BANGLADESH METEOROLOGICAL DEPARTMENT
LOCAL TRAINING

MODULE 3: AGROMETEOROLOGY

Project:

Strengthening Meteorological Information Services and Early Warning Systems (Component-A)

PREPARED BY:
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Purpose

The purpose of this module is to acquaint the participants with the basic concepts of meteorology so that the participants of Bangladesh Meteorological Department, can is to support food and agricultural production and activities. to help develop sustainable and economically viable agricultural systems, improve production and quality, reduce losses and risks, decrease costs, increase efficiency in the use of water, labor and energy, conserve natural resources and decrease pollution by agricultural chemicals or other agents that contribute to the degradation of the environment. Although sometimes combined, climate information is used mainly for planning purposes, while recent weather data and weather forecasts are used mostly in current agricultural operations.

Delivery and Description

Methodology

This module is designed in such a way that the participants get explicit idea regarding the meteorology terms and concepts. Besides, we also wish that the participants will be able to incorporate the knowledge in their everyday life to enhance their official works. To achieve this objective, we have made the sessions based on the most important topics of Agro Meteorology that are used in everyday life. We have included sufficient practical exercises to ensure that the participants not only learn how Meteorology affect in agriculture and how to use meteorological changes for better agricultural production, but they can also implement them.

Key learning outcomes

After attending the training, the participants will have explicit idea on the concepts of the Agriculture Meteorology, and they will be able to apply this knowledge in their respective organization.

Disclaimer

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SESSION 1: INTRODUCTION TO AGRO-METEOROLOGY

1.1 Agro-Meteorology

Agricultural production, especially crop production is highly dependent on the weather conditions.

Agrometeorology or Agricultural meteorology studies meteorological and hydrological factors in relation to agriculture. Agrometeorology studies the behavior of the weather elements that have direct relevance to agriculture and their effect on crop production. Weather and climate are the factors determining the success or failure of agriculture.

Weather: Physical state of the atmosphere at a given place and given time. e.g. Cloudy day
Climate: Long term regime of atmospheric variables of a given place or area e.g. Cold season.

1.2 Importance of Agrometeorology

Some importance of Agrometeorology:

- Helps in planning cropping patterns/systems.
- Selecting of sowing dates for optimum crop yield.
- For cost effective ploughing, harrowing, weeding etc.
- Reducing losses of applied chemicals and fertilizers; helps to avoid fertilizer and chemical sprays when rain is forecast

- Judicious irrigation to crops.
- Efficient harvesting of all crops.
- Reducing or eliminating outbreak of pests and diseases.
- Efficient management of soils, which are formed out of weather action.
- Managing weather abnormalities like cyclones, heavy rainfall, floods, drought etc.; achieved by weather forecasting.
- Mitigation measures such as shelterbelts against cold and heat waves, effective environmental protection. etc.
- Avoiding or minimizing losses due to forest fires.

Agricultural production is still dependent on weather and climate despite the impressive advances in agricultural technology over the last few decades. Knowledge of available environmental resources and expected conditions from below the soil surface through the soil-air interface to the lower atmosphere provides guidance for strategic decisions in long-range planning of agricultural systems. Typical examples are design of irrigation schemes, choice of land-use and farming patterns, and selection of crops and animals, varieties and breeds, and farm machinery. Detailed real-time estimates of meteorological elements and derived indices are important for tactical decisions in short- term planning of agricultural operations. Tactical decisions include average cost-type decisions regarding timing of cultural practices, such as planting, cultivation and harvesting, and "high cost"-type decisions, such as the application of expensive chemicals or the operation of costly crop-protection measures. Regardless of the type of decision, a proper understanding of the effects of weather and climate on soils, plants and agricultural production is necessary to make efficient use of meteorological and climatological information for agriculture.

The practical application of this knowledge is linked to the availability and accuracy of weather forecasts or expected weather patterns, depending on the time scale. 1he forecast requirements range from accurate details of short-term weather (one to three days) at certain critical times to seasonal predictions of weather patterns. Even an indication of the possible climatic variability against the background of historical climate records as obtained from data and other evidence is useful, especially in the case or probability statistics, to ensure that development plans are not rendered meaningless by a significant change in weather behavior.

Although reliable long-term weather forecasts are not yet available on a routine basis, Significant services to agriculture are provided by means of agrometeorological forecasts such as the dates of phenological events, the quantity and quality of crop yields, and the occurrence of animal and crop epidemics. These forecasts make use of established relationships between cumulative weather effects at an early stage of development and the final event expected sometime after the date of issue of a forecast. This approach or crop prediction without weather forecasting is particularly promising for the assessment of crop conditions in order that potential production anomalies may be recognized and quantitatively evaluated as early as possible. Temporary surpluses of certain agricultural commodities sometimes occur in some regions, but these reserves dwindle quickly in the event of successive years with crop failures. Even without these failures such surpluses have disappeared within a short time because of increasing populations and their demands, especially in the developing countries. Long-term planning of global food production must, therefore, take into account the effects of year-to-year fluctuations in weather patterns, as well as of potential climatic changes, on crop yields.

No matter how favorable or unfavorable weather events are distributed over the globe, there are, in the long run, insufficient food supplies to feed the world population adequately at its present rate of increase unless-

a) agricultural technology is greatly improved,
b) natural resources are more efficiently used, and
c) national and international agencies responsible for planning and managing food supplies are provided with up-to-date information on crop conditions and potential crop failures as a basis for their decision-making.

The major role of present-day agricultural meteorology on a global scale is therefore to ensure that adequate agrometeorological data, research tools and knowledge is available to researchers, planners and decision-makers to cope with a variety of agricultural production problems.

Attention must be paid to the special needs of developing countries in their efforts to assess their climatic resources and provide services to agriculture. Forecasting and advisory services are available to farmers in many developed countries and have reached a high-performance level. Similar services are only in the beginning stage, and are often non- existent, in many developing countries. This lack can be overcome through stepped-up training of personnel at all levels, and more active involvement of agro- meteorologists from developing countries in the various activities of the WMO Commission for Agricultural Meteorology.

SESSION 2: SCOPE OF AGRICULTURAL METEOROLOGY

Agricultural meteorology is concerned with meteorological, hydrological and pedological factors affecting agricultural production and also with agriculture's interaction with the environment. Its objectives are to elucidate such effects, and then to assist farmers to apply this supportive knowledge and information in agrometeorological practices and services. It spatially extends from the soil layer of deepest plant and tree roots (pedosphere), through the air layer near the ground in which crops grow and animals live, to the higher levels of the atmosphere in which processes such as the transport and dispersal of seeds and pollen take place. Its fields of interest go from agricultural (including horticultural) production, forestry, animal husbandry, fisheries and other forms of outdoor and indoor production, agricultural planning, processing, transport and storage to agrometeorological components of food security, poverty reduction and sustainable development aspects of the livelihood of farmers/producers as well as of the use of their products.

In addition to large scale climate and its variations, operational agricultural meteorology concerns itself with small scale climate modifications as brought about for example by wind breaks, irrigation, mulching, shading and frost and hail protection. Other important subjects are agroclimatic characterization, pests and diseases and their safe control, covered agriculture, quality of agricultural products, animal comfort aspects, plant production for other than food purposes, including biomass as a renewable energy resource, and ecological considerations.

Much attention is paid to the impacts of climate change and climate variability, including monitoring, early warning and estimation of changes of the risks of extreme events such as drought, desertification and flooding. Specialized agriculture can be inimical to biodiversity while intensive agriculture affects the environment through the generation of air pollutants, greenhouse gases (CO2, methane and nitrous oxide), ammonia and tropospheric ozone. Other modes of production cause soil erosion by wind and water.

Thus, agricultural meteorology has a major role to play in understanding of emissions and pollutions from various unsustainable production systems. Water management to ensure adequate supplies while maintaining the quality of surface and groundwater is a key topic. Applications to aquaculture and fisheries (food aspects) range from site climatologist, hydrodynamics of rivers/reservoirs, estimation of contamination from agricultural run-off and of other ecosystem stresses, to using meteorological factors to predict the occurrence of toxic algal blooms.

Support systems to agrometeorological practices and services comprise data (so quantification), research, training/education/extension and policy environments. Especially in industrialized countries mathematical models are increasingly used in operational agricultural meteorology, in conjunction with Geographic Information Systems (GISs) to provide inputs to Decision Support Systems (DSSs). These models have utilized meteorological observations but now there are also the outputs of operational numerical weather prediction and of climate prediction.

These forecasts may be exploited to increase the utility of models to decision makers. Remote sensing provides access to additional biophysical parameters, e.g. vegetation indices and surface temperatures.

Incorporation of such data into models is being undertaken. The enormous potential of agrometeorological information and services makes the training of farmers and environmental managers in the use of agrometeorological practices and services a matter of great importance.

SESSION 3: COMPONENTS OF AGRICULTURAL METEOROLOGY

There are various components of agricultural meteorology those are:

a) Agrometeorological monitoring - Techniques, data collection and networks, experiments.
b) Plant environment and crop production - Effect of meteorological elements on growth and development of plants, quantity and quality of yields, climate requirements of crops and operational crop condition assessments.
c) Plant injury and crop losses - Pests and diseases, pollution, effects of weather hazards on crops, cold hardiness and frost and freezing damage.
d) Livestock health and production - Environmental problems of livestock housing and health and production.
e) Animal diseases and parasites - Direct and indirect effects of weather on the various types of animal diseases, injury and death, economic losses and forecasting incidence and intensity of animal disease.
f) Climatic resource - Climatological surveys, ecosystem assessment, land use pattern, climatic analogues, climatic variability, climatological statistics and processed data and agroclimatic resource analysis.
g) Soil resources - Soil deterioration and erosion, loss of farmland through urbanization and land reclamation.
h) Water resources - Agricultural water needs, water-use efficiency of crops, irrigation requirements and scheduling, water surplus and drainage and agricultural drought.
i) Management operations - Weather-climate analysis in relation of field workdays, forage crop harvest conditions, hay drying, frost and disease control and weather forecasting requirements of agriculture.
j) Artificial modification of meteorological and hydrological regimes - Protection against adverse weather conditions, controlled climate and weather modification.
k) Forest meteorology - Protection and conservation of forest resources and farm forestry.
l) Economic value of agro-meteorological information and advice - Services used in farm planning and operations.

3.1 Monitoring of Agro-meteorological Activity

Techniques, data collection and networks, experiments

Agro-meteorology is the relationship between agriculture and weather. All farm activities are affected by weather. Few applications of weather to agriculture are Crop management, planning for stability in production, monitoring, protection of crops to harsh, soil formation, livestock production just to mention a few (Agroinfo, 2015). Poultry and livestock productions also depend on weather and meteorology provides the information for successful livestock production and husbandry. To account for the impact of weather and climate variability on crop production, agro-meteorological variables are one of the key inputs required for the operation of crop simulation models. These include maximum and minimum air temperature, total solar radiation, wind direction and speed, relative humidity, precipitation and rainfall (Hoogenboom, 2000). Rainfall plays a major role in determining agricultural production and hence the economic and social well-being of rural communities. The rainfall pattern in sub-Saharan Africa is influenced by large-scale intra-seasonal and inter-annual climate variability (Haile, 2005). Water serves many functions in food sustainability. Different forms of water have different uses in farming activities. Rainwater and other surface and ground water are useful for livestock, fisheries and crop production. Farm pond water needs to be observed for the presence of algae and other harmful organisms during hot, dry weather (Donald et al., 2001). In this study, rainwater was harvested for a period of eight months, while the temperature, wind speed, and direction were monitored. The essence of this was to establish the relationship between the meteorological parameters and physicochemical characteristics of rainwater within the same environment.

Agro-Meteorological Monitoring Systems

In agricultural applications, a timely measurement of meteorological data is of the utmost importance. Specific monitoring stations installed in the area of interest and equipped with all the sensors for the definition of dimension and localization of weather conditions is a more effective approach, especially when it comes to agricultural risk management and insurances.

3.2 Plant Environment and Crop Production

Effect of meteorological elements on growth and development of plants, quantity and quality of yields, climate requirements of crops and operational crop condition assessments.

Plants are affected in every stage of growth by environmental conditions. The weather influence further extends to before planting and after harvesting. The quality of the seed sown depends on meteorological conditions during the year in which it was produced, and even during previous years. Post-harvest operations, such as drying of grain and other crops, are affected by seasonal weather, as is also the storage quality of fruit, vegetables and other farm products. Rational use of meteorological information requires the knowledge of two types of information:

1) Specific influences of climatic factors on the growth and development of living organisms throughout their physiological cycle;
2) Climatic characteristics specific to a given farming area expressed in statistical terms. Such studies provide essential information, particularly in developing countries where the introduction of new crops or new varieties of food or industrial plants can be a major factor in the development of these countries or even for the well-being of their population.

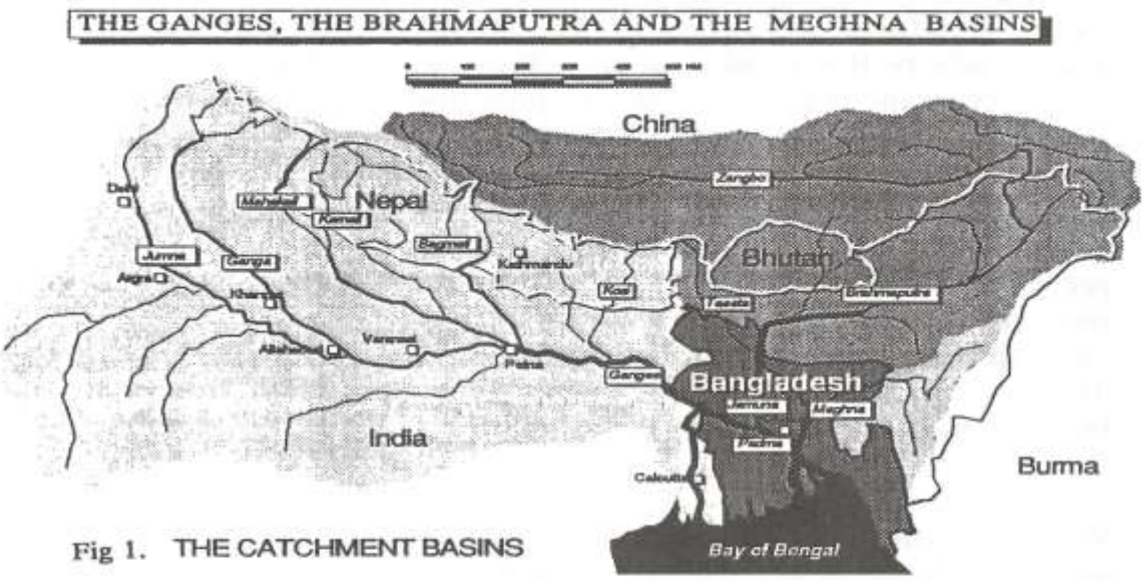


Figure 1: The Gangs, the Brahmaputra and the Meghna Basins

The Commission for Agricultural Meteorology has been always actively involved in the preparation of numerous Technical Notes, training manuals and other WMO scientific and technical publications. In view of the developing critical world food situation, the Commission extended its activities to the acquisition and analysis of experimental crop/weather data on a global basis, initially through the CAgM Working Groups on International Experiments for the Acquisition of Wheat/ Weather and Lucerne/Weather Data. REFERENCES (see Appendix I): WMO-No. 396

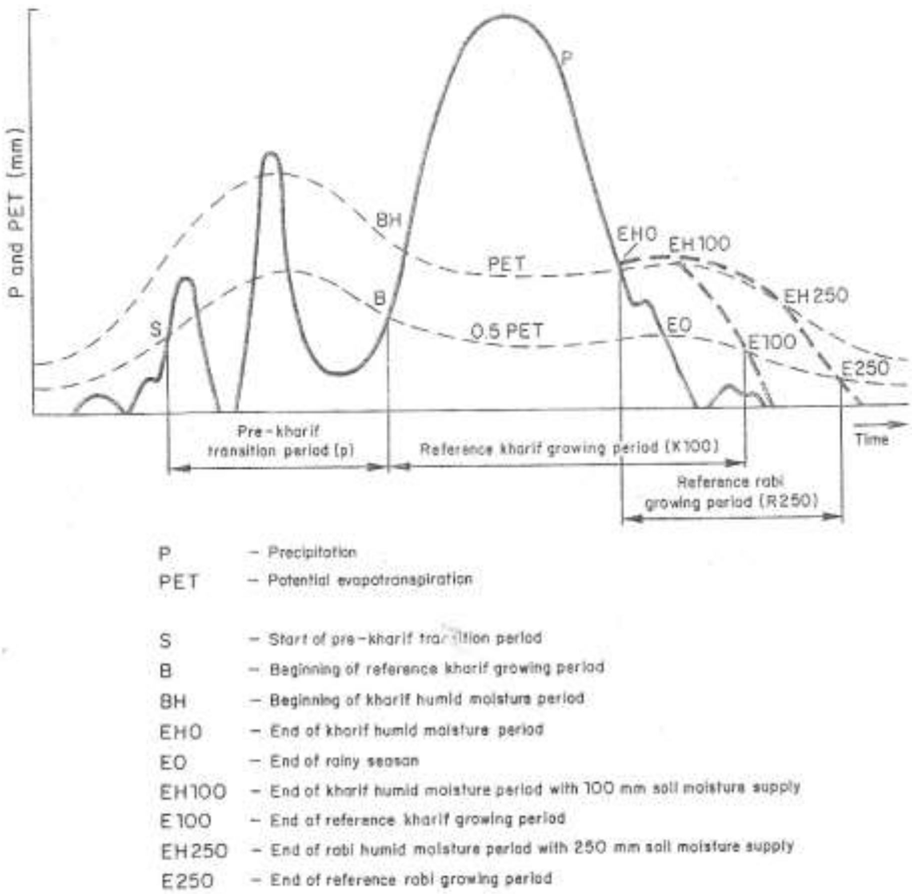


Figure 2: Rainfall growing period Model for Characterization of Moisture Regime

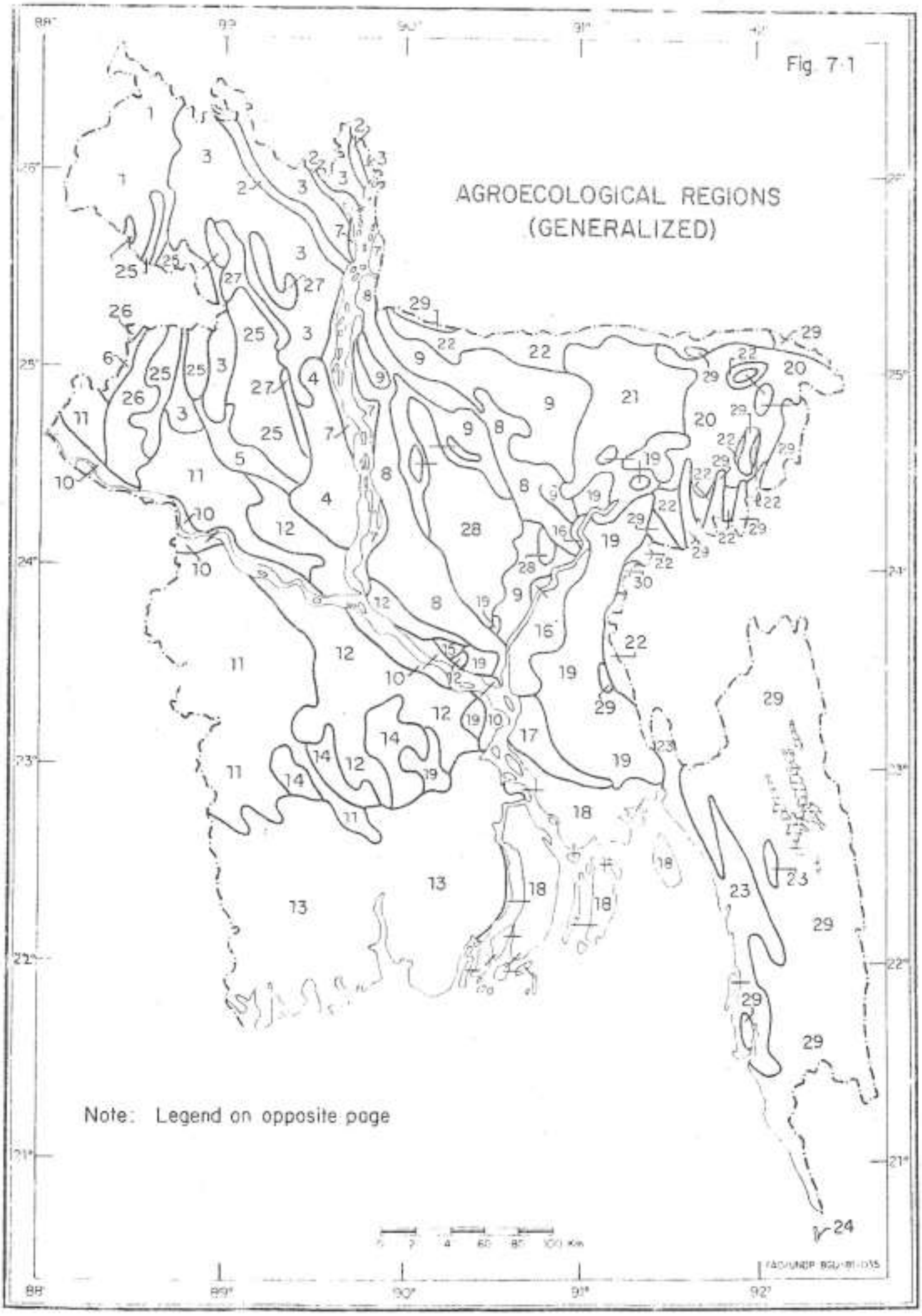


Figure-3: Agroecological Regions (Generalized)

AGROECOLOGICAL REGIONS

1 Old Himalayan Piedmont Plain
2 Active Tista Floodplain
3 Tista Meander Floodplain
4 Karatoya-Bangali Floodplain
5 Lower Atrai Basin
6 Lower Purnabhaba Floodplain
7 Active Brahmaputra-Jamuna Floodplain
8 Young Brahmaputra and Jamuna Floodplains
9 Old Brahmaputra Floodplain
10 Active Ganges Floodplain
11 High Ganges River Floodplain
12 Low Ganges River Floodplain
13 Ganges Tidal Floodplain
14 Gopalganj-Khulna Bils
15 Arial Bil
16 Middle Meghna River Floodplain
17 Lower Meghna River Floodplain
18 Young Meghna Estuarine Floodplain
19 Old Meghna Estuarine Floodplain
20 Eastern Surma-Kusiyara Floodplain
21 Sylhet Basin
22 Northern and Eastern Piedmont Plains
23 Chittagong Coastal Plain
24 St Martin's Coral Island
25 Level Barind Tract
26 High Barind Tract
27 North-eastern Barind Tract
28 Madhupur Tract
29 Northern and Eastern Hills
30 Akhaura Terrace

3.3 Plant Injury and Crop Losses

Pests and diseases, pollution, the effects of weather hazards on crops, cold hardiness, frost and freeze damage

Here the meteorological effect is threefold. The weather influences the susceptibility of plants to attacks by air pollution, pests and diseases. It also enters into the biology of the insects and disease organisms themselves, and thus affects the nature, numbers and activity of pests and the extent and virulence or diseases. Finally, it has an impact upon the timing and effectiveness of control measures, and on the amount and toxicity of spray residues on harvested crops.

Good progress has been made in the meteorological aspects of integrated pest and disease Control. Assistance from agricultural meteorologists is no longer in the experimental rather in the operational stage. Biological and weather conditions should be considered so that the most efficient, most profitable, and least air polluting control method may be used. Weather factors play an important role in the occurrence of and defence against forest and grass fires. Frequency analysis of specific data such as the probability of drought, frost or hail, and particularly the sequences of consecutive days with such events, is more useful than ordinary statistical means.

REFERENCES (See Appendix): WMO Technical Notes Nos. 10, 41, 54, 55, 69, 96, 99, 106, 114, 121, 139, 147

3.4 Livestock Health and Production

Environmental problems of livestock housing and health and production.

Apart from its direct effects, weather affects farm animals through the crops on which they feed and the ground on which they are kept. It affects their feeding. growth, fecundity and health, their geographical distribution, the yield and quality of animal products, the preparation of these products and their capacity for storage and transport. Genotype environment interactions in cattle are generally assumed to exist. The performance of beet cattle in relation to their environment may need more research on a world-wide basis. In temperate zones livestock is probably less sensitive than plants to climatic

stress. Some processes, however, such as milk production, are fairly closely related to temperature and moisture factors.
REFERENCES (see Appendix): WMO Technical Notes Nos. 107, 122

3.5 Animal Diseases and Parasites

Direct and indirect effects of weather on the various types of animal disease, injury and death; economic losses; forecasting incidence and intensity of animal disease

Meteorological factors can influence animal diseases in various ways by affecting:

a) The resistance of hosts to germs/pathogens
b) The resistance and evolution of these germs/pathogens during their biological cycle, particularly when part of this cycle occurs outside the host animal;
c) The conditions under which control measures are applied.

Knowledge of the interrelations between animal, weather and certain diseases is adequate to provides animal-disease forecasts which are available in some countries. These services should be extended to include other animal diseases and more countries.
REFERENCE (see Appendix): WMO Technical Note No. 113

3.6 Climatic Resources

Climatological surveys, ecosystem assessment, land- use pattern, climatic analogues, climatic variability, climatological statistics and processed data, agroclimatic resource analysis.

Climatic resources have been analyzed in the past by the classic climatological approach of means and normal. For a practical interpretation of climate for agriculture an analysis of the frequencies and amplitudes of the occurrences of weather hazards causing plant injuries or crop failures is more meaningful.

Fluctuations in weather and climate significantly affect energy use, water use and global food production. Because of the unequal distribution of these resources over the world, crisis situations have occurred in recent times. There is a growing awareness of the need to asses these resources on a global scale. For the assessment of an area according to agrometeorological principles, the following methodology has been suggested:

a) Determination of bioclimatological requirements of crop varieties;
b) Classification of varieties into bioclimatic groups;

c) Identification of bioclimatic indices which characterize crop growth, development and yield;
d) Comparison of bioclimatic indices with the climatological data available for a region in order to determine agroclimatic types;
e) Agroclimatic zoning by fitting bioclimatic indices to agroclimatic types.

The primary objective in agrometeorology should be a practical approach towards integrating agricultural ecosystems and climatic resources into research and development programmes to increase and stabilize agricultural production.

REFERENCES (see Appendix I): WMO Technical Notes Nos. 56, 79, 81, 84, 86, 100, 125, 133, 143, 144/ WMO-Nos. 117, 340/ WMO Bulletin, Vol. XXIII, No. 3

3.7 Soil Resources

Soil classification, soil deterioration and erosion, loss of farmland through urbanization, sand-dune reclamation.

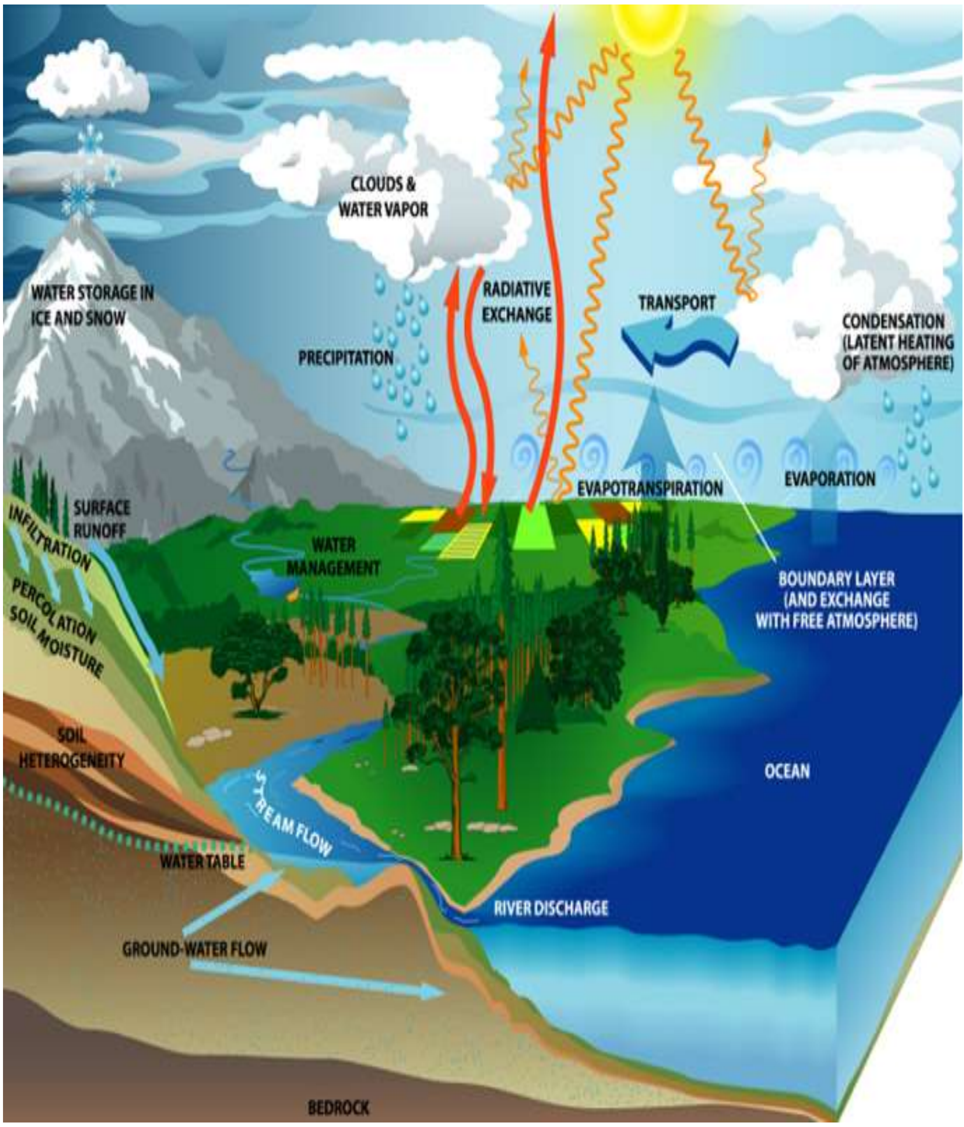
Weathering is an important factor in determining the nature of a soil. Climate and weather affect the chemical, physical and mechanical properties of the soil, the organisms it contains, and its capacity for retaining and releasing heat and moisture. Rainfall, on the one hand, adds chemical constituents to the soil but, on the other hand, washes out soil nutrients. The state of the soil as affecting cultivation, pest control and harvesting is much influenced by weather conditions. The world-wide problem of erosion, its existence and extent are largely determined by local weather factors.

Data are required on erosion and soil deterioration in relation to specific wind statistics such as vectoral characteristics of wind, moderate and high wind speeds and wind in association with rainfall. Data are also required on snowmelt cycles, heavy rainfall (particularly intensities), and the occurrence of dew, which is an important element in rock disintegration in arid regimes. Urban and regional development results in loss of valuable farmland often situated in the best agricultural zones. Field tests and sand-dune stabilization studies have shown that it is not only possible to fix shifting sand dunes but also to exploit them for agricultural use - for example, they have been afforested economically for wood and wood by-products. Another challenge for such areas is the establishment of recreation centres which have high economic value, ensuring income from tourism.
REFERENCE (see Appendix I): WMO Technical Note No.20

3.8 Water Resources

Agricultural water needs, water-use efficiency of crops, irrigation requirements and scheduling water surplus and drainage, agricultural drought.

The water balance of the soil is a subject of greatest importance in many parts of the world but especially in drought regions, as witness the many projects being conducted on this topic and its main components, rainfall, soil moisture, evaporation, runoff and drainage. These studies have very practical applications for developing water resources, planning water use amongst numerous types of consumer (towns, industry, agriculture), determining drainage requirements, and managing water resources for their most profitable use in crop production.



REFERENCES (see Appendix I): WMO Technical Notes Nos. 21, 83, 97, 138, 144/ WMO/IHD Project Reports Nos. 13, 14/ WMO-Nos. 310, 459

3.9 Management Operations

Weather-climate analysis in relation to field workdays; forage crop harvest conditions, hay drying, pest and disease control, weather forecasting requirements of agriculture.

Climatic conditions must be taken into account in planning farm buildings and particularly in designing animal housing and storage space for agricultural products. Weather factors also influence the choice, upkeep and best use of farm machinery.

Climatic conditions must be taken into account in planning farm buildings and particularly in

designing animal housing and storage space for agricultural products. Weather factors also influence the choice, upkeep and best use of farm machinery.

This is an area where the usefulness of applying agrometeorological knowledge and expertise to overall farm planning, management and operations can be demonstrated most effectively. Good progress has already been made and these efforts should be stepped up using climatological data in agrometeorological techniques to determine, on a probability basis, for planning purposes:

a) Soil surface conditions in terms of field workdays;
b) Use of machinery for harvesting and drying grains, forage, legumes, seed crops, etc.;
c) Application and effectiveness of pest- and disease-control measures.

For real-time agrometeorological forecasts, the reliability of the regular generalized weather forecasts is crucial. Agriculture, probably more than any other human activity, would benefit most from extended weather forecasts. There is also a need to specify the synoptic situations which are conducive to good drying, efficient disease and pest control and other farming operations, so that forecasters without special agricultural expertise can still provide useful guidance.

REFERENCES (see Appendix I): WMO Technical Notes Nos. 32, 59, 101, 113, 122

3.10 Artificial Modification of the Meteorological and Hydrological Regimes

Protection against adverse weather conditions, controlled climate, weather modification.

Protection can take the form of:

a) Planning (i.e. selecting) crops, varieties and sites to avoid the relevant meteorological extremes detrimental to plants;
b) Improving sites to avoid or reduce the impact of these extremes.

The extremes normally to be avoided are those of temperature (especially frost), radiation, precipitation, drought and wind. Irrigation, windbreaks and shelterbelts, the storage and conservation of snow and water as well as soil cultural practices, also have important influences on certain elements of the local environment, such as soil moisture, wind velocity and atmospheric humidity.

Controlled climate facilities, such as growth chambers, greenhouses and phytotrons, are important research tools which provide basic data on crop responses to their environment. This information supplements our knowledge of crop-weather relationships as obtained from field experiments or statistical data. The assessment, in both quantity and quality, of weather modification due to man's: activity is an important task of agrometeorological research.

REFERENCES (see Appendix I): WMO Technical Notes Nos. 51, 59, 118, 119, 131, 136, 148

3.11 Forest Meteorology

Protection and conservation of forest resources and farm forestry.

Man's increasingly intensive utilization of forest land for agricultural and other purposes may cause weather and climatic effects in both space and time. The correct application of meteorological information can be of considerable benefit to the protection and conservation of forest resources. Increased attention should be given to research needs in forest meteorology and to the training of suitable Agrometeorologist to deal with problems connected with forest meteorology. At its sixth session, in 1974, the Commission for Agricultural Meteorology expressed its active interest in this important subject and decided that a chapter on forest meteorology should be included in the Guide to Agricultural Meteorological Practices.

REFERENCES (see Appendix I): WMO Technical Notes Nos. 42, 119

3.12 Economic Value of Agro-meteorological Information and Advisory

Services used in farm planning (past weather) and operations (present and forecast weather).

The evaluation of the economic significance of agrometeorological services is a difficult problem, but modern management needs this type of information. The value of such information depends on the meaningful interpretation of the effects of weather and climate on agricultural activities and production. Typical examples are cost/benefit studies of farming operations such as irrigation, frost protection, weather-integrated pest and disease control and use of farm machinery. These evaluations are based on probability statistics relating the occurrence of weather events (e.g. frost) or derived climatological elements (e.g. soil moisture) to agricultural production.

REFERENCES (see Appendix I): WMO Technical Notes Nos. 132, 145 WMO-No. 422

SESSION 4: WEATHER EVENT

4.1 Nor'wester

Nor'wester (Kal-Baishakhi) thunderstorm that generally blows over Bangladesh usually in April-May from a northwesterly direction, locally known as Kal-baishakhi. Nor'wester thunderstorm coincides with the setting in of the summer season. It grows when the atmosphere becomes sufficiently unstable because of localized surface heating or other causes. Air that becomes buoyant rises and is cooled by adiabatic expansion until it eventually reaches saturation point and causes a cumulus cloud. If the atmosphere is unstable further, the cumulus cloud grows vertically to form cumulonimbus cloud and subsequently a thunderstorm, popularly known as nor'wester. The difference between an ordinary shower and this type of storm is that it is always associated with thunder and lightning. It is like a thermodynamic machine in which the latent heat of condensation is rapidly converted into the kinetic energy of ascending air currents.

From mid-March to April the temperature in Bangladesh rises sharply compared to the preceding months (i.e. winter months). In the middle of April, the whole country, especially the northwestern part, records a sharp rise in day temperature. Presence of warm and moist air in the lower layer of the atmosphere is an essential precondition for the development of a nor'wester. Unstable atmosphere and intense convective activity are other important factors for their origin and growth. Nor'westers may be called air mass thunderstorms or convective thunderstorms, since they frequently occur in warm air masses and in the summer.

The main reasons behind the nor'wester is the warm and moist air coming from the southeast which rises up to 2 kilometers, mixes with the relatively cold and dry jet streams coming from the northwesterly and westerly directions. The mixing of these two dissimilar air masses causes storms. The warm and moist air rises due to the Chotanagpur Plateau, Himalayan ranges, and Assam Plateau. The life cycle of a nor'wester is associated with (1) cumulus; (2) mature; and (3) dissipating stages which are determined by the magnitude and direction of the ascending or descending air currents. After 30 to 45 minutes the mature nor'wester begins to decrease in intensity and enters the dissipating stage. Because of very steep temperature lapse rate, high water content of clouds and the cumulous updrafts, hail is common to a nor'wester. The size of a hail is determined by the rate of uplift within a cloud and its high-water content. Thunder and lightning are common with a nor'wester. Nor'westers are more frequent in the late afternoon because of the influence of surface heating in producing convection currents in the atmosphere. In the western region of Bangladesh, nor'westers come in the late afternoon and before evening but in the eastern side it comes generally after evening, moving from a northwesterly to an easterly and southeasterly direction. In this season the morning remains calm. Temperature begins to rise from noon creating a convective current and the storm is formed. The average wind speed of a nor'wester is 40-60 km per hour. But in exceptional circumstances the wind speed may exceed 100 km. The duration of the storm is generally less than an hour but sometimes it may exceed an hour.

4.2 Hail

Hail is something that occurs in most parts of the world. This does cause a lot of damage at times and it can be very troublesome also but what is hail? Hail is a variety of differently shaped ice balls or lumps. These are mostly referred to hailstones and, in most occasions, are not harmful but in some instances, they can be very dangerous.

Hail or hailstones are made up of water ice and can be any size; it can be measured anything from five millimeters and two hundred millimeters. Though, most hail are produced during thunderstorms and heavy rains and aren't worrying.

The damage that can be inflicted by Hail.

Some hailstone sizes can range from pea sized to as big as a nickel. However, the hailstones can actually cause a lot of damage especially to cars and vehicles, aircrafts, buildings, crops and livestock animals also. More often than not, it is the roofs which take full effects of the hailstorm damage and can cause cracks in buildings and leaks in the roof also.

Most roofs that are made from metal can be resistant to damage from the hailstorms. However, aircrafts such as planes and helicopters are going to feel most effects of hail damage especially whilst flying. In fact, they can be highly hazardous to aircrafts because the hailstorms can cause a severe amount of damage to aircrafts within only a few moments.

Even on the ground, hailstorms and hail balls are very troublesome to drivers of vehicles because they can reign down on vehicles and cause a lot of damage to roofs, hoods and even come crashing through sunroofs. Windshields are often the target of hailstones and can crack or shatter them completely. Though, it is not just the vehicles or aircrafts which can be affected by hailstones. Crops can be damaged also by hailstones.

Hail and hailstorms can cause:

- Electricity or power cuts and black outs.
- Injury to humans and animals
- Cause damage to vehicles and aircrafts

4.3 Tornado

A tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground. Because wind is invisible, it is hard to see a tornado unless it forms a condensation funnel made up of water droplets, dust and debris. Tornadoes are the most violent of all atmospheric storms.

Where and when do tornadoes occur?

Tornadoes occur in many parts of the world, including Australia, Europe, Africa, Asia, and South America. Even New Zealand reports about 20 tornadoes each year. Two of the highest concentrations of tornadoes outside the U.S. are Argentina and Bangladesh.

Tornado season usually means the peak period for historical tornado reports in an area, when averaged over the history of reports. There is a general northward shift in "tornado season" in the U. S. from late winter through mid-summer. The peak period for tornadoes in the southern plains, for example, is during May into early June. On the Gulf coast, it is earlier during the spring; in the northern plains and upper Midwest, it is June or July.

Tornadoes can appear from any direction. Most move from southwest to northeast, or west to east. Some tornadoes have changed direction amid path, or even backtracked.

4.4 Precipitation

Precipitation is one of the most important factors of Bangladesh where the economy strongly based on agricultural. About 80% people of Bangladesh live in rural area and directly or indirectly depend on agriculture. The erratic rainfall and their associated extreme events may affect ecosystems, productivity of land, agriculture, food security, water availability and quality, health and livelihood of the common people of Bangladesh. Therefore, a better understanding of precipitation variations has important implications for the economy and society of Bangladesh.

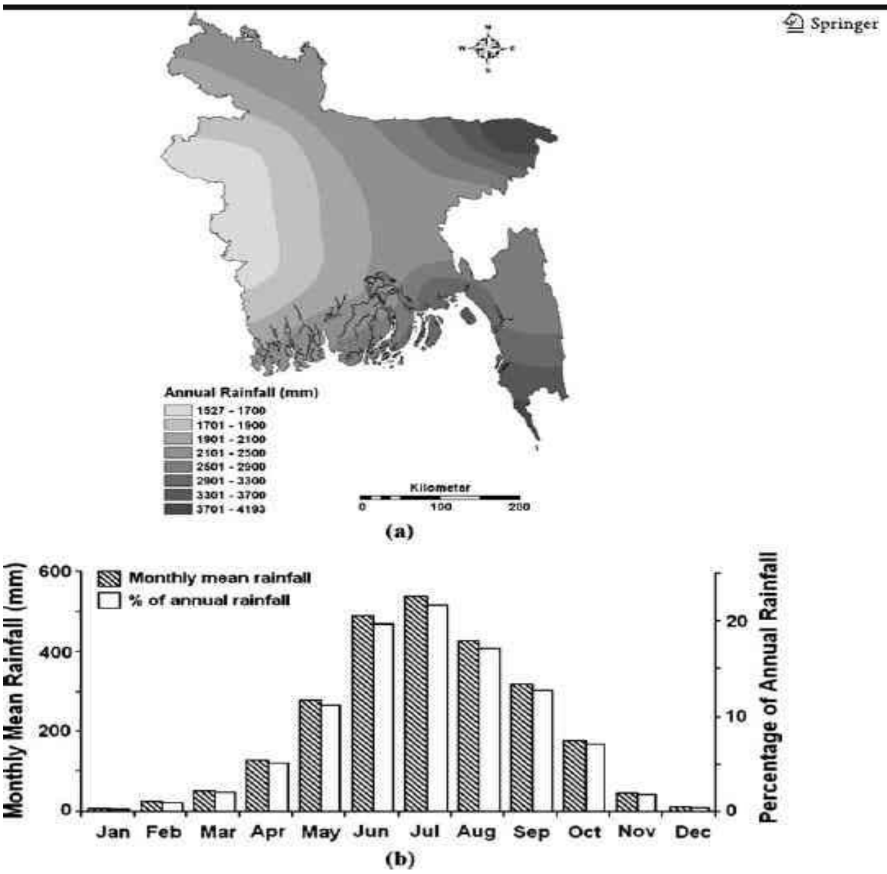


Figure 4: A Spatial variation of mean annual rainfall over Bangladesh; b: Monthly distribution of rainfall in Bangladesh

4.5 Monsoon Depression

Due to this geographical position, Bangladesh experiences the highest amount of monsoon rainfall among SAARC region. The monsoon climate is traditionally characterized by large amount of seasonal rainfall and reversal of wind direction. Most importantly this rainfall is the major source of water to various human activities such as agriculture, hydropower and drinking water. Various weather systems such as tropical disturbances, thunderstorms contribute to monsoon rainfall.

Among these systems, the most efficient rain-producing system is known as the Monsoon Depression (MD).

Heavy Rainfall Events (HREs) are known to occur during the southwest monsoon season over the Indian subcontinent as well as in Bangladesh. These HREs are different from the heavy rainfall associated with tropical cyclonic systems. Rainfall in our country varies greatly in space and time. Maximum rainfall occurs in the monsoon period extending from the month of June to September. Due to high temperature of summer, the moisture-laden south–west monsoon originates from the vast expanse of the Bay of Bengal. By June, this monsoon wind moves all over Bangladesh and precipitates heavily.

4.6 Tropical Cyclone

Tropical cyclones are the most violent storms experienced by the mariner. In West Indian waters these storms are known as hurricanes; in the East Indian and Japanese waters they are called typhoons; in the Indian Ocean they are called cyclones; off Australia, willy-willies; and off the Philippines, baguios. Technically they are tropical cyclones. Owing to common American usage, we shall use the terms hurricane and tropical cyclone interchangeably.

Although tropical cyclones are not regular features of the low latitudes, storms resembling them but of lesser intensity are much less rare. By international agreement this group of related storms has been classified according to intensity as follows: tropical depression—winds up to 34 knots [39 miles per hour]; tropical storm—winds of 35 to 63 knots [40 to 72 miles per hour]; hurricane or typhoon—winds of 64 knots [73 miles per hour] or higher.

A somewhat different classification that includes four storm divisions is widely used in the United States, as follows: tropical disturbance—shows a slight surface circulation with one or no closed isobars; tropical depression— has one or more closed isobars with wind equal to or less than 27 knots [31 miles per hour]; tropical storm—wind from 28 to 63 knots [32 to 72 miles per hour]; hurricane—wind speed greater than 63 knots [72 miles per hour].

Tropical cyclones are relatively small, intense, low-pressure areas having a more or less circular shape. These storms are characterized by the circulation of a single air mass—tropical marine in character without fronts in contrast to the two-fold air-mass structure of mid-latitude extratropical cyclones which has a typical polar-front wave. Hurricanes are also much smaller than extratropical cyclones. Their size is rarely much greater than 300 nautical miles in diameter, and the very intense part is often more restricted.

SESSION 5: INTRODUCTION OF WEATHER & APPLICATION OF AGRO-METEOROLOGY

Bangladesh is a small country situated between the foothills of the Himalaya to the north and the Bay of Bengal to the south. The country is often characterized as having a humid, tropical monsoon climate and is affected by almost all the bad weather which are occurring in the tropical region. Every branch of agriculture is directly or indirectly associated with the weather conditions that prevail in a locality. Farm planning and agricultural operations are greatly influenced by the past, present and future weather.

Agricultural production depends essentially on the nature of the seeds, the nature of the soil, the intelligence of man, but the prime one is weather. Thus, detailed knowledge of weather and climatological conditions is necessary for evaluating and planning the best use of land available for agriculture. Weather, climate along with crop condition information at different stages of growth can help to evaluate the food situation in the country. As such, it is essential to establish the relationship between crop and weather or impacts of weather on crop.

5.1 Background

The development objective of the “Crop Yield Forecasting and Agro-meteorology” project is to generate information about the crop condition at different stages of the growth; and also “Forecasting the Yield and Production” for the benefit of concerned policy makers and planners. Bangladesh is at the eastern end of the great Indo-Gangetic Plain called “Lower Gangetic Bengal” and it is a flat alluvial plain.

The dominant feature of the flat plain is the profusion of rivers. Among the major rivers, the Meghna is the deepest, in contrast, the other two the Ganges-Padma and the Brahmaputra-Jamuna are broader and greater. The most important factor is that these rivers, their tributaries and distributaries drain a vast area of India, the Himalaya mountains and the southern part of Tibet. On occasions, these river systems cannot drain the run-off water back to the bay leading to drainage congestion/flood. Even without any significant rain or near normal rainfall within the country, Bangladesh can be deluged due to excessive rain over the major basins in the adjoining parts of India and Himalaya region.

The country is well endowed with precipitation and excessive run off, but on many occasions the activity becomes erratic and shifts the average seasonal distribution which in turn disrupts the agricultural, social and economic systems. In Bangladesh, it is not the quantity of precipitation rather its distribution throughout the growing season, that is critical criterion in determining flood/drought vulnerability.

Since the major agricultural activities in summer are highly dependent on weather, any deviation from normal, either excess or deficiency can greatly affect the yield. Another important factor is that single episodic weather event such as hail, tornado, massive precipitation or tropical cyclone can destroy the labor and investment for the whole year affecting crop yield and production.

Bangladesh is one of the heaviest rainfall areas is the world, but its winter is almost dry. Rainfall varies widely seasonally and spatially over Bangladesh. Most of the rainfall occurs during rainy season from June to September leading to nearly 72% of the annual fall. During rainy season dry spell does occur called “Break Monsoon” and may last for a period of month and if it coincides with the critical period of the crop growth, it could be disastrous and may lead to crop failure.

In Bangladesh one of the lowest mean rainfall amounting to 1,500 mm occurs over Rajshahi region annually while northeast part of Bangladesh mainly Sylhet region records the highest amount of rainfall amounting to 4,000 mm annually.

In certain parts of the county, particularly in the northern and western regions a cyclic recurrence of abnormal dry condition like drought prevails which is a temporary feature in the context of variability and is experienced during March to May when Norwester/Kal Baisakhi activities are less in the region. The condition may extend to June or mid-July if the arrival of southwest monsoon is delayed in Bangladesh. As most of the crops during summer are rainfed, the amount of precipitation and its distribution accounts for the differences between years of food shortages and years of relative plenty.

5.2 Climate

The climate of Bangladesh is controlled by summer and winter monsoon circulation. The summer circulation (southwest monsoon) maritime in origin; is hot and humid and the major source of rain in Bangladesh; while the winter circulation (northeast monsoon) continental in origin; is dry and cold.

January is the coldest month; the western part is comparatively colder. Days with minimum temperature of 7°-10° C are generally considered to be cold. The western half of the country along the Tropic of cancer is the warmest; the maximum temperature often exceeds 40°C. In general, the climate of Bangladesh during the year may be grouped into four seasons. The seasons and their weather events are as follows:

Season	Period	Characteristics	Weather events	Seasonal rainfall in mm	Seasonal average temperature in 0°C.
Summer season or pre-monsoon	March-May	Transition period from cold and dry to hot and	Norwester, Tornado, Hail, Tropical Cyclone	399	27.4

Season	Period	Characteristics	Weather events	Seasonal rainfall in mm	Seasonal average temperature in 0°C.
		humid; hot summer			
Rainy season	June-September	Somewhat cooler but still not with very high humidity called the monsoon season	Heavy precipitation, monsoon depression, occasionally overcast to cloudy sky	1711	28.6
Autumn season or post--monsoon	October-November	Transitional period from hot and humid to cold and dry	Tropical cyclone	213	25.6
Winter season	December-February	Dry winter	Abnormal dryness, mild to moderate cold	34	20.1

5.3 Data Source and Type available in Bangladesh Relevant to Crop Monitoring and Yield Forecasting

Bangladesh Meteorological Department under Ministry of Defence records weather data as per instruction and guidance of World Meteorological Organization (WMO)at 3 (three) hours interval eight times a day. There are 36 (thirty-six) meteorological observatories over the country. But the spatial distribution of the observatories over the country is not uniform; a dense network of observatories is operated in the southern part of the country; while thin network of observatories is maintained in the western half of the country. A vast area from Mymensingh to Sylhet lies without any observatory. Chittagong Hill Tract region is another area where a little more attention is needed, and a few more observatories are required other than Rangamati observatory.

These weather data which are recorded from the observatories are transmitted to Storm Warning Center (SWC), Dhaka on real time basis. In addition to these, BMD operates a network of 10 Agrometeorological observatories where a few more parameters related to agricultural activities like soil temperature and soil moisture at different depths, radiation, evaporation and wind speed and direction at 2 (two) meter height are recorded.

BMD also operates 3 (three) Pilot Agromet observatories; the objectives of the Pilot Agromet observatory are to study the relationship between crop(s) and weather; the impacts of weather on crops and on varieties of different crops. During discussion with the Director of BMD and other officers, it is felt that these studies have not been conducted in the past nor are conducted at present. It is believed that the concept/objective of these observatories have been virtually dropped.

BMD also maintains two Satellite Ground Stations to receive cloud pictures from different meteorological satellites, however, these pictures are not useful for any indication of vegetation. BMD runs a modem climate division where all kinds of climate data are archived for all observatories since their inception. These data are available on request in different formats depending on the request of the users.

But, the usefulness of the technology of vegetative index suffers severe limitation in Bangladesh because of prevailing multiple cropping system in the country/region. It is very difficult to demarcate the paddy fields from rest of the crop(s) fields from remote sensed picture. Reception of remote sensing products from Internet from FAO, Rome (SDRL) is also unlikely to give any acceptable results in the context of Bangladesh Agricultural practices.

Forecast: BMD issues daily weather forecast for general public and separate weather forecast for the farmers. These forecasts are routinely broadcasted at fixed time of the day.

- BMD prepares a weather bulletin called Agromet bulletin at 10 days interval. The bulletin is sent to different institutions and agencies on a regular basis by post, a few of the addresses are also connected by fax. Bulletin contains station/observatory wise cumulative rainfall and their departure from normal, average maximum and minimum temperature and their departure from normal, rate of evaporation per day, episodic events which affected the country along with little summery of the past 10 days weather. Bulletin also contains forecast for next 10 days, expected rate of evaporation per day and an advisory on the requirement of the supplementary irrigation during rainfall deficiency period, where crop(s) are likely to suffer from water stress.
- Daily rainfall information's are also sent to Prime Minister's office and to different Ministries and personnel of the Govt, of Bangladesh, by fax.
- Monthly and three-monthly rainfall forecasts are issued by BMD. These forecasts are sent to concerned agencies of the Govt, as well as to the press. But the acceptable accuracy for three monthly forecasts is questionable.
- BMD issues farmer's forecasts daily. The bulletin contains general weather information along with thunder activities. The forecast is routinely broadcasted at fixed hour. The forecast does not contain any specific information on farming. The forecast bears less merit in comparison with the farmer's forecast of the developed countries as well as neighbouring country. Specific and detailed information on weather from the period of sowing to harvest are the requirements which needs to be forecasted. Seeds; for example, will not germinate below a certain level of soil temperature and without necessary quota of soil moisture. Thus, the effect of soil temperature and soil moisture on germination and plant growth are of great importance. Early sowing causes considerable damage to seeds leading to less germination; while late sowing may endanger yield and quality. The

information's on soil moisture and soil temperature at a given place/region from the network of Agromet observatory can permit the forecaster to determine a mean optimum date for crop sowing and which can be forecasted.

- Rainfall is one of the most variable meteorological elements. Irrigation helps to make up the water requirement of a crop arising due to rainfall deficiency in any area. A meteorologist has the knowledge of rainfall and can make an estimate of its possible variation. The rate of water use by plants during transpiration is a function of meteorological elements and can be estimated from the energy balance equation. Information of evaporation loss will help the farmer and management people to estimate water loss occurring after the last rain or irrigation and hence to determine his own or area's crop water requirement and the time of irrigation.

Water loss forecast - an example

"Free water loss during the past 24 hours average 70 mm. Expected free water loss today is 60 mm and tomorrow 80 mm. Rainfall probability will remain low for the remainder of the week and crops will begin to suffer moisture stress unless supplementary water is irrigated/applied."

Since the purpose of irrigation is to supply optimum amount of water to the crop at different stages of growth, a meteorologist can predict what amount and at how frequently the crop is to be irrigated. The right amount of water at right time of plant's life is of paramount importance to avoid any drought related food shortages.

- The relationship between climate, plant disease and pests are slowly being discovered. The life cycle of insect, pests and their successive generation are largely influenced by weather factors. Weather factors can either foster or suppress insect life. Feeding habits are also controlled by weather. The path of insect pest's migration is also largely determined by wind pattern. Thus, the importance and practical use of weather and climatological data to determine strategy, tactics and logistics in programmes to monitor and control pests and disease vectors need no emphasis. The Agrometeorologist is one of the major contributors to the programme. Most plant diseases develop and spread in wet condition with a high rate of development depending on temperature. Therefore, effective and economic control of most diseases requires a vegetative wetting forecast.

Vegetative wetting forecast - An example

"During the past 24 hours there have been eight hours of wet vegetation with mean temperature of 16°C. During the next 24 hours, ten hours of wetting by rain are expected, with a mean temperature of 16°C. These combined wetting periods will produce a light to moderate "X" infection period in "Y" group. Growers should be prepared to commence spraying tomorrow to prevent the development and spread of scab infection"

All these forecasts are essential component of agricultural activities to avoid risk due to natural calamities. These forecasts are required to be issued regionally or district wise by the concerned forecasting agency regularly. These are to be broadcasted routinely at fixed hour of the day from the local radio station. Since these forecasts are of very specific type than general weather forecasts which are issued for general public as such, highly specialized persons are needed to be involved in these field.

Natural Calamities in Bangladesh Those Effect Crops: - International consultants who worked in the project in the past reported that below normal rainfall in Bangladesh is linked with EL-Nino activity. It is evident that EL-Nino-Southem Oscillation (ENSO) has impact in global scale especially in the Pacific regions but how does it act and influence this region is still a matter of speculation which needs to be studied. For example during last severe EL-Nino period in 1997 Pacific Ocean water temperature rose by 4-5 °C and created drought like situation in Southeast Asia; but normal rainfall in India and a little above normal rainfall in Bangladesh was recorded despite a weaker monsoon circulation prevailed in the upper atmosphere across the Indian Sub-continent (WMO).

- Flood in Bangladesh is not uncommon; since the birth of this land this part of the world was deluged by flood and will continue to be deluged in future. The country experiences flood almost every year with considerable damage to properties, crops and human lives.

During the last 130 years 1870 - 2000, there were 13 major floods in Bangladesh. These were, however, not at regular intervals; phases with no widespread inundation during 1923 - 1954 and 1956 - 1973. There is absolutely no statistical evidence that frequency of major flooding has increased over the last 130 years (Hofer and Messerlig 1997).

The annual losses in production due to flooding are directly to both the intensity and area affected while late flooding during September may aggravate the situation. There will be little time for retransplantation during late flooding. Late transplantation will be affected by the shortage of water on the ground as monsoon rain virtually ceases by first dekadal in October. Yield also is likely to be affected by the low temperature during late November and December.

- Aus, Aman and Boro are the three paddy crops cultivated in Bangladesh. Aus, Aman are grown during summer season and are rainfed while Boro, the cold climate crop is planted in winter days and is fully irrigated one. The varieties are grown according to the season, giving the crop greatest possible benefit from environmental conditions. Boro yields are higher due to adequate sunshine, while yields of Aus and Aman are lower due to cloudiness during monsoon season.
- Thunderstorms/showers called Norwester occur during the pre-monsoon season (March - May). Norwesters bring about one fifth of the total annual rainfall. Decreased thunderstorm activities during this period can delay sowing of summer crops such as, Aus, Broadcast Aman, Jute etc. and may threaten the crop production. Increased or normal thunderstorm activities likely to help Aus and aman crop condition while Boro crop is likely be affected badly. Norwester activities are associated with high wind (the wind often

exceeds 100 km per hour) and hail. Since April and May is the usual period for Boro harvest; high wind and hail at that time is likely to cause extensive damage, leading to below normal Boro production.

- Wheat is another crop which has recently been introduced in Bangladesh as one of the major winter crops. Its cultivation is partly irrigated and partly rainfed depending upon available winter rainfed.
- The tropical cyclone is one of the most talked weather events in Bangladesh. It affects the country during pre and post monsoon season causing extensive damage to crop over a vast area. Since cyclone is a big body of diameter more than 400 km, the losses due to cyclone often leads to havoc.

SESSION 6: INTERACTION BETWEEN METEOROLOGICAL AND HYDROLOGICAL FACTORS

6.1 Introduction

In recent decades' frequently occurred drought disaster has significant impacts on industrial and agricultural production' human's livelihood and ecological environmental protection (Mishra and Singh' 2010). With the social and economic development and population explosion' water resources shortage has been a worsening problem. Thus, drought has attracted more and more attention from all sectors of society. According to the WMO's statistics' the loss caused by meteorological disaster occupied more than 85 % of the total natural disaster's losses; in which' about 50 % of these meteorological disasters were caused by droughts (Obasi' 1994). China is one of the countries that experienced frequent and serious drought disaster (Li et al.' 2017' 2015; Zou et al.' 2005). For example: a large-scale drought occurred in 2000 spread to 20 provinces of China' resulting in substantial economic losses. More than 12 provinces of China were affected by the 2009 drought event' and especially in some northern provinces' the drought degree reached an extreme level. In another example' a drought with 100-year return period swept across southwest China during summer 2009 to spring 2010' resulting in a large decrease in most river levels (Lu et al.' 2011).

Due to the differences of purpose or target in drought re-search and the complexity of drought formation cause' there are several drought classifications: meteorological drought' hydrological drought and agriculture drought. Meteorological drought describes water shortage phenomenon caused by the imbalance between precipitation and evaporation during a specific period. In general, water shortage degree (calculated with precipitation) would be used as a measure of meteorological drought because of the accessibility of precipitation data. The popular drought indices calculated by precipitation include continuous rainless days, precipitation anomaly percentage, precipitation Z index, and Standardized Precipitation Index (SPI, McKee et al., 1993), etc. The above single precipitation factor-based indices lack the consideration of evaporative demand, and thus may be cannot objectively characterize the drought process (Li et al., 2014). To overcome this limitation in drought calculation, many efforts have been conducted to develop new drought indices by introducing extra influencing factors. For example, the Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness (Palmer, 1965), and has been widely used in drought research. Vicente-Serrano et al. (2010) proposed a new meteorological index, Standardized Precipitation Evapotranspiration Index (SPEI), combining the sensitivity of PDSI to changes in evaporative demand and the robustness of multitemporal nature of SPI. Hydrological drought represents the abnormal water shortage caused by the imbalance among precipitation, surface and sub-surface runoff. It measures the anomaly of river streamflow, and its common indices include anomalous percentage of river discharge, anomalous percentage of reservoir storage, and water resource scarcity index, etc. Vicente-Serrano et al. (2011) developed the Standardized Streamflow Index (SSI) for hydrological drought analysis. It evaluates the water shortage degree of a stream or set of streams in multi-temporal scales. Thus, this index could be an appropriate choice for hydrological drought analysis (Li et al., 2014).

The main objective of this paper is to conduct the connection analysis between meteorological and hydrological droughts in a semi-arid region of the middle Yellow River. The SPEI and SSI were used to represent the meteorological and hydrological indices, respectively, and calculated in a typical basin (Qingjianhe River basin) for the period of 1961-2007. Response of hydrological systems to meteorological conditions would be analyzed for better understanding the regional water resources scarcity.

6.2 Connections between meteorological and hydrological droughts

The correlation analysis was carried out between SPEI and SSI at different timescales (from one to 12 months) for inter-comparison. The time series of Pearson R correlation coefficient could be calculated between two drought index series. As an example, Fig. 5 shows the Pearson R correlation coefficients between SPEI and SSI with 1, 3, 6, 9, and 12-month time scales and different time lags (from one to 12 months). The time lag represents the time for response of hydrological system to climate variable on a basin scale. Results suggested that the correlation between these two drought indices was relatively low (R < 0.6). It indicated that the response relationship of hydrological system to precipitation and evaporation was highly nonlinear, even on annual time scale. The main reason should be the influence of intensive human activities (i.e., the increasing constructions of soil and water conservation measures). For example, the local people have constructed 274 main silt dams from 1955 to 2009, with the total water storage of 251 million m3 (see their locations in Fig. 1). These main silt dams controlled more than 25 % of total area of the Qingjianhe River basin. This runoff-retaining function should certainly affect the correlation between climatic factors and hydrological response.

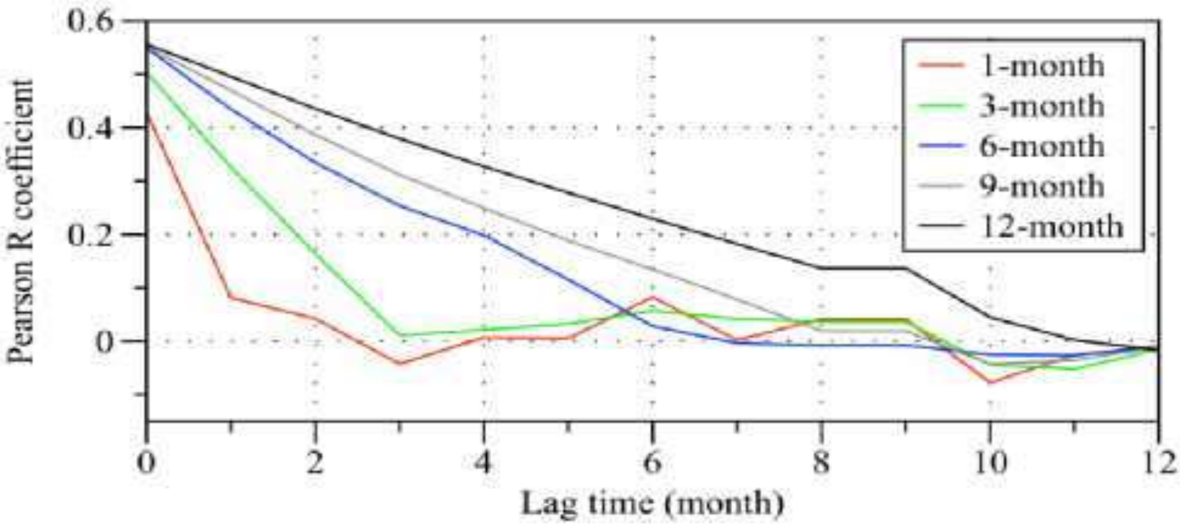


Figure-5: Correlation analysis between SPEI and SSI for different lag times.

The correlation analysis also suggested that there were obvious increasing tendencies of Pearson R correlation with accumulated timescales in SPEI vs. SSI, with the largest correlation values at zero-month time lag. This indicated that, in such small size basins, less than one month was enough for hydrological system response to climate factors.

SESSION 7: HORTICULTURE, ANIMAL HUSBANDRY AND FORESTRY

7.1. Horticulture

Horticulture is, at the most basic level, the science or art of cultivating fruits, vegetables, flowers, or ornamental plants. The origin of the term lies in two Latin words: hortus (meaning "garden") and cultus (which means "tilling").

The word horticulture comes from two Latin words which mean “garden” and “culture.” Horticulture is the art and science of growing and handling fruits, nuts, vegetables, herbs, flowers, foliage plants, woody ornamentals, and turf. Examples of horticulture include the following: landscaping. The horticulture industry can be divided into three areas: pomology, olericulture, and ornamental horticulture. Pomology is the planting, harvesting, storing, processing, and marketing of fruit and nut crops.

7.1.1 Comparative Analysis Between Climate and Agriculture

Climate is the prime element influencing the crop production. Though Sylhet is one of the major agricultural regions of Bangladesh in recent decade urban heat island effect redraw the scenario towards crop failure and livelihood change. This research is based on available secondary data and personal interviews.

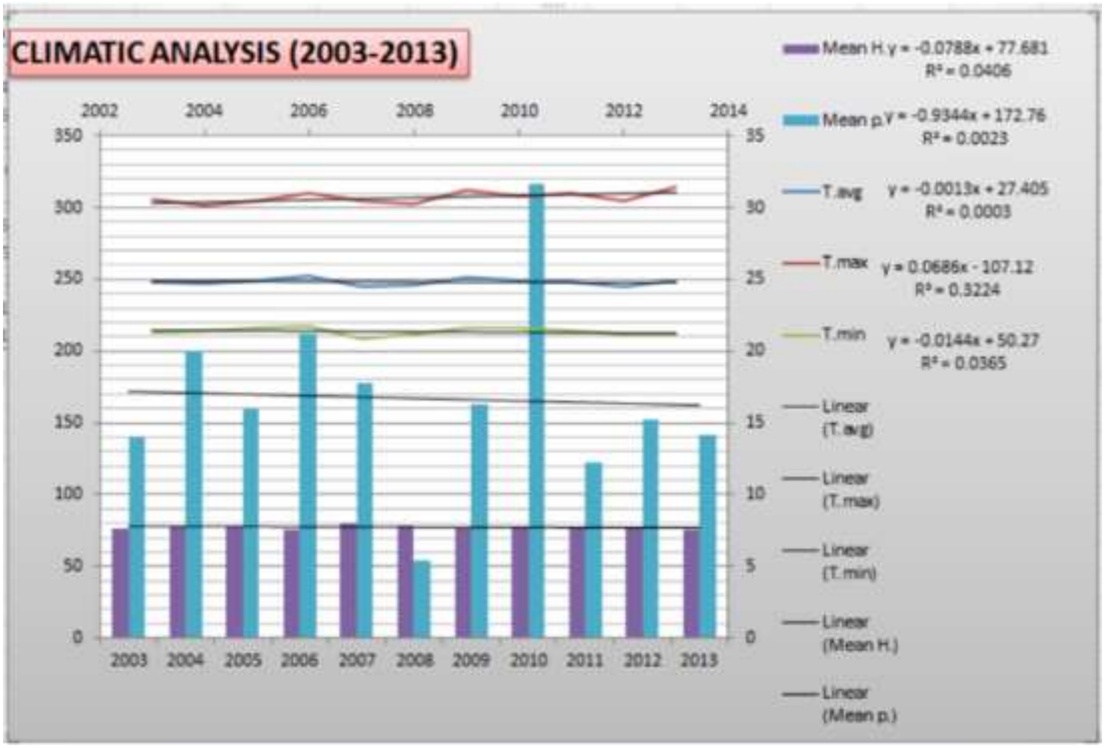


Figure-5: Trend of Climate Change in Recent Decade of Sylhet Sadar

In the above figure we have tried to find out the deviation of climate from standard line which is a clear demarcation of changing climate. Though the climate of the study area is changing at a low rate, the influence of such micro change can be catastrophic if the balance broken down. Because of increasing urbanization and deforestation, the present condition can be unstable any time in the upcoming decade. We already facing various natural disasters because of erratic rainfall excessive heat which results various agricultural crops to go extinct e.g. Wheat or Ginger. Such climatic extremes can lead to large scale livelihood change and a breakdown in regional economy. The above figure also illustrates large scale fluctuation in maximum average temperature and yearly average rainfall which is a red alert for the present climatic condition of the study area.

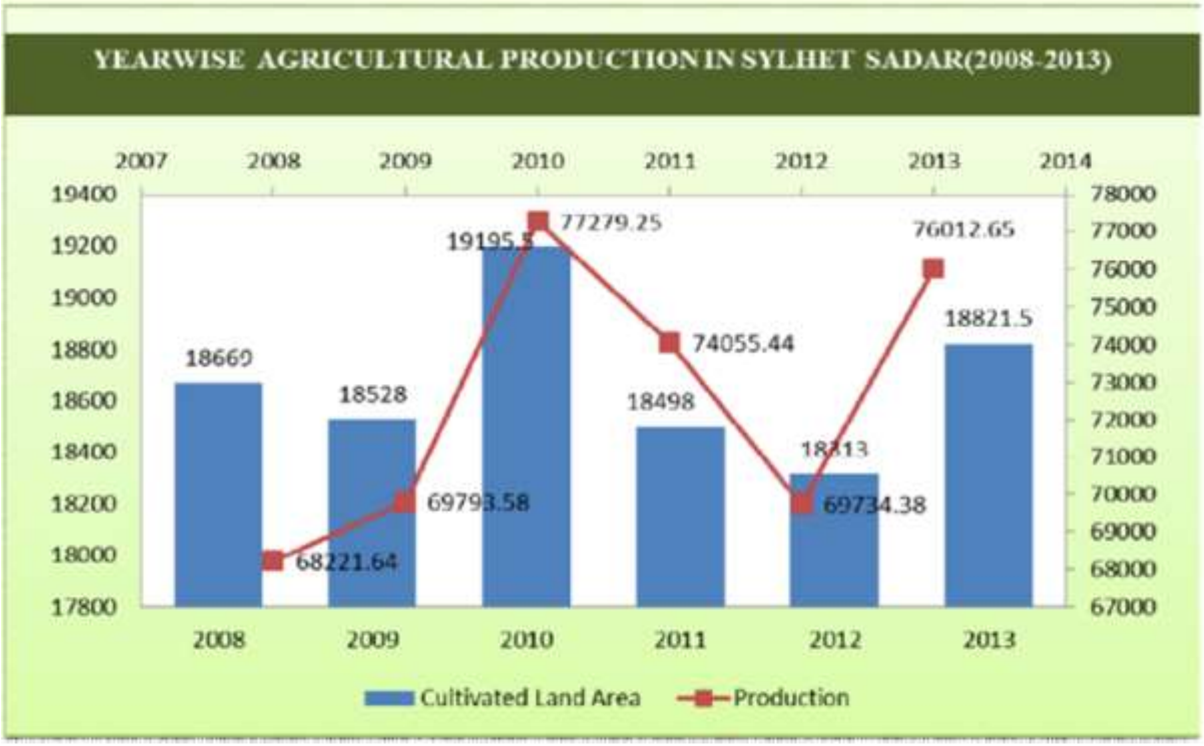


Figure-7: Year wise Agricultural Production Scenario of Sylhet Sadar

Figure 7 express the year wise change in total production with the change in cultivated land in Sylhet Sadar. From the overall analysis we have found a direct relation between rainfalls and agricultural production. Maximum crop productions within the last 6 years have been found in 2010 when the rainfall was maximum (Figure 6). The lowest production recorded in 2012 within the observed 6 years when the rainfall was relatively low, and temperature was comparatively high. The rate of humidity through the years of last decade was comparatively same, which is a clear notification of maintaining moisture balance of the environment of the study area. There is also a clear impact of temperature on the average crop production, e.g. in 2009 the temperature of the study area was relatively high (Figure 6) and the result is clear in figure 7.

7.1.2 People's Perception about the effect of Climate Change on Agriculture

As the peoples dependent on agriculture are not much educated, we have found many interesting things interviewing them. We have counted around 100 people from five different zones of Sylhet Sadar. 90% of them believe in climate change especially they emphasize on high temperature and low rainfall. Around 80% of them were farmer and 20% was local people indirectly attached with agriculture. The people live near the bank of Surma River affected most because of increasing riverbank erosion resulting land loss. There is also a opposite situation of lowering the water level of Surma river and increasing sedimentation in the adjacent part. About 30% among the observed people shifted their livelihood because of large scale agricultural loss or land loss. 20% of them shifted to cultivate the crops that the cultivated in the past years.

From the perception of the respondent some common things about the agriculture of the study area was came out.

- Intense heat during the summer and intensive foggy situation during the winter.
- Riverbank erosion is increasing day by day.
- Insects are dominating through the year forced the farmers to use more fertilizers and insecticide.
- Erratic rainfall (imbalance in monsoon rainfall)
- Change in seasonal Lag
- Agricultural land continuously harmed by increasing urban pollution and waste contamination.
- Surma River can't hold much water in the pre-monsoon and post-monsoon as before, so the peoples adjacent to the river have to use water pump for irrigation purpose.

7.2. Animal Husbandry

Animal Husbandry is a branch of agriculture concerned with the domestication of, care for and breeding of animals such as dogs, cattle, horses, sheep, goats, pigs and other like creatures. Animal husbandry began in the so-called Neolithic ('new stone') Revolution around 10,000 years ago but may have begun much earlier. Examples of animal husbandry are:

- Beekeeping.
- Farming.
- Raising cattle.
- Sheep farming.

Animal husbandry refers to a wide range of job types that focus on the care and breeding of different kinds of animals. Professionals in the field include livestock, dairy and poultry farmers. These farm professionals are responsible for breeding, marketing and caring for the animals on the farm.

Animal husbandry refers to the care of livestock animals, says the Oxford Dictionary. If you work in the field of animal husbandry, you'll keep animals safe and healthy as you plan and supervise breeding, care for newborn animals, devise a nutritious diet, and prepare animals for slaughter or sale.

7.3. Forestry

Forestry is the science and craft of creating, managing, using, conserving, and repairing forests, woodlands, and associated resources for human and environmental benefits. Forestry is practiced in plantations and natural stands. A practitioner of forestry is known as a forester.

The total forest area of Bangladesh is 2.6 million hectares, which is nearly 17.4% of the total land area of the country. The forestry sector accounts for about 3% of the country's gross domestic product (GDP) and 2% of the labour force. However, these figures do not reflect the real importance of the sector in terms of monetary value. The GDP figure does not count the large quantities of fuel wood, fodder, small timber and poles, thatching grass, medicinal herbs, and other forest produces extracted illegally. The low contribution of the forestry sector to the GDP is also explained by several other factors, e.g. value added from wood processing is counted under the industry sector, rather than the forestry sector. The benefits provided by forest ecosystems include: goods such as timber, food, fuel and bioproducts; ecological functions such as carbon storage, nutrient cycling, water and air purification, and maintenance of wildlife habitat; and social and cultural benefits such as recreation, traditional resource uses and spirituality. Services provided by forests cover a wide range of ecological, political, economic, social and cultural considerations and processes. The contribution of forest resources in protecting watershed and irrigation structures, reclaiming land from the sea, protecting coastal areas from storm damage, and in maintaining and upgrading the environmental quality, has not been quantified. However, economic, social and environmental importance of ecosystem services provided by forests is increasingly recognized globally. The primary challenge for sustainable forest management is finding ways to continue to benefit from ecological services without compromising the forest's ability to provide those services. Owing to such factors as over exploitation, conversion of forestland into agriculture, fire and grazing, forest resources in Bangladesh have been continuously depleting in terms of both area and quality. Between 1990 and 2015, Bangladesh annually lost 2600 hectares of primary forest (FAO 2015). Primary forest land gradually decreased from 1.494 million hectares in 1990 to 1.429 million hectares in 2015. Thus, annual rate of deforestation in Bangladesh was 0.2% during 1990¬2015 (FAO, 2015).

7.3.1 Importance of The Sector

Forests provide essential ecosystem services beyond carbon storage and emissions offsetting - such as health (through disease regulation), livelihoods (providing jobs and local employment), water (watershed protection, water flow regulation, rainfall generation), food, nutrient cycling and climate security. Protecting tropical forests therefore not only has a double-cooling effect, by reducing carbon emissions and maintaining high levels of evaporation from the canopy (IPCC, 2013), but also is vital for the continued provision of essential life-sustaining services. These services are essential for the well-being of people and the planet however, they remain undervalued and therefore cannot compete with the more immediate gains delivered from converting forests into commodities (Mitchel et al., 2008, p. 17). Ecosystem services operate from local to global scales and are not confined within national borders; all people are therefore reliant on them and it is a collective interest to ensure their sustained provisioning into the future.

Forest is very important renewable resources which plays a crucial role for the livelihoods of local communities. In addition, forests provide valuable ecosystem service: they maintain local climate and strongly influence global fluxes of oxygen and carbon dioxide; protect topsoil, prevent soil erosion and maintain food wave. From late 1960, the Bangladesh Forest Department (FD) started coastal afforestation programmes on the newly accreted coastal chars and offshore islands. In coastal areas, foreshore afforestation is a proven cost- effective method to dissipate wave energy and reduce floods on embankments during storm surges. Effectively acting as a barrier against gusts and storm surges, forests can save lives and protect communities vulnerable to climate change.

Intensive forestry programmes can create employment opportunities and help alleviate poverty. In 1990 employment in forestry sector was 1.65 million FTE and gradually decreased to 1.5 in 2015. Contrarily the female employment increased from 0.15 million FTE to 0.60 million FTE in 2015 (FAO, 201 5).It indicates that although employment in forestry sector gradually decreased but the percentage of female employment has steadily increased from 10 percent in 1990 to 40 percent in 2010. Despite considerable thrust on poverty alleviation in all plan documents since the independence of Bangladesh, still 31.5% of the population lives below the national poverty line (ADB 2016). Role of forests in poverty alleviation is immense. There are at least 19 million of people who are absolutely dependent on forests for their livelihoods in Bangladesh. There could be another 19 million who are dependent on forests in one way or another (Rahman & Ahmed, 2016). Rahman (2011b) reported that contribution of village forest income to total household income varied from 8.9% to 18.6%. Forest degradation will hinder prospect of sustainable development. Forests and trees are rooted in life and livelihoods. They can be grown, improved, and looked after - they are measurable and renewable. It would be hard to find a simpler and more universal way of changing the world for the better than by planting and managing trees.

7.3.2 Forest and Climate Change

Forest and climate change have a two-way relationship. Tropical deforestation releases 1.5 billion tonnes of carbon each year into the atmosphere (CSIRO, 2007). Avoiding deforestation can play a key role in reducing greenhouse-gas-induced climate change. Contrarily climate change will likely alter the frequency and intensity of forest disturbances, including wildfires, storms, insect outbreaks, and the occurrence of invasive species. The productivity of forests could be affected by changes in temperature, precipitation and the amount of carbon dioxide in the air (EPA, 2016a). Sea Level Rise (SLR) could erode and inundate coastal ecosystems and eliminate wetlands (EPA, 2016b).

Bangladesh is a low CO2 emitting country, but forest of Bangladesh is a rich repository of carbon. Bangladesh forests stocked a total 127.28 million tonnes carbon in above and below ground biomass including dead wood, litter and forest soil (FAO 2015).

Despite uncertainties exists with respect to projections of climate change and its impact on forest ecosystems, evidence is growing to demonstrate that climate change, coupled with socioeconomic and land use pressure, is likely to adversely impact forest biodiversity, carbon sink, biomass productivity, and the livelihoods of forest dependent communities. The Eastern hilly areas of Bangladesh will undergo change and the changes are likely to be triggered by changing moisture, CO2 fertilization and temperature regimes (Chaturvedi, 2016).

Due to 32 cm Sea Level Rise (SLR), 84% of the Sundarban will be deeply inundated in 2050 and in 2100, for 88 cm SLR the whole of the Sundarban will be lost. Increased salinity intrusion due to sea level rise poses great threat to the Sundarban. The Sundarban has already been affected due to reduced freshwater flows through Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing the different species of plants and animals to be adversely affected. Increased saltwater intrusion is considered as one of the causes of top dying of Sundari trees. The impact of sea level rise will further intrude the saline water to landward. SLR of 32 cm will intrude 10 to 20 ppt salinity level more in the Sundarban. The rate of saltwater intrusion will also affect the ability of the ecosystem to adapt (Mohal et al., 2006).

Shifting of vegetation boundaries due to climate change in combination with the lack of biodiversity richness, disturbed and fragmented habitats pose a serious threat. The fragmented and isolated forests with low biodiversity could hamper the dispersal and migration of forest species to suitable niches and such forests are potentially vulnerable to climate-driven 'dieback' Chaturvedi (2016).Thus climate change could adversely affect forest ecosystems, biodiversity and even mitigation potential of forests. The natural disasters associated with climate change impact and biotic pressure on natural resources in Bangladesh is very high. If forest cover decline in same pace, the potential for forests' carbon sequestration will be reduced substantially. In this context, the country has to face the challenge of climate change vulnerability and depleting forest resources. There is a need to reduce forest fragmentation, degradation and disturbances in order to facilitate the dispersal and migration of forest species from one place to another in response to climate change.

Climate change, as a critical issue, has been focused with a firm commitment to pursue an environmentally sustainable development process. Sustainable development initiative for environment and climate change will complement and benefit from adaptation and mitigation activities.

7.3.3 Sustainable Development Goals (SDGS) And Forestry

The SDGs, a UN initiative, officially known as Transforming our world: the 2030 Agenda for Sustainable Development, are an intergovernmental set of aspiration with 17 goals and 169 specific targets to be achieved over the next 15 years. Forests are essential for achieving all 17 SDGs and understanding this requires a broader approach and a long-term perspective, along with a redefinition of 'forestry' to include all of the ways that forests and trees contribute to sustainable development (CIFOR, 2016). However, a review shows that 9 SDGs with 20 targets are related to forestry activities in Bangladesh.

SESSION 8: HEAT WAVE, COLD WAVE AND FOG

8.1 Heat Wave

A heat wave is a prolonged period of excessively hot weather, which may be accompanied by excessive humidity. A heat wave or heat wave is a period of excessively hot weather, which may be accompanied by high humidity. A heat wave is usually measured relative to the usual weather in the area and relative to normal temperatures for the season. Temperatures that people from a hotter climate consider normal can be called a heat wave in a cooler area if they are outside the normal climate pattern for that area.

Severe heat waves have caused catastrophic crop failures, thousands of deaths from hyperthermia, and widespread power outages due to increased use of air conditioning. A heat wave is considered extreme weather that can be a natural disaster and a danger because heat and sunlight may overheat the human body. Heat waves can usually be detected using forecasting instruments so that a warning call can be issued.

The impact of heat wave can be tangible (one that can be easily measured in monetary terms) or intangible (anxiety or fear of future natural disasters, inconvenience, disruption, and stress-induced ill health). Heat wave impacts crop growth and development at different levels like soil moisture uptake, root and shoot growth, photosynthesis, respiration, plant water uptake and final yield. Heat wave competes for soil moisture by hastened evaporation, leaving almost no moisture for uptake by plants. Heat wave also causes an overall environmental degradation, which is a major factor contributing to the vulnerability of agriculture, forestry and rangelands to heat waves. Quite often, poor people work on the agricultural lands. These under-nutritioned and weak poor people, when exposed to extreme heat, are simply knocked down health-wise. This is another factor that adversely affects agricultural problem.

Agricultural activity is also affected by water availability. Due to extreme heat all around, there is a great demand for water in municipal sectors, leaving restricted water for agriculture.

8.2 Cold Wave

A cold wave is a weather phenomenon that is distinguished by a cooling of the air. A cold wave is a rapid fall in temperature within a 24-hour period requiring substantially increased protection to agriculture, industry, commerce, and social activities. The precise criterion for a cold wave is determined by the rate at which the temperature falls and the minimum to which it falls. This minimum temperature is dependent on the geographical region and time of year. Impact of cold wave varies from location to location and commodity to commodity. Frost, and more particularly the freezing and rupturing of a plant cell walls, can damage many crops, particularly early or late in growing seasons. Prolonged cold snaps can also lead to stock losses.

Bangladesh as a tropical country enjoys a moderate winter. However, for last few years the country had experienced some severe cold waves that caused serious disruption to livelihood and distress to the affected people. In January 2010 northern and southwest parts of the country experienced a rapid fall in temperature with cold winds and dense fog resulting significant rise in respiratory illnesses, and in some cases deaths, while in January 2011 the Meteorological Department recorded the temperature as 2 to 5 degrees Celsius lower than the normal average temperature (about 10°C) during that time of the year. Winter is characterized by very light northerly winds, mild temperature with mean temperature in the range of 18-22 C. Sometimes minimum temperature goes below 10°C and cold wave situation occurs. to define that Bangladesh Meteorological Department use different categories of cold wave such as- mild cold wave (when minimum temperature lies between 8-10°C), moderate cold wave (when minimum temperature lies 6-8°C) and severe cold wave (when minimum temperature goes below than 6°C) respectively. The impact of Cold Waves is as notorious as other regular natural calamities of Bangladesh as far as the damage, distress and disruption as well as death toll is in concern. The impacts of cold wave in previous years are given below:

Year	District	No.	Impact	Source
2011	21 districts (Barisal, Barguna, Bhola, Chuadanga, Gaibandha, Ishwardi, Khulna, Kishoreganj, Kurigram, Kurigram, kustia, Manikganj, Nilphamari, Pabna, Panchagar, Pirojpur, Rangpur, Sirajganj, Satkhira, Sherpur and Thakurgaon)	39	The dense fog creates disturbance in agricultural production a lot. The "BORO" rice is not at good condition. Other agro products such as vegetable, mustard, wheat etc. are also not in good situation for better production. In such circumstance farmers are advised to provide fungus annihilator in their crop land.	BMD reports, The Daily Star, January 9, 2011 http://www.ifrc.org/docs/appeals/11/MDRBD008 drefOU1
2012	22 districts (Bogra, Dinajpur, Faridpur, Gaibandha, Jessore, Joypurhat, Kurigram, Lalmonirhat, Madaripur, Moulvibazar, Mymensing, Kushtia, Naogaon, Nawabganj, Nilphamary, Natore, Pabna, Panchagarh, Rangpur, Rajshahi, Sirajganj and Thakurgaon)	72	• The normal life and livelihoods of people have become severely disrupted by the cold wave, wherein the homeless and income groups like day laborers are worst sufferers including old aged, and children who are facing fatal problems due to the non-availability of warm clothes • The overall health situation is deteriorating day by day. People specially children, old age and women are suffering from cholera, diarrhea and pneumonia. • There has been a negative impact of the cold wave situation on poultry and cattle, and if this situation persists, then they might be attacked by disease.	Annual Report, Disaster Response and Recovery, DDM, 2012
2013	24 districts (Barisal, Bogra, Chandpur, Chittagong, Chuadanga, Comilla, Cox's Bazar, Dhaka, Dinajpur, Faridpur, Feni, Iswardi, Jessore, Khulna, Madaripur, Rajshahi, Rangamati, Rangpur, Shitakundu, Sylhet, Sreemangall, Sayedpur, Satkhira and Tangail)	80	• Potato, Boro Paddy, Muster crops and different seed beds of Current period are affected • Day-laborers were unable to go to work; women in the poor families faced difficulties to do their household chores; children, women and elderly people suffered from respiratory illness, pneumonia, • Rota viral diarrhea and other cold related diseases	National Report, Disaster Response and Recovery, DDM, 2013

Year	District	No.	Impact	Source
2014	22 districts (Barisal, Chuadanga Comilla, Gaibandha, Gopalganj, Faridpur, Kurogram, Kushtia, Meherpur, Moulvibazar, Mymensingh, Madaripur, Natore, Pabna, Rangpur, Rangamati Rajshahi, Sitakundu, Sayedpur, Pirojpur, Srimangal and Tangail)		• People were suffered from pneumonia, diarrhea, bronchitis, fever and other cold related diseases due to cold waves in many regions of country. Children and the elderly were major victim of cold related disease. • During January, the cold wave claimed 11 lives died being children and the elderly. • Day laborers were unable to go to work. Women in the poor families faced difficulties to do their household chores. • The cold weather also disrupted communications via roads, rivers and air	The Ittefaq, January 9, 2014 The Janakantha, January 11, The Prothom Alo, January 16, 2014
2015	13 districts (Chuadanga, Dhaka, Jibannagar, Kishoreganj Kurigram, Rajshahi, Naogaon, Pabna, Gaibandha, Sayedpur, Sylhet, Sirajganj and Thakurgaon)	75	• The cold weather also disrupted communications via roads, rivers and air. Three flights of Novo Airways were delayed by about 30 to 40 minutes to reach Chittagong from Dhaka. Ferry service on Mawa-Kawrakandi routes suspended around 10 hours • Boro (winter rice variety) seedbeds in many areas of the district were damaged under the impact of cold wave marked by foggy weather and lack of sunlight. The cold wave also caused damages to winter vegetables. • Rice mills were closed due to low temperature	BMD reports, The Daily Star, January 21, 2015, The Janakanta Newspaper, January 19, 2015

8.3 Fog and Types of Fog

Fog is often described as a stratus cloud resting near the ground. Fog forms when the temperature and dew point of the air approach the same value (i.e., dew-point spread is less than 5°F) either through cooling of the air (producing advection, radiation, or upslope fog) or by adding enough moisture to raise the dew point (producing steam or frontal fog). When composed of ice crystals, it is called ice fog.

(1) Advection fog: Advection fog forms due to moist air moving over a colder surface, and the resulting cooling of the near-surface air to below its dew-point temperature. Advection fog occurs over both water (e.g., steam fog) and land.

(2) Radiation fog (ground or valley fog): Radiational cooling produces this type of fog. Under stable nighttime conditions, long-wave radiation is emitted by the ground; this cools the ground, which causes a temperature inversion. In turn, moist air near the ground cools to its dew point. Depending upon ground moisture content, moisture may evaporate into the air, raising the dew point of this stable layer, accelerating radiation fog formation.

(3) Upslope fog (Cheyenne fog): This type occurs when sloping terrain lifts air, cooling it adiabatically to its dew point and saturation. Upslope fog may be viewed as either a stratus cloud or fog, depending on the point of reference of the observer. Upslope fog generally forms at the higher elevations and builds downward into valleys. This fog can maintain itself at higher wind speeds because of increased lift and adiabatic cooling. Upslope winds more than 10 to 12 knots usually result in stratus rather than fog. The east slope of the Rocky Mountains is a prime location for this type of fog.

(4) Steam fog (arctic sea smoke): In northern latitudes, steam fog forms when water vapor is added to air that is much colder, then condenses into fog. It is commonly seen as wisps of vapor emanating from the surface of water. This fog is most common in middle latitudes near lakes and rivers during autumn and early winter, when waters are still warm and colder air masses prevail. A strong inversion confines the upward mixing to a relatively shallow layer within which the fog collects and assumes a uniform density. Under these conditions, the visibility is often 3/16 mile (300 meters) or less.

(5) Frontal fog: Associated with frontal zones and frontal passages, this type of fog can be divided into three types: warm-front pre-frontal fog; cold front post-frontal fog; and frontal-passage fog. Pre-frontal and post-frontal fog are caused by rain falling into cold stable air thus raising the dew point. Frontal passage fog can occur in a number of situations: when warm and cold air masses, each near saturation, are mixed by very light winds in the frontal zone; when relatively warm air is suddenly cooled over moist ground with the passage of a well-marked precipitation cold front; and in low-latitude summer, where evaporation of frontal-passage rain water cools the surface and overlying air and adds sufficient moisture to form fog.

(6) Ice fog: Ice fog is composed of ice crystals instead of water droplets and forms in extremely cold, arctic air (−29°C (−20°F) and colder). Ice fog of significant density is found near human habitation, in extremely cold air, and where burning of hydrocarbon fuels adds large quantities of water vapor to the air. Steam vents, motor vehicle exhausts, and jet exhausts are major sources of water vapor that produce ice fog. A strong low-level inversion contributes to ice fog formation by trapping and concentrating the moisture in a shallow layer.

In summary, the following characteristics are important to consider when forecasting fog:

- Synoptic situation, time of year, and station climatology.
- Thermal (static) stability of the air, amount of air cooling and moistening expected, wind strength, and dew-point depression.
- Trajectory of the air over types of underlying surfaces (i.e., cooler surfaces or bodies of water).
- Terrain, topography, and land surface characteristics.

8.4 Fog Characteristics

A general summary of characteristics important to fog formation and dissipation are given here. This is followed by general fog forecasting guidance and guidance specific to advection, radiation, and frontal fogs.

1. Formation: Fog forms by increasing moisture and/or cooling the air. Moisture is increased by the following:
   - Precipitation.
   - Evaporation from wet surfaces.
   - Moisture advection. Cooling of the air results from the following:
   - Radiational cooling.
   - Advection over a cold surface.
   - Upslope flow.
   - Evaporation.

2. Dissipation: Removing moisture and/or heating the air dissipates fog and stratus. Moisture is decreased by the following:
   - Turbulent transfer of moisture downward to the surface (e.g., to form dew or frost).
   - Turbulent mixing of the fog layer with adjacent drier air.
   - Advection of drier air.
   - Condensation of the water vapor to clouds. Heating of the air results from the following:
   - Turbulent transport of heat upward from air in contact with warm ground.
   - Advection of warmer air.
   - Transport of the air over a warmer land surface.

- Adiabatic warming of the air through subsidence or downslope motion.
- Turbulent mixing of the fog layer with adjacent warmer air aloft.
- Release of latent heat associated with the formation of clouds.

3. General Forecasting Guidance: In general, the following has been considered-
    - Fog may thin after sunrise when the lapse rate becomes moist adiabatic in the first few hundred feet above ground.
    - Fog lifts to stratus when the lapse rate approaches dry adiabatic.
    - Marked downslope flow prevents fog formation.
    - The moister the ground, the higher the probability of fog formation.
    - Atmospheric moisture tends to sublimate on snow, making fog formation less likely.
    - Rapid formation or clearing of clouds can be decisive in fog formation. Rapid clearing at night after precipitation is especially favorable for the formation of radiation fog.
    - The wind speed forecast is important because speed decreases may lead to the formation of radiation fog. Conversely, increases can prevent fog, dissipate radiation fog, or increase the severity of advection fog.
    - A combination advection-radiation fog is common at stations near warm water surfaces.
    - In areas with high concentrations of atmospheric pollutants, condensation into fog can begin before the relative humidity reaches 100 percent.
    - The visibility in fog depends on the amount of water vapor available to form droplets and on the size of the droplets formed. At locations with large amounts of combustion products in the air, dense fog can occur with a relatively small water vapor content.
    - After sunrise, the faster the ground temperature rises, the faster fog and stratus clouds dissipate.
    - Solar insolation often lifts radiation fog into thin multiple layers of stratus clouds.
    - If solar heating persists and higher clouds do not block surface heating, radiation fog usually dissipates.
    - Solar heating may lift advection fog into a single layer of stratus clouds and eventually dissipate the fog if the insolation is sufficiently strong.

4. Specific Forecasting Guidance: Consider the following when faced with advection, radiation, or frontal fog situations.

(a) Advection Fog: Advection fog is relatively shallow and accompanied by a surface-based inversion. The depth of this fog increases with increasing wind speed. Other favorable conditions include:

- Light winds, 3 to 9 knots. Greater turbulent mixing associated with wind speeds more than 9 knots usually cause advection fog to lift into a low stratus cloud deck.

- Coastal areas where moist air is advected over water cooled by upwelling. During late afternoon, such fog banks may be advected inland by sea breezes or changing synoptic flow. These fogs usually dissipate over warmer land; if they persist through late afternoon, they can advent well inland after evening cooling and last until convection develops the following morning.
- In winter when warm, moist air flows over colder land. This is commonly seen over the southern or central United States and the coastal areas of Korea and Europe. Because the ground often cools by radiation cooling, fog in these areas is called advection-radiation fog, a combination of radiation and advection fogs.
- Warm, moist air that is cooled to saturation as it moves over cold-water forms sea fog:
- If the initial dew point is less than the coldest water temperature, sea fog formation is unlikely. In poleward-moving air, or in air that has previously traversed a warm ocean current, the dew point is usually higher than the cold-water temperature.
- Sea fog dissipates if a change in wind direction carries the fog over a warmer surface.
- An increase in the wind speed can temporarily raise a surface fog into a stratus deck. Over very cold water, dense sea fog may persist even with high winds.
- The movement of sea fog onshore to warmer land leads to rapid dissipation. With heating from below, the fog lifts, forming a stratus deck. With further heating, this stratus layer changes into a stratocumulus cloud layer and eventually into convective clouds or dissipates entirely.

<u>(b) Radiation Fog:</u> Radiation fog occurs in air with a high dew point. This condition ensures radiation cooling lowers the air temperature to the dew point. The first step in making a good radiation fog forecast is to accurately predict the nighttime minimum temperature. Additional factors include the following:

- Air near the ground becomes saturated. When the ground surface is dry in the early evening, the dewpoint temperature of the air may drop slightly during the night due to condensation of some water vapor as dew or frost.
- In calm conditions, this type of fog is limited to a shallow layer near the ground; wind speeds of 2-7 knots bring more moist air in contact with the cool surface and cause the fog layer to thicken. A stronger breeze prevents formation of radiation fog due to mixing with drier air aloft.
- Constant or increasing dew points with height in the lowest 200 to 300 feet, so that slight mixing increases the humidity.
- Stable air mass with cloud cover during the day, clear skies at night, light winds, and moist air near the surface. These conditions often occur with a stationary, high pressure area.
- Relatively long time for radiational cooling, e.g., long nights and short days

associated with late fall and winter in humid climates of the middle latitudes.

- In nearly saturated air, light rainfall will trigger the formation of ground fog.
- In valleys, radiation fog formation is enhanced due to cooling from cold air drainage. This cooled air can result in very dense fog.
- In hilly or mountainous areas, an upper level type of radiation fog—continental high inversion fog— forms in the winter with moist air underlying a subsiding anticyclone:
- Often a stratus deck forms at the base of the subsidence inversion and lowers. Since the subsiding air above the inversion is relatively clean and dry, air at the top of the cloud deck cools by long-wave radiational cooling which intensifies the inversion and thickens the stratus layer.
- A persistent form of continental high-inversion fog occurs in valleys affected by maritime polar air. The moist maritime air may become trapped in these valleys beneath a subsiding stagnant high-pressure cell for periods of two weeks or longer. Nocturnal long wave radiational cooling of the maritime air in the valley causes stratus clouds to form for a few hours the first night after the air becomes trapped. These stratus clouds usually dissipate with surface heating the following day. On each successive night, the stratus cloud deck thickens and lasts longer into the next day. The presence of fallen snow adds moisture and reduces daytime warming, further intensifying the stratus and fog. In the absence of airmass changes, eventually the stratus clouds lower to the ground.
- The first indicator of formation of persistent high-inversion fog is the presence of a well-established, stagnant high-pressure system at the surface and 700-mb level. In addition, a strong subsidence inversion separates very humid air from a dry air mass aloft over the area of interest. The weakening or movement of the high-pressure system and the approach of a surface front dissipates this type of fog.
- Radiation fog sometimes forms about 100 feet (30 meters) above ground and builds downward. When this happens, surface temperature rises sharply. Similarly, an unexpected rise in surface temperature can indicate impending deterioration of visibility and ceiling due to fog.
- Finally, radiation fog dissipates from the edges toward the center. This area is not a favorable area for cumulus or thunderstorm development.

<u>(c) Frontal fog:</u> Frontal fog forms from the evaporation of warm precipitation as it falls into drier, colder air in a frontal system.

- Pre-frontal, or warm-frontal, fog (Figure -8) is the most common and often occurs over widespread areas ahead of warm fronts.
- Whenever the rain temperature exceeds the wet-bulb temperature of the cold air, fog or stratus form.
- Fog usually dissipates after frontal passage due to increasing temperatures and surface winds.

- Post-frontal, or cold-frontal, fog occurs less frequently than warm-frontal fog.
- Slow-moving, shallow-sloped cold fronts (Figure-9), characterized by vertically decreasing winds through the frontal surface, produce persistent, widespread areas of fog and stratus clouds 150 to 250 miles behind the surface frontal position to at least the intersection of the frontal boundary with the 850 mb.
- Strong turbulent mixing behind fast moving cold fronts, characterized by vertically increasing winds through the frontal surface, often produce stratus clouds but no fog.

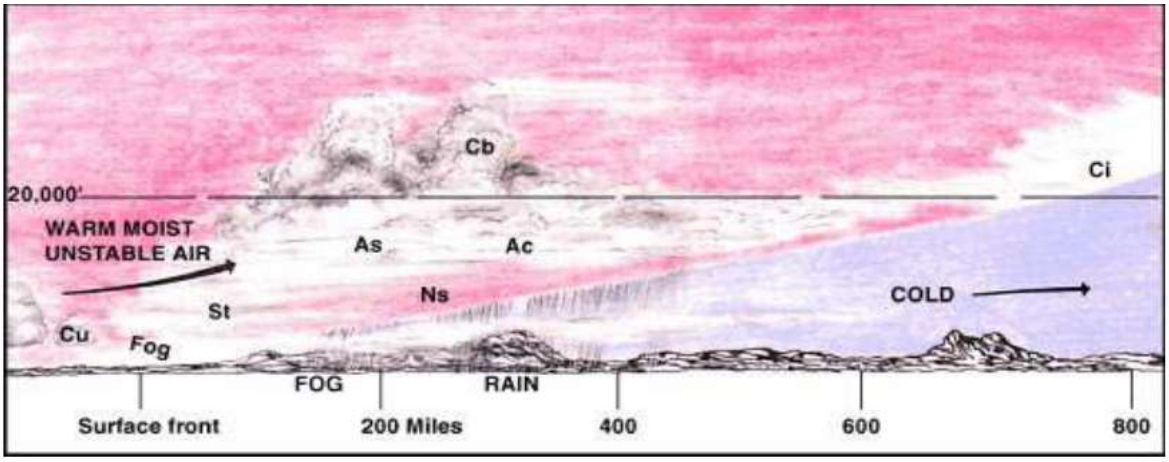


Figure-8: Pre-frntal Fog Associated with Warm Fronts

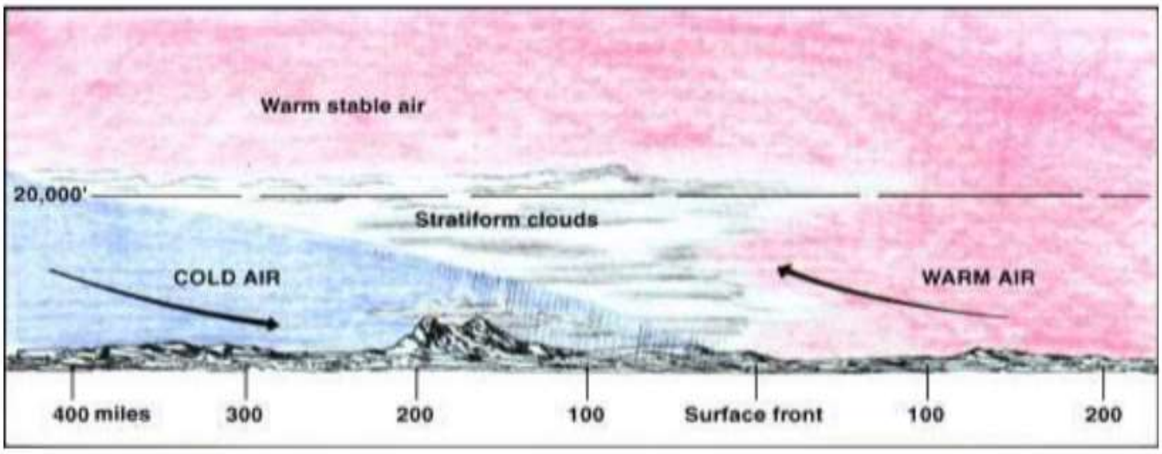


Figure-9: Post- frontal Fog Associated with Slow-Moving Cold Fronts

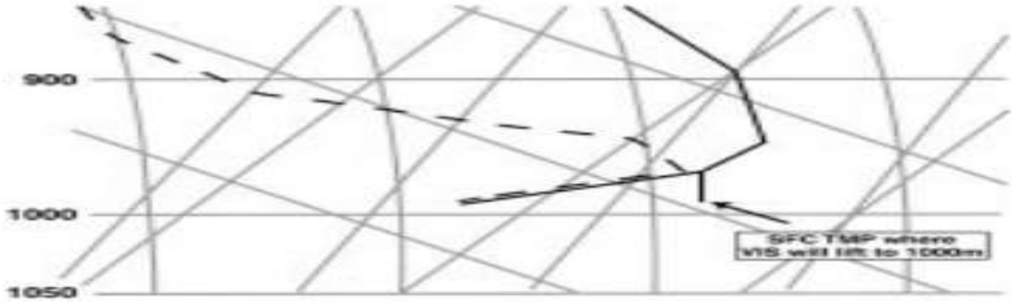


Figure-10: Radiation Fog

SESSION 9: WEATHER AND CLIMATE FORECAST FOR AGRICULTURE

9.1 Requirements of Weather Forecasts for Agriculture

9.1.1 Climate-Based Strategic Agronomic-Planning

Weather plays an important role in agricultural production. It has a profound influence on the growth, development and yields 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) physical damage to crops and (ii) soil erosion. 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 during transport and viability and vigor of seeds and planting material during storage.

Thus, there is no aspect of crop culture that is devoid of the impact of weather. However, (a) 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 amongst crops, with the same crop with the varieties and with the same crop variety with its growth stages. Even on a climatological basis weather factors show spatial variations in an area at a given time, temporal variations at a given place and year to year variations for a given place and time. For cropping purposes weather over short time periods and year-to-year fluctuations at a place over the selected interval have to be considered. For any given time-unit the percentage departures of extreme values from a mean or median value, called the coefficient of variability, is a measure of variability of the parameter The shorter the time-unit, the greater is the degree of variability of a weather parameter. Again, intensity of the above three variations differ amongst weather factors. Over short periods of time, rainfall is the most variable of all parameters, both in time and space. In fact, for rainfall the short-period inter-year variability is large, which necessitates expressing variability in terms of percentage probability of realizing a given amount of rain or specify the minimum assured rainfall amounts at a given level of probability. For optimal productivity at a given location crops and cropping practices must be such that while their cardinal phased weather requirements match the temporal march of the concerned weather element(s), endemic periods of pests, diseases and hazardous weather are avoided. In such strategic planning of crops and cropping practices, short-period climatic data, both routine and processed (like initial and conditional probabilities), have a vital role to play.

9.1.2 Usefulness of Weather Forecasts

Occurrences of erratic weather are beyond human control. However, 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. Rural proverbs abound in giving thumb rules for anticipation of local weather and timing of agricultural operations in light of expected weather. Basu (1953) found no scientific basis for anticipation of weather in many proverbs/folk lore in vogue. In a recent study Banerjee et al. (2003) have arrived at conclusions similar to that of Basu (1953). However, the proverbs/folklore show that the keenness of farmers to know in advance the likely weather situations for crop operations is time immemorial. 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 thicker sowings. However, once the crop season starts the resources and technology get committed 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, the usefulness of 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 is warranted. 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.

9.1.3 Essential of Weather Forecasts for Agriculture

Receipt of forecasts of late start of the crop season necessitates agronomic changes from the normal at the field level. Organization and execution of such a strategy comes under the category of high cost decisions and will take quite some time. Therefore, pre-seasonal forecasts must have a validity period of at least 10 days and not less than a week. Field-measures to counter the effects of forecasted hazardous weather, pests, diseases etc. take time and hence mid-seasonal forecasts must preferably be communicated 5 days and not less than 3 days in advance. Dissemination of weather forecasts after their formulation to agricultural users should be quick with minimum possible temporal lag. Some of the measures like pre-seasonal agronomic corrections, control operations against pests and diseases, supplementary irrigation and pre-poning of crop harvests will be high cost decisions. Therefore, the weather forecasts must not only be timely but must also be very accurate. Weather forecasts must ideally be issued for small areas. In the case of well-organized weather systems, the desired areal delineation of forecasts can be realized. In other cases, the area(s) to which the weather forecasts will be applicable must be unambiguously stated.

9.1.4 Some Unique Aspects of Agricultural Weather Forecasts

There are some aspects of weather forecasts for agriculture that are quite distinct from synoptic weather forecasts. In synoptic meteorology the onset and withdrawal of the monsoon is related to changes in wind circulation patterns in the upper atmosphere and associated changes in precipitable water content of air in the lower layers. Preparation of field for sowing and sowing of crop with adequate availability of seed zone soil moisture requires copious rains. Rains that do not contribute to root zone soil moisture of standing crops are ineffective. Agriculturally Significant Rains, ASRs (Venkataraman, 2001) are those that enable commencement of cropping season and that contribute to crop water needs. For agricultural purposes it is the start and end of ASRs that are important. ASRs may be received early as thundershowers or may be delayed. Venkataraman and Krishnan (private communication) have drawn attention to the feasibility of commencement of cropping season much ahead of the monsoon season in Karnataka, Kerala, West Bengal and Assam in India with the help of pre-monsoon thunderstorm rains. The climatological dates of withdrawal of monsoon and end of ARS in a region can also differ significantly. Both start and end of ASRs in a province may show intra-regional variations.

Use of Dependable Precipitation, DP at various probability percentage levels and Potential Evapotranspiration have been suggested for delineation of start and end of crop growth period on a climatological basis (Cocheme and Franquin, 1967; Brown and Cocheme, 1973; Venkataraman, 2002) and have been used in many regions. The methods however differ in time-units employed, probability level chosen for DP and fraction of PET used as a measure of adequacy of crop- rainfall. Based on considerations of level of Evaporative Power of AIR, EPA, rainfall amount required to overcome the evaporative barrier and phased moisture needs of crops demands Venkataraman (2001) had suggested (a) use of weekly or decadal periods and (b) that commencement and end of ASR be taken as the one when DP at 50% probability level begins to exceed PET and become less than 50% of PET respectively. Monthly values of PET can be interpolated to derive short period values. So, when rainfall probability data for weeks or decades and monthly values of PET are available the commencement and end of ASRs can be easily delineated.

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 and the rains once started persisting without any let up. 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. Land preparation can be done on post-facto receipt of thundershowers. However, dry-sown seeds will get baked out in absence of rains. It is prudent to sow on receipt of forecast of impending rains. So, forecasts of rainy season become crucial in such areas. In temperate regions frost can cause severe menace to agricultural productivity. Frosts normally occur when the screen temperatures reach zero degrees centigrade. The depression of radiation minimum temperature of crops below the screen minimum will vary with places and seasons. The radiative cooling will be maximal under cold nights with clear skies and minimal with warm night temperatures with cloudy skies. Thus, due to nighttime radiative cooling of crop canopies, crop-frosts can occur even when screen temperatures are above zero degrees centigrade. Similarly, Dew which influences the crop water needs and the incidence of diseases, can get deposited over crops at lower relative humidities than what is deducible from a thermohygrograph. The Frictional layer near the ground is ignored by the synoptic meteorologist but low-level winds in this layer influence the long-distance dispersal of insects (like desert locusts) and disease spores (wheat rusts).

It is hence clear that the types of forecast for critical farming operations would have some unique features that would require further processing of some elements of synoptic weather forecasts. The above aspect is dealt with in a detailed manner and on a weather element-wise basis in a subsequent chapter.

9.2 Current Status of Weather Forecast

A deterministic definition states that "weather forecast describes the anticipated meteorological conditions for a specified place (or area) and period of time"; an alternative and more probabilistic definition states that "weather forecast is an expression of probability of a particular future state of the atmospheric system in a given point or territory". In view of the above a Weather forecast may be defined as a declaration in advance of the likelihood of occurrence of future weather event(s) or condition(s) in a specified area(s) at given time-period(s) on the basis of (i) a rational study of synoptic, three-dimensional and time-series data of sufficient spatial coverage of weather parameters and (ii) analyses of correlated meteorological conditions. The positive effect of weather forecasts in agriculture is maximized if weather forecasters are aware of the farmer's requirements and farmers know how to make the most use of the forecasts that are available. Response amongst varieties of a crop to weather phenomenon is one of degree rather than of type. However, the type and intensity of weather phenomenon that cause setbacks to crops vary amongst crops and with the same crop with its growth stages. Because of crop-weather reasons, crops and cropping practices vary across areas even in the same season.

In the provision of weather forecasts for agriculture the emphasis should be on the lookout for incidence of abnormal weather and prevalence of aberrant crop situations. Now, one cannot determine abnormality unless one 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" (i) giving the times of occurrence and duration of developmental phases from sowing to harvest of major crops in the regions of their forecast interest and (ii) specifying the types of weather phenomenon for which weather warnings and forecasts are to be issued in the 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 in the crop season, for the national short-time period adopted for agrometeorological work, should also be given and such guides made available to the farming community so that any farmer will know immediately the normal features of weather for a given crop and season in his place. The week is the accepted time-unit for agrometeorological work in India. The Crop-weather calendars in use in India, using the week as the time-unit, vide a sample depicted in, are excellent examples of the type of compiled information that would assist forecasters in framing weather warnings and forecasts for use of farmers.

In weather forecasting we now have a very wide range of operational products that traditionally are classified in the following groups:

1. Now-casting (NC)
2. Very Short-Range Forecast (VSRF)
3. Short Range Forecast (SRF)
4. Medium Range Forecast (MRF)
5. Long Range Forecast (LRF)

Each weather forecast can be defined on the basis of the following criteria:

6. Dominant technology
7. Temporal range of validity after emission
8. Characters of input and output time and space resolution
9. Broadcasting needs
10. Accuracy
11. Usefulness

Table 1 shows a general description of different types of weather forecasts founded on criteria from 1 to 5; Table 2 presents an almost qualitative description founded on criteria 5 and 6.

Table 1 – Definition of weather forecasts

Type of weather forecast	Acronym	Definition	Characters of output	Dominant technology	Other aspects	Time and space resolution of typical products
Nowcasting	NC	A description of current weather variables and 0 - 2 hours description of forecasted weather variables.	A relatively complete set of variables can be produced (air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount and type, cloud amount and type, etc.)	Analysis techniques, extrapolation of trajectories, empirical models, methods derived from forecaster experience (rules of thumb). Basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radar, images from meteorological satellites, local and regional observations and so on)	A fundamental prerequisite for NC is the operational continuity and the availability an efficient broadcasting system (e.g.: very intense showers affecting a given territory must be followed with continuity in provision of information for final users.	Typical time resolution is 1 hour; typical space resolution is of the order of gamma mesoscale (20-2 km).
Very shortrange forecast	VSRF	Up to 12 hours description of weather variables	A relatively complete set of variables can be produced (see nowcasting)	Analysis techniques, extrapolation of trajectories, interpretation of forecast data and maps from NWP (LAM and GM), empirical models, methods derived from forecaster experience (rules of thumb). The basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radar,	A fundamental prerequisite for VSRF is the availability an efficient broadcasting system (e.g.: frost information must be broadcasted to farmers that can activate irrigation facilities or fires or other systems of protection).	Typical time resolution is 1-3 hours; typical space resolution is of the order of beta mesocale (200-20 km)

Type of weather forecast	Acronym	Definition	Characters of output	Dominant technology	Other aspects	Time and space resolution of typical products
				images from meteorological satellites, NWP models, local and regional observations and so on)		
Shortrange weather forecast (*)	SRF	Beyond 12 hours and up to 72 hours description of weather variables	A relatively complete set of variables can be produced (see nowcasting)	Interpretation of forecast data and maps from NWP (LAM and GM), empirical models, methods derived from forecaster experience (rules of thumb). The basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radars, images from meteorological satellites, NWP models, local and regional observations and so on)	In SRF the attention is centred on mesoscale features of different meteorological fields. SRF 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 6 hours; typical space resolution is of the order of alfa or beta mesoscale (2.000-20 km).
Mediumrange weather forecast (*)	MRF	Beyond 72 hours and up to 240 hours description of weather variables	A relatively complete set of variables can be produced (see nowcasting)	Interpretation of forecast data and maps from NWP (GM), empirical models derived from forecaster experience (rules of thumb). The basic information is represented by NWP	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,	Typical time resolution is 12-24 hours; typical space resolution is of the order of alfa mesoscale (2.000-200 km).

Type of weather forecast	Acronym	Definition	Characters of output	Dominant technology	Other aspects	Time and space resolution of typical products
				models. Techniques of "ensemble forecasting" are adopted in order to overcome the problem of depletion of skill typical of forecasts founded on 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 are created. This ensemble mean will likely have 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.	web, etc.) and can represent a fundamental information for farmers.	
Longrange forecast	LRF	From 12-30 days up to two years	Forecast is usually restricted to some fundamental variables (temperature and	Statistical (e.g.: teleconnections), and NWP methods. Coupling of atmospheric models with	An Extended-range weather forecast (ERF), beyond 10 days and up to 30 days, is sometimes	Typical time resolution is 1 month; typicall space resolution

Type of weather forecast	Acronym	Definition	Characters of output	Dominant technology	Other aspects	Time and space resolution of typical products
			precipitation); other variables like wind, relative humidity and soil moisture are sometimes presented. Information can be expressed in absolute values or in term of anomaly.	ocean general circulation models is sometimes adopted in order to enhance the quality of long-range predictions.	considered.	is of the order of the beta macroscale (10.000 – 2.000 km).

(1) It is recently observed that SRF and MRF are converging toward a unique kind of forecast, due to the fact that Numerical Weather Prediction (NWP) models are the base for SRF and MRF too. It could be more correct to distinguish between forecasts based on Global Models - GM & Limited Area Models - LAM ((from now to h + 72 h) and forecasts based only on GM (from h+72 to h + 7-15 days).

Table 2 – Accuracy, usefulness and main limitations of weather forecasts for agriculture

Type of weather forecast	Accuracy (*)	Usefulness		Main limitations
		Real	Potential	
Nowcasting	Very high	Very low	Low	Unsuitability of broadcasting system; insufficient flexibility of agricultural technology.
Very short-range forecast	Very high	Low	Moderate	Unsuitability of broadcasting system; insufficient flexibility of agricultural technology; farmers doesn't know how to make the most use of available forecasts.
Short-range weather forecast	High	Moderate	High	Further adaptation of forecasts to farmer's requirements is needed; farmers doesn't know how to make the most use of available forecasts.
Medium-range	High or moderate	High	Very high	Further adaptation of forecasts to farmer's requirements is needed; farmers

Type of weather forecast	Accuracy (*)	Usefulness		Main limitations
		Real	Potential	
weather forecast	until 5 days; lower after			doesn't know how to make the most use of available forecasts
Long-range forecast	Very low	High in warning of delays in arrival of weather systems. Very low otherwise	Poor	Reliability (the reliability of LRF is higher for the tropics than for mid latitudes. This is because tropical areas have a moderate amount of predictable signal, whereas in the mid-latitudes random weather fluctuations are usually larger than the predictable component of the weather).

(*) Subjective judgement of a weather forecaster working at mid latitudes. The judgement is referred to cloud coverage, air temperature and precipitation occurrence.

9.3 Consideration points for agro-meteorological forecasts

9.3.1 Elements of agricultural weather forecasts

An agricultural weather forecast should refer to all weather elements, which immediately affect farm planning or operations. The elements will vary from place to place and from season to season. Normally a weather forecast includes the following parameters.

- Amount and type of coverage of sky by clouds;
- Rainfall and snow;
- Maximum, minimum and dew point temperatures;
- Relative humidity;
- Wind Speed and Direction;
- Extreme events like heat and cold waves fog, frost, hail, thunderstorms, wind squalls and gales, low pressure areas, different intensities of depressions, cyclones, tornados.

An agricultural weather forecast should contain the following information also:

- Bright hours of sunshine;
- Solar radiation;
- Dew;
- Leaf wetness;
- Pan evaporation;
- Soil moisture stress conditions and supplementary irrigation for rainfed crops;
- Advice for irrigation timing and quantity in terms of pan evaporation;
- Specific information about the evolution of meteorological variables into the canopy layer in some specific cases;
- Micro-climate inside crops in specific cases.

9.3.2 Format of forecast

Formats of forecasts for agriculture are highly variable in different agricultural contexts in function of the strong variability of users, crops, agro-techniques, etc. Specialized forecasts can be referred to crops, animal husbandry, forestry, fisheries and horticulture.

Issues of forecasts cannot be devoid of a technical slant, but the forecast has to be frames in as simple a dialogue as possible to enable the farmer to readily grasp its content. Therefore, use of "intermediaries" (employed by the National Meteorological Services and/or the extension wing of agricultural services) as a vital link between the forecasters (and their products) and the farmers to explain to the farmers the use of forecasts as agrometeorological services for field operations must be provided for.

A forecast produced for educational purpose and released weekly by University of Milano (IT) is presented. This product is composed of three main parts:

- a general evolution
- forecast for seven days (cloud coverage, precipitation, wind, air temperature, other phenomena like foehn, frost, etc.)

- forecast of water balance, net primary production and growing degree days.

9.3.3 Forecasts for agricultural purposes

For arriving at forecasts additionally needed for agricultural purposes as detailed above, the initially framed forecasts would require to be modified/ processed. A more specific description of processing of weather forecasts of single weather variables for agricultural uses is presented hereafter.

A. Sky Coverage

Forecast of sky coverage can be defined adopting some standard classes like sky clear (0-2 octas), partly cloudy (3-5 octas), most cloudy (6-7 octas), overcast (8/8). It is also important to give information about the character of prevailing clouds. For example, high clouds produce a depletion of global solar radiation quite different from that produced by mid or low clouds. It is also important to give an idea of the expected variability of sky coverage in space and time. A probabilistic approach can be also adopted in order to increase the usefulness of this kind of information.

B. Bright Sunshine

Sun shining though clouds will not affect crop performance as in such a case the reduction will be in diffuse radiation from the sun-lit sky and the latter is only a fraction of Total Global Solar Radiation. So, in cloud cover forecast the fraction of cloud covering the sun should also be specified in addition to the total cloud cover.

C. Solar Radiation

The main parameters, extraterrestrial radiation, Ra and possible sunlight hours, N required to derive solar radiation, Rs from bright hours of sunshine, n, are readily available on a weekly basis for any location and period (Venkataraman, 2002). The relationship between the ratio of Rs/Ra and n/N t is a straight-line type. The value of the constants, however, varies with seasons and locations but are readily determinable.

D. Precipitation

Snow and rainfall are probably two of the most difficult forecasted variables. Quantitative forecasting of rainfall, especially of heavy downpours, is extremely difficult and realizable only within a couple of occurs of their occurrence and using highly sophisticated Doppler Radars. However, for crop operations quantitative forecast of rain is not half as important as forecast of (i) non-occurrence of rains (dry spells) and (ii) type of rain spell that can be expected.

Forecasts of rain can be defined adopting some standard classes (Table 4) that could be defined in function of the climate and the agricultural context of the selected area. A probabilistic approach is quite important in order to maximize the usefulness of this forecast. Adopting the scheme of Table 4 it is possible to produce daily information like this:

- Most cloudy or overcast with rainfall (class 3, high probability)
- Partly cloudy with improbable rainfall (class 2, very low probability)
- Sky clear with absence of precipitation.

Use of the same terms for likelihood of occurrence of rainfall and rainfall amounts as at Table 4 above will confuse the public. It is better to use different terms for the two purposes. Thus, for forecasts on chances of occurrence of rain plain language such as Nil, Very Low, Low, High and Very High chance should be used. If quantity can also be forecast, plain language terms such as scanty = < 1mm; moderate = 1-10mm; Heavy = 10-50mm and Very Heavy = > 50mm should be used. The probability of occurrence of a given quantity of rainfall will vary with places and periods. So, if probability is to be indicated for quantum of rain it should be based on climatological values of assured amounts of rainfall at various probability percentages in the area(s) and the period to which the forecast refers.

Fog can contribute significantly to crop water needs and can be measured by covering the funnel of a rain gauge with a set of fine wires. Quantitative data on fog precipitation may not be available. However, nomograms for predicting occurrence of fog at airports are available with forecasters and the same can be adopted for use in agricultural weather forecasts.

Dew is an important parameter influencing leaf-wetness duration and hence in facilitating entrance of disease spores into crop tissues, Dew is beneficial in contributing to water needs of crops in winter and in helping survival crops during periods of soil moisture stress, as the quantum of Dew collected per unit area of crop surface is many times more than that recorded with Dew Gauges. Dew is also desirable for using pesticides and fungicides in 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. Thus, nomograms used by forecasters for predicting fog can be used to predict dew in absence of low-level air turbulence and by factoring into the temperature criteria the expected depression of crop-minimum temperatures below the screen minimum.

E. Temperature

Forecast of air temperature is important for many agrometeorological applications. Forecasts of temperature of soil, water, crop canopies or specific plant organs are also important in some specific cases. Crop species exhibit the phenomenon of Thermoperiodicity, which is the differential response of crop species to daytime, nocturnal and mean air temperatures (examples: Solanaceae to Night temperatures; Papillionaceae to Daytime temperatures and Graminaceae to mean air temperatures). It is possible to derive mean day and nighttime temperatures from data of maximum and minimum temperatures.

Forecasts of temperature are generally expressed as range of expected values (e.g.: 32-36°C for maximum and 22-24°C for minimum). If forecast is referred to mountainous territories, temperature ranges could be defined for different altitudinal belts, taking into account also the effects of aspect. A particular attention could be reserved to temperature forecasts in particular moments of agricultural 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 (Examples: Wheat, Maize and Rice: 4.5, 10 and 8 degrees centigrade respectively). 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 by various crops have to be maintained. A probabilistic approach can then be adopted to forecast the probable dates of specific crops reaching particular phenological stages.

F. Humidity

For the day as a whole Dew Point temperature is a conservative parameter and is easier to forecast as changes in Dew Point temperatures are associated with onset of fresh weather systems. From maximum, minimum and dew point temperatures, minimum, maximum and average humidity can be arrived at. The user-interests understand the implications of the term Relative Humidity much better than other measures of moisture content of air like vapour pressure and precipitable water. So ultimate forecast has to be in terms of Relative Humidity. Forecast of relative humidity can be important in some specific cases. Probability of critical values (very high or very low) could be also important.

G. 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 an idea of the expected variability in speed and direction of wind. The monthly Wind Roses at a station is a climatological presentation which indicates the frequency of occurrence of wind from each of the 8 accepted points of the compass and frequencies of occurrence of defined wind speed ranges in each of the 8 directions. Wherever possible the wind roses must be looked into before issue of forecasts.

For agricultural purposes wind speed and direction are required at 2 meters height. But, weather forecasts of wind refer to heights greater than 2 meters. Change in wind direction between 2 meters and the forecast height will not occur. However, wind speed at 2 meters will be considerably lower than at the forecast height. Ready reckon tables to convert wind speeds at any height to that at 2 maters are available and may be used to forecast wind at 2 meters height.

The term Kilometers Per Hour(KmpH) is much better understood by user interests than the terms Beaufort Scale, Meters per Second, MpS or Knots. So, wind speeds must be forecast for 2-meter height in KmpH.

H. Leaf Wetness

Leaf wetness is produced by rainfall or dew, or fog. Duration of this phenomenon can be important in order to plan different activities like distribution of pesticides, harvest of crops and so on. Leaf wetness is a parameter that is scarcely recorded. A number of empirical methods cited by Matra et al. (2005) have been used to derive leaf-wetness durations from meteorological parameters. It is possible to derive the hourly march of temperatures from maximum and minimum temperatures (Venkataraman, 2002) The temperatures during night hours have to be decreased by a value equal to the depression of the radiation minimum below the screen minimum. As mentioned earlier, dew point temperature is a conservative parameter. Thus, the number of hours when dew point temperature is above the adjusted air temperature will give leaf wetness duration. Now the time taken for the moisture deposited on the crop leaves to evaporate has also to be included in the leaf wetness duration. The amount of moisture deposited on the crop may be many times more than indicated by instruments. So, the estimated moisture deposition has to be multiplied by a crop factor and the product divided by the evaporative power of the morning air. As a thumb rule two hours after sunrise may be added to the estimated duration of leaf wetness.

I. Evapotranspiration

Forecast of evapotranspiration can be important in order to improve the knowledge of water status of crops. This kind of forecast is founded on correct forecast of solar radiation, temperature, relative humidity and wind speed. For real-time use forecasts of evapotranspiration has to be founded on forecast of Pan Evaporation as detailed below.

The Evaporative Power of Air, EPA determines the peak water needs of vegetative crops and is the datum to which all measurements of evapotranspiration, ET should relate. FAO (Allen et al., 1998) has advocated the use of Reference Evapotranspiration ETo as a standard measure of EPA. Computation of ETo requires data of net radiation over a green crop canopy, low level wind and saturation deficit of air. An empirical method to compute ETo from routinely available meteorological data has been proposed. ETo refers to turf grass. Agricultural crops have peak water needs greater than that of turf grass and tall crops can have higher peak water needs than short ones. Data to compute ETo on an operational basis are neither available widely nor readily.

Evaporation from pans filled with water, EP is subject to weather-action in a manner similar to that of EPA. EP is also easily measured. Methodology to compute ETo using measured values of solar and atmospheric radiation and use of the same to derive ratios of ETo to EP at a number of stations covering typical climate regimes have been detailed by Venkataraman et al. (1984), Use of pan coefficients to derive ETo under varied surroundings and typical setting of the pans have been suggested (Allen et al., 1998). Data on EP and studies relating ET of crops to EP are available. The ratio of peak ET to EP, called Relative Evapotranspiration, RET can vary in space and time but is not difficult of determination.

J. Water Balance

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. This kind of forecast for rainfed crops is founded on correct forecast of precipitation and evapotranspiration. The water balance approach to arrive at soil moisture excess or deficiency would require daily forecasts of rain in the first month of crop growth and on a short-period basis thereafter. Influence of physiological control on crop water uptake during maturity (Hattendorf et al., 1988; Venkataraman, 1995) is also important. Since irrigation water is applied ahead of crop-water consumption for forecasts of irrigation scheduling forecasts of evapotranspiration and likely rainfall amounts on a short-period basis will do.

K. Extreme Events

The low level of predictability of extreme events acting at meso or micro scale (frost, thunderstorms, hail, tornadoes, etc.) is an important limitation to the usefulness of forecasts for agriculture. In Table 5, obtained from a subjective evaluation founded on state of art forecast technologies, is represented the level of predictability of some extreme events with strong effects on agriculture. In order to give correct information to farmers, the adoption of a probabilistic approach could be important.