valuable approach to environmental management practices (Hahn and Mader, 1997). This THI-hrs analysis of the 1995 heat wave and others have reinforced the LWSI thresholds for categories of risk, and support an environmental profile for single heat wave events that create conditions likely to result in deaths of Bos-taurus cattle in feedlots: 15 or more THI-hrs per day for three or more successive days at or above a base level of 84 (Emergency category of the LWSI) with minimal or no nighttime recovery opportunity. Death losses can be expected if shade, precautionary wetting, or other relief measures are not provided during such conditions. Conditions in the "Danger" category of the LWSI also may cause mortality in highly vulnerable animals (e.g., new entrants to the feedlot; those at or near market weight; animals not yet acclimated to hot weather; sick animals, especially with respiratory problems). Successive heat waves with intervening cool periods can create excessive heat loads and potentially lethal conditions for cattle even when the conditions during secondary heat waves are comparatively moderate. This is likely a result of increased feed intake during the cool periods. It should be further noted that costs associated with death losses, while drastic, are often greatly surpassed economically by performance losses (growth, efficiency) of surviving cattle (Balling, 1982).

In the Northern Plain states, with greater than normal snowfall and wind in the winter of 1996/1997, up to 50% of the newborn calves and over 100,000 head of cattle were lost in many areas (Mader, 2003). In the winter of 2000/2001 (Hoelscher, 2001), feedlot cattle efficiencies of gain and daily gain decreased approximately 5 and 10% from previous years as a result of late-autumn and early-winter moisture combined with prolonged cold stress conditions. In January 2007, Colorado faced the most severe snow storm in the past sixty years, causing decreased hay supplies and large death losses to livestock. The exceptional drought in Southern High Plains that began in the fall of 2010 and continued for a year caused incredible losses as calves were placed early in feedlots, culled at much higher rates than normal, or moved to regions where grass and hay are more readily available.

Cattle mortalities also increase during periods of extreme heat stress (Hahn, 1985). Heat stress can decrease dry matter ingested and increase dry matter digestibility (Lippke, 1975) and decrease the rate of weight gain (Mitlohner et al., 2001). But the extent of production loss is often difficult to estimate because heat stress effects are typically hidden among high natural and managerial sources of variation (Linvill and pardue, 1992). Animals exposed to cold weather require more energy to maintain their body reserves and to maintain their body temperatures (Vinning, 1990). In the winter, the influence of wind can have a negative impact on cattle performance and its effects are magnified when combined with cold temperatures. One way cattle compensate for colder weather is to increase feed intake. However, cattle have a physical limit on how much they can consume. Once that point is reached, they will need higher quality feeds and supplements to compensate for the increased energy requirement.

Deng *et al.* (2007) use the Temperature Humidity Index (THI) to analyze the impact of weather on dairy cow production in the southeast, where summer temperatures are high with high relative humidity. The THI index is used to account for the interaction between temperature and humidity. They reported that milk yields decline as the rectal temperature increased, and with the same high temperature, cows exposed to low humidity performed better than those exposed to high humidity. THI can be calculated using Johnson (1963) formula as follows:

$$THI = 0.72\ (tdb + twb) + 40.6$$

Where, tdb and twb are dry bulb and wet bulb temperatures (°C) respectively

Heat stress begins to occur in dairy cattle/ buffaloes when the THI is > 72. Some of the signs that the dairy cattle and buffaloes exhibits with the increases in THI, range from mild changes in metabolism and milk production to animals death depending upon the stress levels.

For assessing the cold stress, the Wind Chill Index (WCI) is used to indicate the cold stress levels on animals. Wind chill is the apparent temperature felt on exposed skin of animals due to wind speed. The following formula (Paul Allman Siple and Charles Passel) is used to calculate WCI, when temperatures fall below 45°F.

$$WCI = 0.0817\ (3.71 \times wind^{0.5} + 5.81 - wind \times 0.25)\ (TD - 91.4) + 91.4$$

When temperatures are between 46°F and 59°F, the following formula is used.

$$CSI = [(TD - 45/14)] \times TD + [(59 - TD)/14] \times WCI$$

Where, WCI = Wind Chill Index, wind = wind speed in miles / hour,
CSI = Cold Stress Index and TD= Dry Bulb Temperature (°F)

The combined effects of temperature and wind are often expressed as a wind chill index. The wind chill index, rather than ambient temperature, is used to estimate effective temperature when considering the severity of cold stress. For example, when the temperature is 20 °F with no wind, the wind chill index is 20°. At the same ambient temperature, 5, 15 and 25 mph winds would result in a wind chill index (or effective temperature) of 13°, 4° and -7 °F, respectively. By any means reducing the exposure of animals to wind will dramatically reduce cold stress. In general, a cow's energy requirements increase 1% for each degree the wind chill is below 32°F. For a wet cow, the increased energy requirement begins at 59 °F and increases 2% for each degree drop.

Table 3 : Probabilities of extremely warm, wet and dry seasons 2080–99 suggested by IPCC GCM model projections in Asia *(in per cent)*

Sub region	Season	Extreme warm	Extreme wet	Extreme dry
East	DJF	96	18	2
	MAM	98	35	2
	JJA	100	32	1
	SON	10	20	3
South	DJF	99	14	-
	MAM	100	32	1
	JJA	96	29	3
	SON	100	39	3

Note: DJF: December to February, MAM: March to May, JJA: June to August, SON: September to November.
Source: Adapted from Christensen et al. (2007)

Climate change and animal adaptability:

Weather and extreme events have adverse effects on several aspects of animal production (Upadhyay *et al.*, 2007). There is a range of thermal conditions within which animals are able to maintain a relatively stable body temperature by means of behavioral and physiological means (Bucklin *et al.*, 1992). Heat stress results from the animal's inability to dissipate sufficient heat to maintain homeothermy. High ambient temperature, relative humidity and radiant energy compromise the ability of animals to dissipate heat. As a result, there is an increase in body temperature, which in turn initiates compensatory and adaptive mechanisms to restablish homeothermy and homeostasis. These readjustments generally referred to as adaptations, may be favorable or unfavorable to economic interests of humans, but are essential for survival of the animal (Stott, 1981).

Thus, an increase in air temperature, such as that expected in different scenarios of climate change, would affect directly animal performance by affecting animal heat balance. Air temperature affects energy exchanges through convection and evaporation (Hahn, 1976). When temperature increases, evaporation becomes the most important way of heat loss, since it does not depend on a temperature gradient (Shibu et al. 2008). Under that circumstance the combination of temperature and humidity acquire more relevance, since increased humidity enhances temperature effects. The comfort limit depends on level of production. Animals producing at higher level are more sensitive to heat stress (Johnson, 1987; Singh and Upadhyay, 2008, 2009). Not only intensity of stress, but also the length of the daily recovery period is important in determining animal responses (Hahn *et al.*, 2001 and Upadhyay *et al.*, 2007).

Animal Diseases

Global warming is likely to cause an increase in animal diseases that are spread by insects and vectors. Higher temperature and humidity will favor spread and growth of insects/vectors. Incidences of both protozoan and viral diseases affecting livestock will spread in susceptible population. Incidence of protozoan diseases like Trypanosomiasis and Babesiasis are likely to increase in high producing crossbred cattle and may be higher in future. Some of the viral diseases may also reappear and affect both small and large ruminants' population. Frequency and incidence of mastitis and foot diseases affecting crossbred cows and other high producing animals may increase due to increase in number of stressful days. Climatic conditions favorable for the growth of causative organisms during most part of the year due to temperature rise will facilitate spread of diseases in other seasons and also increase area for their spread.

Mitigation strategies to overcome the effects of climate change:

Since climate change could result in an increase of heat stress, all methods to help animals cope with or at least alleviate the impacts of heat stress could be useful to mitigate the impacts of global climate change on animal responses and performance. Three basic managemental tools/ schemes for reducing the effect of thermal stress have been suggested (Kumar *et al.*, 2009):

(a) Physical modification of the environment;
(b) Development of genetically less sensitive breeds and
(c) Improved nutritional and management practices.

Physical modification of the environment: The methods for micro environment modification include: shades, ventilation, combination of wetting and ventilation. Shades are the simplest method to reduce the impact of high solar radiation/ climate change. Shades can be either natural or artificial. Tree shades have proved to be more efficient (Hahn, 1985). If sufficient natural shade is unavailable, appropriate shelter should be constructed. Shades are effective in reducing heat stress/ physiological responses in the dairy animals (Singh and Upadhyay, 2008, 2009). The protected animals show lower physiological responses (RR, PR, RT & ST) during afternoon and yield more milk and protein (Singh and Upadhyay, 2009). The artificial shade structure did not differ from tree shades in terms of the effects on animal well-being (Valtorta *et al.,* 1997). Proper ventilation in a shelter is important for the relief from heat stress, if possible, natural ventilation should be maximized by constructing open-sided constructions (Bucklin *et al.*, 1992). Forced ventilation provided by fans is a very effective method for lowering the temperature (Kumar *et al.*, 2009). An effective way of cooling dairy cattle and buffaloes are spray evaporative cooling. Several cooling devices viz.: mist, foggers and sprinkling systems are available. However, the single use of a sprinkling and fan system for 30 minutes before milking has proved to be useful to provide relief dairy animals from heat stress in terms of efficiency to reduce the impact of heat waves under a grazing system (Valtorta *et al.,* 2002).

Managemental strategies during heat stress for improving productivity:

- Increase number of feedings/day particularly during morning, afternoon and night hours i.e. feeding during cooler hours to reduce SDA of feeds.
- Maintain energy intake with decreased dry matter intake.
- Increase dietary protein density to compensate lower intake.
- Increase dietary mineral concentration (Na, K etc.).
- Ratio / balance of cations (Na & K) and anions (Cl & S) are also important.
- Feeding Total Mixed Ration (TMR) should be preferred over component or separate ingredient feeding.
- Well balanced TMR- diet formulation at optimum fibre level- encourages DMI; minimize rumen fermentation fluctuation & pH declines.
- Feed supplementation of antioxidants as vitamin E and Selenium.

Additional means of reducing Heat Stress effects:

- Selective crossbreeding- The exotic breeds of cattle which are more heat tolerant due to more sweat gland density (Jersey) should be given more preference over less heat tolerant (Holstein Friesian) .
- Selection of heat tolerant animals with in breed for future breeding programmes.

Chapter - VI

Weather Forecasts and Agro Advisories

WEATHER FORECASTS AND THEIR UTILITY IN AGRICULTURE

S.C. Bhan

Need for Weather Forecasts for Agriculture

Weather plays an important role in agricultural production systems through its influence on growth, development and yield of a crop, incidence of pests and diseases, water needs and fertilizer requirements in terms of differences in nutrient mobilization due to water stresses and timeliness and effectiveness of prophylactic and cultural operations on crops. Weather aberrations may cause (i) physiological under-performance by the crop plants, (ii) physical damage to crops, (iii) soil erosion and (iv) may render the agricultural inputs ineffective. The quality of crop produce during movement from field to storage and transport to market depends on weather. Bad weather may affect the quality of produce while lying in the fields/indoor storages or during transport and may adversely impact the viability and vigour of seeds and planting material during storage.

There is no aspect of crop operations that is devoid of the impact of weather. However, the weather requirements for optimal growth, development and yield of crops; incidence, multiplication and spread of pests and diseases; and susceptibility to weather-induced stresses and affliction by pests and diseases vary with the variety of a crop, its growth stages and among different crops. For optimal productivity at a given location crops and cropping practices must be such that their cardinal phased weather requirements match the temporal march of the concerned weather element/s, and hazardous weather are avoided. Such a synchronisation, however, is not possible on all the occasions as the weather elements do not follow the same pattern every year. Forecasts for weather elements, therefore, have to be provided so that necessary pro-active steps could be taken to minimise the impacts of adverse weather. Weather forecasts also help in taking benefits of the expected favourable weather by strategic/tactical alterations in the cropping pattern, field operations and input scheduling. Agronomic strategies to cope with changing weather are available. For example delay in start of crop season can be countered by using short duration varieties or crops and closer spacings. However, once the crop season starts, the resources and technology are same and the only option then left is to adopt crop-cultural practices to minimize the effects of mid-seasonal hazardous weather phenomena on the basis of advanced intimation of their occurrences. For example, effects of frosts can be prevented by resorting to irrigation or lighting up of trash fires. Thus, medium range weather forecasts with a validity period that enables farmers to organize and carry out appropriate cultural operations to cope with or take advantage of the forecasted weather, are useful. With the rapid advances in Information Technology and its spread to rural areas, the demand for provision of timely and accurate weather forecasts for farmers is on the increase.

Some Unique Aspects of Agricultural Weather Forecasts

Weather forecasts for agriculture need to be distinct from general weather forecasts due to their applications for specialised operations/decisions. Preparation of field for sowing and sowing of crop with adequate availability of seed zone soil moisture requires copious rains. Rains that do not sufficiently contribute to root zone soil moisture of standing crops are less effective and therefore need to be provided in quantitative terms. The adequacy of rainfall, for example, needs to be indicated in conjunction with evaporative power of the atmosphere which in turn requires forecasts for other weather variables such as temperature, humidity, wind and sunshine. While clear weather is required for sowing operations, it must be preceded by antecedent seed zone soil moisture storage. Thus, forecasts of clear weather following a wet spell are crucial. Such forecasts of dry spells following a wet spell are also required for the initiation of disease control measures. There are areas where frequent thunderstorm activity precedes the arrival of rains associated with well-defined weather systems. In such cases the agronomic strategy should be to utilize pre-seasonal rains for land preparation and resort to dry sowings in anticipation of rain in the next few days. In temperate regions frost can cause severe menace to agricultural productivity. Frosts normally occur when the screen temperatures are 3-4 degrees Celsius above freezing temperature. Appropriate indications for such temperatures need to be given in the forecasts meant for agricultural use.

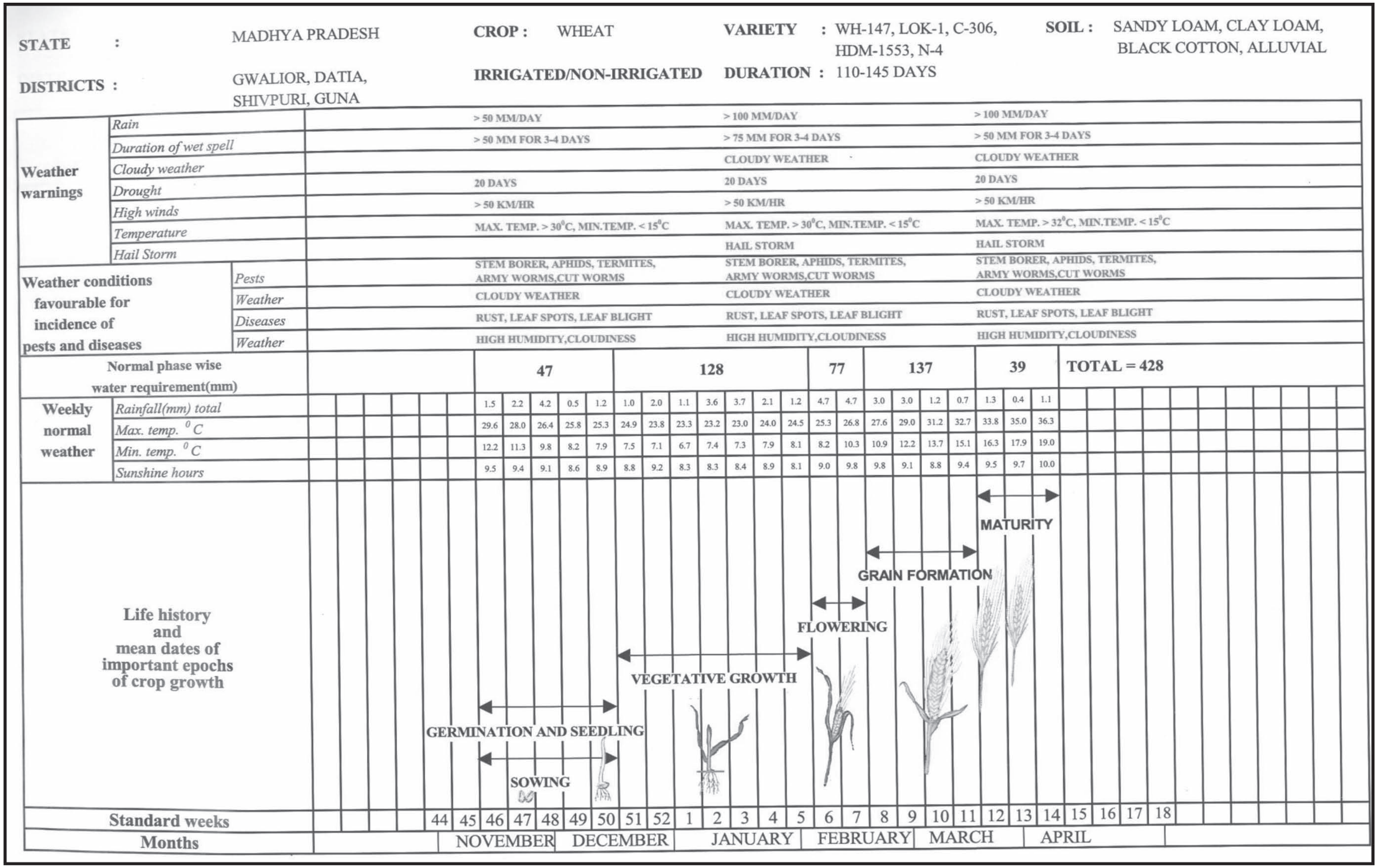


Fig. 1 : Crop Weather Calendar

In the provision of weather forecasts for agriculture, the emphasis should be on the lookout for incidence of abnormal weather relative to the crop situations. However, abnormality cannot be determined unless the forecaster knows what the normal picture is, both with reference to crops and weather. Thus, the first step in familiarizing the weather forecasters with the weather warning requirements of farmers is the preparation of "Crop Guides to Forecasters" giving (i) the times of occurrence and duration of developmental phases from sowing to harvest of major crops in a regions of their forecast interest and (ii) specifying the types of weather phenomenon for which weather warnings and forecasts are to be issued in different crop Phases. Such guides can be used by the forecasters to prepare period-wise, region-wise calendars of agricultural weather warnings. In the crop guide to forecasters, normal values of important weather elements for different crops in the crop season (in short-time steps, say, weekly time steps) should be given along with the significant weather parameters for which weather forecasts and warnings are required to be given. This guidance generally known as 'crop-weather calendars' should be made available to both the farming community and the forecasters so that farmer will know the normal features of weather for a given crop and season in his place; and the forecaster knows what are critical limits of different weather parameters for which forecasts need to be provided for a given area/crop/time. A sample 'crop-weather calendar' is given in Fig. 1.

Types of Weather Forecasts

Different types of weather forecasts and their applications in agriculture are discussed below

Operational weather forecasts are traditionally classified in to following groups:

i. Now-casting (NC)
ii. Very Short Range Forecast (VSRF)
iii. Short Range Forecast (SRF)
iv. Medium Range Forecast (MRF)
v. Long Range Forecast (LRF)

The basic descriptions of different types of temporal forecasts are given in Table 1.

Weather forecasts of different temporal scales are used in agricultural planning and operations in a variety of ways starting from planning for a particular crop/variety to post harvest operations/processing and export/import decisions

The long range forecasts are used for seasonal planning on

- Type of crop/variety to be sown
- Proportion of area under different crops
- How much of land, if any, to keep fallow
- Redistribution of inputs (seed, fertilizer, pesticides etc.)
- Arranging for Power and Water Resources
- Preparation of Contingency Plans
- Post harvest arrangements for marketing/storage/processing
- Preliminary enquiries on exports/imports
- Help make the best use of a good season and minimize the harmful impacts of the adverse one

The prevailing weather and forecasts in short and medium range, particularly of precipitation and temperature are vital for

- deciding sowing - yes/no, at what depth
- Transportation/re-distribution of agricultural inputs (seeds, machinery, chemicals, fertilizers and water)
- Whether to irrigate or not; depth of irrigation (enhanced irrigation use efficiency)
- assessing likely incidence of pests and diseases
- Time and doses of fertilizers and chemicals (prophylactic/reactive) for enhanced fertilizer and chemical use efficiency and reduced environment and health hazards
- harvest and post-harvest operations including storage, transportation, marketing and processing)
- necessary interventions, wherever needed, by the Government in view of significant aberrations in the weather over different parts of the country.

Table 1 : Basic description of forecasts of different temporal scales

Type of weather forecasts and description	Characters of output	Dominant technology	Other aspects	Time and space Resolution
Nowcasting A description of current weather variables and 0 - 3 hours description of forecasted weather variables.	A relatively complete set of variables can be produced (temp, RH, wind speed and direction, solar radiation; amount and type of clouds and precipitation.	Analysis techniques, extrapolation of trajectories/radar echoes, empirical models, and methods derived from forecaster experience (rules of thumb). Basic information is represented by data from networks of Automatic Weather Stations (AWS), Lightning detection systems, meteorological radar, meteorological satellites.	A fundamental prerequisite for NC is the operational continuity and the availability of an efficient broadcasting systems (eg: very intense showers affecting a given territory must be followed with continuity in provision of information for final users).	Typical time resolution is hourly; typical space resolution is of the order 2-20 km.
Very short range forecast Up to 12 hours forecast of weather variables	A relatively complete set of variables can be produced (see nowcasting)	Synoptic Analysis techniques, extrapolation of trajectories, forecasts from rapid cycle meso-scale NWP models, empirical models, methods derived from forecaster experience (rules of thumb). The basic inputs are data from networks of Observatories, AWS, radars, satellites and NWP models,	The prerequisite for VSRF is the availability of efficient dissemination systems (eg: frost information must be sent to farmers that can activate irrigation facilities or fires or other systems of protection).	Typical resolution is 3 hours; and mesoscale (2-200 km) in space
Short range weather forecast Beyond 12 hours and up to 72 hours Forecast description of weather variables	A relatively complete set of variables can be produced (see nowcasting)	Interpretation of forecast data and maps from NWP with value addition from forecaster experience. The basic inputs are data from networks of Observatories, AWS, radars, satellites and NWP models,	In SRF the attention is centred on mesoscale features of different meteorological fields. SRF can be disseminated by a wide set of media (newspapers, radio, TV, web, etc.) and can represent a fundamental information for farmers.	Typical time resolution is 6 hours; typical space resolution is of the order of mesoscale (2-200 km).
Medium range weather forecast Beyond 72 hours and up to 240 hours description of weather variables	A relatively complete set of variables can be produced (see nowcasting)	NWP models. Instead of using just one model run, many runs with slightly different initial conditions are made. An average, or "ensemble mean", of the different forecasts is created. This ensemble mean generally has more skill because it averages over the many possible initial states and essentially smoothes the chaotic nature of climate. In addition, it is possible to forecast probabilities of different conditions using the ensemble technique.	In MRF the attention is centred on synoptic features of different meteorological fields. MRF can be broadcasted by a wide set of media (newspapers, radio, TV, web, etc.) and can represent a fundamental information for farmers.	Typical time resolution is 24 hours; typical space resolution is of the order of meso to synoptic scale (100-2000 km).
Long range forecast More than 10 days and up to a year	Forecast is usually restricted to some fundamental variables (temperature and precipitation); other variables like water balance are sometimes prese-nted. Information can be expressed in absolute values or in term of anomaly.	Statistical and NWP methods. Coupling of atmospheric models with ocean general circulation models is now-a-days adopted in order to enhance the quality of long-range predictions.	An Extended-range weather forecast (ERF), beyond 10 days and up to 30 days, is sometimes considered as a separate class of forecasts. Basic techniques used, are dominantly NWP based. Forecasts in extended range are provided in both quantitative and probabilistic terms.	Typical time resolution is 1 month; typical space resolution is of the order of the synoptic to macroscale (200-1000 km)

Elements of Weather to be Forecasted

Weather forecast in agriculture should refer to all weather elements which affect farm planning or operations. The elements vary from place to place and from season to season. Normally, a weather forecast includes the following parameters.

- Precipitation (type, amount and intensity
- Maximum and minimum temperatures
- Relative humidity
- Wind Speed and direction
- Amount and type of coverage of sky by clouds
- Extreme events like heat and cold waves, fog, frost, hail, thunderstorms, wind squalls and gales.

Weather forecasts specially tailored for agricultural purposes should also contain the following information:

- Bright hours of sunshine
- Solar radiation
- Dew, Leaf wetness
- Pan evaporation
- Soil moisture stress conditions
- Micro-climate inside crops in specific cases.

A more specific description of processing of weather forecasts of single weather variables for agricultural uses is presented hereafter.

a) Temperature

Forecast of air temperature is important for many agrometeorological applications. Crop species exhibit the phenomenon of Thermo-periodicity, which is the differential response of crop species to daytime, nocturnal and mean air temperatures. It is possible to derive mean day and night time temperatures from data of maximum and minimum temperatures. Forecasts of temperature are generally expressed as range of expected values (e.g.: 30-32°C for maximum and 20-22°C for minimum). Particular attention could be reserved to temperature forecasts at particular stages of crop cycle, taking into account the values of cardinal and critical temperatures for reference crops.

Other thermal variables with a specific physiological meaning (e.g.: accumulation of thermal units or chill units) can be the subject of specific forecasts. However, the base temperature above which the accumulations will apply varies with crop types. Therefore, for forecasting dates of attainments of specific phenological stages of crops, time-series data showing actually realized heat or chill accumulations up to the time of issue of forecasts have to be maintained. A probabilistic approach can then be adopted to forecast the probable dates of specific crops reaching particular phenological stages.

b) Precipitation

Precipitation (type and amount) is probably the most needed and also the most difficult variable to forecast. Quantitative forecasting of rainfall is required for planning agricultural operations. However, for crop operations, it is as important to have the forecast of (i) occurrence/non-occurrence of rains (wet/dry spells) and (ii) type of rain spell that can be expected. Forecasts of rain can be defined adopting some standard classes (light/moderate/heavy etc.) that could depend on the climate and the agricultural context of the selected area.

Fog and dew can contribute significantly to crop water needs. They are beneficial in contributing to water needs of crops in winter and in helping survival of crops during periods of soil moisture stress. Dew is also desirable for using pesticides and fungicides in the form of dust. The meteorological conditions required for dew formation are the same as those for fog formation except for the need for absence of air-turbulence in the air layers close to the ground and crop-canopy temperature being lower than the screen temperatures. Dew is an important parameter influencing leaf-wetness duration and hence in facilitating entrance of disease spores into crop tissues.

c) Wind speed and direction

Forecast of wind speed is important for many different agricultural activities. Wind direction could be defined too. It is important to give information on expected variability in wind speed during the course of a day.

d) Cloud Cover

Forecasts for cloud cover should cover both the amount and the type of clouds. For example, high clouds produce a depletion of global solar radiation quite different from that produced by mid or low clouds.

e) Leaf Wetness

Leaf wetness is produced by rainfall, dew or fog. Duration of this phenomenon can be important in order to plan different activities like application of pesticides, harvest of crops and incidence of some plant diseases. Leaf wetness is a parameter that is scarcely recorded. A number of empirical methods can be used to derive leaf-wetness durations from meteorological parameters.

f) Evapotranspiration

Forecast of evapotranspiration can be important in order to improve the knowledge of water status of crops. A quantitative forecast of (i) the probability of water excess or stress for rainfed crops and (ii) the timing and amount of irrigation for irrigated crops are very highly useful.

h) Extreme Weather Events

Though the level of predictability of extreme events acting at meso or micro scale (frost, thunderstorms, hail, tornadoes, etc.) is low, these forecasts are important for agriculture, given the potential impact of the extreme weather events on agriculture.

Communicating Agricultural Weather Forecasts

Timely communication of weather forecasts for agricultural operations is of utmost importance as many critical operations related to economic and food security aspects are based on these forecasts. Whereas the forecasts for longer time scales can be communicated using the slower modes such as news papers, workshops, group discussions etc., the forecasts for shorter time validity need to be communicated as soon as possible to the farmers. The latest means of communication including radio, television, internet and mobile phones (voice and text messages) must be used for effective use of the forecasts. For the same temporal distribution of weather parameters, different crops will react differently. Also, the effects of weather or weather-induced stresses and incidence of pests and diseases are critically dependant on the state and stage of crops during which they occur. The effects of anomalies of a weather element on a given crop are location-specific. Thus, the requirement for these special forecasts will vary between and within the seasons, from place to place, from crop to crop and with the kind of operation i.e., cultivation, post harvest processing etc. The agricultural weather forecasts must be written by a trained agricultural meteorologist in consultation with farm management specialists for the current farm operations, such as for planting, irrigation, applying fertilizers, pesticidies, cultivation, harvest and post harvest processing, as well as for solving other weather related agricultural problems.

AGROMET ADVISORIES FOR MINIMIZING THE IMPACT OF EXTREME WEATHER EVENTS IN INDIA

N. Chattopadhyay

Extreme weather events and climate anomalies have major impacts on agriculture. India being mainly an agricultural country, the economy and further its growth purely depends on the vagaries of the weather and in particular the extreme weather events. Failure of rains and occurrence of natural disasters such as floods and droughts could lead to crop failures, food insecurity, famine, loss of property and life, mass migration, and negative national economic growth.

Extreme weather events like heavy rains, cyclone, hail storm, dry spells, drought, heat wave, cold wave and frost causes considerable loss in crop production every year. Impacts of extreme events can be direct or indirect. Direct impacts arise from direct physical contact of the events with people, their animals and property. Indirect impacts of extreme agrometeorological events are those induced by the events. Indirect impacts often occur away from the scene of the extreme event or after the occurrence of the event. Indirect impacts include evacuation of people in the event of cyclone landfall, disruption to household and leisure activities, stress induced sickness and apprehension and anxiety of future extreme events like floods or bush fires. An efficient use of available climatic resources, besides soil and water resources, minimizes the adverse effect of extreme weather and makes benefit of favourable weather**.**

Early warning systems of climate extremes allow sufficient time for individual and communities to act to reduce loss of life and crop damage. There are two phases of early warning systems: prevention and preparedness. Providing forecasts and warnings of severe weather, extreme temperatures and drought or flood in a timely manner contributes to preparedness. Use of improved climate and weather information and forecasts along with efficient early warning systems contribute to the preparedness for extreme weather events.

Important extreme events and agriculture: The most important of these extreme climatic events from agriculture and livestock point of view are:

(i) Tropical storms (cyclones, hurricanes, typhoons, etc.) associated with high winds, flooding and storm surges.

(ii) Floods (other than those related to tropical storms) heavy rains due to monsoons, water logging and landslides.

(iii) Severe thunderstorms, hail storms, tornadoes and squalls.

(iv) Drought and heat waves.

(v) Cold spells, low temperature, frost, snow and ice-storms. (vi) Dust storms and sand storms. (vii) Weather related fires (the lightning).

(viii) Pest and diseases of crop and livestock.

Occurrence of extreme weather in different seasons: Most of the natural hazards are weather related

(ii) Winter (Jan-Feb) : Cold wave, Fog

(iii) Pre-Monsoon (Mar-May) : Cyclonic disturbances, Heat wave, Thunder storms, Squalls, Hail storm, Tornado

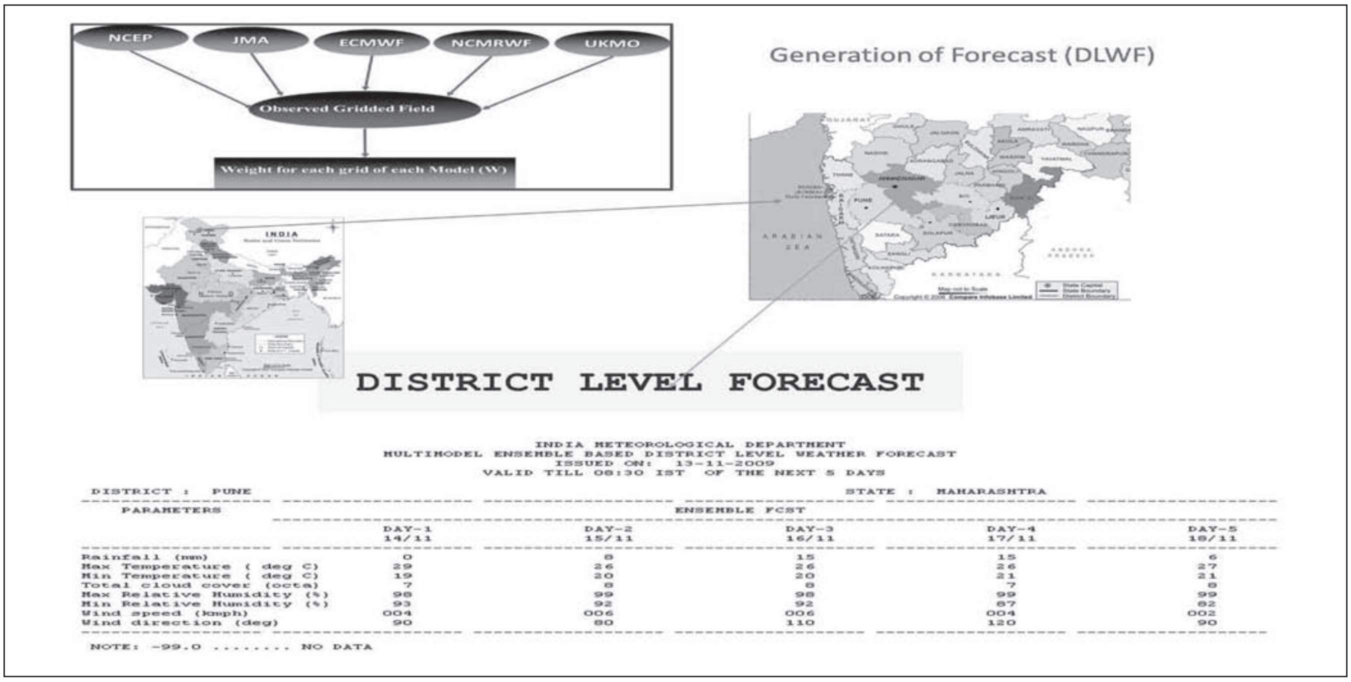
(iv) Monsoon (Jun-Sep) : Southwest monsoon Circulation, Torrential rains, floods

(v) Post-Monsoon (Oct-Dec) : Cyclonic disturbances

Agromet advisory services for management of extreme events: The primary role of combating negative impact of extreme events under the Agromet Advisory Services is to generate ways and means of adjusting crop cultivation plans/ practices depending on the time of occurrence of the extreme events.

India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) is operating an Integrated Agro-Meteorological Advisory Service (IAAS) at district level in India, which represents a small step towards agriculture management in rhythm with weather and climate variability leading to weather, proofing for farm production. In order to minimize the adverse impact of malevolent weather. Integrated Agromet Advisories scheme provides a very special kind of inputs to the farmer in the form of advisories that can make a tremendous difference to the agriculture production.

Medium range weather forecast under AAS: Under IAAS, from 1st June, 2008 IMD has started issuing quantitative district level weather forecast upto 5 days. The products comprise of quantitative forecasts for seven weather parameters viz., rainfall, maximum and minimum temperatures, wind speed and direction, relative humidity and cloudiness. In addition, weekly cumulative rainfall forecast is also provided. IMD, New Delhi generates these products using Multi Model Ensemble technique based on forecast products available from number of models in India and other countries. These include: T-254 model of NCMRWF, T-799 model of European Centre for Medium Range Weather Forecasting (ECMWF); United Kingdom Met Office (UKMO), National Centre for Environmental Prediction (NCEP), USA and Japan Meteorological Agency (JMA). Weather forecasting system setup is shown in Fig. 1.



PARAMETERS	ENSEMBLE FCST				
	DAY-1 14/11	DAY-2 15/11	DAY-3 16/11	DAY-4 17/11	DAY-5 18/11
Rainfall (mm)	0	8	15	15	6
Max Temperature (deg C)	29	26	26	26	27
Min Temperature (deg C)	19	20	20	21	21
Total cloud cover (octa)	7	8	8	7	8
Max Relative Humidity (%)	98	99	98	99	99
Min Relative Humidity (%)	93	92	92	87	82
Wind speed (kmph)	004	006	006	004	002
Wind direction (deg)	90	80	110	120	90

NOTE: -99.0 .... NO DATA

Fig. 1 : Structure of medium range weather forecast

The products are disseminated to Regional Meteorological Centres and Meteorological Centres of IMD located in different states. These offices undertake value addition to these products using synoptic interpretation of model output and communicate to 130 AgroMet Field Units (AMFUs), located in different State Agriculture Universities (SAUs), institutes of Indian Council of Agriculture Research (ICAR) etc. on every Tuesday and Thursday (Fig. 2).

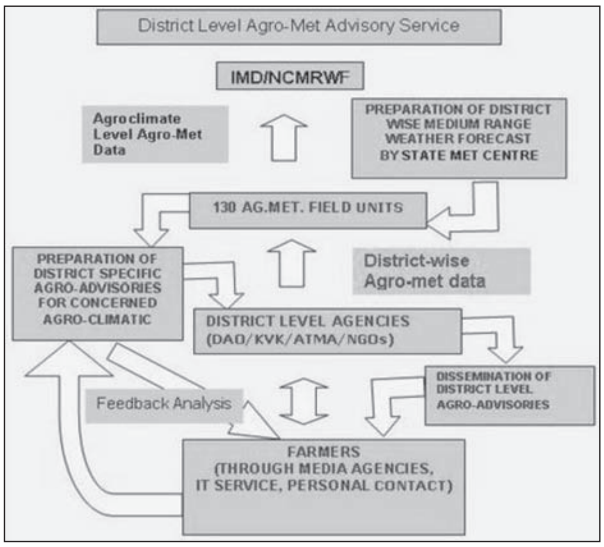


Fig. 2 : District level Agro-met Advisory Service

Observational network under AAS: At present different network of observations are used in India to monitor and assess the extreme events (Fig. 3)

- Conventional Observational Network,
- AWS,
- Buoy/ Ship Observations,
- Cyclone Detection Radars,
- Doppler Weather Radars, Satellites

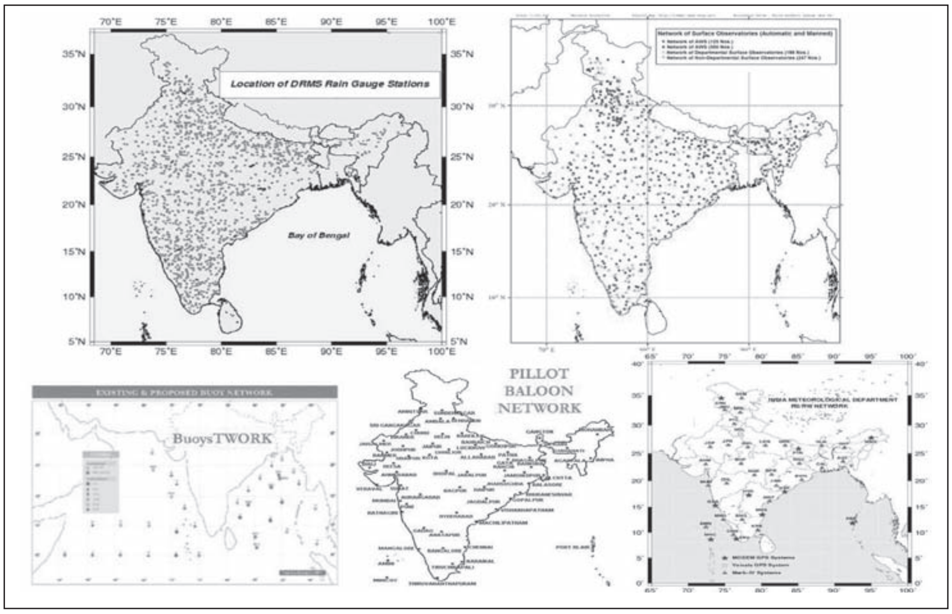


Fig. 3 : Network of Observations

Satellite and radar observations are very crucial for monitoring and assessment of hazards, especially in the Himalayan region and North Indian Ocean.

Special weather forecast for extreme events:

Special weather forecast for agriculture provides the necessary meteorological input to assist farmers in making decisions. The requirements for these special forecasts will vary during the season, from season to season and from crop to crop. These forecasts are normally issued for planting, taking crop protection measures, forestry operations as well as for taking other weather related agricultural operation. Special forecast issued are as follows:

(a) Tropical cyclone (North Indian Ocean) track, intensity, structure changes and landfall process (wind and gust, rainfall and storm surge);

(b) Heavy rain and strong winds triggered by tropical cyclones, SW and NE monsoon, troughs and ITCZ migration, and orography;

(c) Thunderstorms and hail associated with severe convection;

(d) Extreme hot and cold conditions and frost;

Nature of Impacts and Management of Extreme Weather on Agriculture through Agromet Advisory Services

a. Cold injury and frost: A key factor in protection of crops from cold injury is stable air temperatures and snow cover throughout the winter. Thaws, resulting in packing or disappearing snow cover, worsen dormancy conditions and reduce or destroy the protective properties of snow cover. The prevention of crop damage by frost can be controlled by breaking up the inversion that accompanies intense night time radiation. This may be achieved by heating the air by the use of oil burners which are strategically located throughout the agricultural farm. Other methods of frost protection include sprinkling the crops with water, brushing (putting a protective cover of craft paper over plant) and the use of shelterbelts (windbreaks). Long periods of extreme cold weather combined with other meteorological phenomena can result in the loss of winter crops, fruit crops and vineyards due to frost injury. Low soil temperature at the depth of plant roots can cause frost injury. Such reductions in soil temperature occur with strong frosts, in the absence of snow cover and with deep freezing of the soil. Under low temperatures basically a plant dries out and the protoplasm (the living part of cells) dies. Damage to the part of a plant does not always result in damage or destruction of the whole plant. A determining factor is the degree of frost injury to a tillering node; if it is heavy the whole plant will perish. The winter crops most frequently destroyed by frost are those grown on uplands, where snow cover is less and the depth of soil freezing is greater. The main agrometeorological factor influencing frost damage in winter crops is low soil temperature at the depth of the tillering node. Long (three days or more) and intensive cooling causes complete devastation of the crops. Destruction of cell structure (frost); desiccation; slow growth, particularly during cold waves; cold dews, heavy snowfall damages woody plants. Unseasonal occurrence of frost affects reproductive organs of plants.

Sample advisory for frost injury

- Apply irrigation to safeguard the crops viz., apple, pear, early sown wheat from cold/frost injury.
- Arrange for smoking nearby the field to protect the crops.
- During evening hours, wipe out the water droplets on the leaves by pulling rope from the two sides of field. This will prevent formation of ice crystals

b. **High temperature:** It causes increased evapotranspiration; induced sterility in certain crops; poor vernalization; survival of pests during winter. High temperatures at night are associated with increased respiration loss. "Heat waves", lengthy spells of abnormally high temperatures are particularly harmful.

Sample advisory for heat injury

- As temperatures are still higher than normal it may inhibit plant growth and yield of wheat, farmers are advised to irrigate the field at frequent intervals to bring down canopy temperature if there was no significant rain over the State for last few weeks, and dry weather will prevail for next five days.

c. **Winds:** Winds in dry climatic zone affect growth of the plant mechanically and physiologically. The sand and dust particles carried out by wind damage plant tissues. Emerging seedlings may be completely covered by strong winds. Winds also cause considerable losses by inducing lodging, breaking the stalks and shedding of grains and ultimately decreasing the yield. Many agricultural lands have been lost through wind action by the encroachment of sand, dunes, dust storms and sand storms which carry away the top humus soil, leading to deterioration and degradation of the landscape and desertification. Physical damage to plant organs or whole plants (e.g. defoliation, particularly of shrubs and trees) is due to the soil erosion; excessive evaporation. Wind is an aggravating factor in the event of bush or forest fires. Crop damage by winds may be minimised or prevented by the use of windbreaks (shelterbelts) which reduce the impact of wind speed. These are natural (e.g. trees, shrubs, or hedges) or artificial (e.g. walls, fences) barriers to wind flow to shelter animal or crops. Properly oriented and designed shelterbelts are very effective in stabilizing agriculture in regions where strong wind causes mechanical damage and impose severe moisture stress on growing crops. Windbreaks save the loose soil from erosion and increase the supply of moisture to the soil in spring.

Sample advisory for winds

- Wind speed is greater than 20 knots and further will be greater than 34 knots, avoid applying fertilizer to the crop in particular districts.
- Apply the necessary fertilizer in the remaining districts of the state as wind is calm.

d. **Hailstorm:** Hail impact is usually rather localized, but the damage to crops**-** particularly at critical phenological stages and infrastructure may be significant. Even light hail tends to be followed by pest and disease attacks. Protection of crops is not possible for annual crops on large fields. Only on perennials and cash crops such as orchards, hail net may be used.

Sample advisory for hailstorm

- Cover the orchards with hail nets in Kangra, Chamba, Una, Hamirpur, Bilaspur, Solan, Mandi, Simla districts as there is a chance of hailstorm in these districts.

e. **Dust storm/sand storm:** In many countries, field afforestation is the main measure to protect the soil from dust storms. Improving soil resistance to erosion can be achieved by careful selection of cultivation methods, applying mineral and organic fertilizers, sowing grass and spraying various substances that enhance soil structure. It is also important to reduce the areas where dust can gather, especially in tracts of areas characterized by erosion. One major protection strategy is to establish well-developed plant cover before the dust storms. This can encourage a reduction in the wind speed in the layer next to the ground by forming effective buffer. Measures to reduce the wind speed at the soil surface and to increase the hooking of soil particles are both crucial. Such measures include the establishment of tree belts and wind breaks. Leaving stubble in fields, non-mould board ploughing, application of chemical substances promoting the hooking of soil particles, soil-protective crop rotation using perennial grasses and seeding of annual crops are also important. In regions with intensive wind erosion, especially on wind shock slopes or on light soils, stripe cultivation may be used. Potential applications of a Sand and Dust Storm Warning Systems (SDSWS) for agricultural users can be used to alert agricultural communities, particularly farmers to take preventive action in harvesting grain or vegetable crops.

f. **Cyclone:** Disaster preparedness for impending cyclones refers to the plan of action needed to minimize loss to human lives, damage to property and agriculture. Preparedness for cyclones in agricultural system can include early harvesting of crops, if matured, safe storage of the harvest. Irrigation canals and embankments of rivers in the risk zone should be repaired to avoid breaching. Beyond this, as the storm approaches the area, nothing more can be done, but to secure as much of the property as possible and find safety.

Sample advisory for cyclone

- Mature crops may be harvested immediately.
- Horticulture crops may be provided support to avoid being uprooted.
- Fishermen are advised not to venture in to the sea because of cyclonic storm and tidal waves.

g. **Flood:** Preconditioning of an area is very important for determining how significant damage a flood can make. Soil, vegetation and water supply factors are important to consider. Soils that are saturated prior to an extreme weather event are more likely to result in a damaging flood than soils that are relatively dry. Fields that have recently been tilled and devoid of vegetation are much more susceptible to soil erosion. Vegetation that is able to use much of the water and that can act as a barrier to moving water can reduce flood severity and impacts. Water storage systems that are able to capture and hold most of the incoming water will be effective in reducing flood damage. In rain-fed agricultural systems, managers typically anticipate rainfall during the growing season sufficient to naturally or artificially irrigate crops. There is often a balance needed between retaining enough water for agricultural production and environmental health and maintaining enough available storage volume to capture incoming water and prevent floods. Many other crops (e.g. corn) would not be adaptable to such conditions and would not be appropriate alternatives to rice.

h. **Drought:** In arid, semi-arid and marginal areas it is important for those responsible for planning of land use and agricultural programmes, to seek expert's climatological advice regarding rainfall expectations. There is an urgent need for a detailed examination of rainfall records of these regions. More emphasis should be placed on the drought management policies especially in dry land farming areas to minimize the food grain loss. Agricultural planning and practices need to be worked out with considerations of the overall requirements within an individual agroclimatic zone (Fig. 4). Crops which need a shorter duration for maturity and require relatively little water need to be encouraged in drought prone areas.

Fig. 4 : Drought prone areas of the centre

Sample advisory for drought:

As there was no significant rain during last few weeks in most of the districts of the state and due to dry conditions, evaporation rate increases up to 14 mm / day. Monsoon is likely to arrive late. Under such weather situation farmers are advised to undertake sowing of relatively early maturating varieties of rice (upto 125 days) in place of medium and late duration varieties under rainfed conditions to avoid drought conditions at the time of maturity.

Dissemination of Agrometeorological Advisories

Critical factors for successful dissemination include relevance of information to weather and climate sensitive decision making in agriculture, followed by good outreach. The task of AAS is to provide information to help farmers make the best possible use of weather and climate resources. Good communication and working relationships need to be set up with the agricultural extension, Krishi Vigyan Kendra (Agriculture Science Centres), Kisan (Farmer) Call Centre etc. to promote participatory methods for interactions with farmers (fig. 5). Due care must be taken regarding content of the message which must be relevant to the weather based decision making by the farmer. This involves the identification of weather and climate sensitive decisions and interactions between the weather forecasters from meteorological Centres and the agriculture scientists from Agriculture Universities and/ or Institutes of Indian Council of Agriculture Research to develop weather based advisories and technological action.

Under IAAS system, information is disseminated through multi-modes of delivery including mass and electronic media. It include, All India Radio, Television, Print Media (local news paper in different vernacular languages), internet (Web Pages) as well as group and individual relationships through email, telephone etc. The use of electronic media such as e-mail or the Internet is picking up as the access of these methods to the farming community is on significant rise. Among others, advisories on extreme events are being communicated to the farmers of the country through agromet service. Based on this input farmers can adopt coping mechanisms that withstand negative impacts of extreme weather through activities such as the use of drought-resistant or salt-resistant crop varieties, the more efficient use of water resources and improved pest management.

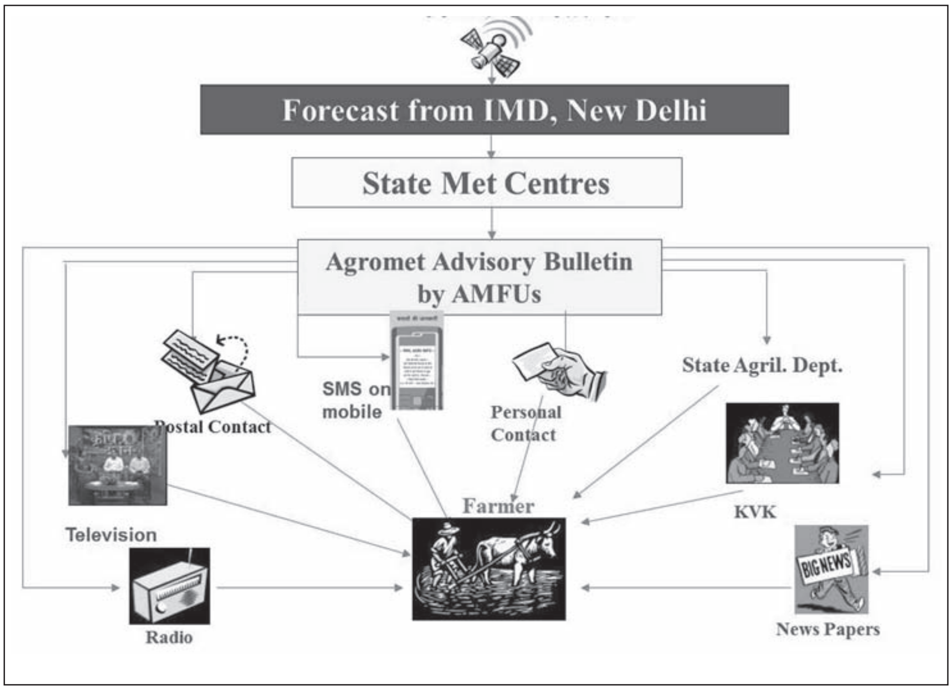


Fig. 5 : Operational Communication linkages between Agromet Advisory Service Unit and end-users (farmers) for effective communication.

Thrust Areas

The thrust areas for management of extreme events through Agromet Advisory Service include:

- Improvement in scientific understanding,
- Improvement in monitoring and prediction of disastrous weather like heavy rain/snowfall over data sparse Himalayan region and adjoining plains and cyclonic disturbances over north Indian Ocean using land/Ocean and space based tools
- Improvement in nowcast of meso-scale disastrous events like thunderstorm, hailstorm and tornado,
- Improvement in space based telecommunication measures and
- Active initiation of Forecast Demonstration Projects on
  — Cyclone,
  — Thunderstorm,
  — Fog and
- Heavy rain during monsoon due to Continental Tropical Convergence Zone (CTCZ).
- Development of suitable adaptation and mitigation measures to minimize the effect of extreme weather in agriculture.

FOREWARNING OF INSECT PEST AND DISEASES IN PLANTATION CROPS IN THE HUMID TROPICS

G.S.L.H.V. Prasada Rao

Considerable crop losses are caused due to insect pest and diseases in the humid tropics. Many of the restrictions on productivity and geographical distribution of plants and animals are imposed by climatic constraints and biotic pressure exerted by pests and diseases. The geographical distribution of pests is mainly based on climatic factors. The climatic conditions show a gradient from place to place and there is a related gradient in the abundance of a particular pest or disease. The periodic or seasonal nature of incidence and outbreaks of several pests and diseases of many crops can be ascribed to weather conditions as the triggering factors. These epidemics of diseases are principally weather-dependent, either in terms of local weather conditions being favourable for growth and development of the causal organisms, or the prevailing winds help to disseminate air-borne pathogens or spores of pathogens such as mildew, rusts, scabs and blights. A large number of pests and diseases which affect plants are kept in check by seasonal fluctuations in atmospheric temperature or relative humidity and other factors. The surface air temperature, relative humidity, dewfall, sunshine, cloud amount, wind, rainfall and their pattern and distribution are the primary weather factors influencing the incidence or outbreaks of pests and diseases of crops. In the humid tropics, the weather variables such as air temperature, intermittent rainfall, cloudy weather and dewfall may play a crucial role in the outbreaks of pests and diseases, as these are very conducive factors. If the occurrence of pest or disease in time and space can be predicted with reasonable accuracy and response time on the basis of relevant weather parameters, appropriate and timely control measures can be progrmmed and adopted. Crop losses can thus be minimised. Appropriate insecticide or fungicide interventions can certainly reduce the pesticide load in the environment and the related pollution and health hazards. Hence, insect pest and disease forewarning systems play a major role in integrated pest management and the sustenance of agricultural production at desired levels. It is more so in the case of plantation crops since majority of crops are perennial in nature and crop damage due to pest and diseases is having long standing effects.

Seasonal Abundance

The majority of insect pests and diseases are commonly seen during the rainy season, while aphids, thrips, scales, mealy bugs, whiteflies and mites are relatively more frequent during summer. Blast and powdery mildews of many crops are common in winter.

Coconut Pests and Diseases

The cockchafer beetle is commonly known as root grub or white grub. The population peaks occur in June and July and less in summer. This pest is more dependent on soil environment rather than atmospheric variables, as the immature stages develop in the soil environment. Sandy and sandy loam soils are much favourable for multiplication of this pest under favourable microclimatic conditions. Rhinoceros beetle, red palm weevil and black-headed caterpillar are the other major pests. Bud rot, Bronze wilt, root wilt and stem bleeding are some of the major diseases in coconut. The stem bleeding disease is common in northern districts while root wilt in southern districts of Kerala. Continuous heavy wet spell, followed by long dry spell is one of the factors for the incidence of stem bleeding in coconut. The fungus enters through cracks on the stem and it is characterised by the oozing of a dark red brown viscous liquid through these cracks. It is severe when the soil moisture depletion takes place in summer. The incidence and intensity of stem bleeding can be predicted based on the summer drought indices. The bud rot of coconut occurs sporadically during the rainy season. The disease is common in the humid climates during the monsoon and post monsoon seasons. The micro-climate that prevails in and around the crown of coconut palm influences the incidence of bud rot to a large extent. The crop diseases which are caused by Phytophthora are strongly weather-dependant.

Tea Mosquito in Cashew

The tea mosquito bug is the most serious pest of cashew across the cashew tracts, causing inflorescence blight and drying up of tender shoots and nuts. The most favourable period for rapid multiplication and population build up of the pest is from December to February, synchronizing with the flushing and flowering phases of cashew. The pest population appears to be very less when the minimum temperature recorded is below 10 ^{0}C. The pest population is moderate to severe if the minimum temperature varies between 15^0 and 22 ^{0}C. It is low to moderate if the minimum temperature is between 12 ^{0}C and 15 ^{0}C and 22 ^{0}C and 24 ^{0}C. Based on this information, the hot spot areas can be demarcated. Based on the hot spots, it is revealed that the pest population is moderate to severe across the West Coast while being low to moderate across the East Coast. The pest incidence appears to be less intense in high ranges, where cashew is grown.

Foot rot of black pepper is a severe menace and the disease incidence is severe during south west monsoon. It is positively correlated with continuous rainfall and relative humidity while negatively with maximum temperature and bright sunshine. Abnormal leaf fall in rubber is seen invariably when a five-day rain spell with an overcast sky exists. The epidemics can be normally expected within 9-15 days after the first overcast day, depending on the onset of south west monsoon. The initiation of the disease is usually noted by mid-July. However, the disease incidence may deviate according to variations in the southwest monsoon.

Forewarning of Crop Diseases

Initial field inoculum and leaf wetness are very important for forewarning several crop diseases. Using Leaf Wetness Counter forewarning of diseases is possible under field conditions. Assmann Psychrometer, Whirling Psychrometer, Psychron, Leaf Wetness Recorder and Leaf Wetness Counter are some of the instruments used for micrometeorological observations in addition to dew gauges which indicate the incidence and intensity of crop diseases. The endemic areas could be very well identified by systematic collection of data on pest and disease incidence, through surveillance, along with the threshold weather variables. As the pest and disease incidence builds upon host plants under favourable physical environments, it is difficult to understand the system and to forewarn the further build-up of pest and disease, unless concerted efforts are made for generating sound database. Lead time is very important in the case of pest and disease forewarning so as to respond positively and effectively by the farmers to minimise crop losses against pest and disease outbreaks. Pest surveillance plays a major role in this direction. For the last three decades, several models viz., linear and non-linear regression equations, logistic models and computer based simulation models have been used for predicting or forewarning pest and diseases. Most of these models are seen in literature from abroad, where they are put in operation. In India, the forewarning and early warning systems against major crop pests and diseases are still not operational, despite the availability of some models. Databanks on pest population trends in time and space in relation to weather conditions are to be developed on major crop pests. Avenues for predicting the occurrence of pests and diseases with reasonable degree of accuracy have to be explored and appropriately refined models developed for adoption.

WEATHER INDUCED DISEASES WITH ABRUPT OCCURRENCE AND WIDER AERIAL COVERAGE - THEIR CAUSES, IMPACTS, FOREWARNING AND MANAGEMENT

Suseelendra Desai

Disease is an output of the interaction among host, pathogen, and the environment over a period of time. Given that a susceptible host and an aggressive pathogen are available, weather and nutrition determines the intensity of the disease over time. The environment can affect both the susceptibility of the host (e.g. by creating stress in the plant) and the activity of the pathogen (e.g. providing moisture for spore germination). The pathogen and the host can affect each other's performance. The plant can also change its environment, by creating a microclimate around it that is either congenial or non-conducive for the pathogen. The important parameters of host that can influence disease development are susceptibility; growth stage and form; structure and density of the plant population and overall health. For pathogen, to cause disease, it should be present in the vicinity, pathogenic, adaptable with reproductive fitness and possess efficiency of survival and dispersal. The important weather parameters are temperature; rainfall/dew; leaf wetness period, wind, bright sunshine hours and soil conditions.

Plant Disease and Weather

Mere presence of a pathogen on a particular plant will generally not cause serious disease unless the environmental conditions are favourable. This includes the aerial environment and the soil (edaphic) environment. Human attempts at controlling disease usually involve manipulating the environment in some way. For example, breeding wheat cultivars to tolerate dry conditions allows Australian farmers to plant the crop in areas that are not favourable for pathogens such as powdery mildew and leaf rust. Properties of the aerial environment that influence disease development include moisture levels, temperature and pollution.

Moisture is particularly important to pathogenic bacteria and fungi. Rain splash plays an important role in the dispersal of some fungi and nearly all bacteria, and a certain period of leaf wetness is necessary for the germination of most airborne spores. By using water for dispersal, propagules are dispersed at a time when they are likely to be able to germinate as well. Because the process of germination and infection takes time, the duration of leaf wetness also influences the success of the infection. The duration necessary for infection varies with temperature. Usually, a longer period of leaf wetness is needed to establish an infection in cooler temperatures, as germination and infection are generally accelerated in warmer conditions.

Temperature also affects the incubation, or latent, period (the time between infection and the appearance of disease symptoms), the generation time (the time between infection and sporulation), and the infectious period (the time during which the pathogen keeps producing propagules). The disease cycle speeds up at higher temperatures, resulting in faster development of epidemics. The period of leaf wetness, combined with temperature information can be used to predict outbreaks of some diseases (infection periods) and be used to time preventive treatments, such as spraying. High concentration of pollutants can affect disease development and, in extreme cases, damage the plants directly by causing acid rain.

The edaphic (soil) environment affects soil-borne diseases, largely by determining the amount of moisture available to pathogens for germination, survival and motility. Germination and infection success also rely on the soil temperature. The fertility and organic matter content of the soil can affect the development of disease. Plant defenses are weakened by nutrient deficiency, although some pathogens, such as rusts and powdery mildews, thrive on well-nourished plants. Other diseases thrive in soils that are specifically low in organic matter.

Causes of Abrupt Disease Occurrence and its Impacts

The pathogen, the host and the environment interact, usually in ways that are difficult to quantify and predict. Control measures can include sowing of a crop species early, to avoid exposing seedlings to a disease during the time of year that provides the best environmental conditions for the pathogen.

Because moisture and temperature influence the growth of fungi, characterizing weather conditions favorable for fungi may be used to predict the abundance and richness of fungi in habitats with different climate conditions. To estimate habitat favorability to fungi, the relationship of fungal abundance and species richness to various weather and environmental parameters was studied in the Intermountain West. It was observed that fungal richness was positively correlated with fungal abundance ($r = 0.75$). Measures of moisture availability, such as relative humidity or vapor pressure deficit, explained more of the variance in fungal abundance and richness than did temperature. Weather variables that took into account the proportion of time habitats experienced favorable or unfavorable relative humidity and temperatures were the best predictors, explaining up to 56% of the variation in fungal abundance and 72% for fungal richness.

The persistence of leaf surface moisture, a condition critical for the development of most foliar fungal pathogens (Jones, 1986), plays a key role in the epidemiology of fungal diseases. Numerous studies have shown an increase in the incidence and severity of disease with increasing duration of leaf wetness (Cowling and Gilchrist, 1982; Evans *et al.*, 1992; Filajdic and Sutton, 1992; Montesinos *et al.*, 1995; Basallote-Ureba *et al.*, 1999; Suheri and Price, 2000). Many foliar pathogens require extended periods in free water for spore germination, germ tube growth, and host penetration (Everts and Lacy, 1990; Wadia and Butler, 1994; Vloutoglou *et al.*, 1996; Gilles *et al.*, 2000). Therefore, plant traits that reduce the time that leaves remain wet after rain or dew could reduce susceptibility to foliar pathogens and potentially slow disease spread. In natural ecosystems, foliar pathogens can exert important selection pressures on plants (Alexander and Burdon, 1984; Esquivel and Carranza, 1996; Gilbert, 2002), suggesting that the ability to repel water from a leaf surface may be an adaptation for the prevention of fungal infection. The mechanistic links between leaf water retention and fungal infection can provide a unifying framework for understanding variation in infection among plant species and across different habitats.

High relative humidity and several hours of free surface water are critical for both spore germination and successful infection (Huber and Gillespie, 1993; Cook and Whipps, 1993; Harrison *et al.*, 1994). In addition, infection i.e., invasion of plant tissue by the fungus and disease i.e., the expression of symptoms such as lesions or necrosis (Agrios, 2005) on plants due to air-borne fungi are favoured by temperatures of 15–40 ^{0}C (Cook and Whipps, 1993; Griffin, 1994). Field studies on plant pathogens have demonstrated that the growth of fungi is favoured by high moisture and moderate temperatures (Frolich and Snow, 1986; Griffin, 1994; Colhoun, 1973; Taylor, 1979; Rowan et al., 1999) and that low relative humidity and extreme temperatures inhibit growth and spore germination (Harrison et al., 1994; Juniper, 1991). Other studies on soil fungi also show that prevalence differs among habitats and seasons and correlates positively with moisture and negatively with temperature (Harrison et al., 1994; Johansen and Rushforth, 1985). This apparent positive relationship between moisture and fungal growth and abundance may result from the high surface-to-volume ratio of fungi, making them vulnerable to water loss.

Disease Forewarning

Forewarning of disease outbreaks enables the effective use of control measures, such as chemical or biological treatments, the prediction of crop yields and of the market potential for that crop. Disease forewarning involves the use of weather data and biological data to predict disease incidence. Usually, disease forewarning is only performed on economically important diseases, and as a method of cost reduction. If controlling a particular disease involves an expensive or time-consuming treatment, being able to predict outbreaks of the disease allows the treatment to be timed correctly, increasing its effectiveness, and reducing the cost compared to repeated treatments. Because environmental conditions vary from season to season, disease forewarning is necessary to predict the chance of disease in a certain set of conditions.

Disease can be predicted using computer modeling and empirical correlations relating to weather conditions, levels of inoculum, test plots and site factors and the predictions can then be communicated to growers. Computer modeling of plant diseases uses systems analysis to accumulate all the factors that affect the development of a certain disease into a computer-based model, and make predictions of disease under different environmental conditions. A disease needs to be well understood in order to formulate an accurate model, and models based on diseases that we know little about are generally not very accurate. The more straightforward approach of developing empirical correlations between particular weather factors and disease has had considerable success. This does not attempt a complete modelling of all factors involved in a disease, but only those most important in affecting the disease. The accuracy of the model can then be measured statistically by comparing its predictions to what actually happens.

Monitoring the weather is the most important consideration in disease forewarning because of the overriding effect that weather has on disease development. While broad scale weather data has been used for disease forewarning, it is well known that the microclimate within the crop has a more direct impact on disease. Devices have been developed to monitor microclimate factors such as duration of leaf wetness and temperature, and with time, they will be affordable and accurate enough for widespread use on individual farms. Synoptic weather forewarning charts can be used to predict 'critical periods' - the occurrence of conditions favourable for disease development - so that farmers can spray their crop before it happens. There are now several self-calculating disease forewarning monitors available commercially that use environmental data and past season data to predict outbreaks of particular diseases.

Some disease forewarning methods are based solely on monitoring inoculum levels, often as indicated by the amount of disease already present. This method can be successful when disease is developing steadily under relatively uniform or predictable weather conditions, but not for diseases that can spread explosively in favourable conditions. Monitoring the amount of disease present can indicate whether the amount of disease is likely to exceed a certain threshold, at which point control measures become economical. There are numerous methods of directly monitoring the concentration of spores in the air as an indication of the chance of disease. Trapping vectors of diseases can also be useful in predicting the occurrence of viral diseases. In addition, estimation of populations of soil-borne pathogens by examining soil samples is necessary for predicting the outbreak of the diseases they cause. Monitoring systems can be combined with data specific to the site and the crop, such as soil type, topography and irrigation levels, in order to increase the accuracy of predictions

Test plots (or trap plots) of susceptible cultivars can be planted throughout a cropping area to give early warning of the arrival of inoculum or disease vectors. Alternatively, inoculation of the test plot with the pathogen can give an indication of favourable environmental conditions for disease development. Test plots are also useful for monitoring the occurrence of minor diseases on new cultivars.

The formation of a prediction is useful only if it can be communicated to the growers who will be affected by it. General warnings for areas are broadcast over the radio or internet. Predictions based on monitoring by individual farmers or groups of farmers in an area remove the need for widespread communication systems. Computerized decision support systems based on local monitoring can educate and empower farmers when making decisions about their crops.

Starting from simple thumb rules, the disease prediction models can go to very complex models involving several analytical tools. The purpose of a model is to help grower to arrive at a decision about crop health management. Some of these models also could go as sub-routines in crop growth models which are useful to ultimately workout the predicted yields. However, due to complexity of the processes involved in disease development, very few crop growth models have considered including the disease sub-routines. Even such models like DSSAT do not take all parameters of disease development and thereby leaving unaccounted variability. Various techniques of computer modeling and simulation like artificial neural networks, fuzzy logic or Montecarlo analysis and the conventional multiple regression approaches are being used to help synthesize and develop scientists' understanding of this complex plant-pathogen-environment relationship. The resultant models enable exploration of the factors that govern disease epidemics. The same models have potential to guide breeding programs and work to develop strategies that will prolong the usefulness of disease-resistance genes.

Thumb rules: Thumb rules are qualitative knowledge-based models that could be used for disease prediction. These thumb rules are derived based on past experience of definitive relationships among host, pathogen and environment. 'Dutch rules' for prediction of late blight of potato, Mill's rules for prediction of apple scab are some examples. These rules are not quantifiable and also not fit for numerical analysis.

Empirical or mechanistic models: These models are developed based on elaborate experiments and deriving simple relationships between various parameters associated with disease development. These are mainly descriptive models covering various weather parameters and their influence on disease development. However, these models cannot be used for quantification or analysis of disease purposes. They also include geophytopathological maps showing disease spread.

Mathematical models: Mathematical models are developed by applying the mathematical relationships between host, pathogen and environment interactions. The analytical models use the epidemic analysis on a theoretical basis without taking into consideration the external factors. These include parameters such as apparent rate of growth of infections, disease growth under non-restrictive environment, equations developed for fitness and survival of the pathogens etc. The statistical models include use of tools such as correlation, regression methods. These models could be linear or non-linear relationships between various interacting parameters of a disease.

The simulation models include the art and science of constructing composite models and mimicking one system with the other. Simulation models, when run on the computer, generate growth parameters by considering algorithms based on a detailed flow diagram of the events of disease development. The first computer-based plant disease simulator is EPIDEM for early blight of potato and tomato. Later several simulation models were developed either as a stand-alone model or as a sub-routine of the crop growth model. With the advent of internet, web-based decision support systems are also in place for various diseases. The web-based models are easy to develop as they do not need expertise of computer programs and the web pages could be written with a relative ease as compared to complicated programs such as Java, J-Builder etc. Magarey *et al*., (2005) developed a generic infection model based on temperature and wetness duration. The model is generic in the sense that it was developed to describe any pathosystem when appropriate parameters are supplied.

The production and availability of decision support systems (DSS) as aids in applying or using disease control methods have become common in contemporary agriculture, perhaps because it has become easier to obtain and process the data that are needed to provide this kind of advice. Another factor affecting adoption of DSS is the ability to reach large audiences with relatively little effort. While increased availability of this kind of information is undoubtedly a benefit for most users, the quality of such information should be sufficient to allow maximization of the economic and environmental benefits that can result from the use of such systems. Thus, other ways of development of such systems could be useful. In addition, clear and objective methods are needed to evaluate and compare different DSS, although the ultimate criterion is adoption by the end-users.

With the development of more rapid computing technologies, it is possible to compute a large number of simulations to support new modeling methods for plant disease forewarning. The development of disease forewarning models is based on determining the value of unknown parameters for an appropriate model. One method for estimation of parameters is maximum likelihood estimation (MLE), first developed by R.A. Fisher. The basic idea behind MLE is that one can calculate the probability of observing a particular set of data given the model of interest and this is called the likelihood of a sample. The likelihood of observing the actual data for each of the potential parameter values is calculated to determine which set of parameter values maximizes the likelihood. Rajini Jain *et al.*, (2009) studied, prediction models for forewarning powdery mildew of mango using variables viz. temperature and humidity using logistic regression (LR), Rough sets (RS) and decision tree induction (DT) methods and they found that both RS and DT methods have shown better performance over LR approach.

Stochastic models: These models are based on probability distributions and generally adopted when a reliable estimate of the expected value is desired and when there is a curvilinear relationship between stochastic characteristic and one of the state variables. From these models generally variance of the model is expected output. These models include heavy calculations needing electronic calculation aids. These models are more common in human and animal diseases where the target organisms are mobile without a continuum and the probability is involved in such cases.

Validation - Where are we & What Next ?

In our early days, we started with correlations and regressions and developed relations between host and disease. Unfortunately, most of the disease forewarning systems developed in India during early era of plant disease epidemics, adapted the successful procedures used in developed nations. However, for monsoon-influenced crop production systems, these procedures do not hold good as they need a different logic to understand disease development. Hence, most of the mathematical models developed by those methods failed to validate across locations. With our enhanced understanding about disease development, we accept that simple mathematical models do not help to understand the epidemics. Simialrly, we tried to develop simple thumb rules and here also regionality parameter was neglected. Also, in many of such models, the pathogen parameters and their biocontrol agents were neglected and thereby leaving a large amount of variability un-accounted for. Today, our understanding of the epidemic has greatly improved due to availability of modern scientific tools such as GIS, remote sensing, a better knowledge about the pathogenicity factors, host-pathogen interactions, and more importantly our ability to measure weather parameters in a more precise way. Most disease forecasts are based on favorability of weather for disease development. Input data for the forecasts are usually derived from automatic weather stations (AWS) that may be irregularly and incompletely dispersed across a region. Therefore, interpolation or extrapolation from nearby AWS sites is often necessary. Simple interpolation from a network of AWS sites may produce disease forecasts with enhanced on-farm resolution. However, complex terrain can make such interpolation impractical and inaccurate. Large AWS networks also require maintenance and substantial financial support. We do have access to satellite datasets which could be used for better understanding of the disease environment. Mesoscale weather models are capable of simulating weather conditions such as air temperature and humidity at a resolution of as high as 100 meter, and then clustering as a supercomputer, overcoming some of these previous limitations.

The successful development of a plant disease forewarning system also requires the proper validation of a developed model. There is increased interest among plant disease modelers and researchers to improve producer profitability through validation based on quantifying the cost of a model making false predictions (positive and/or negative). An economic validation of a plant disease forewarning system requires the examination of false positive and false negative predictions.

Issues in Weather Induced Diseases

Unlike endemic diseases which have been associated with certain crops and geographic locations, the spatio-temporal distribution of weather induced diseases is dependent on various predisposing situations such as introduction of new crops vulnerable to hitherto existing pathogens but not multiplying for want of suitable hosts (Tobacco streak virus on sunflower in Maharashtra and Karnataka in 2007; on groundnut in Anantapur district of Andhra Pradesh) or favourable weather for a minor disease to break out as epidemic (frequent rains during November-December 1997 leading to an early outbreak of leaf rust in central India during the 1997-98 crop season on the highly susceptible ‘Dhar local’ wheat land race) or slow adaptation of pathogens to new genotypes and thereby affecting disease cycle (advancement of date of first appearance of late blight of potato in Finland over a period of 12 years and thereby increasing cost of disease management) or development of new race of pathogen that can overcome modified environmental conditions and infect the crop. These situations are only a few to cite whereas many such cases are going unnoticed. Also, lack of a good tracking system to monitor the change through a robust survey and surveillance system is a bottleneck for monitoring the disease development in crop populations. Trained manpower, interdisciplinary approach to understanding disease epidemiology, advanced research facilities, dedicated field staff and application of modern tools such as GIS and remote sensing for disease monitoring are some issues that need to be addressed urgently to bridge the gaps in current understanding of changes in weather induced disease occurrence and spread to reduce crop losses due to diseases.

INSECT PEST DYNAMICS – ROLE OF WEATHER

Y.G. Prasad

Insects and crops have co-evolved over a long period of time. As a result insects have adapted themselves to a particular crop or group of crop plants and also have specialized feeding niches. Pest forewarnings provide lead time for impending attacks and thus minimise crop loss and optimize pest control leading to reduced costs of cultivation. Pest forecasts will have to take several factors into consideration while being devised in the form of model outputs and disseminated as alerts to farmers. Many pests and diseases are regular in their appearance at susceptible stages of crop growth e.g., pod borer, *Helicoverpa armigera* (Hubner) on pigeonpea at flowering period. The pest appears year after year with its population fluctuating around a seasonal mean. Some pests and diseases are endemic to certain locations (e.g., rice gall midge) while some are cyclical or sporadic in their appearance (e.g, Bihar hairy caterpillar, *Spilosoma obliqua* Walker on sunflower). Some are characterized as outbreak pests or diseases because of their potential to rapidly increase in their abundance in a short span triggered by certain congenial factors leading to widespread epidemics viz., brown plant hopper, *Nilaparvatha lugens* Stal and blast in rice; *Spodoptera litura* (Fab.) on soybean and cotton; mealybug, *Paracoccus marginatus* Williams and Granara de Willink on papaya and several other crops. Species which have a wider host range have better chances of carry over to the next season or year. Species which are monophagous or oligophagous have resting or dormant phases in their lifecycles to tide over unfavourable weather condtions or lack of a susceptible host or crop stage. Pest and disease appearance on a crop follows its life cycle and is also intricately connected to the crop phenology. Some insects complete only a single generation a year (e.g. red hairy caterpillar, *Amsacta albistriga* Walker) while others have multiple and often overlapping generations. Pest forecast models need to consider these intrinsic attributes of the insect pest while determining enviromental and host factors.

Factors Influencing Pest Abundance

Pest populations fluctuate in timing and intensity of their occurrence depending on location and season. Mostly they tend to fluctuate over a mean level. This average population over time when computed across several years results from the sum of action of all positive and negative factors influencing pest populations. Pests of host plants in undisturbed habitats such as forestry have their natural cycles in response to their ecosystem interactions and are most likely to attain equilibrium points in their population levels. Pests of agro-ecosystems fluctuate within and between short spans of time i.e., season and off-season, as they experience rapidly changing environments due to changes in cropping systems and a host of management interventions. As a result crop pests show greater degree of instability in population levels.

An abnormal increase in the numbers of a species on any crop in a short span of time over a large area leads to a significant impact on production and productivity and is considered as a pest outbreak or epidemic. Many factors are responsible for such an outbreak. Foremost among them is the prevalence of congenial weather conditions for insect multiplication and rapid buildup. Growing susceptible cultivars of crop plants in monocultures on a large scale year after year may help insect pests to multiply and spread fast. Sometimes indiscriminate use of insecticides for pest control disrupts the ecological balance between phytophagous insects and their natural enemies leading to pest outbreaks apart from causing pest resurgence and pesticide resistance. Invasive pest species exhibit outbreak tendency due to lack of natural enemies which are crucial in regulation of pest populations. In general, insects are influenced by extrinsic factors such as weather and crop (Table 1).

On a global scale, seasonal temperatures and rainfall patterns constitute major factors that determine the distributions of organisms in space (Birch, 1957). Tropical insects on the average have the same annual variability as insects from temperate zones, but insect populations from dry areas, temperate or tropical, tend to fluctuate more than those from wet areas (Wolda, 1978).

Table 1 : Weather factors influencing pest population dynamics

Factors	Parameter	Influence on
Weather	Temperature (maximum and minimum)	Insect developmental rate, survival, fecundity, diapause
	Humidity (maximum and minimum)	Survival, egg hatch
	Rainfall (amount and distribution)	Adult emergence, oviposition, spread, mortality (wash-out)
	Bright sunshine hours / Photoperiod	Food quality, oviposition, diapause
	Wind speed and direction	Dispersal and migration
	Microclimatic parameters (canopy temperature, humidity, leaf wetness, soil temperature)	Development and rate of spread, mortality Plant diseases: spore germination, infection and sporulation
Crop	Genotype	Rate of development, survival
	Phenology	Pest appearance and intensity
	Crop diversity, geometry & stand	Insect diversity, abundance, survival and dispersal
	Nutrition	Fecundity
	Time of sowing	Pest onset
	Cropping system practices	Off-season survival, carry over
	Density dependent mortality factors	Pest regulation

In nature pests are regulated by their natural enemies: parasitoids, predators and pathogens which are again influenced by bio-physical factors (Thomson et al., 2010, Hence *et al.,* 2007). Therefore, precise understanding of population dynamics can result from comprehensive ecological studies. However, despite best efforts gaps in pest ecological databases exist due to the complexity of interactions among the ecosystem components. It is important to realize that weather is only one of the many driving variables that influence pest dynamics.

Modeling Pest Dynamics

Pest prediction models are mathematical descriptions of biological or empirical data as influenced by the environment. They summarize biophysical relationships in the form of equations and provide a basis to test the significance of this relationship. Important points for consideration in any model development are: the level of detail at which a given model is to be developed as the level of detail is linked to the objective and data availability to develop and run the model. Models can range from strictly empirical to most complex and sophisticated descriptive models. A model may be discrete or continuous, static or dynamic, and deterministic or stochastic.

Building and running pest forecast models require access to weather and climate data, in addition to pest and plant data. Models usually require as inputs, measurements of temperature, rainfall and humidity, although other variables may be required either as direct inputs or in computing values for variables not measured. Weather variables need to be measured at the field level, at regional stations, or on a broader scale depending on the need. For many farm management actions, data representative of the field conditions are expected and hence data is taken from automatic weather stations or the nearest observatory.

There are several approaches adopted by modeling groups to achieve the common aim of providing pest forecasts. These approaches broadly fall into two categories: empirical and process-based. Empirical approaches involve estimating pest and disease incidence and intensity through experimentation and surveys on crops not subjected to control interventions and establishing relationships with concurrent, prevailing weather and/or past weather factors. These studies could be conducted at single stations in which the emphasis is on delineation of differences in meteorological conditions in epidemic and non-epidemic years or multi-station studies in which the emphasis is on delineation of meteorological conditions leading to changes in periods and intensity of infestations. A multi-station study is preferred as it facilitates corroboration of the general surmises and leads to maximization of data in a short period if observations are recorded on crop stands sown at periodic intervals at a number of stations (Venkataraman and Krishnan, 1992). It should be noted that findings from empirical field studies can straight away be applied in climatologically analogous areas but can give misleading results when applied to other areas.

Process-based models are essentially descriptive or mechanistic and are dependent on insect life cycles, ecological and physical processes. These models are complex to build, sophisticated to run and are essentially computer based. Correlation and regression approach to modeling has been widely adopted in the tropics in Asia. Phenology and processed based modeling is in vogue in temperate and tropical regions of developing countries.

Regression Models

Regression models consider pest / disease incidence variables as dependent and suitable independent variables such as weather variables, crop stage; population of natural enemies/predators etc. is used. The form of the model is:

$$Y = \beta 0 + \beta 1\ X1 + \beta 2X2 + \ldots\ldots\ldots + \beta pXp + e$$

where, β0, β1, β2,…….βp are regression coefficients, X1, X2, ……, Xp are independent variables and e is error term. These variables are used in original scale or on a suitable transformed scale such as cos, log, exponential etc.

In case of regression models based on weather indices, using weekly and fortnightly weather variables, suitable indices are worked out which are used as regressors in the model. If information on favourable weather conditions is known, subjective weights based on this information can be used for constructing weather indices. In the absence of such information correlation coefficients between Y and respective weather variable/product of weather initial & final periods for which weather data were included in the model and e is error term. (Chattopadhyay *et al.*, 2005a, Chattopadhyay *et al.,* 2005b, Desai *et al.,* 2004 and Dhar *et al.,* 2008)

In regression analysis, the unfitted errors between a regression model and observed data are generally assumed as observation error that is a random variable having a normal distribution, constant variance, and a zero mean. However, in fuzzy regression analysis, the same unfitted errors are viewed as the fuzziness. Fuzzy regression can be quite useful in estimating the relationship among variables where the available data are imprecise and fuzzy. Fuzzy regression method is based on minimizing fuzziness as an optimal criterion, which can be achieved by linear programming procedures.

Forewarning models can be developed using the principal component technique as normally relevant weather variables are large in number and are expected to be highly correlated with each other. Using the first few principal components of weather variables as independent variables forecast models can be developed. Discriminant function analysis is applied to time series data on weather variables. For this analysis, a series of data for 25-30 years are required. Based on the pest and diseases variables, data can be divided into different groups – low, medium and high etc. and using weather data in these groups, linear or quadratic discriminant functions can be fitted which can be used to find discriminant scores. Considering these discriminant scores as independent variables and diseases / pest as a dependent variable, regression analysis can be performed. Johnson *et al.,* (1996) used discriminant analysis for forecasting potato late blight.

Machine Learning Techniques

Machine learning techniques offer many methodologies like decision tree induction algorithms, genetic algorithms, neural networks, rough sets, fuzzy sets as well as many hybridized strategies for the classification and prediction. Decision tree induction represents a simple and powerful method of classification that generates a tree and a set of rules, representing the model of different classes, from a given dataset. Decision Tree (DT) is a flow chart like tree structure, where each internal node denotes a test on an attribute, each branch represents an outcome of the test and each leaf node represents the class. The top most node in a tree is the root node. One of the strengths of decision trees compared to other methods of induction is the ease with which they can be used for numeric as well as non-

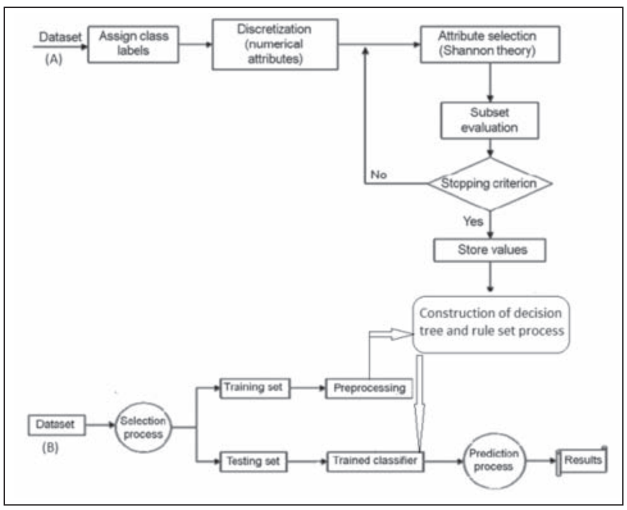


Fig. 1 : (A) Data mining process for construction of decision tree; (B) Training and testing process (Pratheepa et al. 2011)

numeric domains. Another advantage of decision tree is that it can be easily mapped to rules. A decision tree analysis for predicting the occurrence of the pest, *Helicoverpa armigera* and its natural enemies on cotton based on economic threshold level was developed (Pratheepa *et al.*, 2011). The data mining process for construction of decision tree and set of rules is shown in Fig. 1. The occurrence of cotton bollworm *H. armigera* (Hübner) was greatly influenced by its natural enemies, viz. spiders and *C. carnea* and by abiotic factors. In this analysis, population dynamics of the pest and its natural enemies was studied using Shannon information measure with decision tree induction approach. The developed classification model has the ability to successfully treat 'categorical' variables as well as 'continuous' variables in the database. Pest incidence was classified into two classes, viz. low and high based upon economic threshold level (ETL). R^2 for low and high class values was 0.66 and 0.21, respectively. Our studies showed that season influenced the population dynamics of *H. armigera* among all the factors. It was found that the misclassified testing data were 8.8%. The confusion matrix for the testing set revealed that the classification was done more accurately using the training set. Hence, this approach could be successfully utilized to understand the role of natural enemies and weather factors on the occurrence of *H. armigera* (Hübner) as well as prediction of this pest.

Artificial Neural Networks (ANNs) is another attractive tool under machine learning techniques for forecasting and classification purposes. ANNs are data driven self-adaptive methods in that there are few apriori assumptions about the models for problems under study. These learn from examples and capture subtle functional relationships among the data even if the underlying relationships are unknown or hard to describe. After learning from the available data, ANNs can often correctly infer the unseen part of a population even if data contains noisy information. As forecasting is performed via prediction of future behaviour (unseen part) from examples of past behaviour, it is an ideal application area for ANNs, at least in principle (Kumar, et al. 2010). However, the technique requires a large data base.

Insect Development and Phenology Models

Insects are incapable of their own internal temperature regulation and hence their development depends on the temperature to which they are exposed. The studies of population dynamics often involve modeling growth as a function of temperature. The rate summation methodology has perhaps proven to be the most viable approach to such modeling (Stinner *et al.*, 1974). The most common development rate model, often called degree-day summation, assumes a linear relationship between development rate and temperature between lower and upper development thresholds (Allen 1976). This method works well for optimum temperatures (Ikemoto, 2005). The linear model assumes that rates are proportional to temperature, and since amounts are integrals of rates, the amount of development is the integral of temperature (or a linear function of it) along a time axis and has units of temperature-time (e.g., degree-days). Temperature-dependent development in insects can be approached using either developmental time or rate of development. Rate of development is traditionally utilized because rate models were created from biochemical and biophysical properties (Sharpe and DeMichele 1977). Most of the earlier models failed to take into consideration variation between individual insects in their rate of development that is responsible for spread of activity of a pest (Regniere, 1984, Wagner *et al.*, 1984a, Phelps *et al.*, 1993).

Insect species that exhibit seasonality generally have resting phases, diapause or aestivation, in their life cycles which can be accommodated in Monte Carlo simulation modeling (Phelps *et al.*, 1993). Since some temperatures are lethal to organisms, it is obvious that development must be a nonlinear temperature function at the extremes. Non-linear development rate functions based on enzyme kinetics were developed to describe low and high temperature inhibition (Stinner *et al.*, 1974, Logan et al. 1976, Schoolfield et al, 1981, Wagner *et al.*, 1984b). Phenology models help predict the time of events in an insects' development and are important analytical tools for predicting, evaluating and understanding the dynamics of pest populations in agro-ecosystems under a variety of environmental conditions. Accurate predictions, however, require accurate recording of the temperatures experienced by the organisms (Morgan, 1991) also the duration of development (Danks, 2000).

Degree-day models (Higley et al. 1986) have long been used as part of decision support systems (DSS) to help growers predict spray timing or begin pest scouting (Welch *et al.*, 1978). Phenology models are also used as one component of risk analysis for predicting exotic pest establishment (Baker, 1991; Jarvis and Baker, 2001). A well-known example is the DYMEX modeling package (Yonow *et al.*, 2004). Some other modeling packages, for example CLIMEX although not strictly phenology models may also use some developmental requirements for risk assessment (Sutherst *et al.*, 1991, 1999, 2000). Another example is the web-based North Carolina State University-APHIS Plant Pest Forecast (NAPPFAST) modeling system that links daily climate and historical weather data with biological models to produce customized risk maps for phytosanitary risk assessments (Borchert and Magarey, 2005). Resources like the Crop Protection Compendium (CAB International, 2004) often summarize insect development, while the University of California Statewide IPM program lists development data for insects on their website (http://www.ipm.ucdavis.edu/MODELS) for use in DD models. An Insect Development Database containing the developmental requirements for over 500 insect species was created (Nietschke *et al.,* 2007). Insect Life Cycle Modeling software (ILCYM), a generic open source computer aided tool, facilitates the development of phenology models and prediction of pest activity in specific agroecologies (Sporleder *et al.,* 2009).

Pest Simulation Models and Decision Support Systems

Simulation models based on mathematical description of biological data as influenced by environment are more easily applied across locations and environments. Computer programs or software to run these models facilitates the practical application of these models in understanding population dynamics and dissemination of pest forecasts for timely pest management decisions (Coulson and Saunders, 1987) (Table 2). Simulation approach offers flexibility for testing, refinement, and sensitivity analysis and field validation of developed models over a wide range of environmental conditions. Thorough descriptions of cropping systems being managed or studied are needed to explain the interactions among pests, plants, and environment (Colbach, 2010). Systems models or other prediction schemes can be used with appropriate biological, environmental, economic, or other inputs to analyze the most effective management actions, based on acceptable control, sustainability, and assessment of economic or other risks (Strand, 2000).

Table 2 : Prediction models developed under the National Agricultural Technology Project (NATP) and National Agricultural Innovation Project of ICAR

Model / Tool	**Crop**	**Pest**	**Reference**
Life cycle modeling	Cotton	Mealybug	Prasad et al. 2012
Life cycle modeling	Rice	Leaf folder	Padmavathi et al. 2013
CART and NN models	Rice	Yellow stem borer	Kumar et al. 2012
Regression	Cotton	Pink bollworm	Vennila et al. 2011
Artificial neural network	Mustard	Powdery mildew	Ratna Raj Laxmi and Amrender Kumar, 2012
Regression	Pigeonpea	Pod borer	Vishwa Dhar et al. 2008
Degree-day model	Mustard	Aphid	Chakravarthy and Gautam, 2004
Regression	Mustard	Aphid	Chattopadhyay et al. 2005
Regression	Rice	Rice blast	Yella Reddy et al. 2006
Epidemiological, Regression	Mustard	*Alternaria* blight	Chattopadhyay et al. 2005
Online decision tools	Generic	Generic	http://www.crida.in/naip/comp4/dss_pest.html
Online forecast tool	Mustard	Aphid	Vinod Kumar et al. 2012 (www.drmr.res.in/aphidforecast/models.html)
Online forecast tool	Rice	Blast	Kaundal et al. 2006 (www.imtech.res.in/raghava/rbpred/)

Crop Growth Simulation Models Coupled with Pest Sub-routines

Crop system models can be used to generate information on the status of the crop, its pests, and its environment under different scenarios, including different management options. In practice, there are few examples of these models that include all the necessary components and can be used for practical decision making. However, a more practical approach has been the development of individual crop and pest components that can be analyzed at the same time to give information that can improve decisions.

Development of decision support system for agro-technology transfer (DSSAT 4 funded by USAID) allowed rapid assessment of several agricultural production systems around the world to facilitate decision-making at the farm and policy levels. The trend in development of crop system models is to go for modular approach (www.icasa.net). Development of stand-alone decision support systems for pest components could lead to their practical use. In developed countries, dynamic websites that include interactive models, GIS (Geographical Information System) based decision systems, real-time weather, and market information are being rapidly developed and made available on the Internet (www.effita.net) enabling farmers for real time use in crop management.

Conventional approaches of using empirical models for quantifying yield losses due to crop pests are limited in their scope and application since these equations are location and data-specific and insensitive to variable cropping and pest conditions. Crop growth models provide a physiologically based approach to simulate pest damage and crop interactions. There have been many efforts to use crop growth models to simulate the effect of pest damage on crop growth and yield by linking the damage effect of pest population levels to physiological rate and state variables of these models. The insect pest-crop modelling has been discussed in detail by Boote et al. (1983); Coulson and Saunders (1987). A distribution delay model including attrition was applied to simulate population changes of rice leaf-folders. Bases on metabolic pool approach, leaf folder feeding and hence leaf mass losses to the rice plant were described with a generalized functional response model which is 'source' and 'sink' driven (Graf *et al.*, 1992). Furthermore, this model stresses the influence of adult migration and natural enemies on leaf-folder population dynamics, both significant and poorly investigated aspects of the leaf-folder life cycle. Later, a generic approach to simulate the damage effects of single or multiple pests attempted using crop growth models such as CERES-rice (which is a part of DSSAT) in Philippines (Pinnschmidt et al. 1995) and InfoCrop in India (Reji *et al.*, 2008). Pest damage levels from field scouting reports can be entered and damage is applied to appropriate physiological coupling points within the crop growth model including leaf area index, stand density, intercepted light, photosynthesis, assimilate amount and translocation rate, growth of different plant organs and leaf senescence. Equations and algorithms were developed to describe competition among multiple pests and to link the computed total damage to the corresponding variables in the crop models. These approaches provide a basis to explore dynamic pest and crop interactions in determining pest management strategies which minimize yield losses.

Pinnschmidt, H.O., W.D. Batchelor, and P.S. Teng. 1995. Simulation of multiple species pest damage in rice using CERES-Rice. Agric. Syst. 48:193–222.

Operational Pest Forecasting

Farmers are mainly interested in current disease and pest severity data, preferably for their localities to aid their decision-making in crop protection. Pest monitoring data along with complementary monitoring of weather data is crucial to run pest forecast models and make available forecasts for operational use. Weather measurements under field conditions from several geo-referenced sites in the crop cultivated regions additionally provides spatial information which can be used for generating pest forecast maps (Huang *et al.*, 2008). In Bayern (Germany) a measuring network of 116 field weather stations is used to estimate the development of pests in relation to weather requirements based on forecast models and computer-based DSS for near real time dissemination to farmers (Tischner, 2000). The results of crop and horticulture specific models and DSS are supplemented by field-monitoring data which then serve as the main input for the warning services and cost effectively disseminated through the Internet (Bugiani et al. 1996; Jorg, 2000). A computerized national forecasting network in apple orchards transmits data from the field to system headquarters automatically. The national forecasting network in Turkey has been expanded and covered apple orchards in 34 provinces in 2006, using 115 electronic forecasting and warning stations (Atlamaz *et al.*, 2007).

In India, agromet network under the All India Coordinated Research Project (AICRPAM) provides agro-advisories on http://www.cropweatheroutlook.org. An online tool has been developed for forecasting of mustard aphid (*Lipaphis erysimi*) from incidence data on mustard cultivars sown at staggered intervals at multiple locations over a period of 3 years. Multiple step-wise regression models were built between aphid incidence over time and composite weather variables with correlation coefficients as weights. Weather indices were computed for different weeks after sowing until the forecast was provided. Using SAS statistical software, models were devised for forecasting 1) crop age at first appearance of aphid on crop 2) crop age at highest aphid population (aphid counts on 10 cm of terminal shoot) in the season and 3) Peak aphid population on the crop in the season for different locations (Vinod Kumar *et al.*, 2012).

'RB-Pred' a web-based server, was developed for forecasting leaf blast severity in rice based on the weather variables (Kaundal *et al.*, 2006). 'RB-Pred' predicts rice leaf blast severity (%) based on the weather parameters input by the user. It uses the regression module called support vector regression (SVR), a powerful machine learning technique called support vector machine (SVM). The SVM learns how to classify from a training set of feature vectors, whose expected outputs are already known. The training enables a binary classifying SVM to define a plane in the feature space, which optimally separates the training vectors of two classes. When a new feature vector is inputted, its class is predicted on the basis of which side of the plane it maps.

Conclusion

Pest monitoring is the foundation for issue of early warnings, development and validation of pest forecast models and decision support systems which are crucial for design and implementation of successful IPM programmes. Models are useful ways of synthesizing the available information and knowledge on population dynamics of pests in agro-ecosystems and natural habitats. However, any model needs to be tested and validated prior to use. Development of long-term monitoring on a spatial scale on crop-pest-weather relationships will narrow the gaps in knowledge required for reliable forecasts. In the last decade, two ICAR projects were funded by the World Bank and implemented with CRIDA as the consortium lead in the area of pest forecast research in key field crops such as rice, cotton, groundnut, sugarcane, pigeonpea and mustard. Significant contributions were made under the NATP project and useful leads are forthcoming under the ongoing NAIP project (Table 2). Computer-based systems have increased the speed and accuracy of forecasting as well as decreasing its costs. Recent developments in information and communication technology offer great scope for wide dissemination and use of pest forecasts. In the tropics, agro-ecosystems are characterized by greater crop diversity in small parcels of land and dynamically changing weather. Available generic simulation models need to be tested with location specific inputs for greater accuracy. In developing countries there is a strong need to establish functional networks for specific crop sectors with the major objective of pest forecasting through models and decision support systems.

Chapter - VII

Climate Change, Extreme Weather Management and Policy Issues

BASIC ASPECTS OF RESEARCH PROJECT PROPOSAL (WINNING TYPE) ?

S.M. Virmani

Research: The systematic investigation into and study of materials (e.g., natural, human, economic) and sources (e.g., biotic) in order to establish facts and reach new conclusions: as an example we are fighting hunger by raising agricultural productivity through agronomic research.

Research includes development (R&D), which denotes work directed towards the innovation, introduction and improvement of products and processes.

Research project has a continuum:

An individual or collaborative research that is carefully planned and designed to achieve a particular set of aims (outputs).

Proposal: A plan or suggestion, especially a formal or written one, put forward for consideration or discussion by others (donors). The proposal has a format.

Scale of a Research Proposal

- **International:** Involving several countries, states, or agro-eco-zones (meta projects/proposal)
- **Regional:** Involving a region or agro-eco-zones (mega projects/proposal)
- **Sub-regional:** Involving a sub-region or agro-eco-zone (meso projects/proposal)
- **Local:** Involving a localized region or sub-agro-eco-zone (micro projects/proposal)

Often time, however, projects are categorized or scaled on the basis of allocation of funds. This is not a correct method of scaling research projects. The baseline data needs are very different for proposals of different scales. As an example a 1:5 million scale soils map may be quite adequate for International or regional research projects, or 1:1 research project, 1:10,000 or better scale of soils mapping is needed to propose sustainable farming systems.

Scientific (Research) Method – (1)

A method of procedure that has characterized natural science research (since the 17th Century). It consists of setting up of hypothesis, systematic observations, measurements on experiments or surveys and the formulation of conclusions. Finally, it involved testing of the hypothesis and its number of locations, a hypothesis may end-up as a theory or a principle or a set of principles.

Scientific (Research) Method – (2)

Under the same on similar boundary conditions, the scientific method states that "*the results of an experiment must be replicative*" and amenable to simulation or systems modeling.

Scientific (Research) Method – (3)

Boundary conditions in agricultural science are generally referred to as 'maintain data-sets'. These include amongst other observations such measurements/recordings as latitude, longitude, elevation, cultivars/ characters (e.g., heat unit requirement); soil type and its water-holding and nutrient's status, date of planting, water/rainfall regime; temperature, evaporation and moisture-deficits during crop growing season, and date of harvest(s).

The Role of Research (Project Proposal)

The role (and aims) of scientific research (in the contest of a project) must meet one or all of the following objectives:

Rebuilding: It is the process of creating or developing typically an improved system or situation over a period of time (as an example, the rice-wheat production system, prevalent in the Indo - Gangetic plains of Pakistan, India, Nepal, Bangladesh and China, strengthening of animal disease monitoring, surveillance and forecasting, prevention of post harvest losses, development of improved storage and processing of fish). The project must build on the existing knowledge /know-how.

Repairing: It means forming new ideas or theory by bringing together various conceptual elements, typically over a period of time to repair degraded systems. It should be based on empirical knowledge/know-how observed over a period of time (e.g. IPM/INM research or the reconstruction of self-affected or eroded lands, intervention of newer drugs, vaccines and indigenous drug formulations for various animal and fish diseases).

Replacing: It means to pit an agro-ecosystem back to a sustainable productive position over a period of time. As an example, replacing rainy season fallow-sorghum or wheat production system in central India, soybean-wheat or soybean/ pigeon pea production system in semi-arid Vertisols signifies a replacement system. Artificial insemination and embryo transfer technology for improvement of live stock, development of eco friendly and sustainable fish/shell fish farming are a few examples.

Summary

What then is a winning research project proposal?

- It should propose a systematic investigation targeted to a special slot on the R&D continuum.
- The scale of application domain must be clearly defined.
- The scientific research methodology should be detailed in the project proposal.
- The role and the aims of research project should be described upfront in terms of the utilization of the new knowledge towards sustainable production system.
- A winning research project proposal is the one that typically meets the donor's objectives and needs of the society at large, and finally.
- A research project proposal that will win a grant would be innovative; it would explore new areas of research, and would try to discover new techniques/knowledge. The project results when adopted on a large scale would make the world a safer place to live and would aid in sustainable development.

CLIMATE CHANGE SCENARIO OVER INDIA

Arvind Kumar Srivastava

There has been significant rise in the global surface temperature over the past hundred years. Latest IPCC report (2007) highlights that over past hundred years (1906-2005), mean global surface temperature has risen by **0.76 ±0.18 °C**. The report also projects further rise in temperature. It is highlighted that due to this global warming, occurrence of extreme meteorological events like heavy rainfall, heat and cold wave events, intense cyclones etc. may rise across the globe. However, on regional scale, rise in temperature as well as occurrence of extreme events may not be uniform. Therefore, it is desirable that region wise these events are examined. This report briefly highlights the observed changes in the different meteorological parameters over India.

Temperature

Analysis of data for the period 1901-2010 suggests that annual mean temperature for the country as a whole has risen by 0.61 °C (Fig. 1) over the period. It has been generally above normal (normal based on period, 1961-1990) since 1990. This warming is rise in maximum temperature across the country, over larger parts of the data set (Fig. 2). However, since 1990, minimum temperature is steadily rising (Fig. 3) and rate of its rise is slightly more than that of maximum temperature (Annual Climate Summary, 2008).

Spatial pattern of trends in the mean annual temperature (Fig. 4) shows significant positive (increasing) trend over most parts of the country except over parts of Rajasthan, Gujarat and Bihar, where significant negative (decreasing) trends were observed (Annual Climate Summary, 2008).

Season wise, maximum rise in mean temperature (Fig. 5) was observed during the Post-monsoon season (0.76 °C) followed by winter season (0.65 °C), Pre-monsoon season (0.51 °C) and Monsoon season (0.30 °C). During the winter season, since 1991, rise in minimum temperature is appreciably higher than that of maximum temperature over northern plains. This may be due to pollution leading to frequent occurrences of fog.

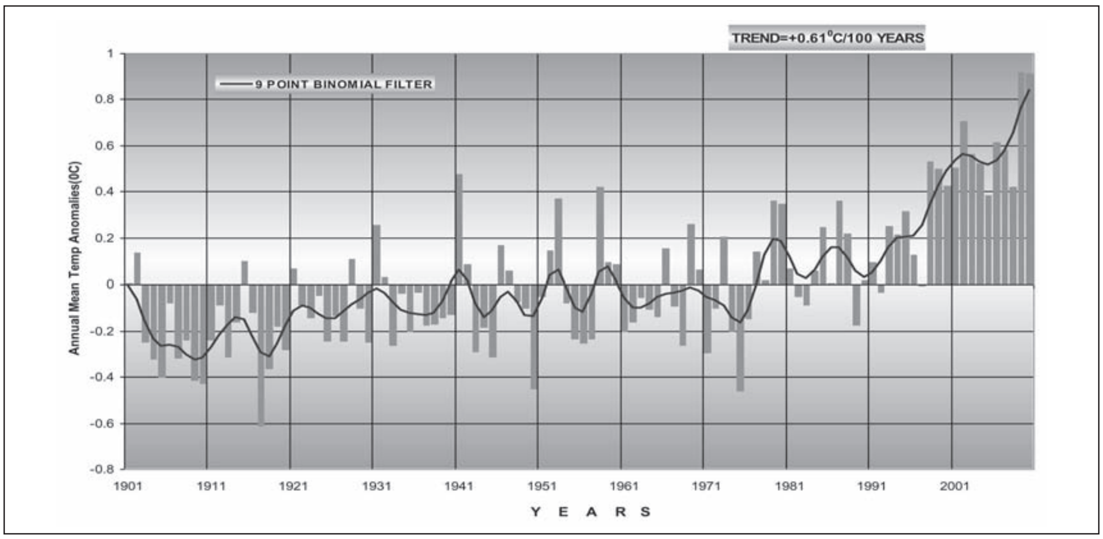


Fig. 1 : All India Annual Mean Temperature Anomalies for the Period 1901-2010 (Based on 1961-1990 Average) Shown as Vertical Bar
(*The Solid Blue Curve Show Sub-decadal Time Scale Variations Smoothed with A Binomial Filter.)*

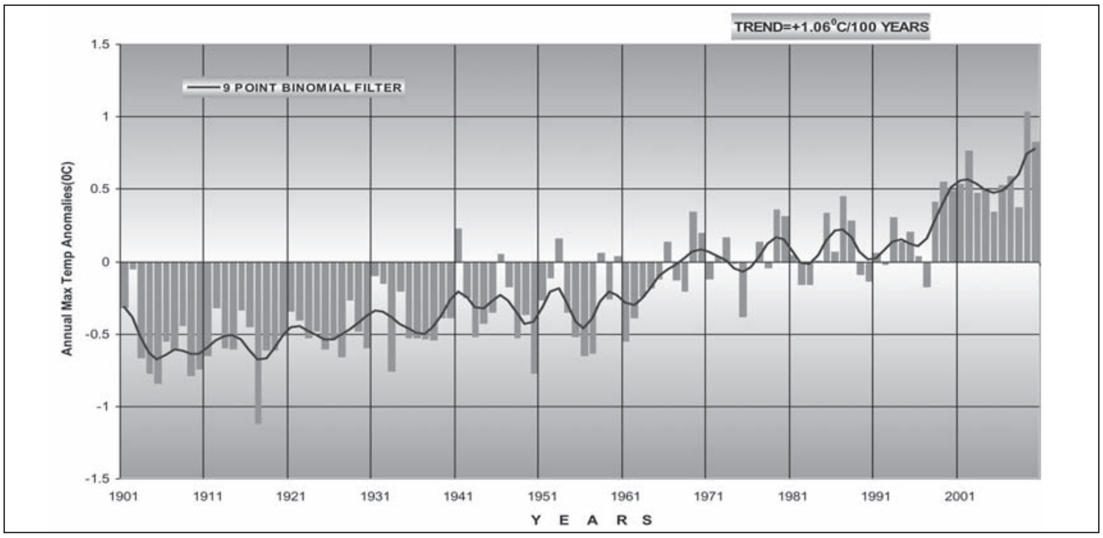


Fig. 2 : All India Annual Maximum Temperature Anomalies for the Period 1901-2010 (Based on 1961-1990 Average) Shown as Vertical Bars.
(The Solid Blue Curve Show Sub-decadal Time Scale Variations Smoothed with A Binomial Filter.)

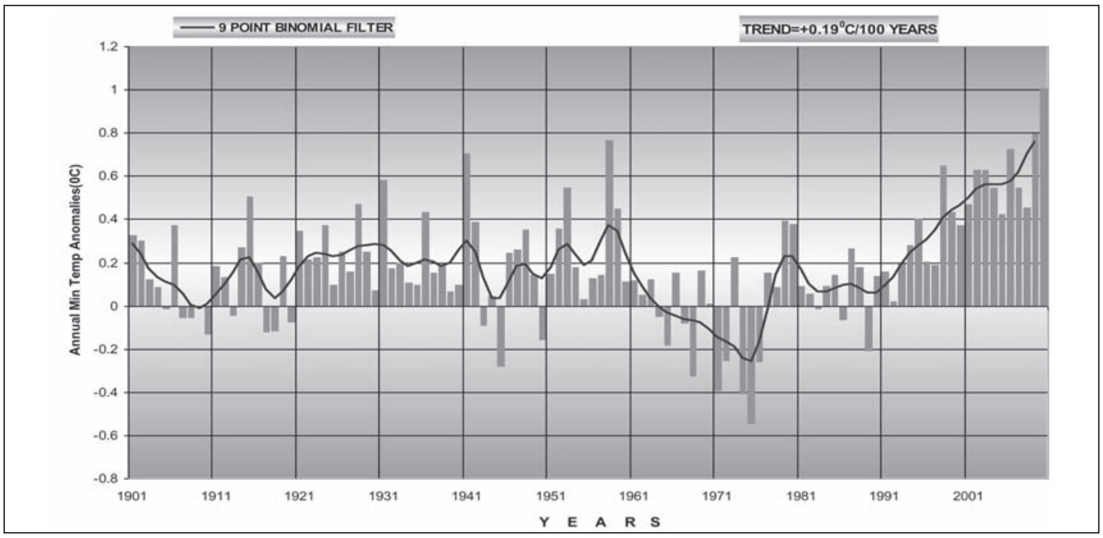


Fig. 3 : All India Annual Minimum Temperature Anomalies for the Period 1901-2010 (Based on 1961-1990 Average) shown as Vertical Bars.
(*The Solid Blue Curve Show Sub-Decadal Time Scale Variations Smoothed With A Binomial Filter.)*

Upper air temperatures have shown an increasing trend in the lower troposphere and this trend is significant at 850 hPa level, while decreasing trend (not significant) was observed in the upper troposphere (Kothawale and Rupa Kumar, 2002).

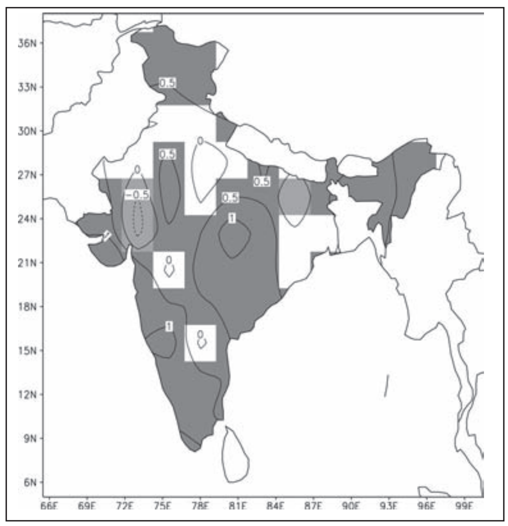


Fig. 4 : Spatial Pattern of Trend (^{0}C/ 100 Years) in Mean Annualtemperature Anomalies (1901-2010). Areas where trends are Significant are Shaded

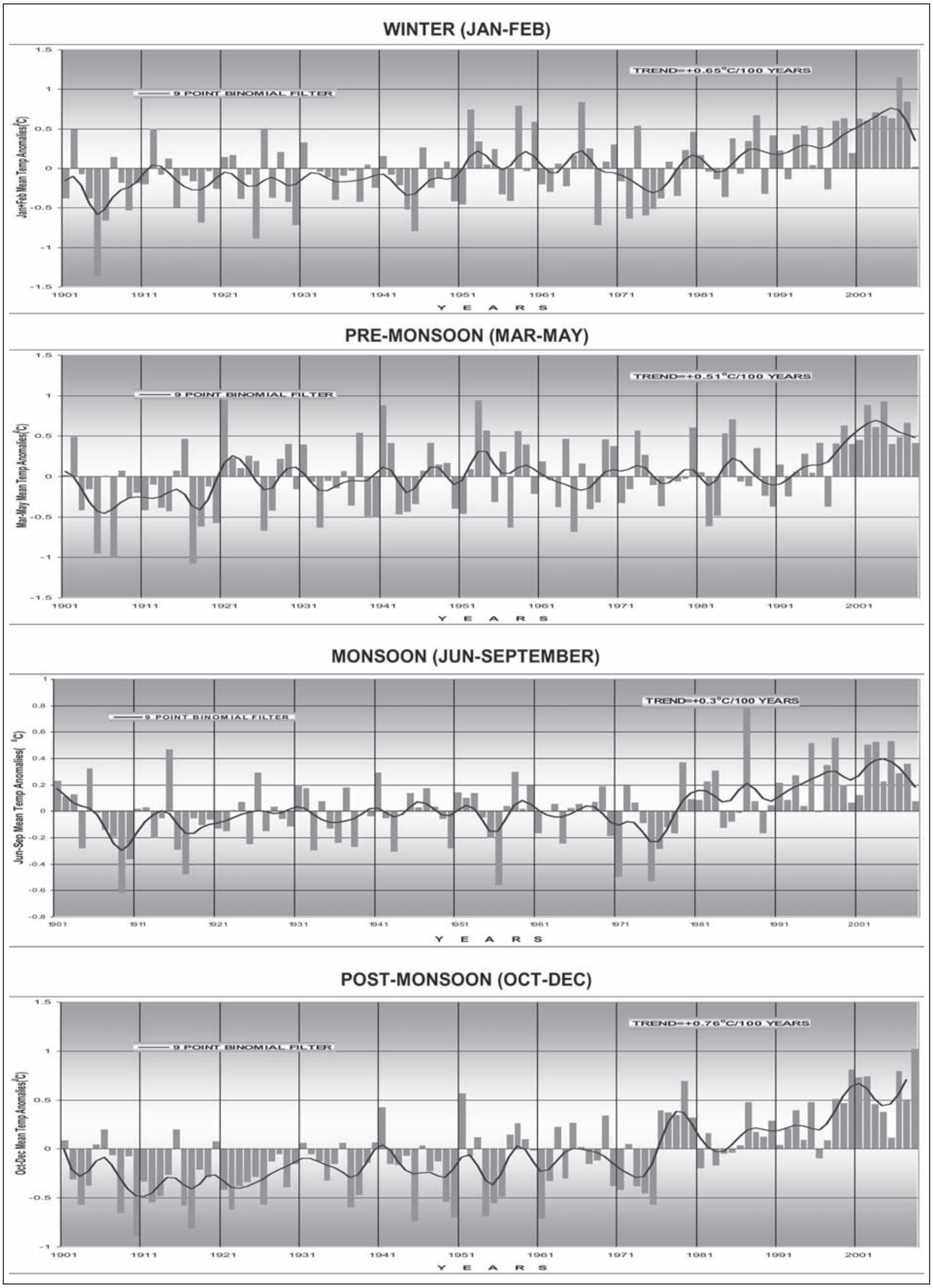
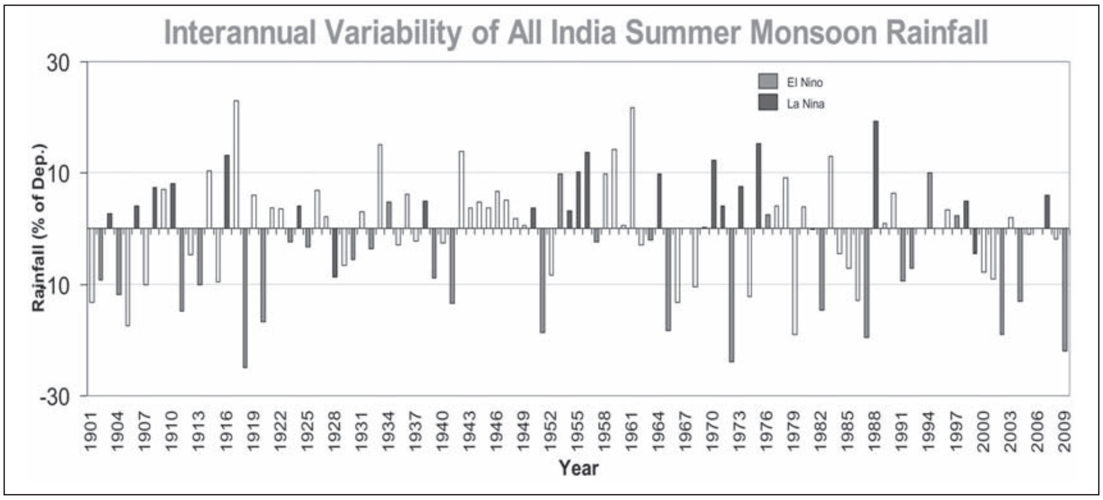


Fig. 5 : All India Mean Temperature Anomalies for the Four Seasons for the Period 1901-2008 (Based on 1961-1990 Average).

Precipitation: All India Annual and Monsoon Season Rainfall

Annual and all India summer monsoon season (June to September) rainfall data for the country as a whole for the period 1901-2008 do not show any significant trend (Figs. 6a & 6b). Similarly rainfall for the country as whole for the same period for individual monsoon months also does not show any significant trend.



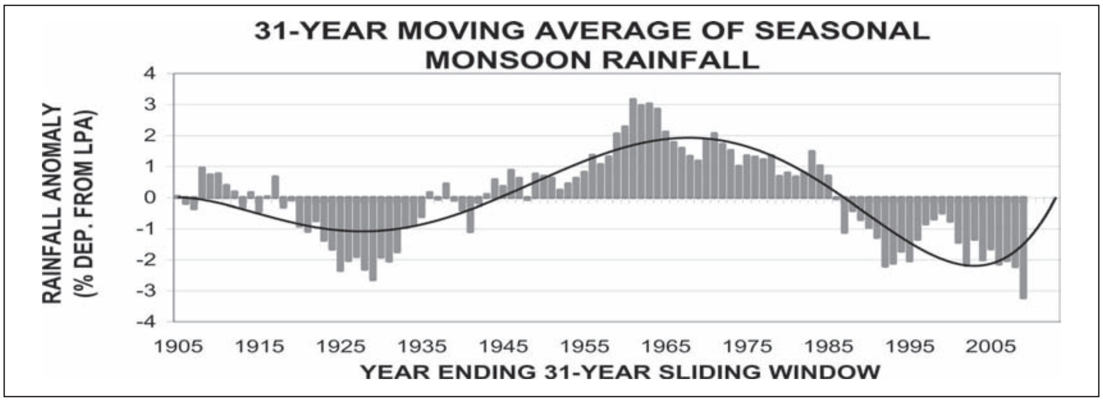


Fig. 6 : Trend in All India Summer Monsoon Rainfall (ISMR) Data for Country as a Whole (A) And 31 Year Moving Average of the ISMR

Sub-divisional Rainfall During Monsoon Season

During the season, three subdivisions viz. Jharkhand, Chattisgarh, Kerala show significant decreasing trend and eight subdivisions viz. Gangetic West Bengal, West Uttar Pradesh, Jammu & Kashmir, Konkan & Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka show significant increasing trends (Fig. 7).

Trends in the sub divisional rainfall data for the individual monsoon months are shown in Fig. 8.

June rainfall has shown significant increasing trend for the western and southwestern parts of the country, whereas significant decreasing trend is observed for the central and eastern parts of the country. July rainfall has significantly decreased for most parts of the central and peninsular India but has increased significantly in the northeastern parts of the country. August rainfall has increased significantly for the subdivisions Konkan & Goa, Marathwada, Madhya Maharashtra, Vidarbha, West Madhya Pradesh, Telengana and West Uttar Pradesh. September rainfall has shown significantly decreasing trend for subdivisions Vidarbha, Marathwada and Telangana and increasing trend for the subdivision Sub Himalayan Gangetic West Bengal (Guhathakurta and Rajeevan, 2008).

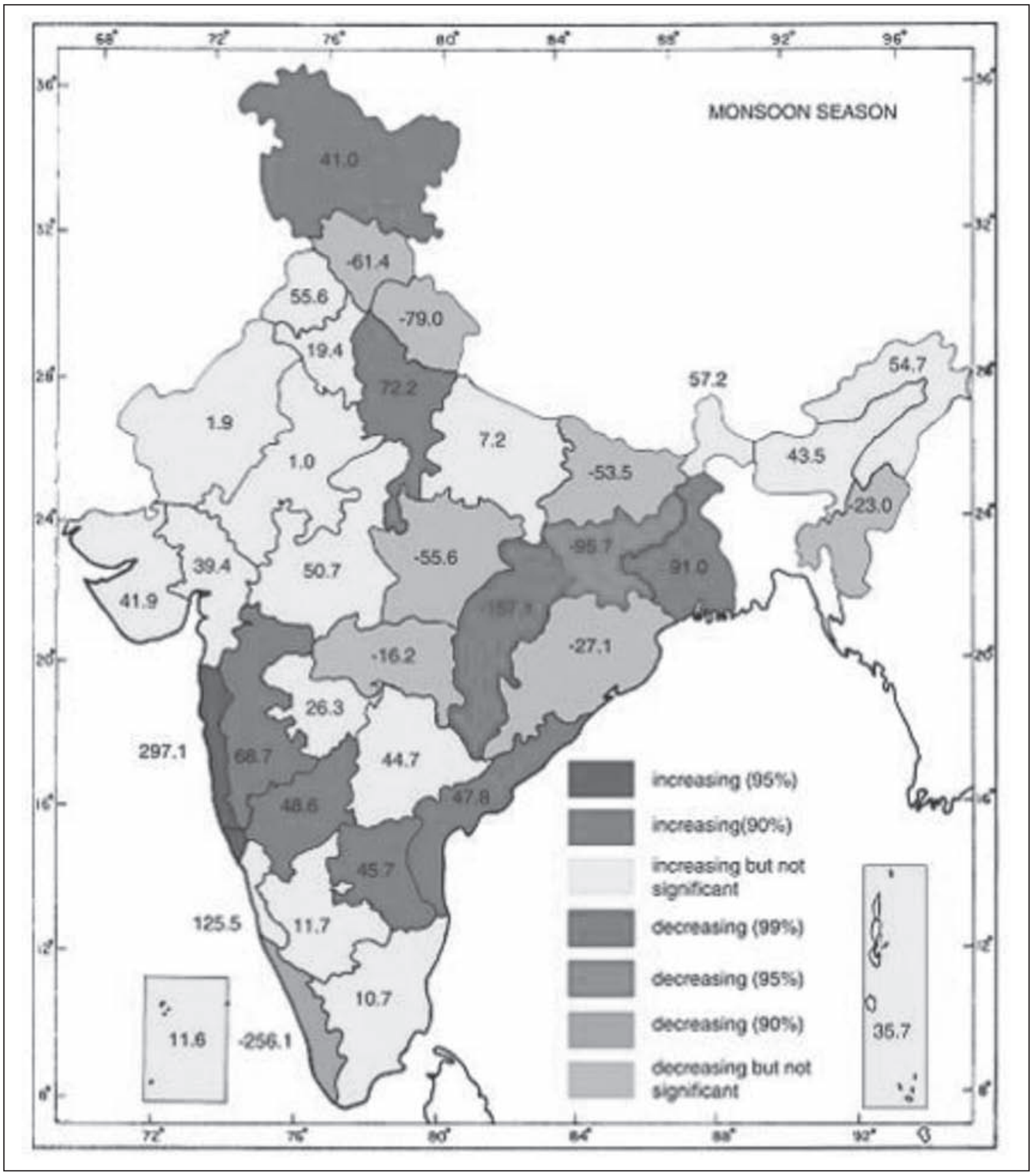


Fig. 7 : Trend in Sub- Divisional Rainfall Data for the Monsoon Season (1901-2005).

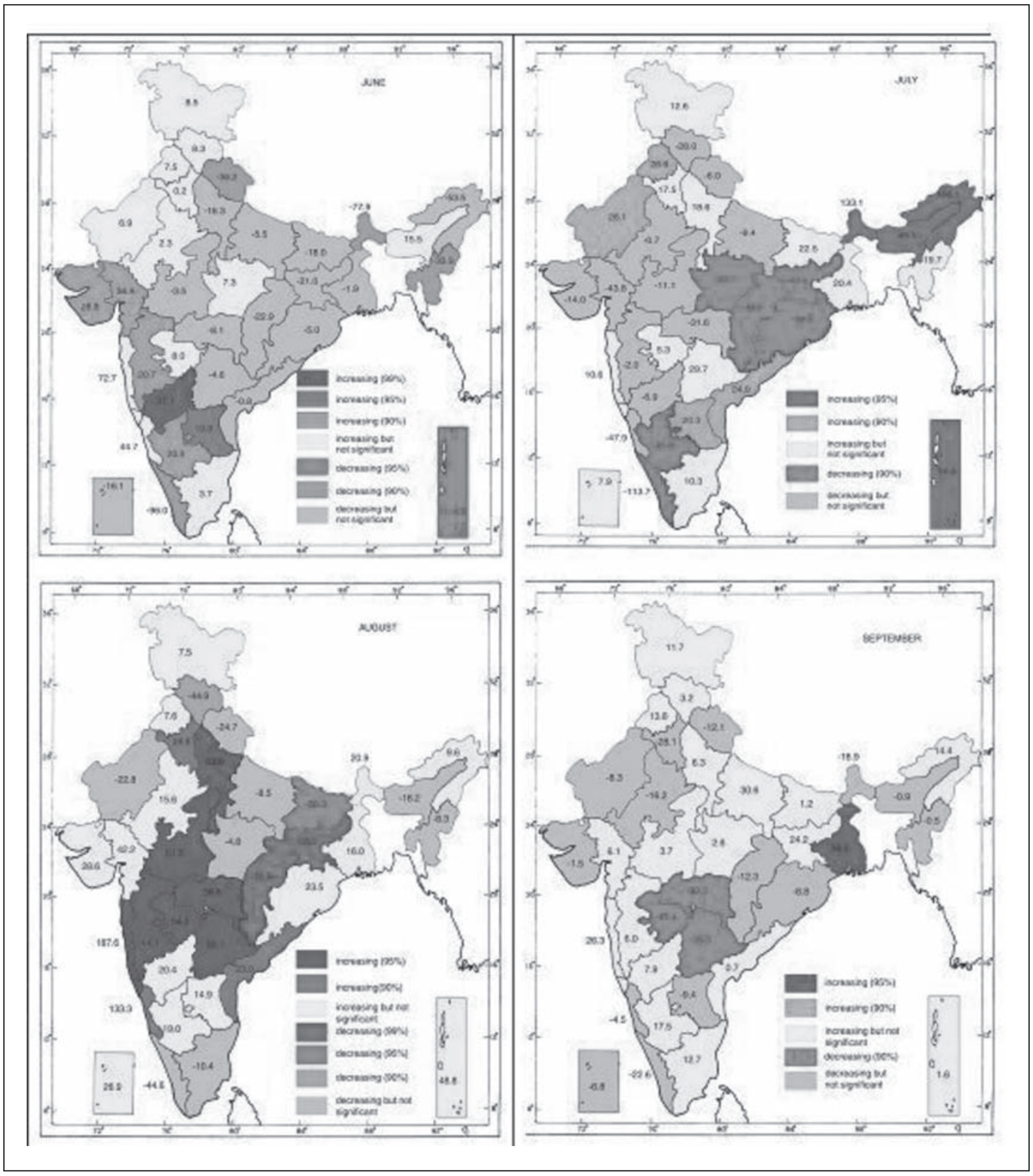


Fig. 8 : Trend in Sub- Divisional Rainfall Data for Individual Monsoon Months of the Monsoon Season (1901-2005).

Sea Surface temperature: Annual Sea surface temperature (SST) data over the north Indian Seas (LAT 0 ^{0}N-30 ^{0}N, LON 40 ^{0}E- 100 ^{0}E) have shown a significant increasing trend (Fig. 9). This rise is 0.38 ^{0}C in 100 years for the data set 1860-2005. Spatial pattern of trend in the annual sea surface temperature (Fig. 10) shows significant positive (increasing) trend throughout the north Indian Seas. For this, monthly NOAA Extended Reconstructed Global Sea Surface Temperature version 2 (ERSST V2) data, downloaded from the CDC web-site were used.

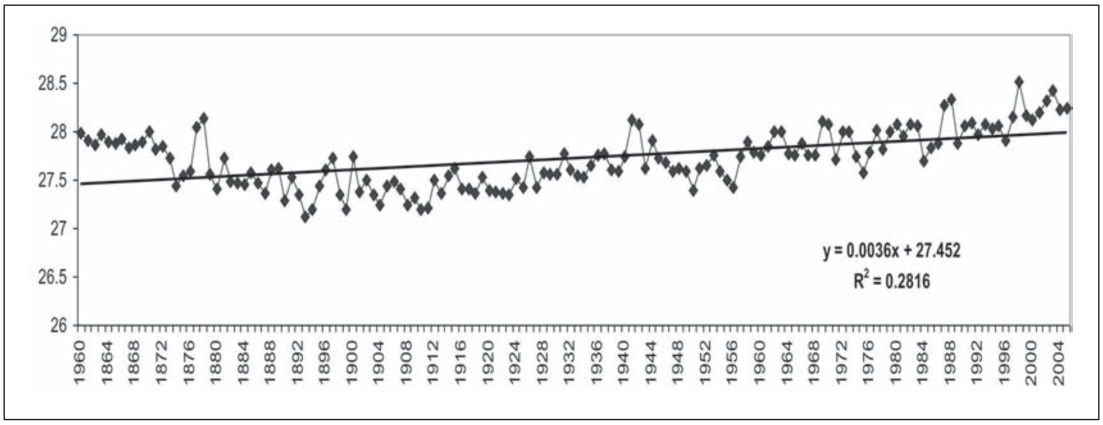


Fig. 9 : Annual Sea Surface Temperature Trend (˚C/ 100 Years) Over the North Indian Seas (LAT 0°N-30°N, LON 40°E- 100°E).

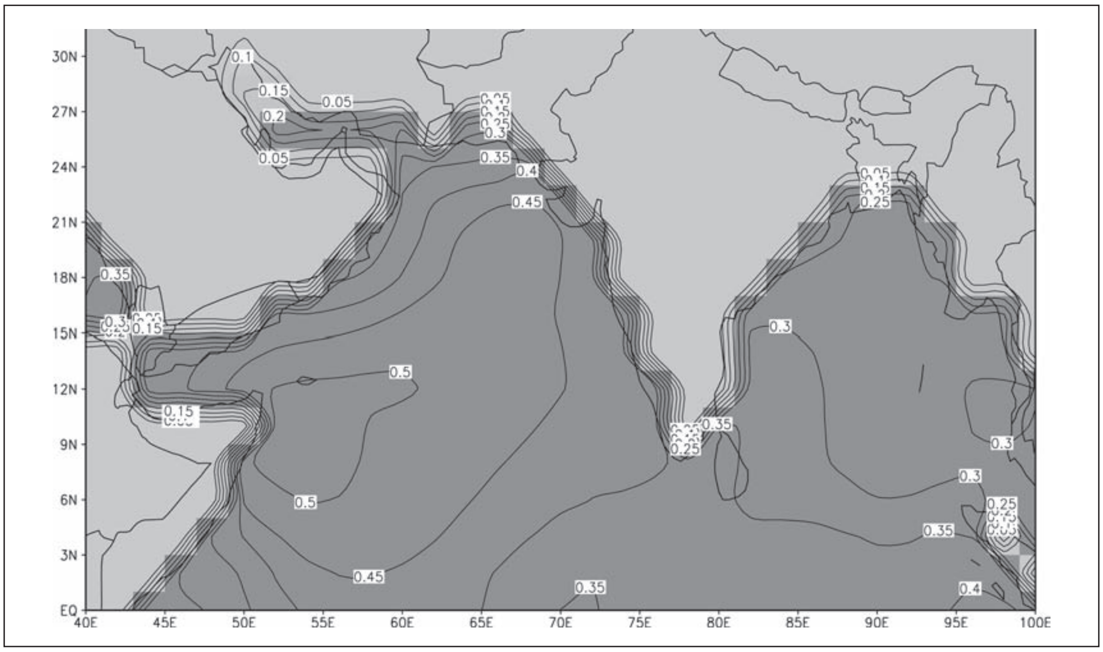


Fig. 10 : Spatial Pattern of Trend in the Annual Sea Surface Temperatures (1860-2005) Over the North Indian Ocean

Cloud cover over the Indian Seas : Both total and low cloud cover over Arabian Sea and the equatorial Indian Ocean are observed to decrease during the ENSO events. However, cloud cover over Bay of Bengal is not modulated by the ENSO events. On inter-decadal scale, low cloud cover shifted from a "low regime" to a "high regime" after 1980 (Rajeevan et al., 2000).

Trend in Ozone : India Meteorological Department maintains a network of 7 ozone monitoring stations over India viz; Srinagar, New Delhi, Varanasi, Nagpur, Pune, Kodaikanal and Thiruvananthapuram. The parameters measured are surface ozone, total ozone and vertical distribution of ozone concentration. Vertical profile measurement of ozone is measured with balloon borne ozone sonde at New Delhi, Pune and Thiruvananthapuram. Studies have shown that for the data set 1957-2007, there are no significant long term trends in ozone concentration over Indian region.

Glaciers of Himalayas : Several studies viz: Mayewski and Jeschke (1979), Jangpang and Vohra (1962), Kurien and Munshi (1972), Srikanta and Pandhi (1972), Vohra (1981), and a recent study by Berthier et al. (2006) highlight that different glaciers over Himalayas are retreating and the rate of retreat has significantly risen in recent years.

Sea level Rise : Latest IPCC report (2007) suggests that over the past decade, sea level rise has shown the highest magnitude in the eastern Indian ocean, region that exhibit large inter-annual variability associated with ENSO. Despite the global mean rise, it has been found that the sea level has been dropping in some regions (eastern Pacific and western Indian Oceans). These spatial patterns likely reflect decadal fluctuations rather than long-term trends. However, a study by Unnikrishnan and Shankar (2007) which used costal tide gauge data of more than 40 years, estimates sea level rise over the north Indian Ocean between 1.06 – 1.75 mm yr^{-1} with a regional average of 1.29 mm yr^{-1}.

Precipitation Chemistry : For the period 1981-2002 significant shift in pH towards the acidic range and increasing trend in sulphate and nitrate concentrations have been observed at most of the GAW stations. Further, decadal variations revealed drop in pH and substantial rise in sulphate and nitrate concentrations in 1991-2000 decade as compared to 1981-1990 decade at majority of the Indian GAW stations (Soni & Sarkar, 2006).

Visibility : Study of the daily visibility data from 1969 onwards for 25 stations in the country (at 2100, 0000, 0300 and 0600 UTC) shows that there is a significant decreasing trend at most of the stations. At 0300 UTC, the visibility is generally low and increases afterwards due to mixing and turbulence in the boundary layer (De et al, 2001).

Extreme Events

a) **Rainfall :** Significant increasing trend was observed in the frequency of heavy rainfall events over the west coast (Sinha Ray & Srivastava, 2000). Most of the extreme rainfall indices have shown significant positive trends over the west coast and northwestern parts of Peninsula. However, two hill stations considered (Shimla and Mahabaleshwar) have shown decreasing trend in some of the extreme rainfall indices (Joshi & Rajeevan, 2006).

b) **Tropical cyclones over the Indian Seas:** For the North Indian Ocean as a whole, the number of cyclonic and severe cyclonic storms shows a distinct decadal variability. Long term linear trend in the frequency of tropical cyclones over the north Indian Ocean as a whole, the Bay of Bengal and the Arabian Sea for different seasons and annual, generally, shows a significant decreasing trend (Srivastava *et al.* 2000; Singh *et al.* 2000). There is sharp decrease in the frequency of cyclones during the monsoon season (Singh, 2001). However, an increasing trend in the frequency of tropical cyclones forming over the Bay of Bengal in the months of May and November, the principal cyclone months, is observed. Cyclone frequency data for the last four decades (1961 onwards), since when significant monitoring tools like Radar and satellite are available, shows a significant decreasing trend for all the months and seasons and once again the maximum decrease was noticed in the monsoon season.

c) **Heat Wave and Cold Wave :** A significant increase was noticed in the frequency, persistency and spatial coverage of both of these high frequency temperature extreme events (heat and cold wave) during the decade (1991-2000) (Pai *et al.*, 2004).

d) **Discomfort indices :** It has been found that in general there is an increasing trend (significant) in the discomfort indices from the last 10 days of April to June over most of the Indian cities (Srivastava, et al. 2007).

CLIMATE CHANGE ACCELERATED LAND-WATER-BIODIVERSITY DEGRADATION AND SYSTEMS APPLIED REMEDIAL APPROACH FOR STABILIZING AGRICULTURAL PRODUCTION

KPR Vittal

Ancient Indian Philosophy (*Vedas*) supports that, all living or non-living materials on our planet earth arise from interactions of five fundamental abiotic elements called *Panchamahabhutas,* representing elements of matter. These are Air (*Vayu*), Water (*Jala*), Earth (*Prithvi*), Space (A*kasha*) and Fire/ Energy (*Agni/Teja*). Any role in the finest balance amongst these elements that impinge primarily on microcosm and the cosmic envelope as a whole, dictates the quality of the environment and in turn life. The great scholar, Charaka (600 BC), opined that as time passes, four time zones (*Yugas*) equally deteriorate qualities of *Panchamahabhutas,* a natural process.

In the past few decades, global warming phenomenon, akin to '*TejaMahabhutaVriddhi'* (increase in temperature of external atmosphere) due to unabated environmentally not-friendly adverse anthropogenic developmental activities has become a serious issue for the existence of life on the earth. Hence it is the right time to think about *Panchamahabhutas* (analogous to the three natural resource pillars *viz.*, climate, soil and water) supporting the agriculture, their impact on biological systems and ultimately on the human beings. In the context of global climate change, it is an utmost need of hour to study multiple abiotic stresses threatening sustainability of agricultural production systems with renewed vigour. The crux of strategy is to imitate nature in adaptation without resorting to collision course for sustenance. However, the present knowledge on plant response or adaptation to various stresses is compared to four visually challenged men describing an elephant (Fedoroff, 2010). Understanding molecular responses behind stress adaptation will help in identification of key players and their probable manipulation for development of super varieties/ breeds.

Abiotic Stressors on Agriculture

Abiotic stress can be termed as the negative impact of environmental factors on the organisms in a specific situation. It is a natural phenomenon that occurs in multiples and interdependent, and its impact varies across the sectors of agriculture (crops, horticulture, livestock, birds, fishes and others). The abiotic stresses like temperature (heat, cold chilling/frost), water (drought, flooding/ hypoxia), radiation (UV, ionizing radiation), chemicals (mineral deficiency/excess, pollutants heavy metals/pesticides, gaseous toxins), mechanical (wind, soil movement, submergence) are responsible for major reduction in agricultural production. Increasing industrialization is contaminating water and land with organics and heavy metals likewise increasing CO_2 and other greenhouse gases in the atmosphere are increasing atmospheric temperature and UV radiation not only threatening crops, livestock but also human beings. Unlike a biotic stress would include such living disturbances as fungi or harmful insects, abiotic stress factors or stressors, are naturally occurring, often intangible, factors such as intense sunlight or wind that may cause harm to the plants and animals and marine life in the area affected. Plants are especially dependent on environmental factors, so it is particularly constraining. Being unavoidable, these affect all other sectors of agriculture including animals both directly and indirectly due to inter-dependence. Thus, it is the most harmful factor concerning the growth and productivity of various sectors of agriculture worldwide.

Abiotic stress comes in many forms. The most common of the stressors are the easiest for people to identify, but there are many other, less recognizable abiotic stress factors which affect environments constantly. The most basic stressors include: high winds, extreme temperatures, drought, flood, and other natural disasters, such as tornados and wildfires. The lesser-known stressors generally occur on a smaller scale and so are less noticeable, they include: poor edaphic conditions like physical and physicochemical properties, high radiation, compaction, contamination, and other, highly specific conditions like rapid dehydration during seed germination. It is of experience that abiotic stressors are at their most harmful when they occur simultaneously. Potential effects of different stressors combination could vary depending on the relative level of each of stressors combined, acute to low, and type of organism and level of adoptability (Mittler, 2006).

Dealing with the abiotic stresses is in reality a very onerous task owing to their complexity, uncertainty and differential impacts over the time and place. The environmental stresses are the major limiting factors in agricultural production having great influence on crop growth and productivity. According to world estimates, average of 50% yield losses in agricultural crops are caused by abiotic factors (Oerke et al, 1994; Theilert, 2006) mostly shared by high temperature (20%), low temperature (7%), salinity (10%), drought (9%) and other forms of stresses (4%). Only 9% of the area is conducive for crop production, while 91% is under stress in the world. In our country, no reliable estimate is available. On harmonization of data of degraded and wasteland statistics of various states by the institutes of the council and National Remote Sensing Centre, the extent is 123 mha. The degraded lands of agricultural importance of water erosion (> 10 t/ ha/ annum), acid soils, acid soils under water erosion, wind erosion, saline soils, eroded saline soils, acid saline soils, saline soils under wind erosion, water logged saline soils, sodic soils, eroded sodic soils, sodic soils under wind erosion, mining and industrial waste and permanent waterlogged areas are 74.0, 5.0, 5.7, 11.4, 0.9, 1.5, 0.2, 0.1, 0.03, 2.1, 0.03, 0.8 and 3.4 mha. In the context of global warming and climate change, further productivity loss due to escalating adverse effects of abiotic stresses could be beyond anybody's guess. Being a tropical country, India is more challenged with multitude combinations of several abiotic and biotic stresses. The country is experiencing declining trend of productivity due to frequent droughts, floods, degradation of land, fluctuating temperatures and pest and disease outbreaks. These problems are likely to be aggravated further by changing climate putting forth major challenge to attain the goal of food security in the 21st century. Thus, the main task ahead is to maintain the efficiency of agro-ecosystems on long term basis to attain a goal of food security of the nation. Hence, understanding abiotic stress responses in plants, animals, birds and fishes is an important and challenging topic ahead in agricultural research.

Impinge of Climate Change on Abiotic Stressors

In the entire solar system and known universe, mother earth has the unique distinction of hosting mankind and several other forms of life in an intricate interdependent ecosystem, owing to its water and oxygen rich atmosphere and an ambient temperature. However, over a period of time and especially in the recent past due to heavy industrialization and excessive usage of fossil fuels by man has resulted in increased CO_2 emissions and also other greenhouse gases like methane and nitrous oxide which resulted in effecting the delicate balance of the atmosphere with a noticeable gradual warming of the atmosphere also known as 'Global Warming' leading to what is known observed beyond doubt as the 'Climate Change'. Disappearing arctic ice, extremes of wind patterns, droughts, precipitation, and frequency of heat waves, intensity of tropical cyclones and increased salinity of the coastline are on record. With some regional variations, the sea level has been observed to have risen by 10-20 cm. The other ecological consequences of the climate change include changes in timing of vegetation development, changes in the timing of migration of the birds and butterflies, breeding and over wintering of birds. All these significant variations in the mean state of the climate are manifestations of climate change. Climate change is also a big threat to biodiversity that is natural reserve of useful traits for future use of human beings.

Coupled with the rising population and increased incomes is the adverse impact of 'Climate Change' on production of staple food crops, fruits, vegetables, pulses, oilseeds etc., besides livestock, birds and fisheries. For a country like India, whose economy is largely influenced by the natural resources and climate-sensitive sectors such as agriculture, the threat due to climate change assumes enormous dimensions. Imminent climate change effects may manifest in monsoon behaving erratically with central India having more dry spells (Krishnan, 2006). Even though the annual rainfall may not change, the number of rainy days can reduce (Ranade and Singh, 2010). In the context of climate change, the drought can offset the benefits of increased temperatures observed at higher elevations. Besides drought, the hazards affecting crop productivity are soil salinity, sodicity, acidic soils, temperature extremes, flooding, chemical and oxidative stress and others. Soil organic carbon was also noted to be affected by increasing temperature (Davidson, *et al.*, 2010). Projected physical chemistry of problem soils weathering, etc.,in the light of climate change is still in the dark, hence climate change effects on edaphic factors is a blind spot. What is more interesting is that, at times, plant is simultaneously subjected to these factors resulting in a compound effect. The increasing night and day temperatures pose a threat to the biodiversity. The desert margins are likely to march into new areas with the present high rainfall regions being worst affected. The trend of decreasing rainfall during monsoon is concomitant with increased rainfall during other seasons, thereby affecting the crop calendar (Singh *et al.*, 2007; Crimins *et al.*, 2011). Already the northern region of the country is experiencing high winter temperatures that reduce the winter wheat yields. In Himachal Pradesh, the apple production has been affected due to increase in the temperature. Over a decade, the cultivation of apple has shifted from an altitude of 800 to 1100 m above mean sea level.

Although we have made rapid strides in extending the irrigation facilities across the regions of the country, still a vast area of the country is still plagued by the vagaries of the unpredictable weather such as droughts, extremes of temperatures, wind velocity, humidity etc. All these factors significantly affect the crop growth and yield, thereby influencing the food production of the country. What is more threatening is the interaction of these stress factors resulting from climate change. Melting of glaciers will result in initial floods but in the long run, the river flows may be alarming.

Modeling Climate Change Effects

In India about 60% of water for irrigation comes from groundwater. It is reasonable to assume that this resource will go down in future with dwindling supplies (Kabel *et. al.,* 2013). Climate change is expected to affect water resources, with implications for both natural ecosystems and human food security.Among the most damaging disasters are droughts. Climate change made the forests more prone to pest attacks/ outbreaks. Large scale tree die-off can detrimentally affect water quality (http://go.nature.com/uKsxFF). Nutrient recycling is affected. Resetting the successional clock is uncertain. It will have strong implications for alterations in biodiversity, ecosystem structure, functions and services, land-atmosphere interactions etc. Thus climate induced forest mortality will be unique (Anderegg *et. al.,* 2013).

The impacts of pumping and irrigation on latent heat flux, potential recharge and water table depth are similar in magnitude to the impacts of changing temperature and precipitation. Thus many semi-arid basins with similar water use may be experiencing effects that are expected under a warming climate (Ferguson and Maxwell, 2012). Fresh water recharge from Himalayan glaciers will change: upstream countries like India and China will build more dams in future, reducing fresh water streams to downstream areas. The combination of more salinity from sea and less charge from downstream will have devastating impacts on coastal populations in the dry season (Kabat, 2013). In the mid lattitudes, emerging picture of enhanced evapotranspiration highlights the possible threat posed by increasing drought frequency (Douville *et. al.,* 2013).

The sea level rise will result in the coastline retreat due to landward movement. The un-quantified basin filling (estimated 32000 lagoons on 13% coastline of the world) and climate change driven rainfall-runoff are the controlling factors (Ranasinghe, 2013).Halting the sea level rise within a few centuries can be achieved only with a large scale deployment of bio-energy systems with C capture and storage (Schaffer, *et. al.,* 2012). Using spatial adaptation as surrogate to for future adaptation, the losses to US maize yield from a 2^0C warming would be reduced from 14% to 6% (Butler and Huybers, 2013).

Adaptation to climate change is occurring rapidly in fisheries (McCay, 2012). Non-genetic parental effects can dramatically alter the response to increasing CO_2 and temperature in marine organisms (Miller *et. al.,* 2012). The sea surface temperature strongly influences deep water oxygeneation creating anoxic areas. However an extreme event in Australia west coast, a hot spot, 2-4^0C temperature rise persisted for 10 weeks in 2011, affected sea weed population leading to migration (Wernberg, *et. al.,* 2013). The frequency will have a greater say in future. Drought induced decline in Perigold black truffle (*Tuber melanosporum*), an ectomycorrhizalactinomycetes, despite cultivation efforts in response to amplified summer dryness in mediterranean habitats (Buntgen, *et. al.,* 2012) due to imbalances in C supply and its nutrition. The physiological drought tolerance, which varied tenfold in 426 grass species studied, showed that native grasslands have well distributed tolerant species, both climatically and phylogenetically. Local/native species help ecosystem functioning in response to climate change. Physiologically drought tolerant species have higher rates of water and CO_2 exchange, indicating severe droughts may generate legacies for ecosystem functioning. Thus grassland has high resilience in changing scenario with local expansion of indigenous species (Craine, *et. al.,* 2013).

The El Nino Southern oscillation phenomenon, characterized by anomalous sea surface temperatures and winds in the tropical Pacific, affects climate across globe. El Ninos occur every 2-7 years. The El Nino/ southern oscillation varies on decadal timescales in frequency and amplitude with a different spatial patterns of surface anomalies each time the tropical Pacific undergoes a regime shift. Recently it is shown that Bjerknesfeed back (coupling of the atmosphere and the ocean through changes in equatorial winds driven by changes in sea surface temperature owing to suppression of equatorial upwelling in the east Pacific) is not necessary for the development of El Nino. The subsurface process of discharging warm water always begins in the boreal summer/ autumn of the year before the event (upto 18 months before the peak) independent of regimes, identifying the discharge process as fundamental to the El Nino onset. This will have effect on Indian Monsoon (Ramesh and Murtugudde, 2013). Modeling suggest severe and wide spread droughts in the next 30-90 years over many land areas resulting from either decreased precipitation or increased evaporation (Dai, 2013).

National Research on Productivity Management

National Agricultural Research System operating under the auspices of Indian Council of Agricultural Research (ICAR) inclusive of State Agricultural Universities (SAU's) is the world's largest network of agricultural research. Council recognized the innate need to initiate research to counter the impact of climate change as early as year 2004 under National Agricultural Research System (NARS) and launched a Research Network on Climate Change on selected crops, livestock and fisheries during X and XI plans with currently multi location research happening at 24 locations across India. Several others are already doing research with impressive results. Earlier breeding efforts to improve the tolerance of the crop plants to the various abiotic stresses have helped in a big way to mitigate the effects of these stress environments. Using traditional breeding approaches, the Subject Management Divisions at the Council, cutting across the boundaries, together developed several varieties that are resistant to stressful environments. However, modern biotechnology allows crop improvement to take place at the level of individual genes and manipulation of the desired genes barring unwanted characters. Transgenic and functional genomics approach hold a big promise in understanding the plant responses to these abiotic stresses and developing plant types resistant to the stresses. Since last decade, with the development of molecular genetic tools and use of Arabidopsis as model system, there have been intense research efforts to identify the genetic loci responsible for abiotic stress tolerance. In India, already so many people have contributed towards understanding the molecular patterns of organisms to tolerate stress situations.

To mention a few, these are- International Centre for Genetic Engineering and Biotechnology (ICGEB) dedicated towards understanding the calcium mediated signal transduction in plants, IARI contributed to understanding drought and high temperature stress responses in wheat and pulses, Centre of DNA Fingerprinting and Diagnostics (CDFD) identified several transporters involved in water stress adaptation in E. coli, University of Delhi South Campus (UDSC) developed salt tolerant indica rice, National Research Centre for Plant Biotechnology (NRCPB) working in the field of transgenic plants development by using osmotin, connexin and codA genes, University of Agricultural sciences (UAS_B) studying the role of Late Embryogenesis Abundant (LEA) proteins in stress tolerance and several others. A brief overview of major successes made in the field of abiotic stress management is given below:

Atmospheric stresses:

Crops: Elevated levels of atmospheric CO_2 has been reported to increase the yields of tomato (IIHR, Bangalore) and onion (DOGR, Rajgurunagar) and dry leaf weight in *Partheniumhysterophorous* Linn. (DWSR, Jabalpur); Scorching of outer rind in pomegranate has been reported due to light stress (NRCP, Solapur). High temperature is reported to decrease yields in mustard, chickpea and wheat whereas yields were found increased in pulses (CRIDA, Hyderabad); In onion clear winter with high humidity and early summer ensured good crop (DOGR, Rajgurunagar); High temperature tolerant varieties are screened in wheat (Pusa Gold, PusaBasant, PusaGehoon, and Harshita); Indian mustard (NPJ-113); Karan Rai (PusaAditya) and Cotton (Arvinda) (IARI, New Delhi).

Livestock: Methanolic extracts of mango leaves, garlic, clove and eucalyptus oil with finger millet straw based diets are effective in decreasing enteric methane emission resulting due to microbial fermentation in the rumen (NIANP, Bangalore); Increase of mean daily rectal temperature by about 0.70 ^{0}C in bucks of Marwari, Sirohi, Jamunapari, Barbari breeds of goat have been reported due to light stress (IVRI, Izatnagar); High temperature caused increased mortality, respiratory rates and decreased feed consumption, blood flow, less production with poor chick quality, fertility, etc. in poultry (PDP, Hyderabad).

Drought stresses:

Crops: Drought tolerant transgenics in cotton are developed via *Agrobacterium* mediated transformation (CICR, Nagpur); Transgenic sorghum lines are developed with genes TPS1, gly I, annbj and nprI with large root and plant growth (CRIDA, Hyderabad); Watershed management technology successful in drought periods for cropping systems: castor + green gram; sorghum + pigeonea; pigeonpea+black gram; castor+greengram; soybean+pigeonpea (CSWCRTI, dehradun); Laser land levelling and raising bund height for rice; routing canal water/ ground water to a fish pond/ secondary reservoir; planting vegetables/ fruits (ICAR-RCER, Patna); Jalkund, a micro-rain water harvesting structure was developed (NEH, Umaim); Submergence tolerant varieties were developed in rice (Asina, Kalaketaki, Khuda, Khadara, Kalaputia, AC 38575, AC 37887) (CRRI, Cuttack); Raised beds/ broad bed and furrows reduced submergence stress of onion during Kharif (DOGR, Rajgurunagar; IIHR, Bangalore).

Livestock: Feed intake reduced ~100% in three days due to water deprivation (IVRI, Izatnagar).

Edaphic stresses:

Genes cloned and transgenics are developed to confer drought and salinity tolerance (*Arabidopsis thaliana* cv Columbia) (IIHR, Bangalore); Transgenics are developed in pigeon pea (Pusa 991) and Indian mustard (NPJ-112) for salinity stress (IARI, New Delhi); Reclamation of alkali soils by gypsum; subsurface drainage in waterlogged saline soils; gypsum and pyrite beds for conjunctive use of canal water with poor quality groundwater, ground water recharge technology under floods; alternate land use, multi-enterprise models; cultivars/ crop species (CSSRI, Karnal); Rootstocks (110 R) accumulated less sodium and chlorides in grapes (NRCG, Pune); Soil amendments are helpful in onion (DOGR, Rajgurunagar); Nitrogen and water stress severely restrict pomegranate growth and development (NRCP, Solapur); Isolation of trait-specific abiotic stress tolerant microbes, their molecular and biochemical characterization; isolation of salt stress tolerant bacteria from Sabher salt lake (NBAIM, Mau); Salinity, temperature and osmotic tolerance/ hardy *Rhizobia* isolated (IISS, Bhopal).

As a natural component of ecosystem, the abiotic stresses affect all the organisms in a variety of ways- plants by limiting phenological expression depending on stressor(s) and feeding, productive and reproductive performance of animals and birds especially under temperature extremes including humidity.

Gaps in Research

A bird's eye view perusal of the path of science in increasing crop productivity shows an obvious circle. Earlier to green revolution, the science was looking for physiological attributes of plants to increase the yield factors. Once the merits of dwarf and short duration plant types were recognized, the plant breeders were vigorous in providing the farmers with numerous options. However, for the reasons of reaching a so called soil or yield fatigue, once again, scientists started looking for new avenues leading to the biotechnology. It has facilitated the scientists in marker assisted breeding to overcome various productivity constraints. But abiotic stresses, a natural part of ecosystem, occur in multiples. Added to this is impending climate change, which is, beyond any doubt, going to make the already vulnerable productivity more severely limited. The farmers are quite aware of the multiplicity of the various stresses which are resultant of atmospheric, edaphic and water related factors. As already mentioned, the 'Systems Biology' approach which integrates the series of –omics i.e. phenomics, genomics, transcriptomics, proteomics, metabolomics and others is getting roots since the early new millennium. It involves all fraternities related to agriculture including livestock, fisheries, birds and others. It is well known that a balance between yield and resistance to stresses is always precarious. This is where the biotechnologist needs a natural resource scientist to feed him on the relative necessities to withstand stresses. This coordination is urgently needed for faster and reliable deliverables so that stakeholder can get benefited timely. *However, the scientists are to produce a super biological system by merging best(s) of various organisms to overcome all these stresses.* In this endeavour, our scientists cannot fall short of in any facilities or information. Although nation already has premier institutes that cater to the research needs of agricultural sciences and the related sectors, what is required is institutionalization state of the art to conduct high quality basic research in the frontier and interdisciplinary areas of agricultural sciences by integrating the components of biotechnology and nanotechnology.

Interestingly, an international study is a case study of developing tailor-made rice crops at Nagoya University, Japan. In rice, Makoto Matsuoka transferred the semi-dwarf trait from Habatakivarierty of rice to Koshihikari. The new variety developed had same taste as parent and higher yield. As expansion of the global population begins to cause increasing food shortages, demand is strengthening for greater yields of tastier, safer and more resilient crops. The natural resource management will have to play an important role in the reduction of disaster risks associated with climate change. The broad areas requiring emphasis to mitigate adverse impacts of climate change are indiscriminate felling of tree plantations and loss of vegetation cover leading to landslides, accelerated soil loss with a potential to prolong the dry periods; clearing of mangrove plantations and drainage of swamps that enhance the flood hazards and mono cropping that increases the risks of genetic erosion and climate related extremes. The multi-disciplinary teams are needed to improve plant and animal species for sustainable use and reduce the problems of environmental degradation within the ambit of the bio-safety regulations.

Coupling Potential Sciences for Remedies

The abiotic stresses are becoming major challenges for sustaining productivity across all sectors of agriculture viz., crop, horticulture, livestock, fisheries, etc. it is essential to harness power of science through frontier science tools like systems biology, metagenomics, nano-biotechnology, bioinformatics, phenomics, remote sensing, etc. for mining, isolating, characterizing, and deploying novel genes for abiotic stress tolerance. The direction is to seek to evolve a novel technology for edaphic, climate change related stresses.

Systems Biology

Now days, the focus of biological research is shifting from the functions of individual genes to behaviours of complicated systems that emerge from the interactions of a multitude of factors. These recent developments necessitate the combination of approaches collectively called systems biology. Future crop improvement programmes using systems biology approach with the integration of experimental results from lab and field conditions will perhaps be the best strategy to address abiotic stresses. Due to advances in systems biology, structural biology and breeding technologies based on genomic information, the ability to design biological functions is coming within reach. However, to truly comprehend the dynamics of the entire system, the complexity, which is generated by the interactions of many factors, must also be understood. To lead biology into a new era with a focus to mitigate or adapt multiple abiotic stresses, it is absolutely necessary to introduce a research approach that integrates molecular, structural analysis, information theory, and mathematical analysis on the foundation of molecular biology. To date, there are limited examples of such research based on understanding life processes as systems due to the lack of life scientists, who cover multiple disciplines. Nevertheless, systems biology, as defined above, will become a central field in the next-generation of life sciences in which all the sectors of agriculture will have the major benefit. Technology plays a crucial role in utilisation and conservation of natural resources. With the advent of new technologies like biotechnology, nanotechnology, the quality of human life has been improved considerably. The recombinant DNA technologies hold big promise towards the development of crop varieties tolerant to variety of the abiotic stress factors such as drought, heat, cold, salinity and others.

Exploiting the Power of Frontier Science Tools

Recently, several new tools like biotechnology, nanotechnology, remote sensing, bioinformatics, phenomics and polymer sciences are available for application in crop improvement, crop production and soil and water management. The challenge ahead is carrying forward the genomic science progress to that at whole plant and crop levels in the field. These frontier sciences and techniques would be exploited in future abiotic stress research for improving climate resilience and sustainability of agriculture.

Plant microbe interactions in the rhizosphere can be utilized for enhancing abiotic stress tolerance in crop plants. Plant-growth-promoting rhizobacteria (PGPR) colonizes the rhizosphere of many plant species and confer beneficial effects, such as increased plant growth and reduced susceptibility to diseases caused by pathogens. In addition, the PGPR-induced physical and chemical changes in plants results in enhanced tolerance to several abiotic stresses. Therefore isolation and characterization of rhizobacteria and bacterial endophytes from abiotic stress tolerant crop plants and their diversity and role in abiotic stress tolerance study is the need of the hour. Science of metagenomics can be utilized for exploring novel microbial genes from various stress environments for abiotic stress tolerance especially for drought, salinity and temperature.

Germplasm Base

Collection, identification and conservation of stress tolerant genotypes from different agroclimatic regions of the country has become more valuable than ever before because of impending climate change, globalization and frequently occurring natural disasters. In the new trade regime, intellectual property rights (IPR) has gained importance as a result of which access for collecting new germplasms is increasingly restricted. Creating germplasms base will help in biodiversity conservation of rare, endangered, threatened and potentially climate adapted species, identification of stress tolerant phenotypes and genotype selection using new molecular tools (Marker Assisted Selection) and bioinformatics.

Integration of Biotechnology with Natural Resource Management

For the first time in the world the council conceived, the natural resource scientists and managers to define the on-time reality of abiotic stresses and the biotechnologists to utilize the defined goals to regroup the genetic make-up to overcome the adversities. This assemblage will result in faster dissemination of adoptable solutions to the farmers. The remote sensing application being so popular can be effectively used for screening germplasm under abiotic stresses. There are several other tools used by natural resource workers which substantially can contribute in these endeavour.

Policy Support Research in the Arena of Biotechnology

Biotechnology is an important tool for engineering crops tolerant to various abiotic stresses like drought, salinity, heat, cold, freezing, etc. Continued degradation of soil and poor soil fertility lowers crop yields so they can no longer support the increasing demand for food. This would, however, require the immediate improvement of the national institutional capacity like Abiotic Stress Management Institute and human resource development. To exploit the potential gains from biotechnology into abiotic stress management in agriculture requires sound policies and regulations. We need to develop public awareness about the biotechnology role in abiotic stress management in agriculture. The possible effects of biotechnological research in abiotic stress management on biodiversity, human health and environmental consequences, should carefully be evaluated. Policy must account for environmental, socio-economic and ethical implications of biotechnology in abiotic stress management research. Capacity building in biotechnology, including bio-safety, is vital and we need to work on this. Therefore, opportunities of agricultural biotechnology for drought, salinity, heat, cold and freezing tolerance must be high on our research agenda, together with biosafety policy issues, which encompass environmental and food safety considerations.

The abiotic stresses are natural processes arising from atmosphere, soil and water related phenomena resulting in loss of about 50% of world agricultural productivity. In the context of global warming and climate change, further productivity loss due to escalating adverse effects of abiotic stresses could be anybody's guess. Especially in arid and semi-arid regions many researches in the three major sectors of crop, livestock and fisheries on the influence and mitigation of the abiotic stresses of atmosphere (temperature -heat, cold, chilling, frost; radiation - UV, ionization; others; gasses - CO_2, and other greenhouse gases), water (drought, flooding/hypoxia, sea water inundation etc.), soil (salinity, alkalinity, sodicity, acidity, water logging, declining water quality etc.), chemicals (mineral deficiency/excess, pollutants, heavy metals/ pesticides, gaseous toxins, etc.), mechanical (aerosols, wind, soil shifting etc.) and a few others were made and are in progress. In view of impending climatic change, addressing multiple abiotic stresses comprehensively is the need of the hour. Not only now to hasten the pace of research but also initiate high quality research programmes of global standard there is a need to consolidate these studies adopting frontier molecular, biotechnological, nanotechnological, etc., tools to develop genetically stable crop, livestock and fisheries fitting in to adaptable farming systems mode.

Much less attention is paid on monitoring, modeling and managing the impacts of climate change on the dynamics of earth surface systems, including rivers, mountains, glaciers and coasts.Earth surface systems provide water and soil resources, sustain ecosystem services, and strongly influence biogeochemical climate feed backs in uncertain/ unknown ways. This is a significant challenge (Knight and Harrison, 2013). Multi-disciplinary teams of scientists comprising biotechnologists, plant biologists, agronomists, breeders, crop physiologists, soil scientists, meteorologists, animal scientists, fishery scientists, bioinformaticists, nanotechnologists, economists, sociologists, and many others are required to work together for quicker results in this emerging field of research. On time reality defined by natural resource scientists and biotechnologists is to utilize the defined goals to regroup the genetic make-up to overcome the adversities. Institutionalization to develop multidimensional research facilities for adapting and mitigating the escalating adverse impacts of abiotic stresses with impending climate change, is a new hope for tomorrow's sustainable agriculture in the era of climate change using frontier research tools. These efforts also will capture, synthesize, adapt, and apply the technological advancements taking place universally. The intermediate products generated of tolerance to multiple stresses can be in the open domain to develop end products. Conjunctively, it builds up human resources through education and capacity building to address the challenges.

OBSERVED AND PROJECTED CHANGES IN CLIMATE EXTREMES IN INDIA

S D ATTRI

The vulnerability of society to rising temperatures, changing precipitation patterns and increasing climatic extremes has become one of the most discussed issues in the global economic, social, scientific and political fora. Global and regional models have been used for producing climate change scenarios with a special focus on the behavior (frequency and intensity) of extreme events like heat waves, cold spells, severe thunder storms, tropical cyclones, storm surges, severe storms, drought etc. Extensive observational data over the past century and also the reconstructed data have been used in climatic change assessment. Better forecasting capability is central to an effective adaptation strategy, particularly in the Indian context where livelihoods are strongly related to the physical environment.

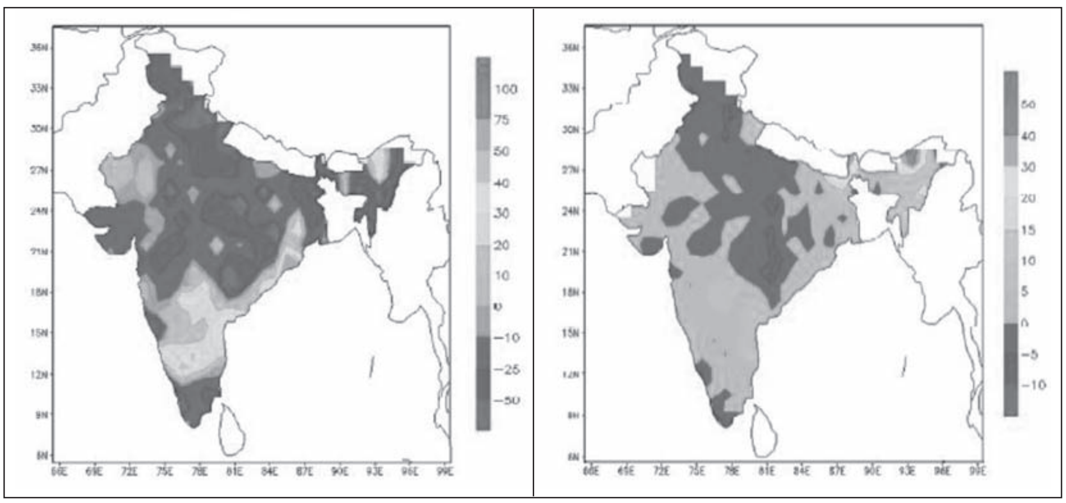
India is one of the world's most vulnerable countries to climate change. It is vulnerable to sea level rise and extreme weather events, and will increasingly face threats to human health, water availability, and food security. Additionally, about 12 percent (40 million hectares) of India is flood prone, while 16 percent (51 million hectares) is drought prone. Thus India is also vulnerable to potential climate change-induced shifts in precipitation patterns.

In India, climate/environment related observations are being taken, both on regular and campaign mode by various Central and State Government Departments, Universities, research institutions and some non-governmental agencies. Efforts are required to bring all these sources of climate system related observations into a single national network for use by research community and climate service delivery.

Observed Trend in Climate Extremes

Extreme rainfall events

Heavy precipitation events have resulted in several devasting floods in India in recent years . The consecutive flash floods over three major metro cities in the same year i.e. Mumbai in July 2005, Chennai in October 2005 and again in December 2005 and Bangalore in October 2005 caused heavy damages to economy, loss of life etc. Other extreme rainfall events of Jodhpur, Leh , Bangalore etc are fresh in the minds of people.



Rainy Days **Heavy Rain Days**

Fig. 1 : Increase/decrease in frequency of Rainy Days and Heavy Rainfall Days in 100 years

Based on rainfall data during 1901-2005, annual normal rainy days varied from 10 over extreme western parts of Rajasthan to the high frequency of 130 days over north eastern parts of the country (IMD NCCRR 3/ 2010). Both non parametric test and linear trend analysis identified decreasing trends in the frequency of wet days in most parts of the country. Trend analysis of frequency of rainy days and heavy rainfall days shows significant decreasing trends over central and many parts of north India and increasing trends over peninsular India (Fig. 1). Also the great desert areas of the country have experienced increase in number of wet days. One-day extreme rainfall intensity increased over Coastal Andhra Pradesh and adjoining areas, Saurashtra and Kutch, Orissa, West Bengal, parts of northeast India, east Rajasthan. Significant decrease both in intensity and frequency of extreme rainfall have been observed over Chattisgarh, Jharkhand and some parts of north India. The flood risk also increased significantly over India. The flood risk was more in the decades 1981-90, 1971-80 and 1991-2000.

The frequency of extreme rainfall (Rainfall ^{3} 124.4 mm) shows increasing trend over the Indian monsoon region during the southwest monsoon season from June to September (JJAS) and is significant at 98% level. It is also found that the increasing trend of contribution from extreme rainfall events during JJAS is balanced by a decreasing trend in category-i (rainfall 64.4 mm/day) rainfall events. Similarly, on monthly scale the frequency of extreme rainfall events show significant (95% level) increasing trend during June and July, whereas during August and September the increasing trend is not significant statistically. Like the frequency of extreme rainfall events, the contribution of extreme rainfall to the total rainfall in a season is also showing highly significant increasing trend during the monsoon season from June to September and during June and July on monthly scale. It is observed that the mean monthly contribution of heavy and extreme rainfall events (rainfall > 64.4 mm in a day) during June-July is 5 to 6% higher than that during August-September and hence contributes significantly to the total rainfall during the first half of the season (June and July).

Temperature trends

Analysis of data for the period 1901-2011 suggests that annual mean temperature for the country as a whole has risen by 0.59°C over the period. It may be mentioned that annual mean temperature has been generally above normal (normal based on period, 1961-1990) since 1990. This warming is primarily due to rise in maximum temperature across the country, over larger parts of the data set. However, since 1990, minimum temperature is steadily rising and rate of its rise is slightly more than that of maximum temperature. Spatial pattern of trends in the mean annual temperature (Fig. 2) shows significant positive (increasing) trend over most parts of the country except over parts of Rajasthan, Gujarat and Bihar, where significant negative (decreasing) trends were observed (Annual Climate Summary, 2009).

Season wise, maximum rise in mean temperature was observed during the Post-monsoon season (0.77 ^{0}C) followed by winter season (0.70 ^{0}C), Pre-monsoon season (0.64 ^{0}C) and Monsoon season (0.33 ^{0}C). During the winter season, since 1991, rise in minimum temperature is appreciably higher than that of maximum temperature over northern plains. This may be due to pollution leading to frequent occurrences of fog.

Precipitation trends:

The all India monsoon rainfall and monthly rainfall for the monsoon months for the period 1901-2009 do not show any significant trend. Similarly rainfall for the country as whole for the same period for individual monsoon months also does not show any significant trend. During the season, three subdivisions viz. Jharkhand, Chattisgarh, Kerala show significant decreasing trend and eight subdivisions viz. Gangetic West Bengal, West Uttar Pradesh, Jammu & Kashmir, Konkan & Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka show significant increasing trends. The alternating sequence of three successive decade (thirty years) having frequent droughts and never three decades having flood years are observed in the all India monsoon rainfall data. The decades 1961-70, 1971-80 and 1981-90 were dry periods. The first decade (1991-2000) in the next 30 years period already experienced wet period.

However, during the winter season, rainfall is decreasing in almost all the sub-divisions except for the sub-divisions Himachal Pradesh, Jharkhand, Nagaland, Manipur, Mizoram and Tripura. Rainfall is decreasing over most parts of the central India during the pre-monsoon season. However, during the post-monsoon season, rainfall is increasing for almost all the sub-divisions except for the nine sub-divisions.

During the monsoon season, three subdivisions viz. Jharkhand (95%), Chattisgarh (99%), Kerala (90%) show significant decreasing trends and eight subdivisions viz. Gangetic WB (90%), West UP (90%), Jammu & Kashmir (90%), Konkan & Goa (95%), Madhya Maharashtra (90%), Rayalseema (90%), Coastal A P (90%) and North Interior Karnataka (95%) show significant increasing trends. The trend analyses of the time series of contribution of rainfall of each month towards the annual total rainfall in each year in percentages, suggest that contribution of June and August rainfall exhibited significant increasing trends, while contribution of July rainfall exhibited decreasing trend. However, no significant trends in the number of breaks and active days during the southwest monsoon season during the period 1951–2003 were observed.

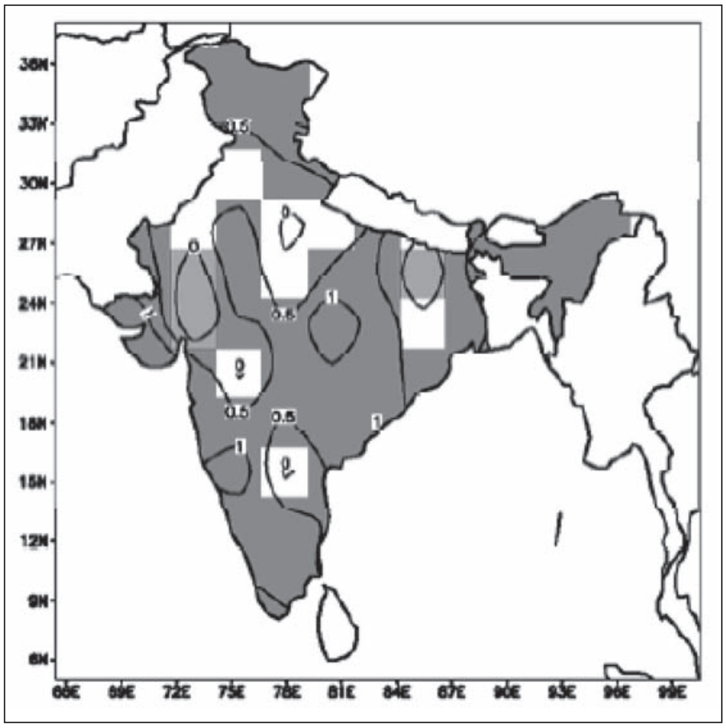


Fig. 2 : Annual mean temperature trends (°C/100 year) 1901-2011

Cloud cover over the Indian Seas:

Both total and low cloud cover over Arabian Sea and the equatorial Indian Ocean are observed to decrease during the ENSO events. However, cloud cover over Bay of Bengal is not modulated by the ENSO events. On inter-decadal scale, low cloud cover shifted from a "low regime" to a "high regime" after 1980 which may be associated with the corresponding inter-decadal changes of sea surface temperatures over north Indian Ocean observed during the late 1970s (Rajeevan *et al.*, 2000).

Heat wave and cold wave:

A significant increase was noticed in the frequency, persistency and spatial coverage of both of these high frequency temperature extreme events (heat and cold wave) during the decade (1991-2000) (Pai *et al.*, 2004).

Discomfort indices:

It has been found that in general there is an increasing trend (significant) in the discomfort indices from the last 10 days of April to June over most of the Indian cities (Srivastava *et al.*, 2007).

Cyclones:

(i) A slight decreasing trend in the annual frequency of cyclones that formed over Bay of Bengal (BOB) during 1900-2009 is seen. But, there is a slight increasing trend in the annual frequency of severe cyclones that formed over the BOB during the said period. Also, there is an increasing trend in the intensification of cyclones to severe cyclones.

(ii) No trend is noticeable in the frequencies of cyclones and severe cyclones that formed over the Arabian Sea during the period 1900-2009.

(iii) Decreasing trend in frequency of cyclonic disturbances (depression and above) during 1891-2009 and increase in low pressure areas during 1888-2009 have been observed.

Drought:

The results of mapping study (IMD 2010) of droughts are summerised as under:

1) In the Northwest region of India, the probability of moderate drought varies from 12 to 30% and probability of severe droughts varies from 1 to 20% in most of the parts and about 20-30% in the extreme north-western parts.

2) In West Central India, the probability of moderate drought varies from 5 to 26% and that of severe drought varies from 1 to 8%.

3) In the Peninsular region, the probability of moderate drought varies from 3 to 27%, and that of severe drought varies from 1 to 9% in major parts.

4) In the Central Northeast region, the probability of moderate drought varies from 6 to 37% and that of severe drought varies from 1 to 10%.

5) In the Northeast region, the probability of moderate drought varies from 1 to 26% and that of severe drought varies from 1 to 3%.

6) In the hilly region, the probability of moderate drought varies from 9 to 31% and that of severe drought varies from 1 to 12% except in Leh and Lahul & Spiti.

In general, it can be concluded that in most parts of India, probabilities of moderate drought are in the range 11 to 20%. Major parts of India show probabilities of severe drought in the range 1 to 5%. In some West Central, Central Northeast and Northeast regions of India, no severe drought is experienced

Projected Trend in Climate Extremes

The projections indicate that above 25°N latitude, the maximum temperature may rise by 2-4 °C during the 2050s and in the northern region the increase in maximum temperature may exceed 4 °C. The minimum temperature in the 2050s is expected to rise by 4 °C all over India, with a further rise in temperature in the southern peninsula. At an all-India level, little change in monsoon rainfall is projected up to the 2050s. There is an overall decrease in the number of rainy days over a major part of the country. This decrease is greater in the western and central parts by more than 15 days. The decreases in the number of rainy days over major parts of the country are also being observed in this study (IMD NCC 3/ 2010).

Simulations of future weather hardening were carried out using PRECIS model for three QUMP (Quantifying Uncertainties in Model Projections) for A1B scenario for the period 1961-1990 (baseline simulation) and for three time slices - 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071- 2098). Three PRECIS runs: Q0, Q1 and Q14 were carried out for the period 1961-2098 and were utilized to generate an ensemble of future climate change scenarios for the Indian region. It appears that there may not be signi?cant decrease in the monsoon rainfall in the future except in some parts of the southern peninsula. Q0, Q1 and Q14 simulations project 16%, 15% and 9% rise respectively in the monsoon rainfall towards the end of the 21st century.

PRECIS simulations for 2020s, 2050s and 2080s indicate an all-round warming over the Indian subcontinent. Data indicates that Q14 simulations are warmer than the remaining two simulations. The annual mean surface air temperature rise by the end of the century ranges from 3.5 °C to 4.3 °C (NATCOM 2012).

RECENT CHANGES IN TROPICAL PACIFIC: ASSOCIATION WITH CLIMATE CHANGE

Ashok Karumuri

Climate change can be defined as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The linear warming trend over the 50 years from 1956 to 2005 (0.13 °C [with a range of 0.10 to 0.16 °C] per decade) is nearly twice that for the 100 years from 1906 to 2005 [*Working Group I (WGI)* 3.2, *Summary for Policymakers (SPM)*]. Increases in sea level are consistent with warming (Fig. 1.1).Global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003 and at an average rate of about 3.1 mm per year from 1993 to 2003. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder, temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3 °C *(WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM)*. Further, global warming has implications for the climate drivers in tropical Indo-Pacific (*IPCC AR4*, 2007; *Ashok et al.*, 2007). This lecture note describes various aspects of the tropical Indo-Pacific Phenomena, their impacts and the change associated with the recent climate change.

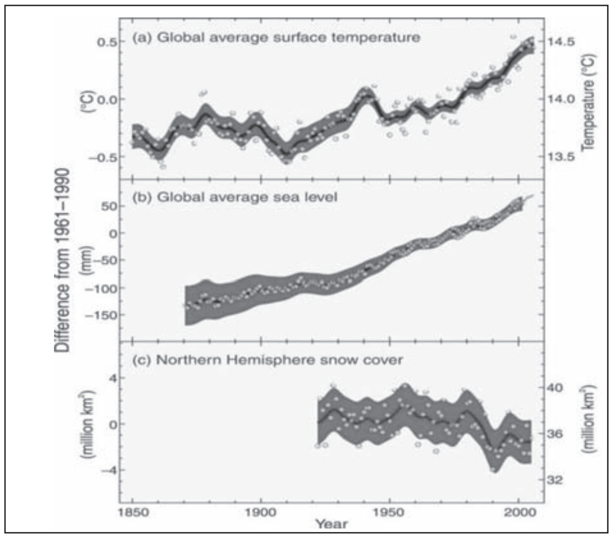


Fig. 1.1 : Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGI FAQ 3.1 Figure 1, Figure 4.2, Figure 5.13, Figure SPM.3}

El Niño-Southern Oscillation (ENSO)

The El Niño-Southern Oscillation (ENSO) is an ocean-atmosphere coupled phenomenon that occurs in the tropical Pacific, in which warming of sea surface temperature (SST) and weakening of the equatorial trades in the central and eastern Pacific accompany the displacement of heavy rainfall from the Indonesian subcontinent to the central tropical Pacific.

a) Evolution of ENSO

ENSO is composed of two components: the El Niño, defined by warmer than normal sea surface temperatures in the eastern tropical Pacific (*Bjerknes*, 1969), and the anomalous atmospheric circulation patterns associated with it known as the Southern Oscillation (*Walker*, 1923, 1924).During the normal conditions warm surface water and air in tropical Pacific are pushed to the west by easterlies winds (Fig. 2.1a). A consequence is upwelling of cold water on the eastern side, and a shallow thermocline. Oceanographic conditions opposite to that prevail on the western side. In the atmosphere, the west is warmer and wetter.

An El Niño event (Fig. 2.1b) is produced when the easterly winds weaken and when sometimes, in the west, westerly’s prevail. This condition is categorized by warmer than normal SST in the east of the tropical Pacific Ocean, and is associated with alterations in the thermocline and in the atmospheric circulation that make the east wetter and the west drier. The phenomenon of El Niño occurs on the western coast of South America near the

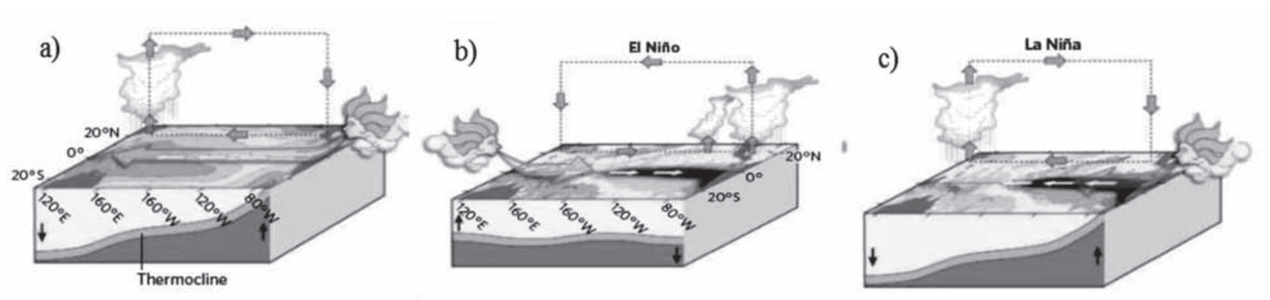


Fig. 2.1 : a) Normal conditions b) El Niño conditions c) La Niña conditions in tropical Pacific (*Ashok and Yamagata*, 2009). (Red color denotes warmer than normal, blue color denotes cooler)

equator, close to Peru and Ecuador during the Christmas season (*Wyrtki*, 1975). La Niña (Fig. 2.1c) is the cold phase of El Niño (*Philander*, 1990). La Niña conditions correspond to an abnormally cool eastern tropical Pacific. These cool conditions are accompanied by a shallow equatorial thermocline in the east and strong trade winds blowing towards the West. These winds cause heat to concentrate in the western tropical Pacific, strengthening both convection and the upper-atmosphere westerly winds that blow back to the east.

The Southern Oscillation (SO), the atmospheric component of ENSO, is an atmospheric oscillation in temperature and pressure between the Pacific and Indo-Australian areas. Thus, when air pressure is high at Darwin, Australia (western Pacific), it is low at Tahiti (eastern Pacific), and when air pressure is low at Darwin, it is high at Tahiti.Southern Oscillation Index (SOI) is a measure of the difference in a Monthly Sea Level Pressure (MSLP) between the western (Darwin, Australia) and central/eastern (Tahiti) equatorial Pacific, representative of the east-west changes in atmospheric circulation associated with the ENSO. SOI was introduced by *Walker and Bliss(* 1932).

b) ENSO impacts

In boreal spring (March-May) the strongest effects are in the western Pacific Ocean. Along the equator rainfall increases and at 10°-15° north/south rainfall decreases during El Niño events. The north of Mexico and the desert states of the U.S. usually get more rain. The North-East of Brazil often stays drier than usual during El Niño years. During June-August of El Niño years eastern Indonesia often suffers droughts. The Indian Monsoon is weaker during El Niño *(Kripalani and Kulkarni, 1997; Krishna Kumar et al., 2006)* consequently effects Indian Agriculture and crop yield. All the kharif crops except sorghum are strongly associated with ENSO conditions (*Krishna Kumar et al.,2004).* During the mature phase of El Niño (September-November), the effects on regional climate are strongest. Large parts of India are often drier than usual, but the Sri Lanka and some southern states get more rain. East Africa, parts of Central Asia and Spain are also on average wetter than normal during El Niño years *(Diaz et al., 2001)*. In boreal winter (December-February), the Philippines and East Indonesia stay drier, whereas the Pacific islands along the equator remain wetter. Florida also gets more rain than normal during El Niño; this effect extends to other southern states of the U.S. and into Mexico. South Africa is more frequently dry, as is the northern coast of South America. Along the coasts of Ecuador and Peru rainfall increases when the coastal waters heat up.

El Niño Modoki

Normal conditions in the Tropical Pacific and El Niño conditions are shown in Fig 2.1a and 2.1b. But since the late 1970s, events with increased Sea Surface Temperatures (SSTs) in the central Pacific, sandwiched by anomalous cooling in the east and west, have been observed through (*Ashok et al.*, 2007, *Ashok and Yamagata,* 2009). The maximum SST anomaly persists in the central Pacific from the boreal summer through to the winter, modifying the atmospheric circulation and resulting indistinctly different global impacts (*Trenberth et al*, 2001, *Ashok et al*, 2007;). (*Ashok et al.*, 2007; *Weng et al.*, 2009) classified it as a new type of tropical Pacific phenomenon, and named El Niño Modoki (Modoki is Japanese word for "similar, but different", *Ashok and Yamagata*, 2009) or Pseudo El Niño. Other names, such as Central El Niño (*Kao et al.*, 2009), canonical El Niño *(Yeh et al.*, 2009) and Warm Pool El Niño (*Kug et al.*, 2009), have been proposed.

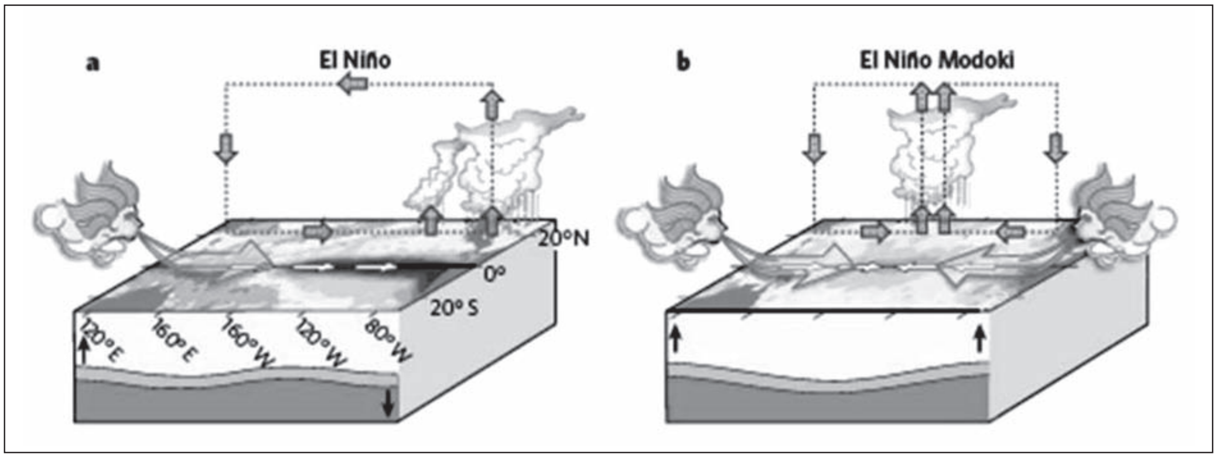


Fig. 3a : El Niño and **Fig. 3b :** El Niño Modoki conditions in tropical Pacific.

Based on the EOF2 pattern (Fig. 3c); Ashok et al. (2007) derive an El Niño Modoki index (EMI). Because of the unique tripolar nature of the SSTA, the index, from SSTA, is derived as follows:

EMI= A-0.5*B-0.5*C

Where, 'A, B, and C' are the area-averaged SSTA over Central tropical Pacific (165E-140W, 10S-10N), Eastern tropical Pacific (110W-70W, 15S-5N), and Western tropical Pacific (125E-145E, 10S-20N).

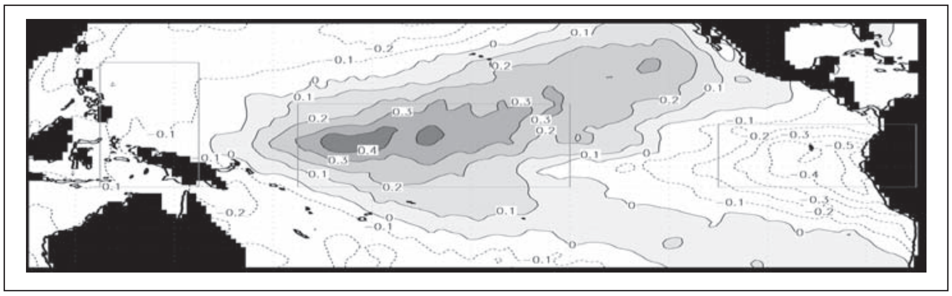


Fig. 3c : EOF2 mode of tropical Pacific SSTA (1979–2004) (*Ashok et al.*, 2007).

i) Potential impacts of ENSO Modoki

The atmospheric condition associated with the western pole located in the equatorial western Pacific apparently influences maritime countries such as Indonesia, Malaysia, Singapore, etc. The partial correlations of the EMI with the JJAS rainfall anomalies over the period 1979–2004, after removing the linear influence of NINO3 index and the IODMI, are shown in Ashok et al. (2007). They demonstrate the extensive influence of the ENSO Modoki on the eastern Australian region more clearly. The eastern tropical Pacific receives surplus rainfall during El Niño years, with deficit rainfall in the tropical western Pacific and the equatorial South America. In the East Asian region, southern Japan suffers droughts during these years owing to the Pacific-Japan pattern [*Nitta*, 1987]. Argentina and southern Brazil experience warmer than normal winter during the El Niño Modoki event. The equatorial eastern Pacific receives less than normal rainfall when El Niño Modoki is active. Some parts of the maritime countries, southern Thailand, the Philippines, southern India, Sri Lanka, and East Africa experience anomalous dry conditions. On the other hand, significantly wet conditions are seen over New Zealand, Pakistan, Kazakhstan, and parts of south central Africa. El Niño Modoki events appear to cause anomalously cold winters in eastern India and Eastern Europe. The subtropical east coast of South America also has cooler than normal Australian summer. El Niño impacts on boreal winter surface temperature seem to be more extensive and different from the El Niño Modoki impacts (*Ashok et al.*, 2007).

Indian Ocean Dipole (IOD)

1. Evolution of IOD

The Indian Ocean Dipole (IOD) refers to an anomalous state of the ocean-atmosphere system (*Saji et al.*, 1999; *Webster et al.*, 1999). During the mature phase of an IOD, which happens during September-October, eastern equatorial Indian Ocean becomes unusually cold and the western equatorial Indian Ocean unusually warm. Cold SSTA suppress atmospheric convection in the east whereas warm SSTA enhance convection in the west. Anomalous winds blow westward over the equatorial Indian Ocean and from the southwest off the coast of Sumatra, the latter being favorable for coastal upwelling. Equatorial jets become weak, reducing the eastward transport of warm water entailing a shallower than usual thermocline in the east. Sea level decreases in the eastern equatorial Indian Ocean and rises in the central part. Thermocline rises in the east and deepens in the central and western equatorial Indian Ocean. Temperature anomalies associated with IOD are also seen in subsurface ocean and the sub-surface signals are strongly coupled to surface signals. Anomalous state of the ocean-atmosphere system described above is referred to as a positive IOD (pIOD) (see fig. 4.1).

The reverse, negative IOD (nIOD) (see fig. 4.2) also occurs, characterized by warmer SSTA, enhanced convection, higher sea level, deeper thermocline in the east and cooler SSTA, lower sea level, shallower thermocline and suppressed convection in the west. The discovery of IOD mode that accounts for about 12% of the sea surface temperature variability in the Indian Ocean and, in its active years, also causes severe rainfall in eastern Africa and droughts in Indonesia. An IOD event can be detected using Dipole Mode Index (DMI) which is defined as the difference in SST anomalies between western and eastern equatorial Indian Ocean. Averages of anomalies are calculated for a box in the western Indian Ocean bounded by 50 ^{0}E–70 ^{0}E and 10 ^{0}S–10 ^{0}N and in the east by 10 ^{0}S–Equator and 90 ^{0}E–110 ^{0}E. The west minus east anomalies is positive during a pIOD year and vice versa. Evolution of the IOD is strongly locked to the seasonal cycle due to the thermodynamic air-sea feedback between an atmospheric anticyclone located to the east of and the ocean underneath being dependent on the seasonal cycle of winds.

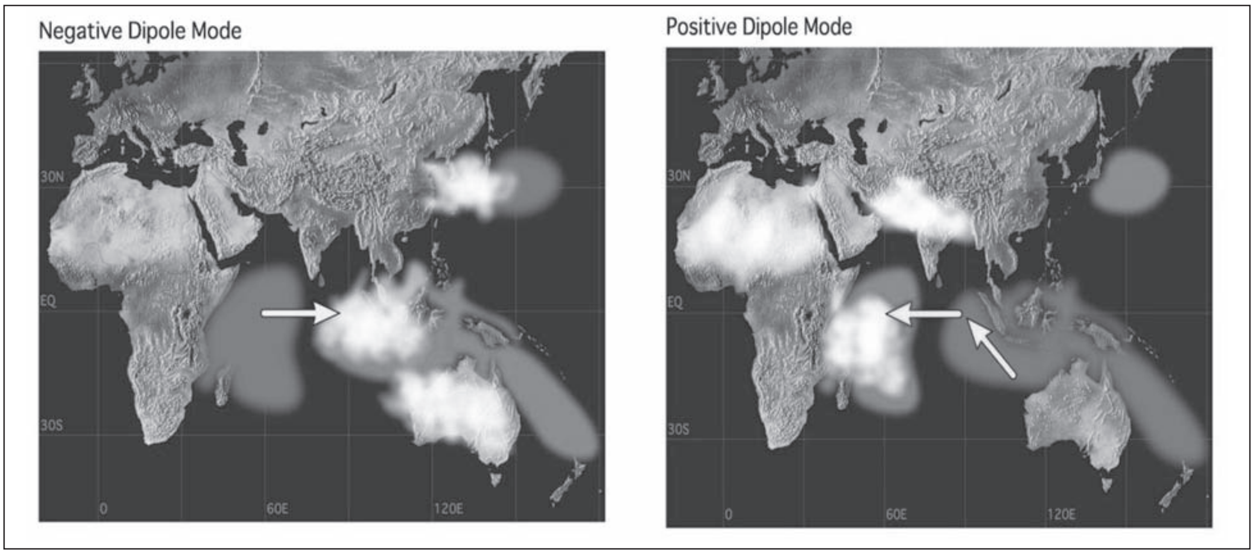


Fig. 4.1 : Negative Dipole Mode; **Fig. 4.2 :** Positive Dipole Mode (Courtesy: *JAMSTEC*)

An event begins to appear during late spring/early summer, matures during September– November and most of the anomalies disappear by January of the following year. Easterly equatorial wind anomalies and warm SST anomalies in the central part of the Indian Ocean begin to appear during spring.

2. Influence of IOD

There is a high propensity of deficit monsoon during warm ENSO events, with deficit in 21 out of 25 such events during 1875–1979, which included 9 of 11 seasons with largest anomalies (*Rasmusson and Carpenter*, 1983). However, while majority of the droughts are associated with a positive Niño 3.4 index (El Niño condition), there are droughts of 1974 and 1985 which are associated with negative SST anomaly in the Niño 3.4 region. The NIÑO 3.4 index is very small in the drought years such as 1966, 1968 and 1979. Again, while in majority of the excess monsoon seasons, SST anomaly in the Niño 3.4 region is negative (La Niña condition), it is positive in 1983 and 1994. Further, in 1997, during the strongest El Niño year in the century, the ISMR was above normal. Kumar et al. (1999) suggested that the relationship between the Indian monsoon and ENSO had weakened in the recent decades. The correlation between DMI and ISMR is rather weak and out of the 11 intense positive IOD events that occurred during 1958–1997, eight events (1961, 1963, 1967, 1977, 1983, 1994, 1993 and 1997; i.e. 73% of the positive IOD events during this period) are associated with positive anomalies of the concurrent ISMR (*Ashok et al.*, 2001). Similarly, out of the three negative IOD events during 1958–97, two events (1960 and 1992) correspond to negative anomalies of the ISMR. When the ISMR-ENSO (negative) correlation is strong, ISMR-IOD (positive) correlation is weak. Similarly, when the ISMR has a strong positive correlation with IOD, the relation between ENSO and ISMR is weak. This strong positive relation between the IOD and ISMR during 1960s and 1990s could be one of the reasons for excess monsoon seasons in 1961, 1994 and near normal monsoon in 1997. However, neither the ENSO nor the IOD can explain all the excess/droughts in the Indian summer monsoon. A few modeling studies with atmospheric general circulation models (AGCMs) and coupled ocean-atmosphere general circulation models (OAGCMs) also suggest that the positive IOD events can intensify the Indian summer monsoon rainfall (*Ashok et al.*, 2001, 2004; *Guan and Yamagata*, 2003). The years of extensive Australian drought were associated with generally low SST in the low latitudes of eastern Indian Ocean. The influence of Indian Ocean SST tends to dominate in the rainfall variability of Africa in the warm phase of ENSO and the Atlantic Ocean controls the rainfall of Africa in the cold phase. There is a tendency for increased rainfall in the tropical eastern Africa and drought in Indonesia in IOD years. The extreme floods in East African countries in 1961–62 and 1997–98 were associated with anomalous conditions in the Indian Ocean.

MANAGEMENT OF EXTREME WEATHER EVENTS AND POLICY ISSUES

R K Mall

The Super Cyclone in 1999, Drought in 2002 /2009, Heat & cold wave/ extreme temperature and Flood / flash flood, cloud burst in recent years in rural & urban areas are a 'wake-up call' from technological, social and economic points of view. This brings out the urgent need to address sustainable alternate livelihoods to enhance resilience. This study reviewed the present status of extreme weather events and their trend, their impact on different sectors, projected climate, disaster management and climate change policy and develops an approach that looks at institutional structures and interfaces as a way of identifying the possibilities and actions for mainstreaming climate change adaptation in the disaster management context. In India Disaster Risk Reduction (DM act 2005) and Climate Change (NAPCC-2008) related Institutional, Policy and Programme Framework already exists; It is now time for convergence for effective development planning and programming: managing risks and uncertainties for all shocks and stresses as simply good business, particularly in the face of mounting evidence that disasters are hampering development and poverty alleviation.

Climate change is expected to increase the frequency and intensity of current extreme weather events, greater monsoon variability and also the emergence of new disaster i.e. sea level rise and new vulnerabilities with differential spatial and socio-economic impacts on communities. Finding clear evidence for an observed change in surface temperature, rainfall, evaporation and extreme events, climate change is getting importance as a significant environmental challenge and disaster. While changes in average climate conditions can have serious consequences by themselves, the main impacts of global climate change will be felt due to changes in climate variability and weather extremes. It is observed during last decade and also projected that extreme weather events i.e. ***heat waves, cold waves, heavy rainfall, floods, droughts, more intense cyclones and flash floods*** will increase and for that we must be concerned about. This unprecedented increase is expected to have severe impact on the hydrological cycle, water resource (drought, flood, drinking water, forest & ecosystems, sea level / coastal area /losses of coastal wetlands and mangroves), food security, health and other related areas.

These changes should be factored into development practices and especially disaster risk management in order to reduce the rising human, economic and financial losses from extreme weather events and climate variability.

Extreme Weather Events / Hydro Meteorological Disasters

India is vulnerable to extreme weather events (Box – 1). Over the decade of the 1990s, both the number and severity of such events increased.

According to MHA (2011) data of major natural disasters/extremes that occurred around the world during the period 1963-2002, floods and droughts cause the maximum damage.

Type of natural disasters around the world	Damage caused by natural calamities (%)
Floods	32
Tropical Cyclones	30
Droughts	22
Earthquakes	10
Other disasters	6

Droughts:

The primary cause of any drought is deficiency of rainfall and in particular, the timing, distribution and intensity of this deficiency in relation to existing reserves. A prolonged period of relatively dry weather leading to drought is a widely recognized climate anomaly. The environmental effects of drought, include salinization of soil groundwater decline, increased pollution of freshwater ecosystems and regional extinction of animal species.

Human factors that influence drought include demand of water through population growth and agricultural practices, and modification of land use that directly influences the storage conditions and hydrological response of catchments and thus its vulnerability to drought. As pressures on water resources grow so does vulnerability to meteorological drought (WMO, 2002). For the purpose of Identification of drought prone areas by Central Water Commission (CWC) the criteria adopted was that "drought is a situation occurring in an area when the annual rainfall is less than 75% of normal in 20% of the years examined. Any block or equivalent unit where 30% or more of the cultivated area is irrigated is considered to have reached a stage, which enable it to sustain a reasonable protection against drought".

Floods:

India is one of the most flood prone countries in the world. Twenty-three out of thirty two-states/union territories in the country are subject to floods and 40 million hectares of land, roughly one-eight of the countries geographical area, is prone to floods. The national Flood Control Program was launched in the country in 1954. Since then sizeable progress has been made in the flood protection measures. By 1976, nearly one third of the flood prone area had been afforded reasonable protection.

Tropical cyclone:

The yearly distribution of tropical cyclones in the north Indian Ocean indicates large year-to-year variations in the frequency of cyclonic disturbances and tropical cyclones, but no distinct periodicity. However, there appears to be a slight decreasing trend with time. The annual average of cyclonic disturbances in the North Indian Ocean is about 15.7 with a standard deviation of 3.1. The annual number of cyclonic disturbances range from 7 (1984) to 23 (1927). On an average, about five or six tropical cyclones form in the bay of Bengal and Arabian sea and hit the coast every year. Out of these, two or three are severe. A severe super cyclonic storm with winds of upto 250 km/h, crossed the coast in Orissa on October 29, 1999. This may prove to have been the worst cyclone of the country in the Orissa region and is responsible for as many as 10,000 deaths, rendering millions homeless and extensive damage.

Extreme temperature:

Extreme positive departures from the normal maximum temperature result in **heat wave** during the summer season. The rising maximum temperature during the pre-monsoon months often continues till June, even in rare cases till July over the northwestern parts of the country. In recent years heat wave induced casualties have somewhat increased. Abnormally high temperatures were observed during April 2002 across the country and a prolonged heat wave over northern regions of India from mid-April through the third week of May caused more than 1000 fatalities. During 2003 pre-monsoon months, heat wave brought peak temperatures of 45 °C to 49 °C in May resulting in a death toll of at least 1500 people.

Occurrences of extreme low temperature in association with incursion of dry cold winds from north into the sub continent are known as cold waves. The northern parts of India specially the hilly regions and the adjoining plains are influenced by transient disturbances in the mid latitude westerlies which often have weak frontal characteristics. These are known as western disturbances.

Thunderstorm, hailstorm and dust storm:

As winter season transforms into spring, the temperature rises initially in the southern parts of India, giving rise to thunderstorms and squally weather, which are hazardous in nature. While the southernmost part of the country is free from dust storm and hailstorm, such hazardous weather affect the central, northeastern, north and northwestern parts of the country.

Future Climate Extremes, Impacts, and Disaster Losses

Confidence in projecting changes in the direction and magnitude of climate extremes depends on many factors, including the type of extreme, the region and season, the amount and quality of observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models.

Models project substantial warming in ***temperature extremes*** by the end of the 21st century. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is very likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas.

It is likely that the frequency of ***heavy precipitation*** or the proportion of total rainfall from heavy rainfall will increase in the 21st century over many areas of the globe. This is particularly the case in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. Heavy rainfalls associated with tropical cyclones are likely to increase with continued warming.

There is medium confidence that ***droughts*** will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration. Projected precipitation and temperature changes imply possible changes in ***floods***, although there is low confidence in projections of changes in fluvial floods. There is high confidence that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels, all other contributing factors being equal. The very likely contribution of mean sea level rise to increased extreme coastal high water levels, coupled with the likely increase in tropical cyclone maximum wind speed, is a specific issue for tropical small island states. Average ***tropical cyclone*** maximum wind speed is likely to increase, although increases may not occur in all ocean basins. It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged (IPCC, 2012).There is high confidence that changes in ***heat waves, glacial retreat, and/or permafrost degradation*** will affect high mountain phenomena such as slope instabilities, movements of mass, and ***glacial lake outburst floods (GLOFs).*** There is also high confidence that changes in heavy precipitation will affect landslides in some regions

Climate Mitigation and Adaptation

Climate mitigation is any action taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life, property. The International Panel on Climate Change (IPCC) defines mitigation as: “An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.”

Climate adaptation refers to the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. The IPCC defines adaptation as the, “adjustment in natural or human systems to a new or changing environment”. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.”

Applying Information on Climate Change and Managing Extreme Weather Events

The implication of climate change for disaster risk reduction is simply to take account of the scientific information on climate trends, particularly regarding extremes. This means that organization working on disaster risk reduction need to establish linkages with institutes that can provide them with that information. These scientific institutes should also reach out to the disaster risk reduction community and assist in the optimal application of the climatic information they produce. In some instances, information will indicate that particular hazards (heat wave, drought, flood and intense cyclone) might become more frequent or more intense; disaster risk reduction efforts could plan for that (IPCC, 2007). Such linkages may also provide access to the rapidly improving international capacity in seasonal forecasting, which provides increasingly reliable probabilistic forecasts of average temperature and rainfall, as well as risks of extremes, with lead time of a few months up to a year.

While such information is important, climate change will also create surprises, as part of the generally increased variability. After a severe drought has hit a particular region, and especially if trends also suggest greater drought risk, it makes sense to start reducing vulnerability to droughts, making use of the window opportunity for risk reduction that opens after a disaster has happened. However, the next disaster might also be an unprecedented flood. Disaster risk reduction efforts should, particularly in their public communication strategies, take account of the possibility of such surprises, and be careful not to see short-term trends in one category of disasters as providing a consistent projection of future climate change.

While we are focusing on weather extremes, several gradual trends also have significant impacts on natural disasters. For one, sea-level rise-projected to be between nine and 88 centimeters until 2010-will greatly affect disaster risks in many coastal areas, partly because it will increase the physical risk of a particular amount of flooding but also because it (and broader climate change) may reduce resilience of coastal ecosystem, such as coral reefs.

A comprehensive special report on managing the risks of extreme weather events and disasters to advance climate change adaptation (SREX) from the IPCC in 2012 has confirmed what scientific evidence has already concluded; that climate change is a leading cause of dramatic weather extremes. Important massage for managing changing Risks of Climate Extremes and Disasters from the SREX report is that:

- *Effective risk management generally involves a portfolio of actions to reduce and transfer risk and to respond to events and disasters, as opposed to a singular focus on any one action or type of action.* Successful strategies include a combination of hard infrastructure-based responses and soft solutions such as individual and institutional capacity building and ecosystem-based responses.
- *Multi-hazard risk management approaches provide opportunities to reduce complex and compound hazards.* Considering multiple types of hazards reduces the likelihood that risk reduction efforts targeting one type of hazard will increase exposure and vulnerability to other hazards, in the present and future.
- *Opportunities exist to create synergies in international finance for disaster risk management and adaptation to climate change, but these have not yet been fully realized.* Technology transfer, coordination, and cooperation to advance disaster risk reduction and climate change adaptation are important.
- *Stronger efforts at the international level do not necessarily lead to substantive and rapid results at the local level.* There is room for improved integration across scales from international to local.
- *Integration of local knowledge with additional scientific and technical knowledge can improve disaster risk reduction and climate change adaptation.* Local participation supports community-based adaptation to benefit management of disaster risk and climate extremes.
- Appropriate and timely risk communication is critical for effective adaptation and disaster risk management. Effective risk communication builds on exchanging, sharing, and integrating knowledge about climate-related risks among all stakeholder groups.
- *An iterative process of monitoring, research, evaluation, learning, and innovation can reduce disaster risk and promote adaptive management in the context of climate extremes.* Addressing knowledge gaps through enhanced observation and research can reduce uncertainty and help in designing effective adaptation and risk management strategies

Adaptive Measures, Concepts, Policy Options and Future Actions

In a parallel, but inter related process global community has also been deliberating on the concepts, strategies and action plan for adopting to the impacts of climate change that have now recognized as irreversible. Our agricultural, water management, livelihood system and lifestyle must adapt to the changing climate conditions before it is too late for our survival. Adaptation has been defined, “adjustment in ecological, social or economic systems in response to actual or expected stimuli and their impacts.

Key components of adoptive capacity include the ability to understand, the implications of climate change related hazards, vulnerability to the hazards due to natural resource stresses, livelihood issues and developmental needs, along with socio-economic issues, thus adjusting to the changing scenarios and needs for long term sustainable development. Records of past climate and hydrological conditions are no longer considered to be reliable guides to the future.

Regional Policy Response in South Asia

With the rising urgency to respond to its effects, climate change has become a core issue for SAARC. Its vulnerability has been in focus in SAARC forum ever since the Kathmandu Third SAARC Summit in 1987 when SAARC expressed its deep concern of the continuing degrading environment. Back then, SAARC decided inter-alia to commission a study on the ‘Protection and Preservation of the Environment and the Causes and Consequences of Natural Disasters’ in a well-planned comprehensive framework. This study was finalized in 1991, suggested an appropriate institutional mechanism for coordinating and monitoring implementation of its recommendations in the form of a SAARC Committee on Environment. (Kathmandu Declaration, 1987). The Heads of the SAARC member states focused and took climate change as a part of their agenda in the Fifth SAARC Summit at Male, Maldives in 1990. It noted with alarm the unprecedented climatic changes predicted by the Inter-governmental Panel on Climate Change (IPCC).

The Sixth SAARC Summit at Colombo recognised the degradation of the environment and SAARC leaders urged the member countries to promote cooperation amongst themselves for enhancing their respective disaster management capabilities and for undertaking specific work-programs for protection and preservation of the environment (Colombo Declaration, 1991). The Eight SAARC Summit at Delhi recognised that international cooperation is vital for building up national capabilities, transfer of appropriate technology and promotion of multilateral projects and research efforts in natural disaster reduction. (Delhi Declaration, 1995).

At the Eleventh SAARC Summit at Kathmandu in 2002 they noted the satisfaction about the growing public awareness of the need for protecting the environment within the framework of regional cooperation. They felt the need to set up a system for cooperation in the field of the early warning as well as preparedness and management of natural disasters along with the programs to promote conservation of land and water resources (The Eleventh SAARC Summit, 2002).

The Fourteenth SAARC Summit (New Delhi, 2007) expressed “deep concern” over the global climate change and agreed to commission a team of regional experts to identify collective actions in this regard. As a follow up action, the New Delhi Declaration called for pursuing a climate resilient development in South Asia.

SAARC Action Plan on Climate Change was adopted during the SAARC Ministerial Meeting on Climate Change on 3 July 2008 at Dhaka and later endorsed by Fifteenth SAARC Summit on August 3, 2008 at Colombo. The objectives of the Action Plan are to identify and create opportunities for activities achievable through regional cooperation and south-south support in terms of technology and knowledge transfer. To provide impetus for regional level action plan on climate change through national level activities and to support the global negotiation process of the UNFCCC such as Bali Action Plan, through a common understanding that would effectively reflect the concerns of SAARC Member States.

In the Sixteen SAARC Summit held at Thimphu, Bhutan in April 2010, climate change was the central issue with summit’s theme “Towards a Green and Happy South Asia”. Highlights and outcome of Thimpu Summit regarding climate change issue are:

- SAARC leaders signed a SAARC Convention on Cooperation on Environment to tackle the problem of climate change.
- The SAARC nations also pledged to plant 10 million trees over the next 5 years.
- India proposed setting up of climate innovation centres in South Asia to develop sustainable energy technologies.
- India offered services of India’s mission on sustaining the Himalayan Ecosystem to the SAARC member states.
- India announced “India endowment for climate change” in South Asia to help member states meet their urgent adaption and capacity building needs posed by the climate change.
- The seven-page ‘Thimphu Silver Jubilee Declaration-Towards a Green and Happy South Asia’ emphasized the importance of reducing dependence on high-carbon technologies for economic growth.

The Thimphu summit provided an opportunity to devise a common climate agenda as a regional group.

The Seventeenth SAARC Summit was held in Addu City, Maldives in 2011 and signed SAARC agreement on Rapid Response to Natural Disasters. A 20-point Addu Declaration was adopted on 11 November 2011 to forge effective cooperation among the member states in a host of areas including economy, connectivity, climate change, food security and to ensure timely implementation of the Thimphu Statement on Climate Change.

Climate Change Policy in India

The Government in India is actively involved with climate change activities since long. India is a Party to the United Nations Framework Convention on Climate Change (UNFCC). The Eight, session of the Conference of Parties (COP-8) to the UN convention on Climate Change in 2002, New Delhi ended here with a Delhi Declaration has successfully resolved the technical parameters necessary for the implementation of the *Kyoto Protocol* (1997). The Delhi declaration gave primacy for the implementation of the Clean Development Mechanism (CDM) in the climate change process. The National Clean Development Mechanism Authority is operational since December 2003 to support implementation of CDM projects.

To address the future challenges, in June 2007, the Government announced the constitution of a high-level advisory group on climate change and prepared a **'National Action Plan on Climate Change (NAPCC)'** and that was released by the Hon'ble Prime minister of India on June 30, 2008 *outlining existing and future policies and programs addressing climate mitigation and adaptation* (http:/pmindia.nic.in/Climate%20Change_16.03.09.pdf); which is in line with the international commitments and relates to sustainable development, co- -benefits to society at large, focus on adaptation, mitigation, and scientific research(NAPCC, 2008). The plan to be implemented thorough eight missions representing multi-pronged, long-term and integrated strategies for achieving key goals:

1. National Solar Mission, 2. National Mission for Enhanced Energy Efficiency, 3. National Mission on Sustainable Habitat, 4. National Water Mission, 5. National Mission for Sustaining the Himalayan Ecosystem, 6. National Mission for a Green India, 7. **National Mission for Sustainable Agriculture and 8.** National Mission on Strategic Knowledge for Climate Change

Now relevant ministries are preparing and submitting their respective plans to the Prime Ministers Climate Change Council.

The Minister of Environment and Forest on October 14, 2009 announced the launch of the **Indian Network for Climate Change Assessment (INCCA)**, which has been conceptualized as a network based Scientific Programme designed to:

- Assess the drivers and implications of climate change through scientific research
- Prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation)
- Develop decision support systems
- Build capacity towards management of climate change related risks and opportunities

Initiatives by ICAR

ICAR has launched in February 2011, a network project called 'National Initiative on Climate Resilient Agriculture (NICRA)' with a view to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. The research on adaptation and mitigation covers crops, livestock, fisheries and natural resource management. The objectives of the scheme are as follows:

- To enhance the resilience of Indian agriculture covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies.
- To demonstrate site specific technology packages on farmers' fields for adapting to current climate risks.
- To enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and its application

The project consists of four components: Strategic Research, Technology Demonstration, Capacity Building and Sponsored/ Competitive Grants. The output of the project would be: Selection of crop genotypes and livestock breeds with greater tolerance to climatic stress, Existing best practices for climate resilience, Capacity Building including Infrastructure and trained man power. The scheme will be implemented by the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad under the supervision of the Natural Resources Management (NRM) Division of ICAR. Currently, the outlay of the project is Rs. 350 crores for the 11th Five Year Plan, out of which Rs. 200 crores is allocated for 2010-11 and Rs. 150 crores for 2011-12 (Planning Commission, 2011).

Disaster Management Policy in India

The emergence of a permanent and institutionalised setup began in the 1990s. A disaster management cell was established under the Ministry of Agriculture, following the declaration of the decade of 1990 as the 'International Decade for Natural Disaster Reduction' (IDNDR) by the UN General Assembly. Further, India witnessed series of disasters such as Latur Earthquake (1993), Malpa Landslide (1994), Orissa Super Cyclone (1999) and Bhuj Earthquake (2002) which reoriented the policy action and led to the shift from financing relief to a holistic approach for addressing disaster management. Consequently, the disaster management division was shifted under the Ministry of Home Affairs in 2003 and a hierarchical structure for disaster management evolved in India. Shifting from relief and response, disaster management in India started to address the issues of early warning systems and forecasting and monitoring setup for various weather related hazards. Consequently, a structure for flow of information, in the form of warnings, alerts and updates about the oncoming hazard, also emerged within this framework.

In 2002, a High Powered Committee Report on Disaster Management recommended establishment of a separate institutional structure for addressing disasters and enactment of a suitable law institutionalizing disaster management. Further, the 10th Five Year Plan of India (2002-2007) identified the need for disaster management interventions beyond merely financing relief. The plan stressed on the need for integrating disaster management with development process. These developments necessitated institutionalization of disaster management framework in India and consequently, the Disaster Management Bill was adopted by in the Parliament in 2004. A National Disaster Management Authority was set up in 2005. Disaster management came to be identified as "*continuous and integrated process of planning, organising, coordinating and implementing measures required for preventing disasters, mitigating the risk, capacity building, increasing the preparedness levels, response actions, disaster assessments, evacuation, rescue and relief and rehabilitation*". The Disaster Management set up facilitated mainstreaming disaster management in many ways; firstly, by mandating the involvement of various development-related sectors in the disaster management framework, and secondly, by directing them to prepare and execute disaster management plans in their respective sectors of functioning, thirdly, by making provisions for separate resource allocation for managing disasters, in the form of Disaster Mitigation Funds, and fourthly by facilitating training of persons for disaster management through the National Institute for Disaster Management.

In this structure, ***National Disaster Management Authority*** is the nodal authority for all disaster management actions in the country. It is the policy making body that frames broad guidelines for other ministries at the centre and authorities at the state level. The state authorities further lay down the guidelines for ministries and departments at the state level and the districts falling in their respective jurisdictions. Similarly, district authorities direct the civil administration, departments and local authorities such as the municipalities, police department and civil administration. The Executive Committees at each level are responsible for execution of the tasks envisaged by the Authorities.

Recent Initiatives

Manual on Drought Management was prepared in November 2009 by National Institute of Disaster management, New Delhi. This manual is a

- Handbook for all the decision-makers / disaster managers, from the *National to village-level.*
- To reflect the new framework for drought management

Forecasting, monitoring, response, and mitigation etc.) as a continuum of activities.

- Information on Integration of new technologies

Early warning, mitigation etc.

- To introduce and institutionalize a new drought management system, which is based on the *technological advances and new innovations* in crop and water management.
- Information on mitigation measures both short-term (relief etc.)and long-term (mitigation) strategies for an effective response (linkages with the existing development programs).
- New approach to drought management

Institutionalization of Climate Change and Disaster Management Research

The Indian subcontinent and the surrounding seas, with more than 1.3 billion people and unique natural resources, have a significant impact on the regional and global environment but lack a comprehensive environmental observational network. Within the government of India, the Department of Science and Technology (DST) has proposed filling this gap by establishing INDOFLUX, a coordinated multidisciplinary monitoring network that integrates terrestrial, coastal, and oceanic environment (Sundareshwar et al., 2007).

Capacity building, networking and resource management form the core of institutionalizing Indian Climate risk management initiatives. This involves a shared vision for policy relevant climate risk research, scientific knowledge and understanding enhancement, institutional capacity strengthening (enhanced instrumentation, modeling tools, data synthesis and data management), technical skill enhancement of climate change and disaster management researchers, inter-agency collaboration and networking improvement, and medium to long term resource commitment

Sporadic research efforts are continuing in India since the last decade; independent climate change research initiatives by government ministries like MoEF, MoWR, MoHFW, MoA, MoST, etc; and the NATCOM project, ICAR projects ; apart from a few initiative at individual experts and institute level. These are the potential partners and future centers for climate change research.

Capacity Development or Capacity Building

Within a decade, the immediate tasks are to enhance capacity for scientific assessment, awareness among the stakeholders and institutionalization of learning process.

While scientific knowledge and research have enriched our understanding of extreme weather events / hydro meteorological disasters and climate change, at the local level the communities have inherited local knowledge and wisdom developed through shared experiences of centuries. Therefore, a reservoir of local capacity needs to be acknowledged, understood, analyzed, utilized and integrated with modern scientific knowledge.

Way Forward

Disaster risk management and adaptation approaches can enhance social, economic, and environmental sustainability. The most effective adaptation and disaster risk reduction actions are those that offer development benefits in the relatively near term, as well as reductions in vulnerability over the longer term. Progress towards resilient and sustainable development in the context of changing climate extremes can benefit from questioning assumptions and paradigms and stimulating innovation to encourage new patterns of response. In India Disaster Risk Reduction (DM act 2005) and Climate Change (NAPCC-2008) related Institutional, Policy and Programme Framework already exists; It is now time for convergence for effective development planning and programming: managing risks and uncertainties for all shocks and stresses, particularly in the face of mounting evidence that disasters are hampering development and enhancing poverty.

NATCOM TO IPCC – EXTREME WEATHER EVENTS

R K Mall

The fourth assessment report of IPCC and first assessment report of Indian Network of Climate Change Assessment (INCCA) in 2010 has confirmed that in future, Climate change is expected to increase the frequency and intensity of current extreme weather/ hydro-meteorological events, greater monsoon variability and also the emergence of new disaster i.e. sea level rise and new vulnerabilities with differential spatial and socio-economic impacts on communities. This unprecedented increase is expected to have severe impact on the hydrological cycle, water resources (drought, flood, drinking water, forest & ecosystems, sea level / coastal area /losses of coastal wetlands and mangroves), food security, health and other related areas.

Even if the most stringent mitigation measures were put in place today, these impacts would continue beyond this century. There are both urgent needs for immediate and adequate adaptation actions before the impacts become unmanageable, as well as needs for preparation for the long-term impacts. A prerequisite for any adaptation effort must be to build on existing knowledge and information and essential adaptive capacities rapidly.

The South Asia region is highly sensitive to hydro meteorological events such as flood, drought, cyclone, extreme temperature, sea level rise etc.

There exist uncertainties in dealing with vulnerabilities associated with climate change and variability because of: a) lack of synthesis of experience in climate trends and extreme events, and b) Insufficient baseline information about current impact, adaptation response/capacity and vulnerabilities.

Extreme Weather Events

India is vulnerable to several extreme weather events (Box – 1).

BOX 1. Examples of extreme weather events

Primary Climatic Events

- Cold wave, Fog, Snow storms and Avalanches
- Hailstorm, Thunderstorm and Dust storms
- Extreme Temperature
- Tropical Cyclone and Tidal Wave
- Floods, Heavy rain
- Droughts (Hydrological, Meteorological and Agricultural etc.)

Secondary Events (May be Climate-Driven)

- Incidence of epidemics or diseases
- Urban and Rural Water shortage
- Crop Plantation Failure or harvest failure
- Malnutrition or under nutrition and hunger
- Landslides, saline water intrusion and mudflows

The IPCC in its Fourth Assessment Report outlined the likelihood of the occurrence of such extremes in the 21st century. Simple extremes, such as higher maximum temperatures and more intense precipitation, are projected to have 90-99% chance of occurring. These amplified simple extremes could lead to extreme weather events like drought and flooding. The analysis of rainfall records of the monsoon trends indicated a 30-year cyclicity of the Indian monsoons (Figure 1). It was observed that drought as well as flood years occurred in turns rather than scattered randomly through the years. Of the 14 major drought years in the 85-year record, 8 occurred in the first 30 year period (1891-1920), one in the second 30 year period (1921-1950) and five in later 25-year period from (1951 –1981).

International Negotiations

The WMO (World Meteorological Organization) and the UNEP (United Nations Environmental Programme) established the IPCC (Intergovernmental Panel on Climate Change) in 1988 to assess the seriousness of the problem of climate change. The First Assessment Report of IPCC, completed in 1990, highlighted the global threat of climate change. In December 1990, the UN General Assembly decided to launch negotiations on what was to become the UNFCCC (United Nations Framework Convention on Climate Change). The Convention was adopted in May 1992, and came into force in March 1994 after being ratified by 50 countries.

By 1995, countries realized that emission reduction provisions in the Convention were inadequate. They launched negotiations to strengthen the global response to climate change, and, two years later, adopted the Kyoto Protocol. The Kyoto Protocol legally binds developed countries to emission reduction targets. India acceded to the Kyoto Protocol on 26 August 2002.

Unfccc's Objective and Provisions

The ultimate objective of this Convention is to achieve, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (http://www.envfor.nic.in/cc).

National Communication (NATCOM)

The NATCOM process comprises comprehensive scientific and technical exercises for estimating GHG emissions from different sectors, reduce uncertainties in current estimations, develop sector- and technology-specific emission coefficients pertinent to India, and assess the adverse impacts of climate change and strategies for adapting to these impacts. NATCOM will also provide the general description of steps taken or envisaged to implement the convention. NATCOM will lead to developing a reliable database and capacity that will help to fulfill commitments under the Convention. The process is also expected to initiate efforts to identify areas of Targeted Research on climate change according to sustainable development plans of the country.

India's Initial Natcom to the Unfccc on Climate Change

India's Initial National Communication in 2004 (NATCOM, 2004) to UNFCCC has consolidated some of the observed and projected changes in climate weather events in India including possible impacts.

Observed Changes: At national level, increasing trend in surface temperature (0.4 °C) during 20th century, no significant trend in rainfall and/or decreasing/increasing trends in rainfall and sharp decrease in rainy days in some parts of the country were observed. Trends of multi-decadal periods of more frequent droughts, followed by less severe droughts were observed. There has been an overall increasing trend in severe storms along the coast at the rate of 0.011 events per year. While the states of West Bengal and Gujarat have reported increasing trends, a decline has been observed in Orissa. A study showed (i) a rising trend in the frequency of heavy rain events, and (ii) a significant decrease in the frequency of moderate events over central India from 1951 to 2000. Using the records of coastal tide gauges in the north Indian Ocean for more than 40 years, It is estimated that sea level rise was between 1.06-1.75 mm per year. The available monitoring data on Himalayan glaciers indicates that while recession of some glaciers has occurred in some Himalayan regions in recent years, the trend is not consistent across the entire mountain chain. It is accordingly, too early to establish long-term trends.

Projected Climate: Some modeling studies have projected Annual mean surface temperature rise by the end of century, ranging from 3 to 5 °C under A2 scenario and 2.5 to 4 °C under B2 scenario of IPCC, with warming more pronounced in the northern parts of India. Simulations by IITM, Pune, have indicated that summer monsoon intensity may increase beginning from 2040 and it will increase by 2100 by 10% (under A2 scenario of IPCC) and changes in frequency and/ or magnitude of extreme temperature and precipitation events were reported.

Impacts: Studies by Indian Agricultural Research Institute (IARI) and others indicate greater expected loss in the Rabi crop and every 1 °C rise in temperature projected reduction in wheat production by 4-5 Million Tonnes. Small changes in temperature and rainfall have significant effects on the quality of fruits, vegetables, tea, coffee, aromatic and medicinal plants, and basmati rice. Pathogens and insect populations are strongly dependent upon temperature and humidity, and changes in these parameters may change their population dynamics. Other impacts on agricultural and related sectors include lower yields from dairy cattle and decline in fish breeding, migration, and harvests.

Changes in climate may alter the distribution of important vector species (for example, malarial mosquitoes) and may increase the spread of such diseases to new areas. If there is an increase of 3.8 °C in temperature and a 7% increase in relative humidity the transmission windows i.e., months during which mosquitoes are active, will be open for all 12 months in 9 states in India.

Based on future climate projections of Regional Climate Model of the Hadley Centre (HadRM3) using A2 and B2 scenarios and the BIOME4 vegetation response model, Ravindranath et. al. showed that 77% and 68% of the forest areas in the country are likely to experience shift in forest types, respectively under the two scenarios, by the end of the century, with consequent changes in forests produce, and livelihoods.

Heavily populated regions such as coastal areas are exposed to climatic events,such as cyclones, floods, and drought, and large declines in sown areas in arid and semi-arid zones occur during climate extremes. Large areas in Rajasthan, Andhra Pradesh, Gujarat, and Maharashtra and comparatively small areas in Karnataka, Orissa, Madhya Pradesh, Tamil Nadu, Bihar, West Bengal, and Uttar Pradesh are frequented by drought. About 40 million hectares of land is flood-prone, including most of the river basins in the north and the north-eastern belt, affecting about 30 million people on an average each year. Such vulnerable regions may be particularly impacted by climate change.

A mean Sea Level Rise (SLR) of 15-38 cm is projected along India's coast by the mid 21st century and of 46-59 cm by 2100. India's NATCOM I assessed the vulnerability of coastal districts based on physical exposure to SLR, social exposure based on population affected, and economic impacts. In addition, a projected increase in the intensity of tropical cyclones poses a threat to the heavily populated coastal zones in the country (NATCOM, 2004).

India Second NATCOM TO UNFCCC

Keeping in view the limitations of the global climate models during the Initial National Communication (INC), high-resolution simulations for India were carried out using the second generation Hadley Centre Regional Climate Model (HadRM2). It was envisaged, during the Second National Communication (SNC), to add new scenarios from the bouquet of emission scenarios available from the IPCC Special Report on Emission Scenarios. Subsequently, the A1B Scenario was chosen as the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory. India now has access to PRECIS - the latest generation of regional models from the Hadley centre. The PRECIS is an atmospheric and land surface model having 50km x 50km horizontal resolution over the South Asian domain and is run by the Indian Institute of Tropical Meteorology (IITM), Pune (NATCOM, 2012).

Observed Climate: Temper*ature*-India's annual mean temperature showed significant warming trend of 0.56°C per 100 years during the period 1901–2007. Accelerated warming has been observed in the recent period (1971–2007), mainly due to intense warming in the recent decade (1998–2007). This warming is mainly contributed by the winter and post-monsoon seasons, which have increased by 0.70 °C and 0.52 °C, respectively in the last 100 years. The pre-monsoon and monsoon temperature also indicate a warming trend. Mean temperature increased by about 0.2 °C per decade (that is, 10 years) for the period 1971–2007, with a much steeper increase in minimum temperature than maximum temperature.

The all India maximum temperature shows an increase in temperature by 1.02 °C per 100 years (NATCOM, 2012). The trend in daily maximum temperature in India is observed to be increasing from January, attaining a peak in the month of May. Beyond May, the temperature starts decreasing up to December. The all-India mean annual minimum temperature has significantly increased by 0.12 °C per 100 years during the period 1901–2007. The spatial changes in minimum temperature are observed to be decreasing in most parts of Western Ghats and increasing in most parts of the Himalayan region and certain parts of the north-eastern region. Unlike maximum temperature, the trend in the minimum temperature during the latest decade is maintained at the rate observed for the most recent three-and-a-half decades. On the seasonal scale, all the seasons show significant warming trend, except post-monsoon, wherein the trend is positive but not significant (NATCOM, 2012).

Rainfall: The all-India monsoon rainfall series (based on 1871– 2009 data) indicates that the mean rainfall is 848 mm, with a standard deviation of 83 mm. The Indian monsoon shows well-defined epochal variability with each epoch of approximately three decades. Though it does not show any significant trend, when averaged over this period, a slight negative trend of 0.4 mm/year is observed. The rainfall is deficient or in excess if all-India monsoon rainfall for that year is less than or greater than mean standard deviation. With this definition, the deficient years are marked red, excess years are marked blue, and the normal years are marked green (Fig. 1). It is seen that in this 139-year period, there are total 23 deficient years and 20 excess years; and the remaining are normal monsoon years. It is observed that the excess and deficit years are more frequent in above and below normal epochs, respectively.

Extreme Precipitation Trends: Trend analysis of one-day extreme rainfall series based on the period 1951–2007 indicates that extreme rainfall is increasing at many places in India. Considering the climatological data, the magnitude of the extreme precipitation event at the station is defined as "its highest 24-hour rainfall reported in a particular month during the entire period of the data availability". Accordingly, it may increase for certain stations, if their previous EPRE are exceeded in the course of time. This definition is adopted in order to examine whether there was any change in the number and intensity of the Extreme point rainfall events (EPRE) in the recent decades, and if so, which parts of the region are affected the most.

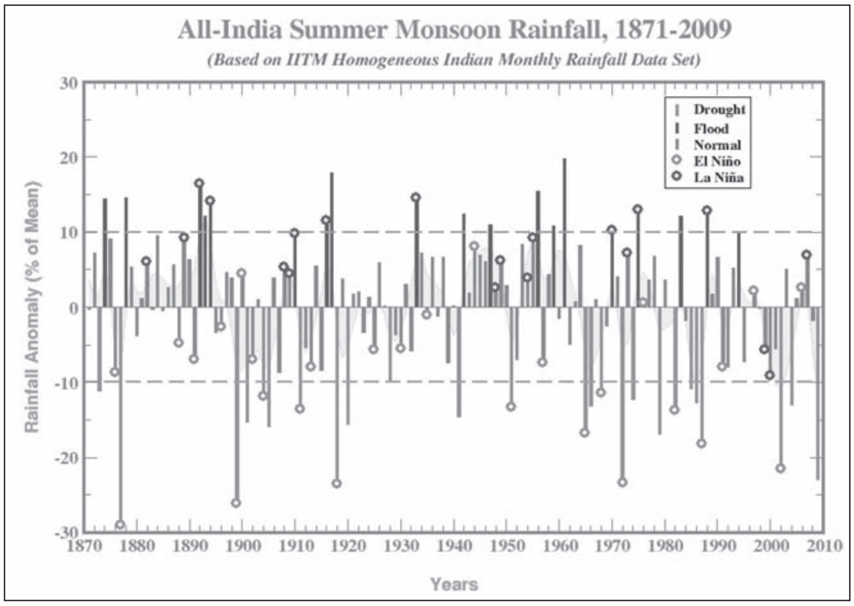


Fig. 1 : Inter-annual variability of Indian monsoon rainfall 1871–2009

The analysis shows that majority of the stations have reported their highest 24-hour rainfall during 1961–80, with an alarming rise in their intensity in the subsequent period from 1980 onwards till 2009. Of the 165 stations analysed, the majority (77.6%) have registered their EPRE during 1961–80. Thereafter, several stations have reported the rainfall events surpassing the intensity of their previous highest rainfall.

Projected Climate: *Temperature and Rainfall:* PRECIS simulation projected that there may not be significant decrease in the monsoon rainfall in the future except in some parts of the southern peninsula. 2020s, 2050s and 2080s simulations project 16%, 15% and 9% rise respectively in the monsoon rainfall towards the end of the 21st century. PRECIS simulations for 2020s, 2050s and 2080s indicate an all-round warming over the Indian subcontinent. The annual mean surface air temperature rise by the end of the 21st century ranges from 3.5 °C to 4.3 °C (NATCOM, 2012).

Changes in extreme precipitation event: The rainy days in future appear to be less in number than the present, especially over north and central India and east peninsula, in two of the three simulations, namely, 2020s and 2050s, whereas 2050s and 2080s simulations indicate less rainy days in the future in north-west India. On the other hand, all the three simulations indicate increase in the rainfall intensity in the 21st century over most of the regions. The rise in intensity may be more in central India. Marginal decrease in the intensity may be seen in the east peninsular region.

Changes in extreme temperature events: The analysis of the three model simulations indicates that both the daily extremes in surface air temperature may intensify in the future. The spatial pattern of the change in the highest maximum temperature suggests warming of 1–4 °C towards 2050s, which may exceed even 4.5 °C in most of the places towards the end of the present century. Warming in night temperature is even more in all the three time slices as compared to the daytime warming. The rise of more than 4.5 °C in nighttime temperature may be seen throughout India, except in some small pockets in peninsular India.

Projected changes in cyclonic storms: Regional model simulations indicate decrease in the frequency of the cyclonic disturbances towards the end of the present century. The number of cyclonic disturbances over the Arabian Sea may be less in the future as compared to the present simulations. However, the analysis indicates that it might be more intense in the future. There is, however, no change in the track of cyclonic disturbances in the future scenarios as compared to the baseline simulations(NATCOM, 2012).

Impact Assessment

Water resources: Impacts of climate change and climate variability on the water resources are likely to affect irrigated agriculture, installed power capacity, water supply in the dry season and higher flows during the wet season, thereby causing severe droughts and flood problems in urban and rural areas. The majority of river systems have shown increase in precipitation at the basin level. Only Brahmaputra, Cauvery and Pennar showed marginal decrease in precipitation during 2021-2050. The situation during 2071-2098 improves, wherein all the river systems exhibit an increase in precipitation. The change in evapotranspiration under the 2021-2050 scenario exhibits an appreciable increase (close to 10%) for the Brahmaputra, Indus and Luni river basins. All other systems show marginal increase or decrease. Only two river basins - Cauvery and Krishna - show some decrease in ET under the 2071-2098. For a majority of the river systems, the ET has increased by more than 40%. The major reasons for such an increase in ET are: (i) increase in the temperature and (ii) increase in precipitation, which enhances the opportunity of ET (NATCOM, 2012).

Indian agriculture : Global warming may also threaten food security of India if there is a negative effect on agriculture. The rising temperatures and carbon dioxide and uncertainties in rainfall associated with global warming may have serious direct and indirect consequences on crop production. It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on different crops, especially on cereals contributing to the food security.

A rise in atmospheric carbon dioxide to 550 ppm under controlled environment conditions - [Free Air CO_2 Enrichment - FACE, Open Top Chambers (OTC)] -, enhanced the yields of wheat, chickpea, green gram, pigeon pea, soybean, tomato and potato by 14% to 27%. In plantation crops like coconut, arecanut and cocoa, increased CO_2 led to higher biomass.

In the case of rice - hybrid and its parental lines – elevated CO_2 positively affected few grain quality traits such as head recovery, test weight, proportion of high density grains and germination characteristics but adversely affected traits like aroma, gelatinisation temperature (measurement of cooking quality), protein and micronutrient contents. Sunflower hybrids grown under elevated CO_2 conditions inside open top chambers, showed a significant increase in biomass (61-68%) and grain yield (36-70%) but the quality of the produce was adversely affected in terms of protein and micro-nutrient contents. The magnitude of the impact of climate change on wheat production in India, assessed through simulation studies, indicated that an increase in 1 °C in mean temperature, associated with CO_2 increase, would not cause any significant loss, if simple adaptation strategies such as change in planting date and varieties are used. The benefits of such simple adaptation strategies, however, gradually decrease as temperature increases to 5 °C. In the absence of adaptation and CO_2 fertilization benefits, a 1 °C increase in temperature alone could lead to a decrease of 6 million tons of wheat production. This loss is likely to increase to 27.5 million tons in case of a 5 °C increase in mean temperature.

Average simulated rainfed yields under current (baseline) scenario were 2144, 2473 and 1948 kg/ha for soybean, groundnut and chickpea respectively. Soybean was observed to have a 10%, and 8 % increase in yield in A1B (2021-2050) and A1B (2071-2100) respectively. In the case of groundnut, except for A1B (2071-2100), which showed a decline of 5% in yield, the other scenarios showed 4-7% increase in rain-fed yields as compared to the current yield. Chickpea showed an increase in yield to the tune of 23% and 52% for A1B (2021-2050) and A1B (2071-2100) scenarios, respectively. Across all locations, the rain-fed yields of soybean and groundnut showed significant positive association with crop season rainfall while association with temperature was non-significant. This indicates that under rain-fed conditions, the availability of water will remain a major limiting factor for the yields realized by the farmers. However, for chickpea, which is a post-rainy winter season crop, the simulated rain-fed yield showed a significant positive association with crop season temperature, while with crop season rainfall (which is received in very meager amount) no significant association was observed. The greater positive impact of future climate on chickpea was associated with both increase in temperature and CO_2 levels as the optimum temperatures for chickpea growth and yield are between 22-28°C which is much above the prevailing crop season mean air temperatures across major chickpea growing regions in India.

The model results indicate that climate change and the consequent increased temperature and altered pattern of precipitation might decrease the cotton yield of northern India to a greater extent than the southern region. Without adaptation, the total potato production in India, under the impact of climate change, might decline by 2.61% and 15.32% in the years 2020 and 2050,respectively. The impacts on productivity and production varied among different agro-ecological zones.

The impact of elevated temperature and CO_2 on coconut yields was simulated for different agro-climatic zones. Overall results indicate that coconut yields are likely to be positively influenced by increase in CO_2 and increase in temperature by 2-3 °C. Cocoa, another plantation crop, is grown as the intercrop either under areca nut or coconut. Being a shade-crop, cocoa is influenced only indirectly by the increase in atmospheric temperature.

The impact of climate change on grapes would be determined by the impact on rainfall during the months of February to April, when the berries mature. Rainfall during the month of October, could increase the incidence of downey mildew disease in grapes. The increase in minimum temperature during fruit maturation plays an important role in the anthocyanin, total phenol, total flavanoids and total acidity content of the berries, which ultimately affect the quality (NATCOM, 2012).

Another fruit, the productivity of which is heavily linked with climatic variations, is apple. The rise in temperature will reduce the chilling hours accumulation, which could be a limiting factor in more tropical areas, especially for cultivars with medium to high chilling requirement. The temperature change will benefit apple cultivation in high altitudinal regions (>2300 meter above sea level). Kinnaur and Lahaul-Spiti districts in the northern state of Himachal Pradesh are likely to be especially benefited, due to an enhanced growing period and reduced extreme cold weather conditions.

Increased heat stress associated with global climate change may cause distress to dairy animals and possibly impact milk production. It is estimated that India loses 1.8 million tonnes of milk production at present due to climatic stresses in different parts of the country. Global warming will further negatively impact milk production by 1.6 million tonnes by 2020 and more than 15 million tonnes by 2050, as per studies conducted by scientific institutions. High producing crossbred cows and buffaloes will be more adversely affected than indigenous cattle.

Droughts and floods: *Droughts:* Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness affecting water-sensitive economies. In this analysis, Soil Moisture Index is developed to monitor drought severity using SWAT output to incorporate the spatial variability. The focus is on agricultural drought, wherein severity implies cumulative water deficiency. In the current context Scale 1 (Index between 0 and –1) represents the drought developing stage and Scale 2 (Index between –1 and –4) represents mild to moderate and extreme drought conditions. Soil Moisture Deficit Index (SMDI) was calculated for 30 years of simulated soil moisture data from baseline (1961–90), MC (2021–50), and EC (2071–98) climate change scenarios. Weeks when the soil moisture deficit may start drought development (drought index value between 0 and –1) as well as the areas that may fall under moderate to extreme drought conditions (drought index value between –1 and –4) have been assessed. It may be seen that there is an increase in the moderate drought development (Scale 1) for Krishna, Narmada, Pennar, Cauvery, and Brahmini basins, which have either predicted decrease in precipitation or have enhanced level of evapo-transpiration for the MC scenario. It is also evident from the depiction that the moderate to extreme drought severity (Scale 2) has been pronounced for the Baitarni, Sabarmati, Mahi, and Ganga river systems, where the increase is ranging between 5% and 20% for many areas despite the overall increase in precipitation. The situation of moderate drought (Scale 1) is expected to improve under the EC scenario for almost all the river systems except Tapti river system, which shows about 5% increase in drought weeks. However, the situation for moderate to extreme droughts (Scale 2) does not appreciably improve much under the EC scenario despite the increase in precipitation. There is some improvement in Ganga, Godavari, and Cauvery basins (NATCOM, 2012).

The vulnerability assessment with respect to the possible future floods has been carried out using the daily outflow discharge taken for each sub-basin from the SWAT output. These discharges have been analysed with respect to the maximum annual peaks. Maximum daily peak discharge has been identified for each year and for each sub-basin. Analysis has been performed to earmark the basins where flooding conditions may deteriorate under the future scenario. The analysis has been performed to ascertain the change in magnitude of flood peaks above 99th percentile flow under baseline (1961–90).

Indian Network for Climate Change Assessment (INCCA)

There has been a significant leap in the understanding of the "science" of climate change and its impacts on socio-economic systems and sectors from the Third Assessment Report (TAR) of the IPCC. With a view to enhance knowledge about the impacts of climate change, the Ministry of Environment and Forests launched Indian Network for Climate Change Assessment (INCCA) on October 14, 2009. The INCCA has been conceptualized as a Network-based Scientific Programme designed to (a) assess the drivers and implications of climate change through scientific research; (b) prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation); (c) develop decision support systems and (d) build capacity towards management of climate change related risks and opportunities. The INCCA is visualized as a mechanism to create new institutions and engage existing knowledge institutions already working with the Ministry of Environment and Forests (MoEF) as well as other agencies (Planning Commission, 2011).

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Annexure I

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