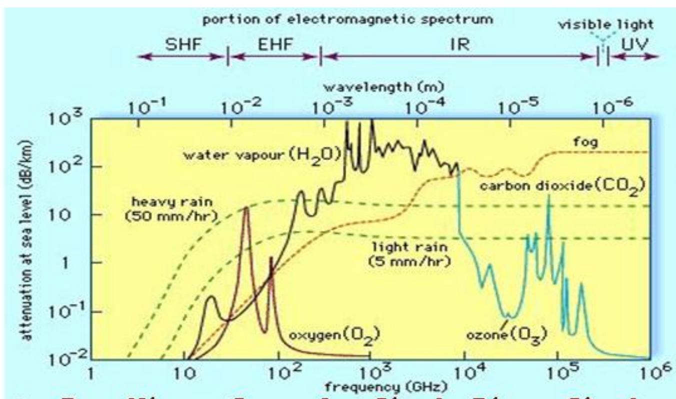
A Text Book on Agricultural Meteorology



Ram Niwas, Surender Singh, Diwan Singh

M L Khichar and Raj Singh

AICRP on Agrometeorology

Department of Agricultural Meteorology

CCS Haryana Agricultural University

Hisar – 125 004, India

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Foreword

Agriculture is one field of the human activity which is specially sensitive to weather and climate. The study of these two aspects in relation to agriculture is referred as Agricultural Meteorology and is a multidisciplinary science. Agricultural meteorology when properly applied can achieve the sustainability of agricultural production system through efficient management of agro-climatic resources and crop microclimate modification. Each and every plant developmental phase is decided by meteorological parameters. Every genotype has its own optimum climatic requirements for expression of its full potential. Therefore, the knowledge of meteorological parameters and their influence on crop growth and yield is essential for agricultural students.

A separate department of Agricultural Meteorology was created in February, 1982 at College of Agriculture, CCS Haryana Agricultural University, Hisar on the recommendations of National Commission on Agriculture (1976). Department offers courses in discipline of Agricultural Meteorology at MSc and PhD levels. However, the undergraduate courses in the discipline of Agricultural Meteorology were framed even before the inception of the department.

There are few text books on or related to Agricultural Meteorology and no single text book cover the course fully at undergraduate level. Therefore, the present effort of the authors in bringing out a comprehensive and informative text book covering complete syllabus at undergraduate level in Agril Meteorology is laudable. The book has been organized in 14 Chapters covering different aspects of Agril Meteorology. The contents are highly relevant and cover both, the basic and applied aspects of agrometeorology.

The faculty members in the Dept of Agricultural Meteorology under the guidance of Dr Diwan Singh, Professor and Head have prepared **'A Text Book on Agricultural Meteorology',** deserve compliments for their efforts. The book dwells upon various basic and applied knowledge of meteorology which forms the syllabi for the students of BSc (Hons) Agriculture. I do hope that the present book will be a valuable source of information for students and teachers engaged in various applications of Agricultural Meteorology.

(**D C Gupta**)
Dean, College of Agriculture
CCS HAU Hisar

December, 2006

Preface

Agricultural Meteorology is an important discipline in the field of agriculture and is taught at undergraduate level in all agricultural universities. Some of the SAUs have separate department of Agricultural Meteorology and imparts education for Master and Doctorate degrees in this discipline. Quite a few text books have been published in the subject of Agricultural Meteorology. The syllabus in Agricultural Meteorology at undergraduate level covers elementary aspects of applied branch of meteorology and climatology in agriculture. Therefore, the present text book entitled 'Agricultural Meteorology' brought out with latest information and illustrations in accordance with the syllabus framed at undergraduate level by ICAR.

This book is organized with a series of pictures that illustrate the principles of Agricultural Meteorology which are fundamental to the understanding of the subject by students and other readers. The text book contains fourteen chapters which have been organized in order of increasing complexity. The chapters contain the definitions, aim, scopes and importance of Agricultural Meteorology, various meteorological parameters viz., radiation, air temperature, air pressure, winds, humidity and evaporation/evapotranspiration. The book also includes chapters on processes of condensation and precipitation, cloud classification monsoon winds, their types, Indian monsoon, significance of weather forecasting in agriculture, its different types and methods and climate of Haryana and India, the impact of climatic elements on crop production and agroclimatic requirements of major crops of Haryana. Significant and relevant issues pertaining to climate change and its impact on crop production, climatic classification, soil agroclimatic zones of Haryana and agroecological zones of India have also been discussed in the book.

The present text book on **'Agricultural Meteorology'** prepared by my colleagues in the department of Agricultural Meteorology contains basic and various applied aspect of meteorology in agriculture. I wish to congratulate the authors for highly useful and relevant publication of immense use.

(**Diwan Singh**)
Professor and Head
Dept of Agril Meteorology

Acknowledgements

The authors wish to acknowledge the financial assistance received from Indian Council of Agricultural Research (ICAR) for publication **"A Text Book on Agricultural Meteorology"** under the Development Assistance Plan Scheme. Special gratitude is expressed to Dr D C Gupta, Dean, College of Agriculture, CCS HAU Hisar for his able guidance and encouragement for preparation of this text book. The subject matter used/quoted in the manual is from many books, journals, technical bulletins and manuals in India and abroad. The original contribution from all the authors and institutions, thus, is due fully acknowledged.

We are highly indebted to the undergraduate students of the College of Agriculture, CCS HAU, Hisar of the past 30 years, who served as critics in the development of a functional approach to the teaching of the discipline of Agricultural Meteorology.

The authors anticipate that the text book will be of immense use to students of agricultural stream who desire to further devote their career for protection of natural ecosystems and for increasing agricultural productivity with sustainability. The suggestions and comments from students, teachers and researchers for further improvement of this book are welcomed.

Hisar **Authors**
December, 2006

1. AIM, COMPONENTS AND SCOPE OF AGRICULTURAL METEOROLOGY

The weather and climate are the most important components of our physical environment, which determines the plant growth, development and yield. So, it is most important to understand the effect of weather/climate on the life processes of plants and animals and to optimize food production through understanding of crop-weather-pest interactions and by minimizing losses through weather vagaries.

Definitions

Weather refers to the physical state of atmosphere (envelop of gasses surrounding the earth) at a given time over a place. **Weather may be defined as instaneous condition of atmosphere over a place**. It is highly variable and constantly changing from hour to hour or day to day. The entity that determines the state of weather is called as factor/element of weather. Weather elements are not separate rather they are interrelated.

The word climate comes from the Greek word 'klima', which literally means inclination/slope. Climate may be defined as the sum total of the different weather conditions of a place from day to day or climate may be defined simply as average state of weather. The term climate refers to a description of aggregate weather conditions. It also includes deviations from average condition as well as the extreme weather conditions. Therefore, **climate may be defined as the average of weather informations of a particular area during a specified period of time i.e. more than 30 years.**

Trewartha defined climate as a composite of day-to-day weather conditions, and of the atmospheric elements, within a specified area over a long period of time.

Critchfield defined climate as "The processes of exchange of heat and moisture between the earth and atmosphere over a long period of time result in conditions which we call climate."

G.F.Taylor defined climate is the integration of weather and weather is the differentiation of climate. The distinction between weather and climate is, therefore, mainly one of time.

Climatology is the combination of two Greek words, klima and logos. 'klima' means slope of earth and 'logos' means study. According to **D.S. Lal,** climatology is that seeks to describe and explain the nature of climate. According to **Critichfied**, it is the science that seeks to describe and explains the nature of climate, why it differs from place to place, and how it is related to other elements of the natural environment and human activities. **Climatology may be defined as the study of distribution of climatic elements over a region for a long period of time**. Briefly, climatology may be defined as study of climate.

Meteorology is the branch of science, which study day-to-day atmospheric conditions and their causes. In brief, it may be defined as the physics of atmosphere or the science, which studies weather. **Meteorology is the science, which study the physical processes occurring in the atmosphere, those produce weather.**

Agricultural meteorology is the branch of meteorology which studies the impact of weather on agricultural farming. It may be defined as the science which studies the interaction between weather and agriculture including field crops, horticultural crops, vegetables, animal husbandry etc. **G.S.L.H.V. Prasada Rao** defined agricultural meteorology as the science which deals with the influence of weather on crop husbandry and animal husbandry.

Physical climatology is the branch of climatology which seeks to describe the factors responsible for bringing about the temporal and spatial variations in heat, moisture and momentum exchange between earth surface and its atmosphere and within atmosphere. Observations on climatic elements such as insolation, sunshine duration, temperature, air pressure, winds, etc. help to study physical environment. These climatic elements, individually or in combination are the resultant of complex exchange processes of heat, moisture and momentum.

Regional climatology is the branch of climatology, which determines and describes the different types of climates. On the basis of spatial scale climatic region is divided into macro-climatic region, meso-climatic region and micro-climatic region. Continental or oceanic factors control macroclimate whereas meso and microclimates are influenced by local factors. **Microclimatology** is the branch of science which study climatic elements in a particular location e.g. in field crops, orchards, animal shed etc. **Applied climatology** is the branch of climatology, which study the application of climatological knowledge to specific practical problems.

Agricultural climatology may be defined as the science, which applies climatic knowledge to understand agricultural problems, or it may be defined as study of climatic elements in relation to agriculture.

Weather elements

Any entity that controls the weather is called as element or factor of weather. There are various factors which individually on in combination control the weather, which are given below:

1. Solar radiation
2. Temperature
3. Air pressure
4. Wind
5. Sunshine
6. Humidity
7. Cloudiness
8. Precipitation, etc.

All these elements are highly variable and constitute the weather. Day to day or hour-to-hour changes in weather are mainly the result of variations in the amount, intensity and distribution over earth of weather elements listed above.

Importance of weather elements

The weather elements constitute a physical environment in which an organism or a plant grows. Success or failure of a bio-system depends upon the weather conditions. The rate of growth and development of a bio-system is largely depend upon its ambient temperature and moisture. The management and execution of agricultural farm practices is also weather dependent. The maximum efficiency of farm practices can be achieved with knowledge of prevailing and anticipated weather. Some of the farm practices are listed below:

1. Selection of animals, breeds, crops and varieties.
2. Management of farm inputs, machinery and labour, etc.
3. Sowing of seeds, nursery preparation, planting of seedlings etc.
4. Scheduling of irrigation.
5. Spraying of biofertilizers, weedicides and pesticides on crops, germicides in case of animals, birds, etc.
6. Application of fertilizers in crops and feeds in case of dairy animals and poultry birds, etc.
7. Harvesting and threshing of field crops, plucking of vegetables and fruits, etc.
8. Transportation of crop produce, vegetables, fruits, animals and their products, etc.
9. Post harvest processing of crop produce, vegetable, fruits, animal products, mushrooms, etc.

If the anticipated weather is not favorable as forecasted by meteorological office, the above said farm practices can be managed accordingly. For example coming weather is associated with hot and dry winds or rough weather, then harvesting and transportation of perishable farm products may be withheld for time to be fine weather or may be transported with special care in case rough weather prolongs, to avoid losses due to unfavourable weather. Also efficiency of farm inputs such as fertilizers, seeds, labour, pesticide spray, etc. can be improved if applied with the knowledge of weather. Heavy rainfall after fertilizer application in crop field causes leaching losses in nitrogenous fertilizers. Rainy weather is not favorable for spraying chemicals in crops as it washes out the spray material from the crop plants.

Effects of weather elements on crops

Light

Light is the primary source of energy, without which living organism could not exist. It is a vital factor to all living things. Green plant obtains the energy necessary for life directly from sunlight. Light is the visible portion of solar spectrum having wavelength range from 0.4 to 0.7 μm. It is also called as photosynthetically active radiation (PAR).

The light intensity affects the crop plants through its effect on photosynthesis. Very low light intensity reduces the photosynthesis as stomata are closed which restrict the intake of CO_2 gas. The rate of photosynthesis increases with increase in light intensity. The light intensity at which respiration equals photosynthesis is called as **light compensation point**. The **light saturation point** is the light intensity at which rate of photosynthesis becomes constant.

The amount of light received by plant is determined by intensity of light and its duration. In natural environment the length of day may have an even greater effect on the total amount of light received than does light intensity. The response of plants to relative length of day and night is known as **photoperiodism**. On the basis of response of day length the plants are classified as:

Long day plant: Plant develops/flowers normally when photoperiod is greater than 12 hours e.g. Cereals (wheat, barley), potato and sugarcane.

Short day plant: The plant flowers normally when photoperiod is less than 12 hours e.g. Tobacco, soybean, maize

Day natural plant/Indeterminate plant: Not affected by the photoepriod e.g. Tomato, cotton, pineapple etc.

Light plays an important role in orienting the growth of plants. This movement or orientation, if caused by light is called **phototropism**. Leaves are usually oriented at right angles to the incident light, in a position to receive maximum radiation e.g. sunflower.

Temperature

Temperature is the intensity aspect of heat energy. Solar radiation is the primary source of both light and heat energy for living organisms. Transfer of heat energy between the plant and its environment is of great importance. When the sun's rays strike the surface of the earth, much of the radiation is degraded into heat energy. Only small portion of light energy absorbed by a green plant is used for food energy. Temperature of day and night also affects the crop. If the days are warm, good for photosynthesis but if nights are warm, the loss of respiration is higher. High night temperature favors growth of shoots and leaves and also affects plant metabolism. Plants, which are adapted to hot climate, if exposed to low temperature for sometime, are found to be killed or injured. Some effects of chilling are development of chloratic condition (yellowing) in sugarcane, sorghum and maize in winter months when night temperature is below 20^0C. When the plants are exposed to very low temperature, water freezes into ice crystals in intercellular spaces of the plants and resulting into the death of cells e.g. frost damages in potato, brinjal etc. The temperature range of 10-40^oC is the favorable range for crop plants. The plant cells get killed when they are exposed to the temperature range from 50 to 60^0C. This point of temperature called **thermal death point**. This varies from plant to plant and species to species. Higher temperature disturbs the physiological activities like photosynthesis and respiration. Higher temperature increases respiration leading to rapid depletion of reserved food. It also increases transpiration loss of water and causes water deficit in crop plants under limited water supply.

Moisture

Its presence in the atmosphere plays a significant role. An abundance of moisture results in a rich natural flora and makes possible a wide choice of crops. Deficiency of moisture, on the other hand, permits only narrow range of potential crops, and is accompanied by hazards to efficient crop production. The presence of moisture in atmosphere is termed as humidity.

Increasing relative humidity decreases the rate of transpiration. Reduction in transpiration reduces the translocation of food material and uptake of nutrients. The relative humidity range from 60 to 80 per cent is good for crop growth. A very high relative humidity is beneficial to maize, sorghum, sugarcane and it is harmful to gram, sunflower and tobacco. Humidity also affects the water requirement through evapotranspiration. High humidity with high temperature favours the outbreak of pest and disease.

Functioning of stomata is often greatly reduced under low moisture/moisture stress condition. Photosynthesis is hampered by reduction of stomatal opening limiting CO_2 absorption. Cell size and shape are reduced under moisture deficient condition and ultimately plant growth and yield is reduced.

Too much water may be harmful to plants just as too little. High soil moisture and humidity condition cause failure in establishing stand of legumes and grasses. Excess of soil moisture in earlier growing season may result in more vegetative growth and delayed flowering.

Rainfall

Rainfall spread is very uneven. Some area is desert receives less than 12 cm and some places receive more than 1000 cm rainfall. Rainfed crops directly depend on rain. The water source such as rivers, tanks and wells, which supply water for irrigation also depend on the rain. Rain occurring during the flowering and grain filling period is very harmful. After the spray it reduces the efficiency of agrochemical. Heavy rain induces soil erosion and leaching of nutrient. Deficient rain causes drought and limits the crop growth and production.

Dew

The condensation of water vapor from adjacent air layer upon surface cooled by radiation loss is called dew. As a result of rapid radiation loss from the earth's surface, the adjacent layer of air is cooled to point of saturation (dew point) and condensation takes place. If the dew point is above 0^0C, the condensed water vapour will be in the form of dew. If it is below 0^0C, white frost will form. Dew acts as a source of moisture for the crop plants. It causes reduction in transpiration rate and saving of soil moisture reserves. Dew fall helps in insect-pest and diseases spread in crop plants.

Fog

When air masses of high moisture content close to the earth surface are cooled, fog may form. Thick fog is more frequent in smoky cities. Fog is important for natural vegetation as moisture source. Fog can also benefit crop plants through a contribution to its water balance. Fog also favours pest and diseases incidence in crops.

Wind

Horizontal movement of air is called wind. Winds are named after direction from which it comes. It blows from north-east to south east, it is named as north east wind. **windward** refers to the direction from which the wind comes and **leeward** refers to the direction in which the wind blows.

Wind influences the plant life both physiologically and mechanically. Wind affects plant directly by increasing the transpiration and intake of CO_2. Thus raising the supply of CO_2 to the plants and thereby increase in photosynthesis. However, the increase in photosynthesis is again upto a certain wind speed beyond which its rate become constant. The warm and dry winds increase evaporative loss and cause moisture stress when soil temperature is very low. Lodging is one of severe injury caused by strong winds which causes great yield loss depending upon the stage of crop. This injury is common in paddy, maize, wheat, sorghum and sugarcane. Strong winds damage fruit trees extensively by breaking leaves and twigs and causing fruit drops.

Aim and Scopes of Agricultural Meteorology

Aim

Agricultural meteorology studies the interaction between physical environment on one hand and agriculture including dairy farming, poultry, bee keeping etc. on the other hand. So, the knowledge of physical environment can be used for increasing production of an agricultural farm. Crop production can be maximized by reducing the crop losses due to pest-disease attack, with the use of pest-weather interaction in timely management of pest and diseases. The ultimate aim of agricultural meteorology is to increase the crop production to maximum level with efficient use of available natural climatic resources and through weather based management of biotic and abiotic stress.

Scopes

1. It is concerned with interactions between meteorological and hydrological variables, on the one hand, and agriculture in the widest sense, including horticulture, animal husbandry and forestry, on the other.
2. To apply knowledge of atmospheric phenomena to practical agricultural use from soil layer of deepest plant roots to higher levels of atmosphere.
3. Exploitation of natural climatic resources and their modification to increase the efficiency of ecosystem.

Agricultural Meteorology is the application of meteorology in various disciplines of agriculture listed below:

1. Agronomy and Agroforestry
2. Plant pathology
3. Entomology and Nematology
4. Horticulture and Vegetables
5. Soil Science
6. Animal Husbandry
7. Water Management Engineering

The scopes of Agricultural Meteorology in above mentioned fields are summarized as below:

1. Efficient and effective agronomic practices can be adopted based on current and probable weather knowledge.
2. Effective crop planning with efficient utilization of climatic resources can be made with proper delineation of agro-ecological zoning.
3. The utilization efficiency of agro-chemicals can be improved with knowledge of physical environment.
4. Weather-crop-pest interaction can be studied, which will help in management of crop insect-pest and diseases.
5. Livestock production can be maximized by proper modification of micro climate of animal and birds sheds.
6. Losses in transport and storage of farm products can be minimized to some extent with knowledge of probable weather.
7. Water management in crops can be improved with the aid of knowledge of physical environment.

Challenges and responsibilities of Agricultural Meteorology

1. To provide food for the population by applying all available meteorological knowledge in solving the problems of agricultural food production and distribution in cooperation with other scientists.
2. Quantitative information in the form of crop condition reports and yield prospects is essential for planning and managing national food production and distribution.

3. Efficient use of global natural resources for food production and on better distribution systems.

Responsibilities

1. To specify the meteorological and biological observations which are required for agricultural meteorology and to organize a special network of agro meteorological observation stations.
2. To collect and process such observations whether of a permanent or temporary nature.
3. To collect from other divisions such of the routine meteorological observations as are required for agricultural meteorological research and investigations.
4. To specify and issue the weather forecasts required for agriculture, and dissemination to agricultural interests.
5. To coordinate research and investigations in agricultural meteorology in close collaboration with other scientific institutions having related responsibilities, and to carry out such research and investigations as are required.
6. To maintain close contacts with agriculturists with a view of keeping them informed of the services which meteorologists can provide to agriculture and in order to be kept informed of the changing needs of agriculturists arising.
7. To prepare and arrange for the publication and wide distribution among agriculturists of bulletins containing meteorological advice and information of interest to agriculturists, to keep those publications upto date by revision, as necessary and to assist, as require, in arranging for the free exchange of these pamphlets among members of meteorological organization.

Components of Agricultural Meteorology

1. Agrometeorological monitoring - Techniques, data collection and networks, experiments.
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.
3. Plant injury and crop losses - Pests and diseases, pollution, effects of weather hazards on crops, cold hardiness and frost and freezing damage.
4. Livestock health and production - Environmental problems of livestock housing and health and production.
5. 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.
6. Climatic resource - Climatological surveys, ecosystem assessment, landuse pattern, climatic analogues, climatic variability, climatological statistics and processed data and agroclimatic resource analysis.
7. Soil resources - Soil deterioration and erosion, loss of farm land through urbanization and land reclamation.
8. Water resources - Agricultural water needs, water-use efficiency of crops, irrigation requirements and scheduling, water surplus and drainage and agricultural drought.
9. Management operations - Weather-climate analysis in relation of field work-days, forage crop harvest conditions, hay drying, frost and disease control and weather forecasting requirements of agriculture.
10. Artificial modification of meteorological and hydrological regimes - Protection against adverse weather conditions, controlled climate and weather modification.
11. Forest meteorology - Protection and conservation of forest resources and farm forestry.

12. Economic value of agro-meteorological information and advice - Services used in farm planning and operations.

Roles

1. To co-operate with and seek advice from agricultural services in all matters of common interest.
2. To supply available meteorological data required by agricultural scientists in their research, experimental or advisory work.
3. To advice on best utilization of agroclimatic resources in improving the agricultural production, introduction of new species of plants and animals and increasing the area in efficient farming use.
4. To assist agricultural and allied interests in combating unfavourable weather and climate.
5. To assist in fight against agricultural pests and diseases by considering both the environmental factors during their life histories and the meteorological factors which may influence the effectiveness of the protective measures taken.
6. To advise on the protection of agricultural products, in storage and in transit against damage by weather.
7. Operationally useful forecasts of meteorological variables that are important to current farming operations together with an agricultural interpretations of such forecasts.
8. Education programmes for farmers to demonstrate the usefulness of weather information for agricultural planning and operations.
9. Joint research projects on agriculture-weather relationships and their applications to farming practices.
10. Joint training and extension programmes on crop-weather aspects for better utilization of weather resources.

Climatic controls

Variation in weather factors is caused by climatic control. The factors, which control the climate of place, are called controls of climate. These controls may operate in different combinations with different intensities. The variation of weather or climatic elements is both spatial and vertical. The following are some of the most important climatic controls:

1. Latitude
2. Land and water distribution over earth
3. Altitude
4. High and low pressure systems
5. Winds
6. Air masses
7. Ocean currents
8. Mountain barriers
9. Distance from sea
10. Topography
11. Soil type and its color
12. Vegetation

2. THE ATMOSPHERE AND SOLAR RADIATION

A blanket of gasses, suspended liquids and solids covers the planet earth. This gaseous envelop around earth is called as **atmosphere**. This comprised of three spheres i.e.

1. **Lithosphere:** It comprises of land.
2. **Hydrosphere:** It comprises of water.
3. **Atmosphere:** It comprises of gases.

The atmosphere is a very thin layer in comparison with radius of earth. It is inseparable from earth because of the gravitational force. The atmosphere extends outward several thousand kilometers. It is transparent to many forms of radiation and it can absorb others. Although air is not so dense as that of land and water, it has weight and exerts pressure but its density decreases with altitude as it is compressible. About half of the total mass lies below 5.5 kilometer and nearly 99 per cent lies within 30 km of the earth surface. Atmosphere acts as a shield, which protects the earth from full range of solar radiation during day and prevent from excessive loss of heat during night. Therefore, atmosphere provides congenial environment for life on the earth. In the absence of atmosphere there would have been great extremes of temperature to the tune of 260^{o}C between day and night. Such situation might have made life impossible on the earth.

Atmospheric composition

The atmosphere is a mixture of many gases (Table 1). It also contains

Table 1. Dry air composition in lower atmosphere

Gas	Per cent by volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.03
Neon	0.0018
Helium	0.0005
Ozone	0.00006
Hydrogen	0.00005
Krypton, xenome, methane	Trace

solid and liquid particles, collectively called as **aerosols**. Four major gases namely: nitrogen, oxygen, argon and carbon dioxide accounts for more than 99 per cent of dry air. Nitrogen alone constitutes nearly 4/5th and oxygen nearly 1/5th by volume. Argon is chemically inert, as are neon, helium, krypton and xenon.

1. **Nitrogen:** It is an important gas in atmosphere, which constitute about 78 per cent by volume. It does not easily enter into chemical reaction with other substances, but it is an important constituent of many organic compounds. Its main function in the atmosphere is to regulate combustion by diluting oxygen.
2. **Oxygen:** It is the second most abundant gas in atmosphere. It is also one of the important constituents necessary for life on earth. It is essential for combustion when any substance burns it is consumed.
3. **Carbon dioxide:** It is a natural constituent of the atmosphere. It constitutes only about 0.03 per cent by volume. It is an efficient absorber of radiant energy in certain wavelengths of the infrared region. It is also important for photosynthesis in green plants, which fix carbon from carbon dioxide in presence of light and release oxygen.
4. **Ozone:** It is found in very minute quantities near the earth surface. This gas is produced in the lower environment in smog through the photochemical reaction.

Nitrogen oxide, a product of combustion dissociates by the action of solar radiation and free oxygen atom, thus released combines with oxygen molecule ($O+O_2 \rightarrow O_3$). The greatest concentration of ozone is found between 20 and 25 kilometers in stratosphere (Fig. 2.1). Ozone is a corrosive and toxic gas and cause irritation when formed in the lower atmosphere. It is also formed by lightening discharges.

5. **Water vapour:** It is one of the most variable gases in the atmosphere, which is present in small amounts but it is very important. The water vapour content of air varies from 0.02 per cent in dry climate to nearly 4 per cent by volume in the humid tropical climate. Like carbon dioxide, water vapour plays important role in insulating action of atmosphere. It absorbs not only long wave terrestrial radiation but also a part of incoming solar radiation. Water vapour is the source of all forms of condensation and precipitation. Latent heat of condensation is ultimate driving force for most of the weather systems.

Structure of atmosphere

The atmosphere is divided into two spheres based on the proportion of gases:

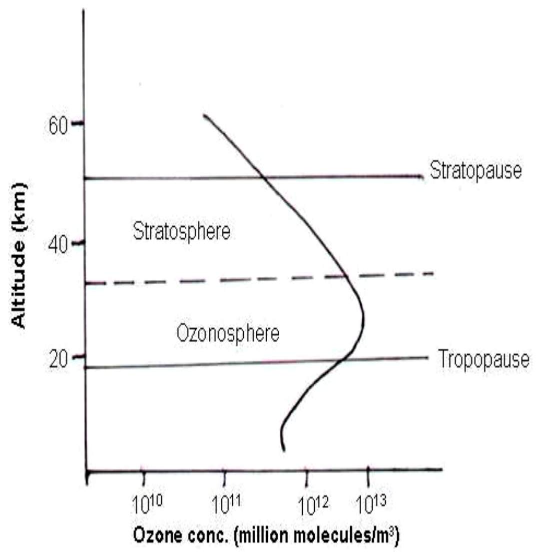


Fig. 2.1. Hypothetical variation of ozone concentration in atmosphere

1. **Homosphere:** The gaseous proportion of the atmosphere remains fairly constant in this sphere is called homosphere. The altitude of this sphere is nearly 80 km.
2. **Heterosphere:** The part of atmosphere above homosphere is called heterosphere where, the proportion of gases changes with altitude.

On the basis of temperature variation with height above the earth surface, the atmosphere is divided into four atmospheric layers (Fig. 2.2).

Troposphere

- Troposphere literally means region of turbulence, derived from Greek word tropos means 'mixing or turbulence'.
- It is the lower layer of the atmosphere
- It extends to an elevation of 16-18 km over equator and 8 kilometers over poles above the earth surface. It tends to be higher in summer than in winter.
- The most important feature of the layer is that there is decrease in temperature with altitude to a minimum of –50 or –60°C with mean lapse rate of 6.5°C/km and 3.5°F/1000 feet.
- The transition zone where the decrease in temperature with altitude ceases is called tropopause or it is the layer where troposphere ends.

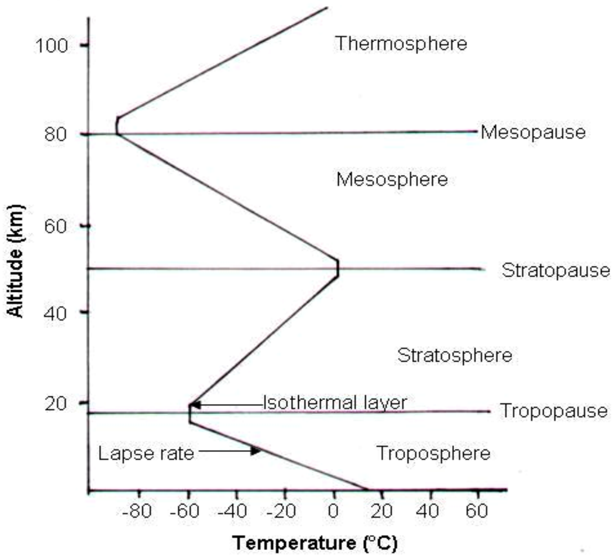


Fig. 2.2. Layers of atmosphere

- It is also called convective region, and convective activities ceases at tropopause.
- Wind velocities increase with height above the earth surface.
- Various types of clouds, thunder storms as well as cyclones and anticyclones occur in this layer of atmosphere.
- Nearly 80 per cent of atmospheric mass is confined in this layer of atmosphere.

Stratosphere

- It begins at tropopause, and extends upto a height of 50 km above the earth surface.
- The lower stratosphere is isothermal (No change in temperature with elevation) in character.
- This atmospheric layer is characterised by increase in temperature with altitude. This increase in temperature is associated with absorption of ultra violet radiation by ozone gas.
- Ozone is present in stratosphere, which absorbs ultraviolet radiation. Its concentration is maximum at 20-25 km altitude.
- The increase in temperature with altitude ceases near its outer limit, called as stratopause. Stratopause is not much cooler than at sea level.
- Cirrus clouds, called the mother of pearl clouds, occasionally from in the lower stratosphere.
- The air in this sphere is very dry, i.e. less than 0.01 gm of water vapour/kg of air.
- Nacreous clouds are the clouds in stratosphere, which display entire spectrum of colours when light above the earth shadow illuminates them.

Mesosphere

- Mesosphere starts from stratopause and extends upto 80 km above the earth surface.
- In this layer, again temperature decreases with elevation and drops to a minimum of –92^{o}C at mesopause, this is the upper limit of mesosphere.
- The lowest temperature point in atmosphere is at mesopause.
- Most of the meteors burn out, as they enters in mesosphere, due to increasing friction in this layer.
- Noctilucent clouds are high level clouds (70-90 km) can only be seen during twilight period. They are best seen when the sun is between 5-8° below horizon. It may be for this reason that these clouds are observed most often at high latitudes, where there are long twilight periods.

Thermosphere

- The uppermost layer of atmosphere is thermosphere.
- Above the mesopause, the temperature increases rapidly at first and then more slowly with height. This increase in temperature may be associated with absorption of 'X' rays in the lower part of thermosphere, called as Ionosphere.
- Ionosphere is characterised by ionization of gases by the action of highly energetic 'X' rays coming from sun. It extends upto 400 km above the earth surface.
- Radio waves are reflected by ionized particles present in ionosphere.
- The temperature increases to 2000^{o}C at about 500 km altitude. But one would not feel that hot that is implied by 2000^{o}C in thermosphere, simply because, although the individual particles have kinetic energies that are representative of such a high temperature, there are few gas particles at such altitudes that the total energy transmitted to a body through collisions is indeed quite smaller compared to the energy transmitted by much colder molecules at sea level.
- Above 500-600 km, the density of particles is so low that collisions among them are in frequent and some of particles may escape from gravitational pull of earth. This zone marks transition between earth surface's atmosphere and thin interplanetary gas is called **exosphere**.
- The aurora borealis in northern and counter part aurora australis, apparently result from excitation of the ionosphere by streams of high-energy particles from the sun.
- The aurora has been observed to increase with increase in sun spot activity.

Solar Radiation

The solar energy is the main source of energy for the processes occurring at the earth surface and in its atmosphere. The amount of energy received from other celestial bodies is negligible in comparison to the solar energy. The energy in the form of radiation that strikes the earth is called **insolation** or the solar radiation that comes to the earth is called as **incoming solar radiation** and the energy in the form of radiation that leaves the earth surface is called **out going radiation**.

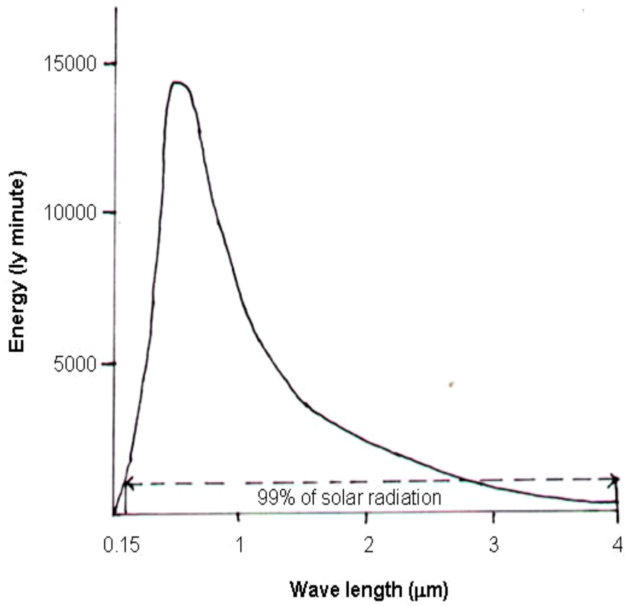


Fig. 2.3. Solar energy distribution per unit wave length

Definitions

1. Solar radiation: The solar energy that reaches the earth surface in the form of electromagnetic wave is called solar radiation. It is also called short wave radiation. Ninety nine per cent solar radiations lies within the wavelength range of 0.15 to 4.0 µm (Fig. 2.3).

2. Radiant flux: It is the amount of energy radiated, transmitted or absorbed per unit time. Its unit is watt (Joule/sec).

3. Radiant flux density or radiation intensity: It may be defined as radiant flux per unit area. Its unit is watt/m^2.

4. Irradiance: It is the radiation intensity incident on a surface.

5. Emittance: Radiant flux density emitted by a surface.

6. Radiance: Radiation intensity (I) emitted in a particular direction divided by apparent area (A) of the source in the same direction. Radiance = I/A

7. Isohel: It is the line joining the places having equal duration of sunshine hours.

Solar constant

The average amount of solar radiation reaching the outer limits of the atmosphere is known as the solar constant or it may be defined as the radiation energy per unit time per unit area on surface, which is held perpendicular to sun rays at outer limit of atmosphere at mean distance between sun and earth. The mean value of solar constant is 1.98 cal/cm^2/minute or 1398 watt/m^2. You may also found in literature the value of solar constant equal to 2.0 langley per minute.

$$\text{Solar constant} = \frac{\text{Total radiation}}{\text{Area of spherical cell}}$$

$$= \frac{56\times10^{26}\ \text{cal min}^{-1}}{4\ \pi\ r^2}$$

$$r = 150\ \text{million km (mean distance between sun \& earth)}$$

$$= \frac{56\times10^{26}\ \text{cal min}^{-1}}{4\ \pi\,(1.5\times10^{13}\ \text{cm})^2}$$

$$= 1.98\ \text{cal cm}^{-2}\ \text{min}^{-1}$$

Solar radiation spectrum

Radiation originates from the visible surface of the sun called photosphere in wavelengths determined by its surface temperature of about 6000°K. The range of wavelengths of solar radiation is called as solar radiation spectrum. It may also be defined as the spread of solar energy over a broad band of wavelengths. Solar spectrum is part of the electromagnetic spectrum (Fig. 2.4) of radiant energy that also includes X-rays, gamma rays and longer radio waves. It comprises mainly ultraviolet, visible and infra-red wave lengths (Table 2). The radiation having wavelength in the range of 0.15 to 0.4 µm, known as ultraviolet radiations. It constitutes about 9% of the total solar radiation and divided into three parts:

Ultraviolet (UV)

1. **UV$_A$:** This radiation has the longest wave length (0.32 to 0.40 µm) of the ultraviolet radiations. It can cause some damage to living cells. It is transmitted to earth surface and not absorbed in stratosphere.
2. **UV$_B$:** The wavelength range, 0.28 to 0.32 µm of ultraviolet radiation is named as UV$_B$. It is absorbed in stratosphere by ozone. Depletion of ozone in stratosphere

results in a significant increase in UV_B that reaches the earth surface. It causes damage to living cells.

3. **UV_C:** It has the shortest wavelength (0.15 to 0.28 μm) of ultra violet radiation. Negligible UV_C reaches the earth surface as all the UV_C is absorbed by ozone. It is lethal and kills the living cell.

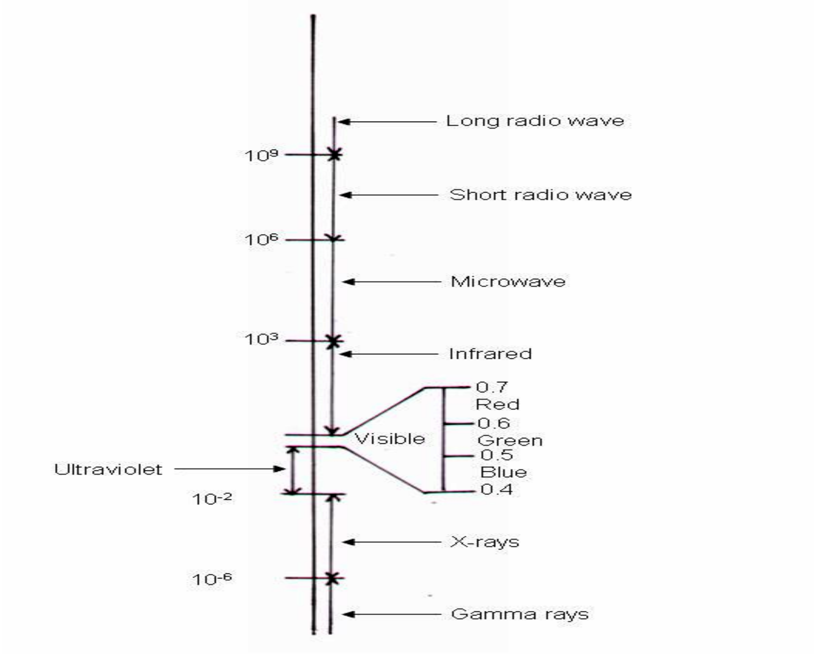


Fig. 2.4. Radiation spectrum (wave length in μm)

Visible

The radiation which lies in the wavelength range 0.4 to 0.7 μm of solar spectrum is known as visible radiation. These radiations are visible to human eye and constitute about 41 per cent of total solar radiation. This part of solar radiation is most important for photosynthesis in green plants. Therefore, it is also named as PAR i.e. photosynthetically active radiation.

Table 2. Solar spectrum

Sr. No.	Radiations	Wavelength band (μm)	Proportion (%)
1.	UV_A UV_B UV_C	0.32-0.40 0.28-0.32 0.15-0.28	9
2.	Visible Blue Green Red	 0.4-0.5 0.5-0.6 0.6-0.7	41
3.	Infra Red NIR MIR TIR	 0.7-1.3 1.3-3.0 >3.0	50

Infra-red

These radiations lie between 0.7 to 4.0 μm wavelengths. This part of radiation spectrum constitutes about 50 per cent of total solar radiation. These radiations are not much important for crop plants. These are simply absorbed by plants, transmitted into heat and released into atmosphere through reradiation and evapotranspiration.

Albedo

It may be defined as the ratio of solar radiation reflected by a surface to the total amount of radiation incident on it, usually expressed in per cent. The albedo of surface is the percentage of the incident radiation reflected by it, is also known as reflection coefficient. The reflection coefficient in case of solar radiation is termed as albedo. Albedo of earth as a whole also known as planetary albedo or global albedo. Its value is 34 per cent, but it varies with latitude, season and nature of surface. The mean albedo of various surfaces (Table 3).

$$\text{Albedo} = \frac{\text{Reflected solar radiation by a surface}}{\text{Total solar radiation incident on the surface}} \times 100$$

Counter radiation

It is the longwave radiation radiated by the atmosphere back to the earth surface. This radiation prevents the earth from excessive cooling.

Terrestrial radiation

The radiation emitted by the earth is known as terrestrial radiation. Terrestrial radiation is also known as outgoing long wave radiation. The long wave radiation (R_L) can be estimated using the formula:

$$R_L = \sigma T^4 (0.55–0.092 \sqrt{ed}) (0.1+ 0.9 n/N)$$

Where,

σ = Stefan - Boltzman constant

T = Surface temperature (^oK)

ed = Saturation vapour pressure at dew point

Table 3. Mean albedo of various surfaces

Sr. No.	Surface	Albedo (%)
1.	Deciduous forest	18
2.	Coniferous forest	13
3.	Desert	28
4.	Fresh snow	80-85
5.	Old snow	50-60
6.	Grain crops	10-25
7.	Grasses	20-25
8.	Sand	20-30
9.	Water at 30^o latitude	6-9
10.	Bare rock	12-18

Long wave radiation

The radiations having the wavelength longer than 4.0 µm wavelengths, known as long wave radiation. The radiation emitted by earth surface is long wave radiation. **Pyrgeometer** is used to measure long wave radiation.

Short wave radiation

The radiations having the wave length less than or equal to 4.0 µm are termed as short wave radiation. Solar radiation is also known as short wave radiation as 99 per cent of solar radiation lies between 0.15 and 4.0 µm wave length. Solar radiation (Rs) is measured with the help of **pyranometer**. It can be computed using the formula:

$$Rs = R_A \left(a+b \frac{n}{N}\right)$$

Where,

R_A = Solar radiation at outer limit of atmosphere,

a & b = Constants (a=0.32 & b=0.46 for Hisar),
n=Actual sun shine hours,
N=Maximum possible sun shine hours.

Exercise: *Calculate the value of short wave radiation and long wave radiation using the given data:*

Mean air temperature = 25°C, radiation intensity outside the atm (R_A) = 625.7 ly/day or 10.7 mm/day, mean relative humidity = 80%, albedo = 20%; actual sun shine hours = 11.8, actual vapour pressure = 6.0 mm of Hg and maximum possible sunshine hours = 12.0

Solution

$$Rs = R_A \left(a + b \frac{n}{N}\right)$$

$$= 625.7\ (0.32+0.46\ (11.8/12.0) = 625.7\ (0.32+0.46\times0.98)$$

$$= 625.7\ (0.32+0.45) \qquad = 625.7\times0.77=481.1 \text{ ly/day}$$

$$\sigma\, T^4 = 2.0\times10^{-9} \times (298)^4 \quad = 2.0\times7.886 \quad = 15.77 \text{ mm/day}$$

$$R_L = 15.77\ (0.55–0.092\times4.07)\ (0.1+0.9\times11.8/12.0)$$

$$= 2.73 \text{ mm/day} = 155.1 \text{ ly/day}$$

Sky radiation

The radiations which come to the earth surface through indirect path are known as sky radiation. Sky radiation is also known as diffuse radiation and it constitute about 23 per cent of total short wave radiation.

Units

Watt/m^2 (1 watt = 1 joule/sec)
Langley/minute (1 Langley = 1 cal cm^{-2})
Lux (1 kilo lux = 92.9 foot candle = 4.0 watt m^{-2})
1 µmole/sec/m^2= 1 µE/sec/m^2

One radiation unit can be converted into other radiation unit as in Table 4.

Table 4. Conversion of units of radiation

wm^{-2}	cal s^{-1} m^{-2}	mm of water s^{-1}	langley s^{-1}	µmol $s^{-1}m^{-2}$
1	0.239	4.12×10^{-7}	0.239×10^{-4}	4.6
4.19	1	1.72×10^{-6}	10^{-4}	10.25
24.27×10^{5}	5.68×10^{5}	1	56.8	1.12×10^{7}
4.18×10^{4}	10^{4}	17.22×10^{-3}	1	19.25×10^{4}
0.218	0.052	0.9×10^{-7}	5.2×10^{-7}	1

Radiation and heat budget

Radiation is the way of transfer by which solar energy reaches the earth surface as short wave and earth and its atmosphere losses energy to outer space in longer wavelengths (Fig. 2.5). The basic form of radiation balance equation for the earth and its atmosphere is:

$$Rn = R_A\ (1\text{-}r) - R_L$$

Where,

Rn = Radiation balance/net radiation
r = Global albedo
R_L = Outgoing long wave radiation from earth to space
(l-r) = Solar radiation absorbed by earth and its atmosphere

Out of total incoming (R_A) about 25 per cent is reflected by clouds and 7 per cent scattered back to space by clouds, dust and gas molecules without heating the air, 2 per cent is reflected to space from the earth surface. This total 25+7+2=34 per cent reflected radiation is called as earth albedo. Although its value at poles is greater than at equator. About 19 per cent of insolation is absorbed in atmosphere by the gases, clouds and solid particles suspended in air. Ozone absorbs most of UV radiation, which is the main source of energy for circulation in stratosphere. Water vapour, clouds and dust are main absorber of the incoming long wave radiation in troposphere.

The earth surface absorbs 47 per cent solar radiation of which 24 per cent as direct and 23 per cent as indirect or diffuse radiation. Thus, 66 per cent of radiation is absorbed by earth and its atmosphere.

The total absorbed solar energy is radiated back to space as long wave radiation. Out of which 6 per cent is radiated back to space directly by earth and 60 per cent is radiated to space by atmosphere.

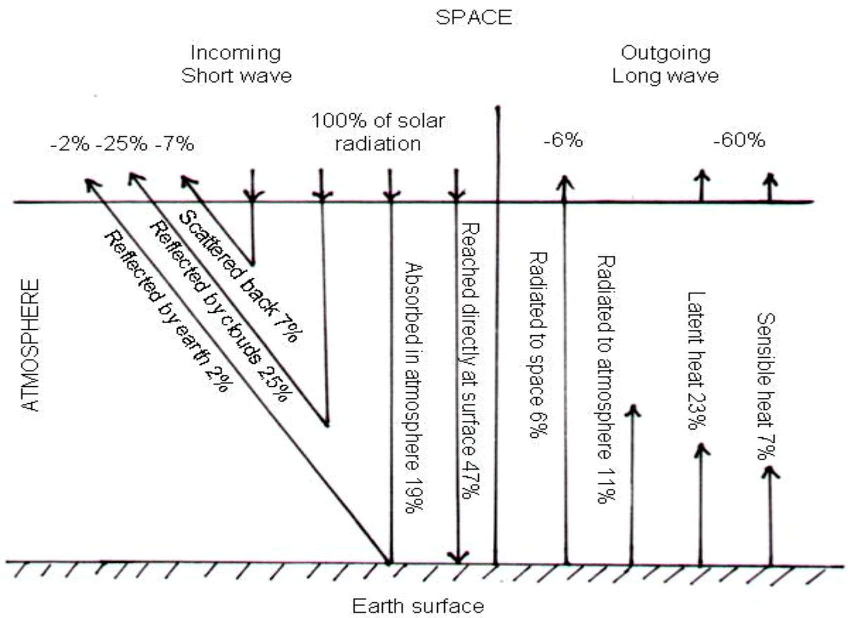


Fig. 2.5. Radiation budget of earth surface and its atmosphere

R_A = 100 units   r = 34 percent = 0.34

R_A (1-r) = 66 per cent R_L= 66 per cent

Rn = 100 (1-0.34) – 66 = 0

Solar radiation absorbed by earth	:	47 per cent
Energy radiated directly to space by earth	:	6 per cent
Radiated energy from earth to atmosphere	:	11 per cent
Energy lost by earth as sensible or convection to atmosphere	:	7 per cent
Energy lost by earth as latent heat by evaporation and released in atmosphere by condensation	:	23 per cent
Solar radiation absorbed by atmosphere	:	19 per cent
Solar radiation reflected and scattered back space by earth and its atmosphere	:	34 per cent
Energy radiated back to space by atmosphere	:	60 per cent

The gain and loss of energy by earth, atmosphere and space are presented in Table 5.

Table 5. Radiation budget

	Earth	Atmosphere	Space
Gain (%)	47	19+11+7+23=60	34+66=100
Loss (%)	6+7+23+11=47	60	100

Factors affecting insolation or radiation distribution over earth surface

Radiation intensity received on the surface of earth varies according to the conditions of the atmosphere as well as seasons. The following factors control the radiation distribution over earth surface:

1. **Angle of incidence:** It is an angle between sun rays and normal to the surface at a point of observation and also called as altitude of sun. Radiation intensity is more when the sunrays are normal to the surface as compared to the sun rays are oblique to the surface or as the incident angle of sun rays decreases, radiation intensity increases. This is because of the fact that normal rays cover less surface area (A), whereas oblique rays cover more area (B) as shown in Figure 2.6 and therefore, radiation per unit surface area is decreased.

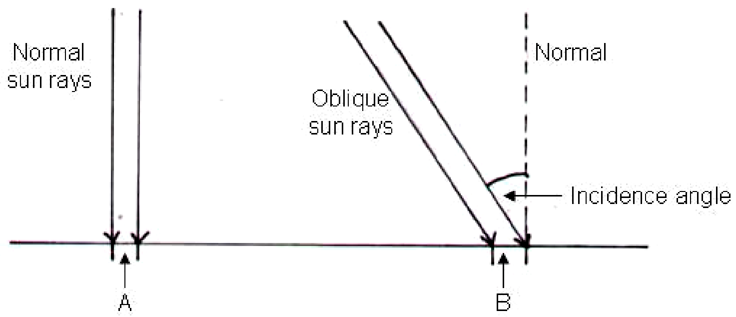


Fig. 2.6. Effect of incidence angle on radiation intensity

2. **Latitude:** Latitude of place determines the angle of sun rays. With increase in latitude the radiation intensity decreases. Therefore, radiation intensity is higher over equator as compared to poles. The sunrays are normal to earth surface over equator and the sunrays become more and oblique as we move toward the poles. The normal rays over equator travel less path (A) whereas oblique rays over higher latitudes travel more path (C) through atmosphere as shown in Figure 2.7. Longer atmospheric path causes more depletion of radiation.

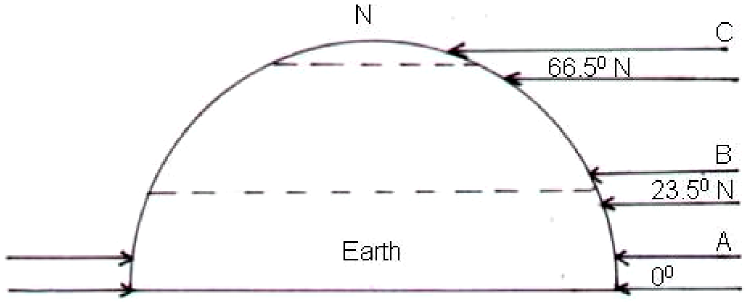


Fig. 2.7. Effect of latitude on path length of sun rays

3. **Duration of sunshine:** It is the duration of shining of sun over a place. It also affects the amount of radiation received at earth surface. The longer periods of sunshine supply more radiation to the surface as compared to shorter sunshine periods. Sun shine duration also Table 6. Maximum day length (hours) in different latitudes

Latitude	Day length (hrs)	Latitude	Day length
0°	12.0	$66^{\circ}.5'$	24.0
$23^{\circ}.5'$	13.6	90°	6 months

determines day length, which varies with latitude (Table 6)
On summer solstice (June 21) the length of the day is maximum and on winter solstice (December 22) it is minimum and vice versa in Southern hemisphere. The day and night are equal on autumnal (September 21) and vernal (March 21) equinoxes (Fig. 2.8).

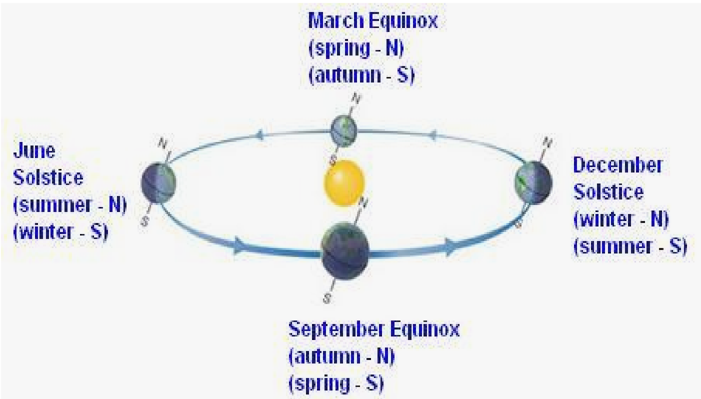


Figure 2.8. Solar Solstices and Equinoxes

4. **Solar constant:** The solar constant varies not much, rather the change in its value is negligible and therefore, it is called constant. Periodic disturbances and explosions in the surface of sun cause the variation in its value. As the sunspots appearance increases, the radiation intensity over earth surface increases.
5. **Distance between sun and earth:** The distance between earth and sun varies because of elliptical orbit of revolution of earth around sun. The mean distance between sun and earth is 150 million km. The earth comes closer to sun at perihelion (the distance is 147 million km on January 3) and goes little farther from sun at aphelion (the distance is 152 million km on July 4). Therefore, the radiation intensity is 7 % greater at perihelion than at aphelion position of earth.
6. **Atmospheric condition:** Reflection and absorption of radiation by clouds, and other atmospheric constituents control the radiation intensity reaching the earth surface. Therefore, areas with cloudy and turbid atmosphere receive less radiation as compared to areas with clear and less turbid atmosphere.
7. **Thickness of atmosphere:** With the increase in thickness of atmosphere the radiation has to pass more path in the atmosphere. Therefore, as the path length increases, the depletion of radiation increases or the atmospheric absorption of radiation increases with the thickness of atmosphere, thereby, less radiation reach the earth surface.

Energy balance

The solar energy available at the earth surface is utilized in different ways. The equation used to express the energy balance is of the form:

$$Rn = LE + A + G + Mi$$

Where,

Rn = Net radiation

LE = Latent heat of evaporation. It is the energy flux used in evaporation as latent heat. LE utilizes 70-80 per cent of net energy available

A = Sensible heat of flux : It is the energy flux used in heating the air. 10-15 per cent energy used as sensible heat.

G = Soil heat flux : It is the energy flux used in heating the soil. Soil heat flux varies from 5 to 10 per cent

Mi = Miscellaneous energy flux : The energy utilized in photosynthesis and other biochemical processes. This flux is very small in comparison to above mentioned fluxes, so it is neglected.

Rn = LE + A + G

Greenhouse effect

The atmospheric gasses (water vapour, carbon dioxide, methane, chlorofluorocarbons and nitrous oxide) allow short wave radiation coming from sun to pass through but they absorb the long wave radiation emitted by earth. So, they trap some of the heat energy radiated from earth. The trapping of heat radiation and warming of atmosphere is somewhat analogues to a green house and the effect is called green house effect. In green house the glass walls and roof allow the short wave radiation to pass through them where it is absorbed by ground. But the emitted long wave radiation by ground is not allowed to escape by glass walls and roof of green house. That heat inside the green house is maintained and warms the green house. This warming or trapping of heat energy is called green house effect.

The trapping heat in the atmosphere might better be called as **atmospheric effect**, because the dominant process responsible for heating the air in a green house is quite different from that which heats the lower atmosphere.

Radiation Laws

1. Stefan-Boltzman law

This law states that the radiation intensity emitted by a black body is directly proportional to fourth power of its surface temperature (^{0}K) i.e.

$$E = \varepsilon\sigma T^4$$

Where, E = Radiation emitted by the surface

σ = Stefan-Boltzman constant (8.14×10^{-11} ly min^{-1} ^{0}K^{-4})

T = Surface temperature ($^\circ$K)

ε = Emissivity = 1 for black body

Exercise: *The temperature of a hot iron plate is 50^{0}C & its emissivity is 0.90. Calculate the intensity of radiation emitted from the hot plate.*

$\sigma = 8.14\times10^{-11}$ *ly min^{-1} ^{0}K^{-4}.*

Solution

The radiation emitted from a material is given by the formula:

$E = \varepsilon\,\sigma\,T^4$

$T = 50\ ^\circ C = 50 + 273 = 323\ ^\circ K$

$\varepsilon = 0.90$

$\sigma = 8.14\times10^{-11}$ ly min^{-1} $^\circ$K^{-4}.

$E = 0.90 \times 8.14 \times10^{-11} \times1.09 \times10^{10}$

$= 0.90 \times 0.814 = 0.673$ ly min^{-1}

2. Plank's law

The law states that energy per unit wave length emitted by a black body is a function of its temperature.

$$E_\lambda = \frac{2\,\Pi h\,c^2\,[\exp(hc/b\lambda T)-1]^{-1}}{\lambda^5}$$

Where, E_λ= Radiation energy emitted per unit wavelength
h = Plank's constant (6.626×10^{-34} J sec)
c = Speed of light
b = Boltzman constant (1.381×10^{-23} J $^0K^{-1}$)
λ = Wavelength

Energy content of a quantum is directly proportional to its frequency, as expressed below:

$E = h\nu$

Energy of 1 mole of quantum (E) = $Nh\nu$; E = Energy content of radiation
N = Avagadro's number (6.02×10^{23}); ν = frequency

Exercise: *Assuming temperature of sun equal to 6000^oK, find out the energy of 0.55 μm wavelength radiation emitted by the sun. $h=6.27\times10^{-34}$ J sec, $b=1.381\times10^{-23}$ J $^0K^{-1}$ and $c=3\times10^{10}$ cm sec^{-1}.*

Solution

Energy per unit wavelength is expressed by the formula:

$$E_\lambda = \frac{2\,\Pi hc^2\,[\exp(hc/b\lambda T)-1]^{-1}}{\lambda^5}$$

Where,
$h = 6.27\times10^{-34}$ J sec
$c = 3.10^{10}$ cm/sec
$b = 1.381\times10^{-23}$ J $^0K^{-1}$)
$\lambda = 0.55\times10^{-4}$ cm
T =6000 ^{0}K

$$E_\lambda = \frac{2\times22\times6.27\times10^{-34}\times9\times10^{20}}{7\times(0.55\times10^{-4})^5\times\exp\left\{\dfrac{6.27\times10^{-34}\times3\times10^{10}}{1.38\times10^{-23}\times0.55\times10^{-4}\times6000}\right\}-1}$$

$$= \frac{396\times6.27\times10^{-14}}{7\times0.05\times10^{-20}\times\exp\left\{\dfrac{18.81\times10^{-24}}{4.554\times10^{-24}}\right\}-1}$$

$$= \frac{2482.9\times10^6}{0.35\times[62.17-1]}$$

$$= \frac{2482.9\times10^6}{21.41} = 115.97 \text{ x } 10^6 \text{ J sec}^{-1}\text{ cm}^{-2}\text{ cm}^{-1}$$

$$= \mathbf{11.6\ KJ\ sec^{-1}\ cm^{-2}\ \mu m^{-1}}$$

Exercise: *Calculate the energy content of visible radiation having the frequency equal to 5.5×10^{11} K cycle/sec.*

Solution

The energy content of the quantum is equal to

$E = h\nu$

$h = 6.625\times10^{-27}$ ergs sec; $\nu = 5.5\times10^{14}$ cycle/sec

$E = 6.625\times10^{-27}\times5.5\times10^{14}$ $= 36.44\times10^{-13}$ ergs

[1 ly $min^{-1} = 4.19\times10^{7}$ ergs cm^{-2} min^{-1}]

One mole of quantum = 1 Einstein (E)

$= 6.02\times10^{23}$ photons (Avagadro's number)

So 1 E of this frequency wavelength is $= 36.44\times10^{-13}\times6.02\times10^{23}$

$= 2.19\times10^{12}$ ergs.

3. Wien's law

This law states that wavelength of maximum radiation intensity emitted is inversely proportional to the temperature (^{0}K) of the body.

$$\lambda_{max} = \frac{2897\ (\mu m\ ^0K)}{T}$$

Where, λ_{max} = Wavelength of maximum emission (µm)

T = Temperature of the surface (^{0}K)

Exercise: *The earth surface temperature is equal to 27^0C and sun temperature is 6000^0K. Find out the wavelength of maximum radiation intensity.*

Solution

The wavelength of maximum emission is equal to

$$\lambda_{max} = \frac{2897\ (\mu m\ ^0K)}{T}$$

$T = 27\ °C = 27+273 = 300\ ^0K$

$$\lambda_{max} \text{ for earth } = \frac{2897}{300} = 9.66\ \mu m$$

$$\lambda_{max} \text{ for sun } = \frac{2897}{6000} = 0.48\ \mu m$$

4. Kirchoff's law

This law states that for a given wavelength, absorptivity of a material is equal to its emissivity. $\mathbf{a_\lambda = e_\lambda}$

Where a_λ and e_λ = Absorptivity & emissivity of a material for given wavelength

For a given wavelength and temperature, the ratio of emissivity to absorptivity of all material is a constant. $e_1/a_1 = e_2/a_2$ = Constant

Where, e_1 and e_2 = Emissivity of the surfaces 1 and 2

a_1 and a_2 = Absorptivity of the surfaces 1 and 2

5. Lambert's Cosine law

This law states that the radiant intensity (flux per unit solid angle) emitted in any direction from a unit radiating surface or incident on a surface varies as the cosine of the angle between the normal to the surface and direction of the radiation.

$1/1_0$= Cos α

Where, I = Radiation Intensity on the surface

I_0 = Radiation intensity when the solar radiation is normal to surface

α = Angle between radiation and normal to the surface. For solar radiation from the solar elevation 'β' incident on a horizontal surface, I/I_0 = Sin β

The zenith distance α is the complement of the angular elevation, (α=90-β)

Exercise: *The radiant flux density of solar beam upon a perpendicular surface is 1.0 ly/minute. Calculate the radiant flux density upon a horizontal surface if the radiation beam makes an angle of 30^0 with normal to surface.*

Solution

As per cosine law:

$I = I_0 \cos \alpha$

$I_0 = 1.0$ ly/min

$\alpha = 30^0$

$I = 1.0 \cos 30^0$ [$\cos 30^0$=0.866]

$= 1.0\times0.866$ = 0.87 ly/min

6. Beer's law: This law states that the fraction of radiation intercepted (I/I_0) by the canopy is an exponential function of leaf area index.

$$I/I_0 = e^{-KF}$$

Where, I = Light intensity at a level inside the canopy

I_0= Light intensity at the top of the crop canopy

K = Extinction coefficient

F = Leaf area index from top to the level inside the canopy at which radiation intensity is to be calculated

By taking log with base e on both sides: $\ln (I/I_0) = -KF$

$$K = -\ln (I/I_0)/F$$

Exercise: *The solar radiation at the top of crop canopy is 0.9 cal cm^{-2} min^{-1}. The leaf area index of the canopy is 2.5 and the extinction coefficient is 0.7. Find out the solar radiation at the bottom of the canopy.*

Solutions

According to Beer's Law:

$I = I_0 e^{-KF}$; $I_0 = 0.9$ cal cm^{-2} min^{-1}

K = 0.7 ; F = 2.5

$I = 0.9e^{-0.7\times2.5}$

$= 0.9\times0.174$ = 0.157 cal cm^{-2} min^{-1}

Exercise: *Calculate the extinction coefficient of cotton crop using the data: I_0=0.98 ly min^{-1}, I=0.2 ly min^{-1} and F = 2.1*

Solution

The extinction coefficient is given by the formula:

$$K = \frac{-\ln (I/I_0)}{F}$$

$$K = \frac{-\ln (0.2/0.98)}{2.1}$$

$$K = \frac{1.59}{2.1}$$

K = 0.76

7. Monteith law

Radiation interception inside the crop canopy is expressed as by this law:

$$I = I_0[S+(1-S)\ \tau]^F$$

Where, S = Fraction of light passing through unit layer without interception

τ = Leaf transmission coefficient

F = Leaf area index

Exercise: *The radiation intensity at the top of wheat crop is 1.1 ly min^{-1}. The leaf transmission coefficient is 0.08 and the fraction of radiation passing through unit layer without interception is 0.42. Calculate the radiation intensity at ground level if the leaf area index is equal to 2.0*

Solution

According to Monteith law, radiation penetration inside the canopy:

$I = I_0[S+(1-S)\ \tau]^F$

$I_0 = 1.1$ ly min^{-1}

S=0.42

τ =0.08

F = 2.0

$I = 1.1\ [0.42+(1-0.42)0.08]^{2.0}$

$= 1.1\ [0.42+0.05]^{2.0} \quad = 1.1\ (0.47)^{2.0} \quad = 1.1 \times 0.221 = 0.24$ ly min^{-1}

Instruments

1. **Pyranometer:** It measures total shortwave radiation i.e. direct and indirect radiation. It is a thermopile based instrument. Reflected radiation can be measured by inverting the sensor over the surface.
2. **Net radiometer:** It is used to measure net radiation i.e. balance between incoming and outgoing radiation over a surface. A differential thermopile is used in this radiometer. It measures net radiation flux over the surface.
3. **Quantum sensor:** It measures radiation in the wavelength range of 0.4 to 0.7 µm, which is called as photosynthetically active radiation (PAR). The sensor is silicon photodiode, which works on the principle of photometric effect.
4. **Pyrgeometer:** The instrument used for measuring long wave or terrestrial/infrared radiations is known as pyrgeometer. The sensor used in this radiometer is a thermopile, which works on the principle of thermo-electric effect.
5. **Spectroradiometer:** The radiometer which measures the radiation in different bands of spectrum. It measures the spectral reflectance of a surface. Ground Truth Radiometer (GTR) used by remote sensing persons is a spectroradiometer, which measures the spectral reflectance in visible and infrared bands.
6. **Luxmeter:** The instrument which is used to measure light intensity is called lux meter. It measures illuminance of a surface by the incident light and its unit is lux (1000 lux = 1 kilo lux).

3. AIR TEMPERATURE

Temperature is a measure of the heat concept of a body. It shows the intensity of heat energy or degree of hotness or coldness. The temperature may be defined as the intensity aspect of heat energy. The temperature measures the average kinetic energy of the molecules. It is the measures of sensible heat energy of a system.

Different scales have been used for the measurement of temperature. These are four scales as given below:

1. **Celsius scale:** This scale is named for the Swedish astronomer Anders Celsius. It is internationally accepted for measurement of temperature. The boiling point of water is 100 ^oC and freezing point of water (Triple point) is 0 ^oC.
2. **Fahrenheit scale:** The Fahrenheit scale is used for temperature as evident from historical records of temperatures in English speaking countries. The freezing point (triple point) of water is 0^oF and boiling point of water is 212 ^oF.
3. **Kelvin scale:** It is based on **absolute zero**, at which molecular activities theoretically would cease. It is used to indicate the temperatures in upper atmosphere and in studies involving energy exchange processes. The value of each degree on Kelvin scale equals to that of a Celsius degree. Absolute zero is at –273.16 ^oC.
4. **Reaumer scale:** The freezing point of water is 0^oR and the boiling point of water is 80 ^oR.

Conversion formulae

- Conversion of temperature values in 0^oC to ^oF or ^oF to ^oC by the formula:

$$\frac{C}{5} = \frac{F-32}{9}$$

- Conversion of temperature values in ^oC to ^oK:

$$K = C + 273$$
$$C = K-273$$

- Conversion of temperature values for ^oC to ^oR:

$$\frac{C}{5} = \frac{R}{4}$$

Exercise: *Convert the given temperature values degree Celsius values into degree Fahrenheit and Kelvin values (i) 10 (ii) 20 (iii) 37 (iv) –273*

Solution

$$\frac{C}{5} = \frac{F-32}{9}$$

(i) $\frac{10}{5} = \frac{F-32}{9}$, $^oF = 18+32 = 50$

$^oK = 273 + 10$, $^oK = 283$

(ii) $\frac{20}{5} = \frac{F-32}{9}$, $^oF = 36+32 = 68$

$^oK = 273 + 20$, $^oK = 293$

(iii) $\frac{37}{5} = \frac{F-32}{9}$, $^oF = 66.6+32 = 98.6$

$^oK = 273 + 37$, $^oK = 310$

(iv) $\frac{-273}{5} = \frac{F-32}{9}$, $^oF = -491.4+32=-459.4$

$^oK = -273 + 273$, $^oK = 0$

Conversion of temperature values from one scale to others is given in Table 1.

Table 1. Conversion of Temperature in different scales

Celsius	Fahrenheit	Kelvin	Reaumer
1^oC	1.8^oC+32	1^oC+273	0.8^oC
$0.5556^oF-17.7779$	1^oF	$0.5556^oF+255.221$	$0.4445^oF-14.224$
1^oK-273	$1.8^oK-459.4$	1^oK	$0.8^oK-218.4$
1.25^oR	2.25^oR+32	1.25^oR+273	1^oR

Definitions

Diurnal range: It is defined as the difference between maximum and minimum temperatures of the day.

Daily mean: It is mean of maximum and minimum temperature values of the day.

Monthly mean: It is computed by adding the daily mean temperatures and dividing by the number of days in the month.

Annual mean: It is computed by adding the monthly means and divided by twelve.

Annual range: It is the difference between mean temperatures of warmest and coldest months.

Normal temperature: It is computed by adding temperature values of more than 30 years and divided by the number of years.

Lapse rate: The decrease in temperature with height is called as lapse rate. The mean value of lapse rate is 6.5 ^oC/km or 3.5 ^oF/1000 feet. It is also called as normal lapse rate.

Adiabatic lapse rate: It is the decrease in temperature with height in a rising air parcel provided there is no exchange of energy with surrounding. The dry adiabatic lapse rate is 10.0 ^oC/km and moist adiabatic lapse rate is 5.0 ^oC/km.

Temperature inversion: Increase in temperature with height is called as temperature inversion. It is reverse of lapse rate. It occurs near the ground (ground inversion) and sometime at higher levels (aloft inversion) in atmosphere.

Isotherm: It is the line joining the places having equal temperatures. The isotherms are drawn on weather map to represent the places having equal values of temperature.

Temperature lag: It is the amount of time between incoming energy maxima and temperature maxima. It is grouped into daily and seasonal lag of temperatures.

1. **Daily temperature lag:** It is the difference in time of maximum incoming radiation and maximum temperature over the day. It is equal to 2.00 hours approximately.
2. **Seasonal lag of temperature:** It is the time difference period between the highest incoming solar radiation and highest temperature over the year.

Continentality: The impact of continental location on weather and climate characteristics of a place is called **continentally.** Air temperature is greatly affected by the location of a place relative to large body of water i.e. sea/ocean.

Specific heat: It is the amount of heat required to raise the temperature of one gram of a substance through one-degree Celsius. The specific heat of water is 1.0 cal/gm.

The air temperature varies from place to place, called **horizontal temperature variation** and its change with height above the earth surface, called **vertical temperature variation.**

1. Horizontal temperature variation

The average global temperature is 15^oC but local temperature averages vary widely. Weather maps for small areas are prepared by drawing the isotherm using actual observed temperatures. But in case of continental or world maps, isotherms are drawn from the mean temperatures reduced to sea level equivalents by adding 6.5°C for each kilometer of elevation. This adjustment is done to eliminate the altitude effect. There is a general decrease in temperature from equator toward poles. If latitude is the only controlling factor then we would expect parallel isotherms to each other, but it is not in actual case. The isotherms are irregular in shape due to irregular distribution of land and water on earth surface in northern hemisphere. But the isotherms are more or less parallel in southern hemisphere due to more uniform surface mainly water. Where there is land, isotherms take sudden swing over the surface. In winter land surface is cooler than water surface and vice-versa in summer. During daytime land surface is warmer than water surface and vice-versa during night. The contrast in land and water temperatures is because of the reasons:

1. Water is mobile so energy absorbed by surface is transferred more quickly by conduction and convection but in case of land, energy transfer to dipper layers is slow only by conduction i.e. a slow process of energy transfer.
2. Water is translucent, so energy penetrates to deeper layers in water as compared to opaque land.
3. The specific heat of water is higher than land.

Interior places on continents have extreme climates whereas costal places have moderate climates e.g. Delhi experiences extreme temperatures as compared to Mumbai. The isotherms dip far to the south in winter in northern hemisphere over land surface and dip far to the north over land surface in summer.

The presence of **ocean currents** also affects the temperature of place. Warm ocean current (drift of ocean warm water from equator towards poles) and cold ocean current (drift of cold water from pole towards equator) increases and decreases the temperature of near by places, respectively, e.g. London situated at 51°N is warmer due warm North Atlantic drift and New York situated at 40°N is colder due to presence of cold Labrador ocean current. **Mountain barrier** also affects the horizontal distribution of temperatures. Mountain ranges tend to guide the cold air masses e.g. in USA. Rocky Mountain assists the prevailing westerlies in diverting most of the cold outbursts from Canada to the east. Himalaya in Asia and Alps in Europe protect the regions to the south from cold polar air.

The **onshore winds** also affect the temperature of place. The ocean currents have their maximum effect on temperature over land surface if the prevailing winds are onshore. For example, the temperature range along the west coast of North America tends to be small due to onshore winds.

Highest official air temperature of 58°C was recorded at Azizia, Libya on September 13, 1922.Lowest temperature recorded was –88.3°C at Vostok Soviet station on August 24, 1960.

Vertical variation in temperature

There is fairly regular decrease in temperature of the air with height above the earth surface. This decrease in temperature ceases near outer limit of troposphere, called as tropopause (Figure 3.1).The average rate of decrease in troposphere is about 6.5°C/km or 3.5°F/1000 feet. It is termed as normal lapse rate. The actual lapse rate varies with altitude and from place to place. Actual lapse rate does not show always a decrease in temperature but indicates no change in temperature with altitude, then it is called as isothermal lapse rate. Some processes in the lower atmosphere may cause increase in temperature with altitude, known as temperature inversion. It is of two types i.e. *ground* inversion (occurs near ground) and *aloft* inversion (occurs at higher levels in atmosphere). Temperature inversion occurs in following conditions:

1. On a calm and clear night in winter season, inversion results due to radiation cooling.
2. Cold air from hiltops slopes downward in valley bottom and creates temperature inversion in valley.

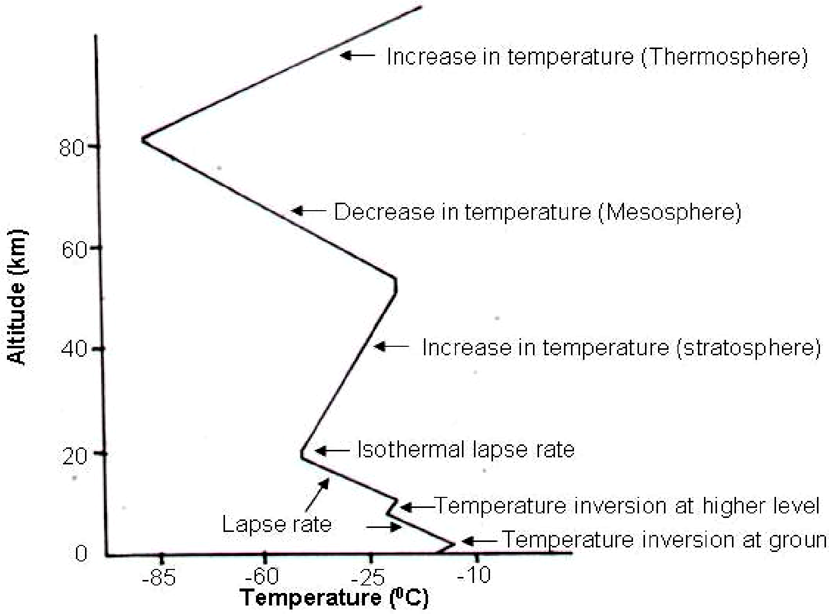


Fig. 3.1. Hypothetical vertical variation in temperature

3. When warm air comes over a cold surface cause an inversion in lower atmosphere.
4. When warm air mass meets with cold air mass, the warm air mass slopes upward over the cold air-mass and results into an inversion, called as **frontal inversion**.
5. When a cold air subsides or sink down and spreads over lower air, causes temperature inversion, termed as **subsidence inversion**, if it is at higher levels then also termed as **aloft inversion**.

Above tropopause, the temperature does not change with altitude in lower stratosphere, known as isothermal lapse rate. Then, air temperature increases with height due to absorption of ultraviolet radiation by ozone layer in stratosphere. This increase in temperature with altitude ceases near stratopause. In mesosphere again temperature decreases with height and drops to a minimum of about –92 ^{o}C at mesopause. Above, this layer, temperature again increases with elevation in thermosphere due to absorption of 'X' rays by ionized gasses present in thermosphere. The temperature increases to a high value of about 2000^{o}C near about 500 km altitude. In thermosphere the temperature increases to an undefined limit.

Factors affecting temperature distribution

1. **Latitude:** Air temperature decreases with increase in latitude in both hemispheres over the earth surface. Therefore, the places near equator are warmer as compared to the places in mid latitudes and near poles. Since the temperature is primarily controlled by radiation and radiation intensity is higher at equator then at poles.
2. **Altitude:** The air temperature decreases with increase in altitude. This decrease in temperature with altitude ceases at tropopause. The normal lapse rate is 6.5^{o}C/km. Since the direct source of atmospheric heat is the earth surface, therefore, as we go higher in atmosphere, we experience lower and lower temperature.
3. **Distribution of land and water:** Land surface is heated more quickly than water when subjected to equal amount of radiation and it also cools more rapidly. This is due to one of the reasons that specific heat of water is three times more than that of land.
4. **Distance from sea:** The distance from sea also affects the temperature distribution of a place. Diurnal range of temperatures is higher over places, which are far away from sea in comparison with costal places. The temperatures are moderate in costal places e.g. temperature range is higher at Delhi as compared to Mumbai.

5. **Slope of the land:** Slope of the land controls the radiation intensity over a place, which in turn controls the temperature. Therefore, south facing slopes are warmer than north facing slopes in northern hemisphere and vice-versa in southern hemisphere.
6. **Nature of soil:** Rocky and sandy soils warm more quickly and cool more rapidly as compared to heavy soils, which contain more water. Therefore, western Haryana is comparatively warmer than eastern Haryana in summer and vice-versa in winter.
7. **Vegetation:** The vegetation cuts off much of the incoming solar radiation and also converts much of the energy into latent heat of evapo-transpiration. So, the places with more vegetation are cooler than the places without vegetation.
8. **Condition of atmosphere:** Clouds absorbs the terrestrial radiation, therefore, cloudy nights are warmer than clear nights in winter. Dust particles also increase the temperature of atmosphere. Dusty atmosphere is warmer than clear atmosphere. This is due to the reason that dust particles absorbs the solar radiation and radiates energy in the atmosphere.

Instruments

Thermometer: The most common instrument for measuring temperature is mercury-in-glass thermometer. Alcohol-in-glass thermometer is also used for measuring temperature.

Minimum thermometer: It is an alcohol in glass thermometer with a dark dumbbell shaped index placed in the bore below top of the alcohol column. It is used to measure minimum temperature.

Maximum thermometer: It is mercury in glass thermometer with a constriction in bore near bulb. It is used for measuring maximum temperature.

Thermocouple: It consists of pair of junctions of two unlike metals. When one junction is kept at constant temperature and other is exposed to a different temperature, an electromotive force is developed in the circuit, which is measured by a potentiometer calibrated in degrees.

Thermistor: It is semi-conducting ceramic element, offers less resistance to the flow of current as its temperature increases.

Thermograph: It gives a continuous record of temperature with time on a graph. It consist of bimetallic element, both metals have different coefficient of expansion. The metals are invar and bronze or iron and tungsten.

4. ATMOSPHERIC PRESSURE

Pressure of air at a given place is the force exerted against a surface by continuous collision of gas molecules. Pressure may be defined as the force per unit surface area.

$P = F/A$

Where,

P = Pressure
F = Force
A = Area upon which force is exerted

Air pressure is the force exerted in all directions as a result of weight of all the air above it. Force exerted by mass of a column of air above a given point is called air pressure.

$$P = \frac{\text{Mass} \times \text{Acceleration}}{\text{Area}} \qquad [F = m \times a]$$

Where,

$\text{Mass} = \rho \times V = \rho \times h \times A$

$$P = \frac{\rho\, h\, A.g}{A} = \rho\, h\, g$$

Where,

ρ = Density of liquid (Mercury=1.3×10^3 kg m^{-3})
h = Height of liquid (Mercury height =76 cm)
g = Acceleration due to gravity (980 cm s^{-2})
$P = 13.6\times10^3$ kg m$^{-3}\times0.76$ m $\times$ 9.8 m s^{-2}
= 101300 (kg m s^{-2}) m^{-2} [1N=1 kg ms^{-2}]
= 101300 N m^{-2}
= 101300 Pa = 1.013×10^5 Pa

Units

1. Height of Hg i.e. inches, cm or mm of Hg.
2. Bar: It is the force equal to 10^6 dynes per square centimeter.
3. Pascle (Pa) : It is the force of 1 Newton per square meter = N/m^2
4. Atmosphere = 1 atm = 29.92 inches or 76 cm or 760 mm of Hg
   = 1013 milli bar (mb)
   = 101325 pascle = 101.3 kilo pascle (KPa)
   = 14.7 lb/inch^2
   = 1.013×10^6 dynes/cm^2 = 1.013 bar
   = 1034 gms/cm^2 = 1.013×10^5 N m^{-2}
   1" = 33.86 mb

One pressure unit can be converted into other pressure units as per Table 1.

Table 1. Conversion of units of pressure

Atmosphere	dynes/cm^2	Pascle	mbar	mm of Hg
1	1013×10^3	$1\text{-}103\times10^2$	1013	760
0.987×10^{-6}	1	0.1	0.001	0.75×10^{-3}
0.987×10^{-5}	10	1	0.01	0.75×10^{-2}
0.987×10^{-3}	1000	100	1	0.75
0.13157×10^{-2}	1.333×10^3	1.333×10^2	1.333	1

Vertical variation in air pressure

The pressure depends on the density of air. Air density depends on its temperature, its composition and force of gravity. Air is more dense near the earth surface because of compression due weight of over lying air layers one upon the other. The air density decreases with height above the earth surface in atmosphere. Therefore, there is a decrease in air pressure with altitude. The rate of decrease in pressure with height is not same from place to place. The mean rate of decrease in pressure with height is 1 cm/100m. In the first few thousand meters above sea level, the pressure decreases at the rate of 1 mb for every 10 meters. It drops to nearly half of its surface value i.e. 1013.2 to 540.4 mb at about 5 km altitude. But this rate is not uniform with altitude. The atmospheric pressure at sea level is 1013 mb, at 50 km altitude it is about 1 mb and near 80 km it decreases to 0.01 mb. The rate of fall of pressure with height is determined partly by the rate of fall in temperature.

Horizontal variation in air pressure

Like air temperature, air pressure also varies from place to place over the earth surface. Horizontal variation in air pressure is represented by isobars on the weather map. Isobars are drawn at an interval of 3, 4 or 5 millibars. Closely spaced isobars represent steep pressure gradient and widely spaced isobars represent gentle pressure gradient. The pressure gradient is at right angle to isobars. Temperature and pressure are closely related to each other. On a world wide scale mean sea-level pressure may vary from less than 990 mb to more than 1030 mb. The world's greatest sea level pressure of 1083.8 mb was recorded at Agata, Siberia on December 31, 1968. The lowest sea level pressure of 870 mb was calculated from an aerial sounding in the eye of Typhoon Tip west of the Mariana Island on October 12, 1979.

The factors, which control the horizontal variation of temperature, also control the pressure variation. Earth surface is heated unevenly by mainly three factors:

1. Unequal distribution of radiation
2. Differential heating of land and water
3. Variation in reflectivity of the earth surface

As the air over an area heated more than another area with same atmospheric pressure. The warm air will rise and its density decreases, thereby air pressure decreases. On other hand, over an area with cold air, pressure will increase.

The equatorial regions have high temperature due to high insolation and would result into low pressure development but on the other hand, polar regions are cooler, which result into development of high pressure.

Coriolis force due to earth's rotation also affects the pressure distribution over earth surface. If this effect would not be in force, then there would be general increase in pressure as we move toward poles. But this general increase in pressure is disturbed by the presence of pressure of a low pressure belt between 60 and 70° latitudes in both the hemispheres. This belt might be produced by the factors associated with earth rotation. So, on the basis of general circulation, globe can be divided into following pressure belts as shown in Figure 4.1.

1. Equatorial low-pressure belt

This low-pressure belt exists over equatorial region between 5 ^{o}N and 5 ^{o}S. It is known as belt of rising air or belt of convergence (Figure 4.2). It is also termed as doldrums (The belt with calm and variable winds). The average pressure in this belt is less than 1013 mbar but in eastern hemisphere it is less than 1009 millibar. This belt is thermally produced due to high insolation over the equatorial region.

2. Sub tropical high pressure belt

This pressure belt lies between 25^{o} and 35^{o} N and S in both hemispheres. This belt is characterized by sinking of air from higher altitudes. Sinking of equatorial air in this zone might be because of two reasons. First cooling of equatorial air at higher level, results in increased density which cause sinking. Second due to earth rotation from west to east, pole ward directed winds are deflected east wards. It causes blocking effect and air piles up aloft and this causes a general sinking. It is also known as belt of divergence (Figure 4.2). These high pressure zones are termed as horse latitudes. The subsiding/sinking air currents create stable atmosphere with dry air masses. All the hot deserts of the world lie in this belt.

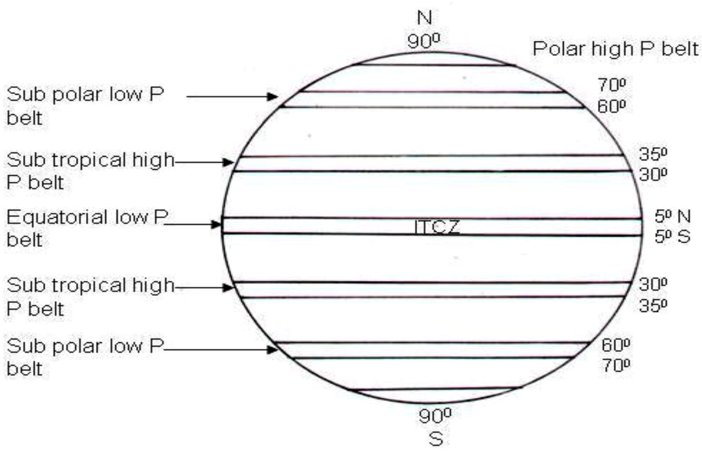


Fig. 4.1. General pressure (P) belts over the globe

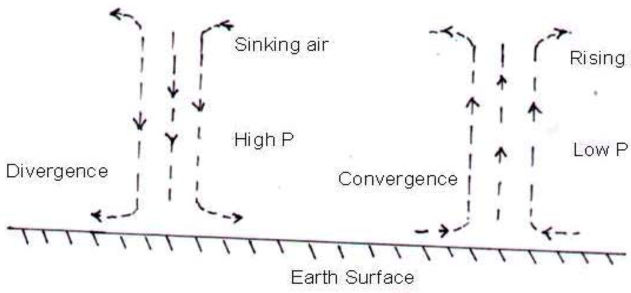


Fig. 4.2. Divergence and convergence of air

3. Sub-polar low pressure belt

This belt of low pressure lies between 60^o and 70^o latitude in both the hemispheres. It is also the belts of rising air/converging air as winds coming from the subtropics and polar areas converge and rise in this belt. This belt results due to rotational movement of earth, which swings up air in this zone. Due to a great contrast between the temperature of winds from subtropical and polar regions, cyclonic storms are developed in this region.

4. Polar high pressure belt

The pressures at poles are consistently high throughout the year. This belt lies over the poles in both hemispheres. The high pressure in these belts is mainly due to extreme low temperatures persist in polar region which result in more dense and heavy air mass. The easterly winds blow out of these high pressure belts towards sub-polar low pressure belt.

Factors affecting pressure distribution over the earth surface

The factors which control the temperature variation from place to place over the earth surface also control the air pressure distribution over the earth surface. This is due to the fact that temperature and pressure are closely related and have inverse relationship i.e. higher the temperature, lower will be pressure or vice-versa. Some of the important factors are given below:

1. Altitude

Air pressure decreases with altitude. The places at higher altitudes, have comparatively lower air pressure than that of places which are at lower altitudes e.g. hill station (Ooty) has lower pressure as compared to stations in plain (Coimbatore).

2. Latitude

The air temperatures are high over equatorial region and low over polar regions. Therefore, air pressure is low at equator and high over poles. The air pressure increases as we move towards poles. But this general increase in pressure with latitude is not infact due to influence of other factors.

3. Land and water surface

Air pressure is more over water surface as compared to land surface in summer season and vice-versa in winter season. Similarly, air pressure is higher over water surface in comparison with nearby land surface during day time and vice-versa during night. Due to this fact land breeze and sea breeze prevails in coastal regions.

4. Condition of atmosphere

Presence of dust particles in atmosphere increases its temperature, thereby air pressure decreases. If water vapour content increases in air, it becomes less dense as compared to dry air. Therefore, air pressure decreases with increase in water vapour content of the air at same temperature.

5. Ocean currents

Air pressure will be lower over the places near warm ocean currents in comparison with the places near cold ocean currents.

Isobar

The line joining the places of equal atmospheric pressure on the weather map is called as isobars. Actual pressure values are reduced to sea level pressures by applying correction to remove altitude effect then they are used for drawing isobars on a continent weather map. If isobars are closely spaced, it indicates a steep change in pressure at right angle to the isobars. When isobars are widely spaced, they indicate slow change in pressure. Two isobars never cross each other.

Definitions

Low pressure area: Low pressure centre enclosed with circular closed isobars is defined as low pressure area. The pressure increases outwards. A low pressure with wind velocity less than 39 miles/hour is called **depression**.

Secondary depression: Small depression formed on the out side of a parent depression.

Trough: The v-shaped projection of low pressure is termed as **trough.**

Ridge: Wedge shaped extension of high pressure which lies between two depressions. It may also be called as wedge.

Col: Pressure distribution between two high pressure areas and two low pressure areas. High and low are opposite to each other.

Pressure gradient: The rate of change of pressure per unit distance between to places at the same elevation is called pressure gradient. It is also known as isobaric slope.

Eye of cyclone: It is the centre of cyclone with calm air, no cloudiness, light winds and no precipitation. This central areas is know as 'eye' of the cyclone.

Altimeter: It is an altitude barometer. Its principle is same as that of aneroid barometer. Its scale is calibrated in height.

Cyclones

It is a circular shape of isobars having low pressure at centre and pressure increases outwards. Air runs spirally inward the centre. The wind direction is anticlockwise in northern hemisphere and clockwise in southern hemisphere (Figure 4.3). It is classified in two types:

1. **Tropical cyclone:** These cyclones are more intense and spread over a few kilometers to several kilometers. It originates due to differential heating of land and water surface near islands in tropical region. Most of tropical cyclones originate between 8° to 15° north and south latitudes. It is more violent and associated with very high winds (75-125 mile/hour) and storms producing rough weather. Tropical cyclones move with trade winds and most prominent in Pacific Ocean. They are also named as Hurricanes in USA, Typhoons in China and Willy-willies in Australia e.g. Cyclone in India (Bay of Bengal and Arabian Sea).

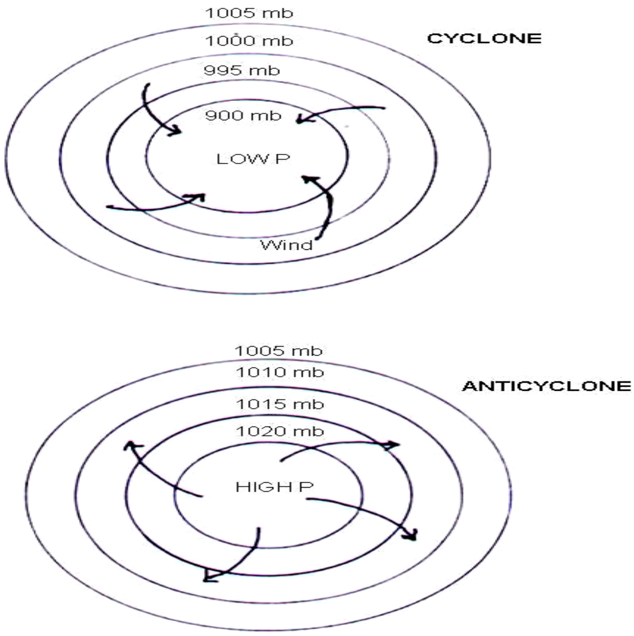


Fig. 4.3 Cyclone and anticyclone in northern hemisphere

2.Temperate cyclone: This type of cyclone originates in temperate or cold regions. Temperate cyclone is concentrated in middle latitudes between 35^{o} to 65^{o} in both hemispheres. Its intensity is less compared to tropical cyclone but have more spread of several hundred kilometers. Its vertical thickness is 9-11 km and horizontal spread is of about 1000 km. Temperate cyclone is accompanied by secondary cyclones. It is associated with cloudiness, light rains and winds e.g. Western disturbances in north India.

Anticyclone

It may be defined as circular shape of isobars with high pressure at centre and pressure decreases outwards. The winds direction is clockwise in northern hemisphere and anticlockwise in southern hemisphere (Figure 4.3). Anticyclone is associated with dry, cool air and little cloud, which produce fine weather. Cyclones and anticyclones are just opposite of each other. Anticyclone is always associated with cyclone or cyclone is always accompanied by anticyclone.

Seasonal distribution of air pressure over the earth

Continents and oceans modify the horizontal pressure distribution. In summer, the relatively hot lands develop low pressure systems and destroy high pressure systems. Similarly, cooler oceans develop high pressure systems and weaken low pressure systems. The reverse pressure system develop over land and water bodies in winter season. For example northern chilled land masses in winter develops high pressure which enhances sub tropical high pressure belt. Hot interior land masses of northern continents develops low pressure in summer, which causes weakening of subtropical high pressure belt. The vast ocean surface of the southern hemisphere has fairly uniform pressure through out the year. But land masses in southern hemisphere show some seasonal variation in air pressure.

Circulation cells

1. Hadley cell

It is also termed as tropical cell. At low altitude air movement is towards the equator, where it gets heat and rises vertically with poleward movement at higher altitude. It is circulation of air between subtropical high pressure belt and equatorial low pressure belt in both the hemisphere. The surface winds in this cell are trade winds (Figure 4.4).

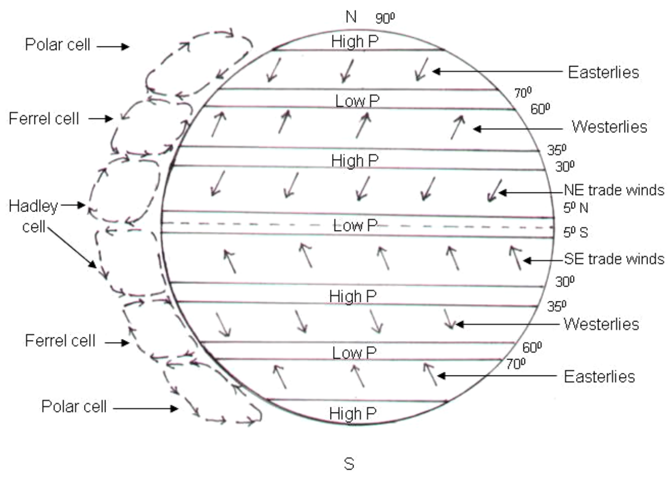


Fig. 4.4. General atmospheric circulation over the globe

2. Ferrel cell

It is a mid-latitude mean atmospheric circulation cell between sub-tropical high-pressure belt and sub polar low-pressure belts. Ferrel named it in 19^{th} century. In this cell the air moves poleward and east ward near earth surface and equator ward and westward at higher altitudes. The surface wind in this cell is westerlies.

3. Polar cell

In this cell air rises and moves poleward at higher levels and sinks at poles and diverges outward from the poles. This cell exists between polar high pressure and sub polar low-pressure belts. The surface winds in this cell are easterlies.

4. Walker cell

The vertical circulation in the tropical atmosphere is known as walker cell. It develops due to difference in sea surface temperature between east and west equatorial Pacific ocean. Ascending branch of walker cell located over Indonesia and descending limb is located over the semi-arid regions of north-west India, Pakistan and middle of East.

Instruments

Atmospheric air pressure is measured with help of an instrument called as barometer. There are four types of barometers:

1. Fortins barometer

It is a mercurial barometer containing mercury in small cistern having an ivory pointer, a flexible leather bag and screw at its bottom. The mercury level is lowered or raised with help of screw. In the cistern vessel a glass tube filled with mercury is inverted. The height of mercury column is measured on main scale and varnier scale for recording air pressure.

2. Kew pattern barometer

It is also mercurial barometer similar to Fortin's barometer but in this barometer, the cistern vessel is fixed.

3. Aneroid barometer

It is a barometer without any liquid and is portable. It consists of evacuated box which respond to change in atmospheric pressure. The compression and expansion of this box is magnified through a liver system and recorded by a pointer which moves on graduated scale of pressure.

4. Barograph

It is based on the principle of aneroid barometer and gives a continuous record of atmospheric pressure with time on a chart.

5. WIND

The horizontal flow of air is called as wind. Horizontal flow of air takes place along the pressure gradient. The wind velocity depends upon the rate of change of pressure per unit distance between two places at same elevation, called as pressure gradient. The moving air exerts a force or pressure on the objects, which obstruct it.

$$P = KV^2$$

Where,

P = Pressure exerted by wind
V = Velocity of wind
K = Constant

Origin of wind

Due to differential heating of earth surface, a low pressure is developed over warmer place and high pressure is developed over colder place. The air moves horizontally from high-pressure area to low pressure area along the pressure gradient as shown in Figure 5.1. This horizontal flow of air is called wind. The direction of wind first is decided by the direction of pressure gradient.

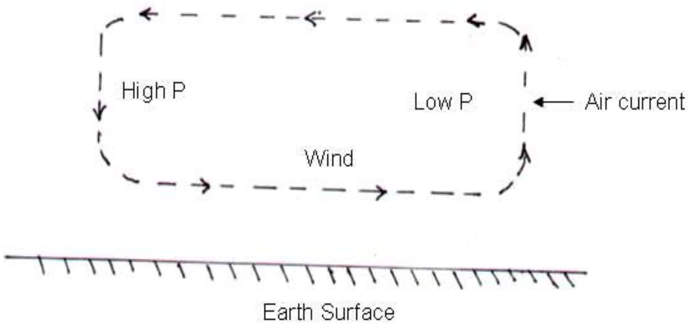


Fig. 5.1. Origin of wind

Forces acting on wind

1. Pressure gradient force (P): This force causes the air movement in the direction of low pressure. It acts in the perpendicular direction of isobars.

$$P = \frac{1}{\rho} \frac{dp}{dz}$$

Where,

ρ = Density of air
dp/dz = Change in pressure per unit distance or pressure gradient

2. Coriolis force (C): The force, which results due to earth rotation. It is also called as coriolis effect, means the effect on wind due to the earth rotation. The wind deflects to its right in northern hemisphere and deflects to its left in southern hemisphere due to the effect of coriolis force as shown in Figure 5.2. The coriolis force is zero at equator and maximum at poles. This force tends to deflect the wind at right angle to its line of motion.

$$C = 2\nu\omega \sin\phi$$

Where,

ν = Velocity of wind
ω = Angular velocity of earth
ϕ = Latitude

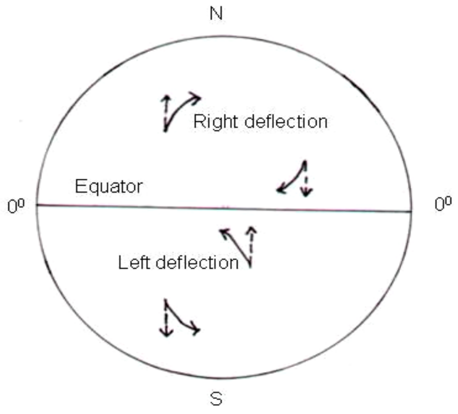


Fig.5.2. Coriolis effect on winds

3. Centrifugal force (Cfg): The force comes into play, when air particles move in curved path. This force takes the particle away from centre (Figure 5.3).

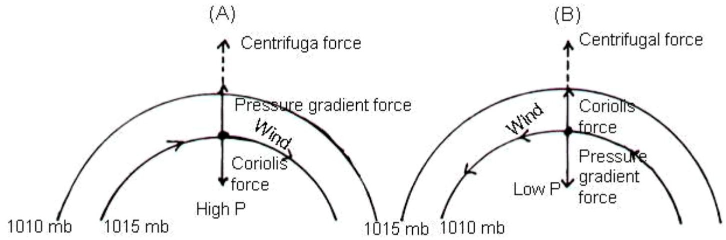


Fig. 5.3. Gradient wind in anticyclone (A) and cyclone (B)

$$Cfg = \frac{mv^2}{r}$$

For a unit mass,

$$Cfg = \frac{v^2}{r}$$

Where, m = Mass of air

v = Velocity of wind

r = Radius of curvature

4. Frictional force: The force which results due to friction between moving air and surface and it increases with surface roughness. It acts in opposite direction of wind motion and reduces the wind velocity (Figure 5.4).

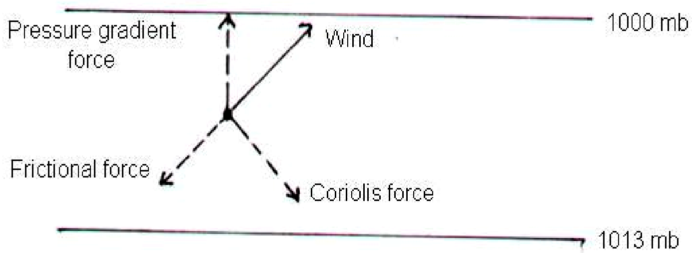


Fig. 5.4. Effect of frictional force on wind

Geostropic wind

It is the wind, which blows parallel to isobars in a straight line, with a balance between coriolis force and pressure gradient force acting on it (Figure 5.5). These winds are observed at higher levels, where there is no frictional force due the surface roughness.

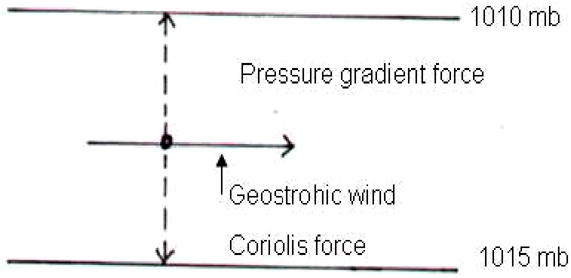


Fig. 5.5. Geostropic wind

Therefore,

$$P = C\ ; \qquad \frac{dp}{\rho\, dz} = 2\, v\, \omega \sin \phi$$

$$\text{Velocity of geostrophic wind } (v) = \frac{1}{2\omega \sin \phi} \times \frac{1}{\rho} \times \frac{dp}{dz}$$

Gradient wind

It may be defined as the wind that results with a balance between pressure gradient force on one hand and the coriolis force and centrifugal force on the other hand (Figure 5.3).

Gradient wind in cyclone:

$$P = C + Cfg$$

$$\frac{dp}{\rho\, dz} = 2\, v\omega \sin \phi + \frac{v^2}{r}$$

Gradient wind in anticyclone:

$$P = C - Cfg$$

$$\frac{dp}{\rho\, dz} = 2\, v\omega \sin \phi - \frac{v^2}{r}$$

Air current

The vertical movement of air is called as air current. It includes eddies, convectional currents, convergence rise and subsidence (Figure 5.1).

Beaufort's scale

With the help of Beaufort scale accurate estimation of wind speed can be made (Table 1).

Table 1. Beaufort's scale of wind classification

Beaufort #	Wind	Mean speed mile/hr	Effect on objects
0	Calm	1	Smoke rise vertically. No ripples in water surface
1	Light air	2	Drifting of smoke and ripples in water surface
2	Light breeze	6	Wind felt on face and leaves movement on trees
3	Gentle breeze	11	Constant movement of leaves and small twigs
4	Moderate breeze	15	Dust and debris raised by wind. Small branches in movement and flags are fully expended.

5	Fresh breeze	20	Large branches in movement and pond water surface in wave.
6	Strong breeze	28	Large branches in movement and telephone wires produce sound.
7	Moderate gale	35	Trees bend and walking becomes difficult
8	Fresh gale	42	Breaking of small branches and twigs. Walking is difficult due to wind.
9	Strong gale	50	Damages building & breaking of large branches. Visibility in water surface is reduced.
10	Whole gale	60	Trees uprooted, serious damage to building
11	Storm	69	Widely destruction
12	Hurricane/ cyclone	>71	Severe destruction

Definitions

Isotach: It is the line on weather map, which joins the places of equal wind speed. Isotach are drawn on weather map to represent places with equal wind speed.

Wind ward: It is the direction, from which wind is coming.

Lee ward: It is the direction towards which wind is blowing.

Vorticity: Whirling motion of fluid particles is known as vorticity.

Haze: Decrease in the visibility of atmosphere due to dust and smoke particles is termed as haze.

Dust evil: It is a whirling dust column of height 1 km or more over the earth surface.

Gale: It is a wind having velocity between the ranges of 28-55 km.

Squall: It is a sudden increase in wind speed (greater than 50 km/hr) for at least one minute and then decreases.

Gust: It may be defined as an eddy moving down with mean speed greater than 25 to 30 km/hr.

Lull: It may be defined as an eddy moving up with mean wind speed less than 5 km/hr.

Buys-Ballots' Law

If we stand with back toward wind direction, the low pressure will be on the left hand and high pressure will be on right hand in northern hemisphere and vice-versa in southern hemisphere.

Units of wind velocity: Knot, meter/sec, kilometer/hour, mile/hour and feet/sec.

1 knot = 1 nautical mile = 1.15 miles/hr = 0.5148 m/s = 1.853 km/hr = 1.687 feet/s

The inter conversion of units of wind can be made as given in Table 2.

Table 2. Inter conversion of units of wind

cm/s	m/s	km/hr	mile/hr	knots
1	0.0	0.036	0.0223	0.01943
100	1	3.6	2.2347	1.943
27.78	0.2778	1	0.6214	0.5396
44.77	0.4477	1.6109	1	0.8696
51.48	0.5148	1.8533	1.1516	1

Types of air circulation

Wind movement in the atmosphere is classified into three circulations.

1. Permanent circulation: It includes the planetary/permanent wind system, where, permanent or continuous exchange of air takes place over macro scale. Trade winds, westerlies and easterlies are primary circulations. It is a regular circulation.
2. Periodic circulation: It is the periodic/seasonal exchange of air, which takes place over synoptic scale. Therefore, it is also called synoptic scale circulation e.g. Monsoons, cyclones, anticyclones and air masses. It is named as periodic/seasonal circulation.
3. Local circulation: It is the air exchange which takes place over mesoscale and microscale. It includes local winds, land breeze, sea breeze, mountain winds and valley winds. It is also called as local circulation. The wind is named with the direction from which it is blowing. So, wind coming from east is called easterly.

Planetary winds/permanent winds

There are three types of winds, which blow between different pressure belts over the globe:

1. **Trade winds:** These winds blow between equational low pressure and subtropical high pressure belts i.e. between 5^0 and 30^0 latitudes in both the hemispheres. They are named as trade winds as they follow a regular path. Trade winds in northern hemisphere are called as north-east trade winds and in southern hemisphere are called as south-east trade winds (Fig. 4.4). The zone of trade winds is also called **Hadley cell**, as it resembles the convective model used by Hadley for the whole earth.
2. **Westerlies:** These winds blow between 35^0 and 60^0 latitudes in both hemiospheres or they blow from subtropical high pressure belt to sub polar low pressure belt in each hemisphere. The direction of westerlies in northern hemisphere is north-west and it is south west in southern hemisphere (Fig.4.4). The westerlies are the zone of cyclonic storms in southern hemisphere, between 40^0 and 60^0 latitudes. These winds are so strong and persistent; they are called as 'roaring forties', furious fifties and screaming sixties in the latitude of forties, fifties and sixties, respectively.
3. **Polar easterlies:** These winds blow from polar high pressure to sub polar low pressure belt in both hemispheres (Fig. 4.4). The polar easterlies carry cold air out-ward from the polar high pressure areas. The direction of these winds is northeast in northern and south east in southern hemisphere. At higher levels, the winds blow in opposite direction to the trade winds at lower levels, therefore, called as anti-trade winds. The polar easterlies zones extend to 65^o latitudes in both hemispheres.

Periodic winds/monsoons

Monsoon is a periodic circulation. The term monsoon is derived from Arabic word 'mausim' or from the Malayan 'monsin', means 'season'. The word monsoon is used for such a circulation, which reverses its direction after every six months i.e. from summer to winter and from winter to summer. In summer, the moist wind blows from ocean to land and in winter, cold and dry wind blows from land to ocean. Monsoon circulation involves 180^0 change in the direction of winds. The principal monsoons of the world are the summer and winter monsoons of Asia and the monsoon circulations over west and east Africa. Asian monsoon system (10^0S to 80^0N) consist three distinct regional systems:

1. Indian monsoon
2. Japanese monsoon
3. Malayam monsoon

The detail of different monsoons is given in the chapter of monsoon.

Local winds

These winds originate due to difference in local features. Local wind is a tertiary circulation over a meso and microscale. It includes the following local wind systems:

1. **Land breeze:** It prevails during night. The land surface cools to lower temperatures than the temperatures over adjacent water surface. A low pressure is developed over water surface and high pressure is developed over land surface. Due to this pressure gradient

between land and sea, air moves from land to sea (Figure 5.6). This is called land breeze. It is developed along the sea cost. It is daily in occurrence.

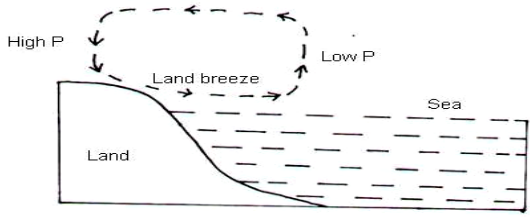


Fig. 5.6. Land breeze during night

2.Sea breeze: It prevails during day time. During day time land surface warms to temperatures higher than near by water surface temperatures. Therefore, a low-pressure area is developed over land surface and high pressure is developed over water surface. Air moves horizontally from sea (water surface) to land along the pressure gradient between sea and land (Figure 5.7). This movement of air from sea to land is called as sea breeze. It is a reverse of land breeze.

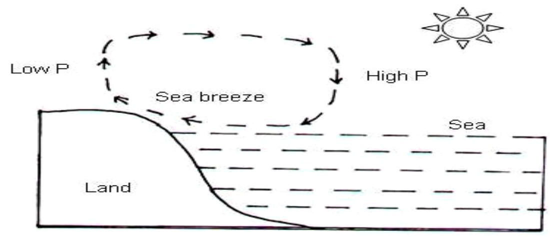


Fig. 5.7. Sea breeze during day

3. **Mountain winds:** On clear night, the mountain tops radiates energy and cool to lower temperatures as compared to valley. The cool denser air moves down along the mountain slope into the valley (Figure 5.8). This air movement from mountain to valley is called mountain wind/mountain breeze. It is daily in occurrence. It is also known as katabatic wind.

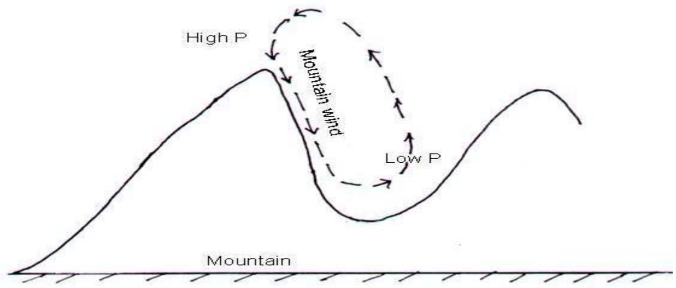


Fig. 5.8. Mountain wind during night

4. **Valley wind:** During day time in the morning, the mountain top gets energy earlier and warms to temperatures higher than valley temperatures. The warm air over mountain top rises above and generates upslope flow of air from valley (Figure 5.9). This movement of air from valley to mountain top is known as valley wind. It is also named as anabatic wind.
5. **Warm local winds:** These are hot and dry winds resulted due to advection of hot and dry air from warm places. Adiabatic warming of air also produces them, as they decent from elevated area to low land area. These are named differently in different parts of the world.

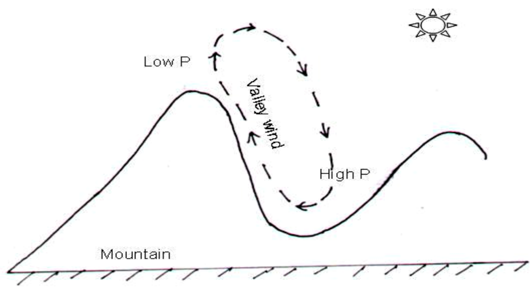


Fig. 5.9. Valley wind during day

1. **Foehn** is warm and dry wind on the northern side of Alps Mountain range in Switzerland.
2. **Chinook** is warm and dry wind on the eastern side of Rocky Mountains in North America.
3. **Santa Ana** is warm and dry wind experienced in California in U.S.A.
4. **Sirocco** is warm, dry and dusty wind blowing from Sahara desert in Southern Italy.
5. **Khamsin:** Hot and dry wind experienced in Egypt.
6. **Simoon:** It is a desert wind. It is a very hot and dry wind experienced in Asiatic and African deserts e.g. Sahara desert.
7. **Loo:** It is a very hot and dry wind experienced in north-west India during summer (May and June). It is also a desert wind.
8. **Harmattan:** It is a hot, dry and dusty wind experienced in west coast of Africa.
9. **Norwester:** Hot and dry wind from high mountain in New Zealand.
10. **Shamal:** Hot and dry wind experienced in Persian Gulf.
11. **Blackroller:** Very strong dust laden wind in Great Plains of North America.

Cold Local winds

These are cold and dust laden winds occur in different conditions:

1. **Mistral:** These cold winds experienced in southern coast of France and Mediterranean coast.
2. **Bora:** Experienced in eastern shore of the Adriatic Sea. These winds also experienced in northern Black Sea Coast in Japan and Northern Scandinavia.
3. **Blizzard:** Strong winds with snow storms in great plains to the east of Rocky Mountains United States of America.

Tornadoes

Tornado is a most violent and destructive whirlwind. It is funnel shaped and its diameter is very small i.e. near about 10 meter. Wind velocity is very high of about 460 mile/hr. Where it touches the ground, there is complete destruction. Tornadoes are experienced in United States of America. It originates due to mixing of dry polar air mass with warm and moist tropical air mass.

Zet stream

It is a stream of very rapid moving air circulating the earth at higher elevation of about 10-12 km i.e. in upper troposphere. Wind speed ranges from 150-300 km.

Instruments

1. **Anemometer:** The instrument which is used to measure wind velocity is called as anemometer e.g. wind cup anemometer, automatic anemometer etc.
2. **Anemograph:** The instrument which gives a continuous record of wind velocity with time on a chart.
3. **Wind vane:** The instrument which is used to measure wind direction is known as wind vane.
4. **Aerovane:** The instrument, which measures both wind velocity and wind direction.

6. HUMIDITY AND EVAPORATION

The humidity represents the presence of water vapour in air at a time and place. Water vapour constitutes only a small proportion of air which vary from nearly zero to maximum of 4 per cent by volume.

Water changes its states: solid, liquid and gas from one to another through the process of melting, evaporation, condensation, sublimation and freezing (Figure 6.1).

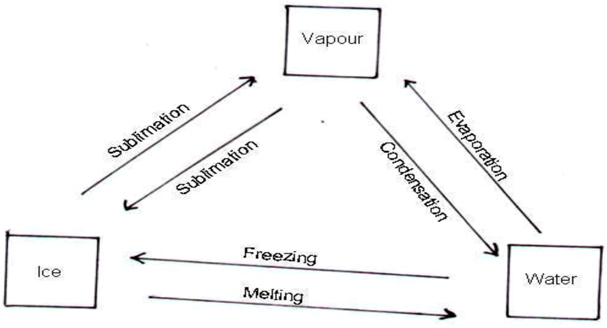


Fig. 6.1. States of water

1. Evaporation

It is a process by which water in liquid form changes to gaseous form. It may be defined as the water loss in vapour form from a soil/water surface. The energy used in this process is called as latent heat. The energy of 540 cal/g of water is used in this process.

2. Condensation

It is reverse process of evaporation. The process by which water vapour changes to liquid form is called condensation. The latent heat utilized in the process of evaporation is released in the process of condensation.

3. Sublimation

The process by which ice (solid state of water) directly converts into water vapours is termed as sublimation. Reverse process of change of water vapours to ice crystals is also known as sublimation.

4. Melting

The process by which water from ice state changes to liquid state. Latent heat of melting is 80 cal/gm of water is used in this process.

5. Freezing

The process by which, water from liquid state changes to ice state is called as freezing. Latent heat 80 cal/gm of water is released in this process.

Humidity terminology

The following terminologies have been used to express the presence of water vapour in air:

Absolute humidity (AH) : It may be defined as the mass of water vapour per unit volume of air or it is the ratio of mass of water vapour to the volume of air. The unit is g/cm^3.

$$AH = \frac{\text{Mass of water vapour (mv)}}{\text{Volume of the air (V)}} = mv / V$$

Specific humidity (SH) : It is defined as the mass of water vapour per unit mass of moist air. Specific humidity is expressed in grams of water vapour in kilograms of air (g/kg). It decreases with increase in latitude. So, it is higher at equator and lower at poles.

$$SH = \frac{\text{Mass of water vapour (mv)}}{\text{Mass of moist air (mv+ma)}}$$

Where, ma = Mass of dry air

Relative humidity (RH): It is defined as ratio of the mass of water vapour present in air at a temperature to the mass of maximum water vapour that air can held at the same temperature. It may also be defined as the ratio of actual vapour pressure to the saturated water vapour pressure.

$$RH = \frac{\text{Mass of water vapour in a given volume of air at a temperature}}{\text{Mass of maximum water vapour that air can held in the same volume and at same temperature}} \times 100$$

OR

$$RH = \frac{AVP}{SVP} \times 100$$

Where, AVP = Actual vapour pressure; SVP = Saturated vapour pressure

Actual vapour pressure

It is the partial pressure exerted by water vapour in given volume of air at a given temperature. Actual vapour pressure is called as saturated vapour pressure when air is saturated. It may also be defined as the pressure exerted by water vapour actually present in air. It is the saturated vapour pressure at dew point.

Saturated vapour pressure

The pressure exerted by water vapour, when air is saturated. It is maximum pressure exerted by water vapour in a given volume of air. It is also the actual vapour pressure at dew point.

Dew point

It is the temperature to which air is cooled and air becomes saturated and condensation of water vapour starts. It is called as dew point or condensation temperature. The 'dew' form of condensation occurs at this temperature. So, the temperature of air at which 'dew' formation starts is called as dew point.

Saturation deficit/vapour pressure deficit (VPD)

It is defined as the mass of water vapour required to bring the air at saturation at the same temperature in same volume of air. The difference between saturated vapour pressure and actual vapour procure is called as saturation deficit.

$$VPD = SVP–AVP$$

Mixing ratio (MR)

It is the ratio of mass of water vapour to the mass of dry air. It is expressed as grams of water vapour per kilogram of dry air. It varies from 1 g/kg in arctic zone to 40g/kg in humid equatorial zone.

$$MR = \frac{mv}{ma}$$

$$SH = \frac{mv}{mv+ma} = \quad 1+\frac{1}{MR}$$

$$MR = 0.622\,\frac{e}{P–e}$$

Where,

e = Vapour pressure

P = Total air pressure

Exercise: *What will be the vapour pressure deficit and relative humidity if saturation vapour pressure is 16.0 mm of Hg and actual vapour pressure is 12.5 mm of Hg?*

Solution

$$\text{Relative humidity} = \frac{AVP}{SVP} \times 100$$

AVP = 12.5 mm of Hg

SVP = 16.0 mm of Hg

$$RH = \frac{12.5}{16.0} \times 100 = 78\%$$

Vapour pressure deficit = AVP–SVP

= 16.0–12.5

= 3.5 mm of Hg

Exercise: *The mass of water vapour is 20g in a one kg sample of air at 25^{o}C. The mass of maximum water vapour the given sample can held at same temperature is 35g.Calculate relative humidity, specific humidity and mixing ratio.*

Solution

$$\text{Relative humidity} = \frac{20}{35} \times 100 = 70\ \%$$

$$\text{Specific humidity initially at } 25^oC = \frac{20g}{1\ kg} = 20g/kg$$

$$\text{Specific humidity at saturation level at same temperature} = \frac{35g}{1\ kg} = 35\ g/kg$$

$$\text{Mixing ratio initially at } 25^oC = \frac{\text{Mass of water vapour (mv)}}{\text{Mass of dry air (ma)}}$$

mv = 20 g

ma = 1000-20 = 980 g

$$= \frac{20}{980} = 20.4\ g/kg$$

$$\text{Mixing ratio at saturation} = \frac{mv}{ma}$$

mv = 35 g

ma = 1000-35 = 965g

$$= \frac{35}{965} = 36.3\ g/kg$$

Vapour pressure

It is the partial pressure exerted by water vapour in air. If we sum up all partial pressures caused by each atmospheric constituent, then it is called atmospheric pressure (P).

$$P = p\ (N_2) + p\ (O_2) + p\ (H_2O) + p\ (Ar) + p\ (Co_2) + ...$$

Where,

$p\ (N_2)$ = Partial pressure due to nitrogen

$p\ (O_2)$ = Partial pressure due to oxygen

p (H_2O)= Partial pressure due to water vapour
p (Ar) = Partial pressure due to argon
p (CO_2) = Partial pressure due to carbon dioxide

Factors affecting humidity

1. **Water vapour content:** Air humidity increases with increase in its water vapour content at the same temperature. The maximum limit of water vapour content that air can held at the same temperature is called saturation. Specific humidity is higher in humid tropics as compared to polar region.
2. **Temperature of air:** The capacity of air to hold water vapour will depend upon its temperature. As the temperature of a given air sample increases, its humidity decreases. So, water vapour holding capacity of air increases with increase in temperature. Temperature and humidity are inversely related.
3. **Distance from water bodies:** The places near water bodies have high humidity as compared to far places. Therefore, humidity is higher in costal region as compared to interior land regions.
4. **Prevailing winds:** The humidity of air coming from dry places is lower as compared to air from wet/humid places, e.g. Easterly winds are more humid than westerly winds during summer in Haryana.
5. **Vegetation:** Presence of vegetation also increases humidity through loss of water vapour in atmosphere by evapotranspiration. So, vegetated regions are more humid than non-vegetated regions.
6. **Condition of atmosphere:** Cloudy day is more humid than clear day. Precipitation is main source of water over land surface. So, rainy weather is more humid than dry or clear weather.

Evapotranspiration

The water loss in vapour form from a water surface or land surface is called as evaporation. While, the loss of water in vapour form from plants is known as transpiration. A combination of evaporation and transpiration is termed as evapotranspiration. Evapotranspiration is combined loss of water in vapour form soil and plants surface. In a crop field, the rate of water loss through evaporation is higher during initial phase of crop development and water loss through transpiration is higher during latter period of crop cycle. The rate of evapotranspiration is maximum during maximum ground cover by canopy i.e. maximum leaf area period.

Actual evapotranspiration (AET)

It may be defined as the water loss in vapour form from a crop surface under actual field conditions. It is also defined as the actual water loss to the atmosphere from a crop field.

Potential evapotranspiration (PET)

The maximum water loss in vapour form from a crop surface to the atmosphere if water is not limiting, is called as potential evapotranspiration.

Evapotranspiration from a reference surface is defined as reference evapotranspiration. For maximum water loss from a crop/vegetative surface to take place, certain conditions are to be fulfilled. So, the maximum water loss in vapour form from an exposed area, fully covered by short healthy green grass with no water limitation, is called as potential evapotranspiration. It is computed by different empirical and micrometeorological methods proposed by different scientists. The methods of evapotranspiration estimation can be divided into direct and indirect methods.

Indirect methods of ET estimation

Empirical/statistical methods

Some of the empirical methods of ET estimation are given below:

Thornthwaite method

Thornthwiate (1948) gave the following formula for computing monthly evapotranspiration:

$$E = 1.6\ (10\ T/l)^{a}$$

Where,

E = Unadjusted PET (cm)

T = Mean monthly air temperature (^{o}C)

I = Annual or seasonal heat index. It is the summation of 12 values of monthly heat indices $i = (T/5)^{1.514}$

a = An empirical exponent

$= 0.675\times10^{-6}\ I^{3} - 0.771\times10^{-4}\ I^{2} + 1.79\times10^{-2}\ I + 0.4924$

For daily calculation the formula is modified as under:

$$PET = \frac{k \times e \times 10}{\text{Days in month}}\ \text{mm day}^{-1}$$

Where,

k = Adjustment factor

Exercise: *Compute the evapotranspiration for a station having mean air temperature of 20^{o}C on 30.10.2005, annual heat index of 134.1, exponent value of 3.2 and adjustment factor of 0.9 using Thornthwaite method.*

Solution

$$e = 1.6\ (10\times 25/134.1)^{3.2}$$
$$= 11.7\ \text{cm}$$

$$\text{Adjusted daily PET} = \frac{11.7 \times 0.9 \times 10}{30}$$

$$= 105.3/30 = 3.5\ \text{mm}$$

2. Blanney-Criddle method

Blany-Criddle (1950) proposed the following method of daily evapotranspiration estimation.

$$PET\ (mm) = (0.0173\ Ta - 0.314)\ Kc \times Ta\ (DL/4465.6)\times25.4$$

Where,

Ta = Mean temperature (^{o}F)

DL = Day length

Kc = Crop coefficient

Exercise: *Calculate evapotranspiration for an agromet station with following weather data using Blanney Criddle method.*

Mean air temperature = 65^{o}F

Day length = 12.0 hrs, Crop efficient for wheat = 0.70

Solution

$$PET = (0.0173\times65-0.314)\ 0.7\times65\ (12/4465.6)\times25.4$$
$$= 0.81\times0.7\times65\times0.0027\times25.4 = 2.53\ \text{mm/day}$$

3. Combination method

Penman (1948) gave the following formula for daily PET estimation from natural surfaces.

$$PET\ (mm) = KE_{o}$$

Where,

K = Penman constant

E_{o}= Evaporation from open surfaces

$$= \frac{\Delta Rn + \gamma Ea}{\Delta + \gamma}$$

Where,

Rn	=	Net radiation (mm of water)
	=	$R_A(l\text{-}r)(0.18+0.55n/N)–\sigma Ta^4(0.55–0.092\sqrt{ed})$ $(0.10+0.90\ n/N)$
r	=	Reflection coefficient of surface (Albedo)
R_A	=	Angot's value of mean monthly radiation (mm of water/day)
Ta	=	Mean temperature (^oK)
n	=	Actual sunshine hours
N	=	Maximum possible sunshine hours
σ	=	Stefan Boltzman constant
ed	=	Saturation vapour pressure at dew point temp (mm of Hg)
	=	RH× ea/100
ea	=	Saturation vapour pressure at mean air temp (mm of Hg)
RH	=	Mean relative humidity
Ea	=	Aerodynamic component
	=	$0.35\ (ea\text{-}ed)\ (1+0.0098\ u_2)$

Where, u_2 =Wind speed in miles/day at 2 m height = (log 6.6/log h) uh

Where, uh = Wind speed at height h (miles/day)

Exercise: *Calculate evapotranspiration using Penman combination approach for an agromet station having weather data given below:*

Penman constant for summer	= 0.8
Mean air temperature	= 25^{o}C
Mean monthly radiation	
Outside the atmosphere	= 10.8 mm of water
Actual vapour pressure	= 16.6 mm of Hg
Saturated vapour pressure	= 23.8 mm of Hg
Wind speed at 10 feet height	= 12.2 miles/hr
Wind speed at 2 meter height	= (log 6.6 ×12.2)/log 10
	= 240 miles/day
Δ/γ	= 2.86
σT^4	= 15.98 mm of water
n/N	= 0.66

Solution

Net radiation = 10.8 [(1-0.15)(0.32)+(0.46×0.66)]–15.98 (0.55–0.092 × 4.07) × (0.10+0.90×0.66)

= (10.8×0.85×0.6236)–15.98× 0.176×0.694

= 5.72–1.95 = 3.77 mm/day

Aerodynamic component Ea = 0.35 (23.8–16.6) × (1+0.0098×240.0)

= 0.35×7.2×2.35

= 5.08 mm/day

$$E_o = \frac{\Delta/\gamma\ Rn + \gamma Ea}{(1+\Delta/\gamma)}$$

$$E_o = \frac{2.86\times3.77+5.08}{1+2.86}$$

$$E_o = \frac{10.78 + 5.08}{3.86} = 4.11 \text{ mm/day}$$

$$PET = 0.8 \times 4.11 = 3.3 \text{ mm/day}$$

Crop coefficient (Kc)

It is the ratio of actual evapotranspiration to potential evapotranspiration. It varies with crop-to-crop, variety to variety and from sowing to maturity of crop. Its value varies from 0 to 1 and some time it may be higher than 1 under advected condition. When AET is equal to PET, its value is 1.

$$Kc = \frac{AET}{PET}$$

Factors affecting evapotranspiration

The evapotranspiration rate is influenced by the factors, which affects both evaporation and transpiration. Some of the factors which control the rate of evapotranspiration are discussed below :

1. **Temperature:** If the air temperature over a crop surface increases, the rate of evapotranspiration increases. Therefore, evapotranspiration will be higher from a crop field with higher ambient temperature as compared to the evapotranspiration from crop field with lower ambient temperature. Evapotranspiration in tropics is higher than that of higher latitudes/polar regions.
2. **Humidity:** The humidity of the environment decides the atmospheric demand for water. High humidity decreases the atmospheric demand of water, thereby evapotranspiration rate is decreased. So, higher the humidity of environment, there will be lower rate of evapotranspiration and vice-versa.
3. **Exposure of surface:** If the exposure of evaporating surface increases, the rate of evapotranspiration also increases but it becomes constant after certain exposure of surface e.g. evaporation rate from a pitch is lower than the evaporation from a open pan filled with same amount of water.
4. **Concentration of water:** The rate of evaporation is higher from pure water surface in comparison with surface of salted water. The presence of salts in water decreases the rate of evaporation. Evaporation from saline soils is less than the evaporation from non-saline soils.
5. **Wind:** Wind acts as a transporting agent over an evaporating surface. So, as the wind speed increases, the rate of evaporation increases. Under 'calm' conditions, first the evaporation takes place and as the air over evaporating surface attains saturation, the evaporation rate falls to nearly zero. So, windy areas have more evapotranspiration than 'calm' areas.
6. **Air pressure:** Atmospheric pressure also influences the rate of evaporation from a surface. Lower atmospheric pressure over evaporation surface results in higher rate of evaporation.
7. **Amount of water available:** Availability of water to the evaporating surface controls the rate of evaporation. The evaporating surface with more supply of water has more rate of evaporation.
8. **Leaf area:** The transpirational loss of water mainly takes place from plant leaves. Therefore, as the leaf area index increases, the rate of transpiration increases. The field crops with more leaf area index have more evapotranspiration as compared to the crops, which have less leaf area index. The rate of evapotranspiration increases with increase in crop growth and attains maxima at maximum leaf area stage.

9. **Plant spacing:** Wider row spacing decreases the rate of evapotranspiration. Therefore, crop with denser plant populations has more evapotranspiration as compared to crop with sparse plant population.
10. **Plant height:** In taller plants, more plant surface area is exposed to environment. Therefore, water loss from the plants increases with increase in plants upto a certain height. Taller plants have more transpiration in comparison with dwarf/short plants.
11. **Stomata aperture:** The stomatal aperture controls the loss of water vapour and intake of CO_2 from the environment. Plant leaves open stomata during daytime and close during night time. Therefore, evapotranspiration is higher during daytime as compared to night time, as transpiration ceases and evaporation decreases during night time. Under stress condition, plants closes stomata to reduces evapotranspiration loss and try to maintain their water status.

Instruments

Psychrometer: It is an instrument which consists of dry and wet bulb thermometer. From the dry and wet bulb temperatures, we can find out relative humidity, dew point and vapour pressure using psychrometeric tables. It is of two types i.e. Assmann psychrometer and whirling psychrometer.

Hygrometer : The instrument used for measurement of humidity is called hygrometer. Its one of the types is hair hygrograph.

Evaporimeter: The instrument which is used to measure evaporation, is called as evaporimeter. Its one of types is U.S.A. class-I open pan evaporimeter.

Lysimeter: It is an instrument used for measuring evapotranspiration. It is a direct method of evapotranspiration estimation. It is of two types:

1. Weighing type lysimeter.
2. Volumetric type lysimeter.

1. Weighing lysimeter

An iron tank is field with soil uniformly so as the soil profile may not be disturbed and placed on a balance installed in the ground in the middle of field. Crop is sown in the tank with the same agronomic practices, which are followed in the crop filled. The change in weight of the tank is recorded on weighing balance. Then evapotranspiration is calculated as:

$$ET\ (mm) = \Delta W \times 0.6 + rainfall\ (mm)$$

Where, ΔW is change in weight.

2. Volumetric lysimeter

This lysimeter measures the evapotranspiration in volumetric term. Evapotranspiration is calculated by recording change in inflow and outflow of water from reservoir i.e. a measured amount of water is added in the reservoir.

$$ET\ (mm) = Water\ added\ in\ reservoir\ (litre) \times 0.7 + rainfall$$

7. CONDENSATION AND PRECIPITATION

Condensation is a process by which water vapor changes to liquid state. The air is cooled to a temperature at which condensation starts is called condensation temperature. It is also called dew point temperature. When the dew point temperature falls below the freezing point (0°C), the water vapor may directly changes to solid state. This process is called sublimation. The condensation depends upon two factors.

1) Relative humidity of the air
2) Degree of cooling

The condensation to take place, the following conditions should be met.

1) **Saturation of air**

The process of condensation will take place only when air attains saturation level. Saturation can be attained by adding water vapor in the air and cooling of the air.

2) **Condensation Nuclei**

The water vapor in the atmosphere, require a surface upon which, it may condense. The water vapors condense on the objects lying on the earth surface, when condensation takes place near or on the earth surface. Condensation when occurs in atmosphere at a distance, the solid particles suspended in air act as nuclei for condensation. These are called as condensation nuclei. In the absence of these nuclei, the clouds (form of condensation) may not form unless, relatives humidity of about 400 per cent is reached due to cooling of air. Tiny dust particulates, microscopic salt particles, carbon particles, smoke particles, fumes etc act as condensation nuclei. Hygroscopic particles, which have affinity for waters, also act as condensation nuclei.

Forms of condensation

Condensation results in different forms depending upon the water vapor content, turbulence and rates of cooling in the atmosphere. Some forms of condensation occurs on earth surfaces (dew and frost) and some occurs in air i.e. fog, mist and cloud.

1. Dew

The deposition of condensed moisture in the form of tiny waters droplets on surface of objects cooled by radiational cooling during night. Clear nights and calm condition are necessary for dew formation, as these conditions favour the cooling of surface objects by radiational cooling. Clouds reduce the radiational cooling during nights as they absorb terrestrial radiation and re-emit radiation towards earth surface. Wind causes turbulence in the lower atmosphere, which mixes lower cooled air with upper warm air and thereby it prevents the air to reach at dew point. Dew formation also depends upon the waters vapor content of air.

2. Frost

It is the deposition of condensed moisture in the form of ice crystal upon a surface, when ambient air temperature falls below freezing point, as the dew point of air falls below freezing levels, the waters vapor directly changes from gaseous to solid states. It is of two types based on appearance.

a) **White frost**

Deposition of condensed moisture in the form of white ice crystal upon a surface object as dew point of air falls below freezing is called white frost. White frost occurs when the atmospheric water vapor content is sufficiently high.

b) **Black frost**

Under low humidity condition (dry condition) of atmosphere, as the temperature falls below freezing level, the water within the cells and intercellular spaces freezes and cause death of plant cells.

The plant leaves look like burnt canopy. This is known as black frost. Frost can be classified based on way/process of cooling of air into two groups.

i) Advection frost

The frost which is resulted due to advected cool air mass, is called as advected frost. During winter, advection of cooled air mass from Himalaya results into the occurrence of frost in north western plains of India.

ii) Radiation frost

The frost occurs due to radiational cooling of air on calm and clear nights are termed as radiation frost. During winter months in Haryana radiation frost occurs on calm and clear nights.

3. Fog

It may be defined as tinny microscopically small drops of water resulted due to condensation in air and suspended in air near the earth surface in sufficient number to decrease the visibility of atmosphere less than 1 km. Fog is also termed as cloud if it occurs at higher levels. So, fog and cloud are same but they differ in place of occurrence in the atmosphere. If it occurs near ground, it is called fog and if it occurs at higher levels it is called as cloud. Fog can be classified into two groups based on the process of cooling of air.

a) Radiation fog

The fog which results dues to radiational cooling of air is known as radiation fog. It is experienced after rainfall on calm and clear nights during winter in northern plains.

b) Advection fog

The fog which results dues to advection of warm & moist air mass over a cool land surface, is called advection fog. This type is experienced in December, January and February in northern plains.

Precipitation

Precipitation may be defined as condensed moisture in liquid or solid forms falling to the earth surface. The atmospheric moisture precipitates to the earth surface in different solid or liquid forms. Precipitation is measured in inches, centimeters and millimeters. All the forms of precipitation are termed as hydrometeors

The form of condensed atmospheric moisture which falls to the earth surface depends upon the following conditions:

1) Dew point or condensation temperature
2) Conditions of atmosphere through which particles pass
3) Types of clouds
4) Processes which result precipitation

Forms of precipitation

1. **Rain**: It is the precipitation in the form of liquid water drops having diameters more than 0.5 mm. The precipitation in the form of smaller, widely scattered drops of water is also called rain. In heavy rains, the rain drops are larger and more in number. Some time rain drops evaporate completely in the atmosphere before reaching ground. The streaks of rainfall are called virga.
2. **Drizzle:** It is uniform precipitation in the form of fine water drops having diameter less than 0.5 mm. The precipitations of very small drops of uniform size and seem to float in air is also called as drizzle. It gives very small amount of water on the ground. Drizzle is generally associated with poor atmospheric visibility.
3. **Snow:** Precipitation of condensed atmospheric moisture in the form of

white and opaque ice grains. Snow consists of a wide variety of ice crystals. Snowfall occurs in the form of snow flakes, which result due to gravitational coalescence. Snow occurs when the temperature at condensation level falls below freezing level.

4. **Rime**: When an object having temperature below 0°C encounter a fog, this type of precipitation results.
5. **Sleet**: It is a form of precipitation of small pellets of transparent or translucent ice having diameter less or equal to 5 mm. it is also called as frozen rain. The precipitation in the form of a mixture of rain drops and snow is also termed as sleet.
6. **Glaze**: When rainfall occurs on a object having temperature below freezing, this type of precipitation results.
7. **Hail**: Precipitation of condensed atmospheric moisture in the form of small bolls or pieces of ice having diameter more than 5 mm is termed as hail. The ice pieces may be of different polygonal shapes i.e. triangle, rectangle, pentagonal, hexagonal etc. The size of hail is sometime very large i.e. 50 mm or more, depending upon the up thrust within the cloud in which hail formation takes place. Cumulonimbus clouds are mainly associated with hailstorms. Hail is most destructive form of precipitation. Hail structure resembles to that of onion. It consists of concentric layers of ice with layer of snow in between.

Formation of hails: The hails are associated with cumulonimbus clouds. Hails development require a great vertical extent of cloud, which is possible only in cumulonimbus clouds. These clouds have a great range of temperature between bases and their top i.e. the base temperature may be around 10°C and top temperatures may be about of –15°C. The strong up draft of air in cumulonimbus clouds carry tinny water drops to greater height where these drops convert into ice crystals. These frozen drops/ice crystal have to fall through the cloud, met with super cooled water droplets and they get coating of ice. These ice balls are lifted up again and again through the cold layer of cloud by upward air currents within the cloud. The ice balls oscillate within the cloud and increase in their size till the down thrust of hail is less than upthrust, as the down thrust exceeds, the ices balls/ pieces escape from the cloud and falls through atmosphere on the ground. The size of hails depends upon the following characteristics of cloud:

1. Upward air currents within cloud
2. Super cooled waters drops concentration.
3. Vertical extend of cloud

A hail stone of 766 g weight fell at Coffeyville, Komsas on September 3, 1970.

Occurrence of Hails

Hail storms seldom occur in tropical and higher latitudes belts. In both hemispheres, hail storms are confined in mid latitudes between 30° and 60°. Oceans are free from hail occurrence because of absence of strong vertical air currents. Spring and early summers period in mid latitudes experience hail storms. Hail storms some time occur during February to May and October and November in Northern India.

Types of Precipitation

Precipitation results from cloud due to adiabatic cooling of rising air. Precipitation is classified on the basis of conditions which cause rising of moist air masses into three types:

1. Conventional precipitation/rainfall

The precipitation, which results due to thermal convection of warm and moist air masses, is called convectional precipitation. Rain, snow and hails are associated with this type of

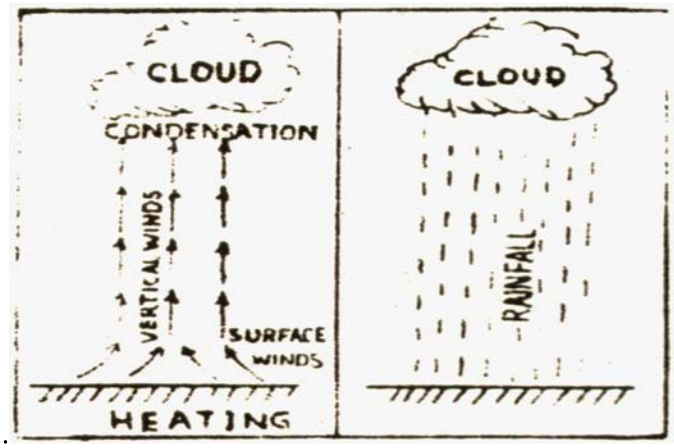


Figure 7.1. Convectional Precipitation

precipitation under favourable conditions it occurs in tropical and temperate zones. Precipitation intensity depends upon the heating rate of surface and supply of moist air with high humidity. It is generally accompanied by thunder, lightning and local winds because of intense thermal air currents. This type of precipitation mainly occurs in equatorial low pressure belt, called doldrums. During noon time cloud formation takes place in the sky and followed by showery rainfall in after noon or evening over this belt.

2. Orographic rainfall

The precipitation resulted when air rises and cools due to topographic barrier, is termed as orographic rainfall/precipitation. This type of precipitation generally occurs when the mountains/barriers lie across the path of moisture laden winds. This type of rainfall occurs in foot hills of Himalaya ranges but not in Aravali hill ranges, as they are parallel to the monsoon winds. The term orographic is derived from the greek word ‘oros’ means mountain. This type of precipitation is commonly found on the windward side of mountains. There always exists relatively dry area on the leeward sides of mountain ranges which is called as rain shadow.

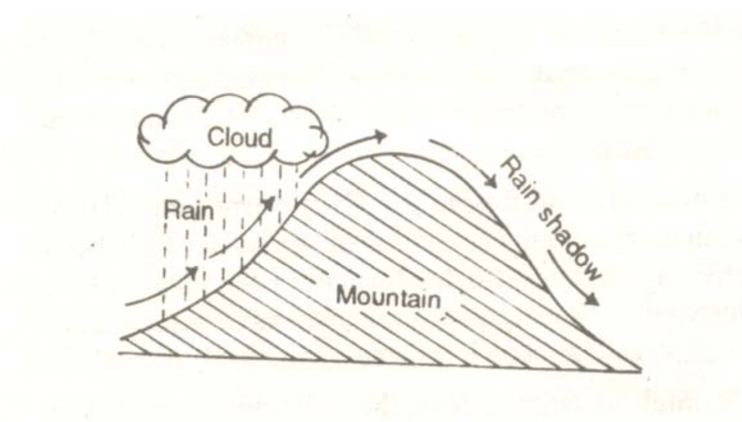


Figure 7.2. Orographic Precipitation

First rainfall increases with slopes upto a certain height and then decreases near peak of the mountain ranges. This decrease in precipitation with height on the leeward side near peak of mountain range is termed as inversion of rainfall.

3. Cyclonic/frontal precipitation

Cyclonic precipitation occurs when deep and extensive air masses of different characteristics converge, rise and adiabatic cooling takes place. It is also called convergence precipitation. In tropical regions where opposing air currents with different temperatures converge, vertical rising takes places and usually accompanied by convection. This convection causes condensation and precipitation. This type of precipitation is called cyclonic precipitation.

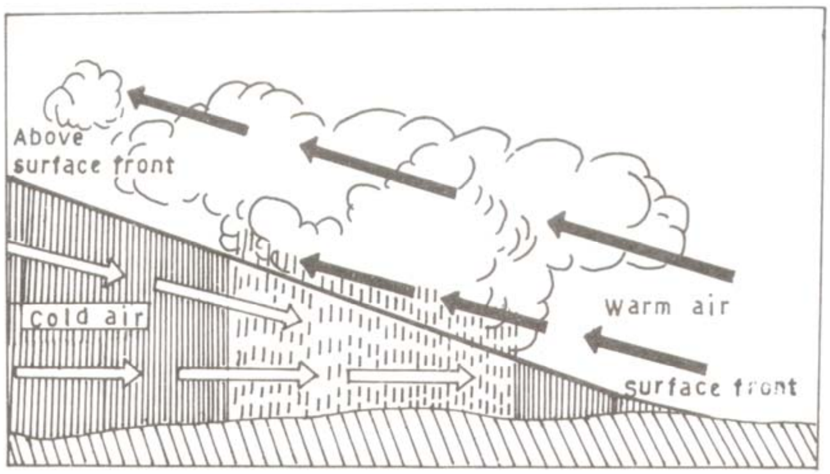


Figure 7.3. Cyclonic or Frontal Precipitation

In temperate regions mostly frontal precipitation occurs. The zones of contact between relatively warm and cold air masses are known as fronts. The warm ands moist air gradually rises over cool and dry air along the front. The convectional activity along the front causes condensation and precipitation. This type of precipitation is called frontal precipitation.

Distribution of annual precipitation

The average annual precipitation over the whole earth is about 80 cm, but it is distributed very unevenly. Equatorial regions and monsoon regions of Southeast Asia record the highest rainfall. Temperate regions receive moderates amounts of precipitation. The dry regions of sub tropical high pressures belt and polar regions receive little precipitation. The distribution of mean annual precipitation over the earth surfaces is divided into different zones:

First Zone

The precipitation zones lies between 10° to 20° wide near the equator in both hemisphere. Maximum precipitation occurs in this zone. The averages precipitation is about 160 cm.

Second zone

This zone lies between 20° to 30° latitudes N and S. It is a belt of lower precipitation due to the presence of subtropical anticyclones. Average annual precipitation is about 80 to 90 cm.

Third zone

This is the second belt of maximum precipitation in both the hemispheres due to maximum cyclonic activity. It lies between 40° to 55° latitudes N and S. Average annual precipitation ranged between 80 to 120 cm.

Fourth zone

This is a zone of minimum precipitation in both hemispheres. There is sudden decrease in precipitation in both hemispheres from about 55° latitudes reaching to a minimum of less than 15 cm in polar regions

The latitudes 0° to 10° N have more precipitation than 0 to 10° S, due to more extension of inter tropical convergence zone (ITCZ) in north The latitudes between 40°-60° S have more precipitation than 40° to 60° N, due to more water surface in this belt in southern hemisphere. Almost 50 percent of annual precipitation falls between 20° N and 20° S latitudes. The total annual precipitation remains same in the both the hemisphere.

Artificial Precipitation

The precipitation received by artificially saturation of a special type of cloud is known as artificial precipitation. It may be defined as the precipitation by artificial seeding of clouds with hygroscopic nuclei. The cloud seeding is of two types based on the temperature of clouds.

i) **Seeding of warm clouds**

Seeding of cloud by water droplets of about 50 μm diameter in the lower parts of deep clouds. The precipitation is also received by injecting fine salt particles which act as hygroscopic nuclei. Dry ice seeding is also done for getting artificial precipitation.

ii) **Seeding of cold clouds**

Seeding of clouds having temperature below -5°C is done with silver iodide. Fine powder of silver iodide is seeded in the cloud which acts as nuclei and produces ice particles in clouds. Silver iodide smoke is also introduced in clouds by aero planes or explosive rockets and balloons.

Artificial precipitation can also be generated by means of lightning and shock waves. The convective activities of atmosphere are affected by the heat produced by lightning and electrical discharges also help in growth of water droplets by coalescence. Therefore, torrential rains occur after lightning in cumulonimbus clouds.

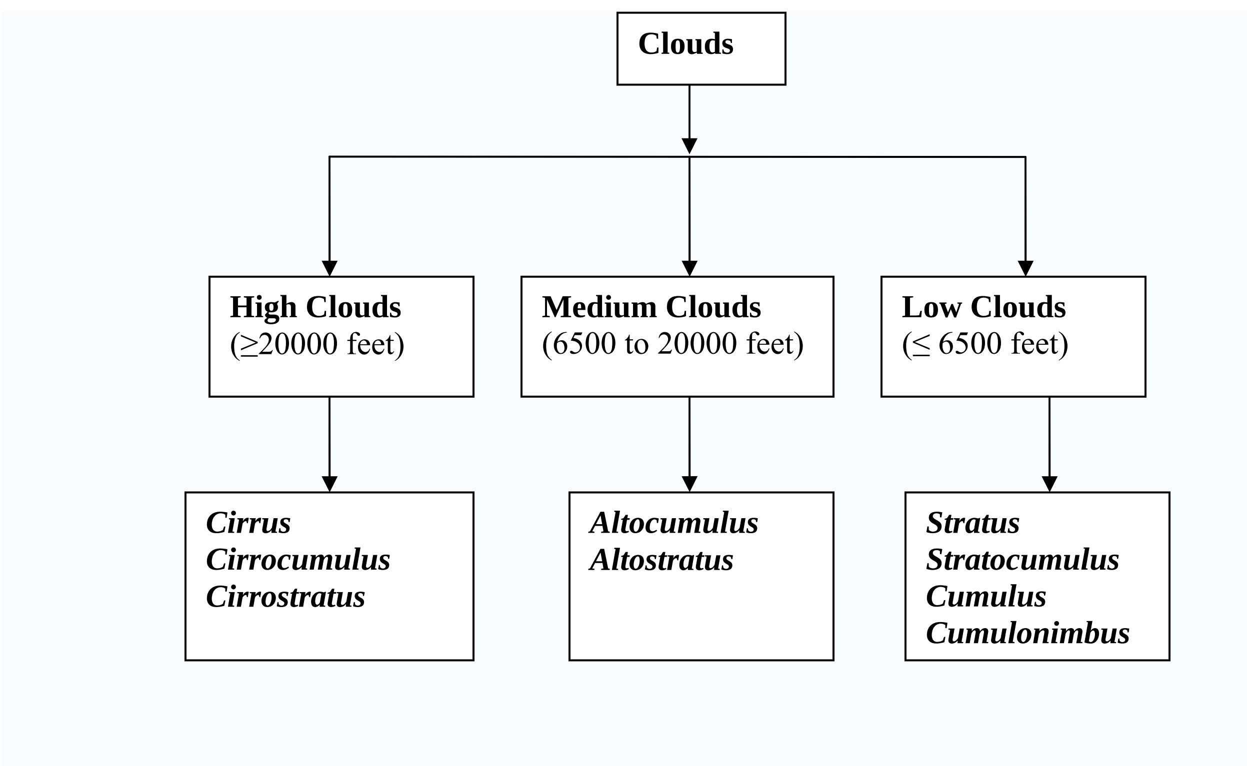
8. CLOUDS AND THEIR CLASSIFICATION

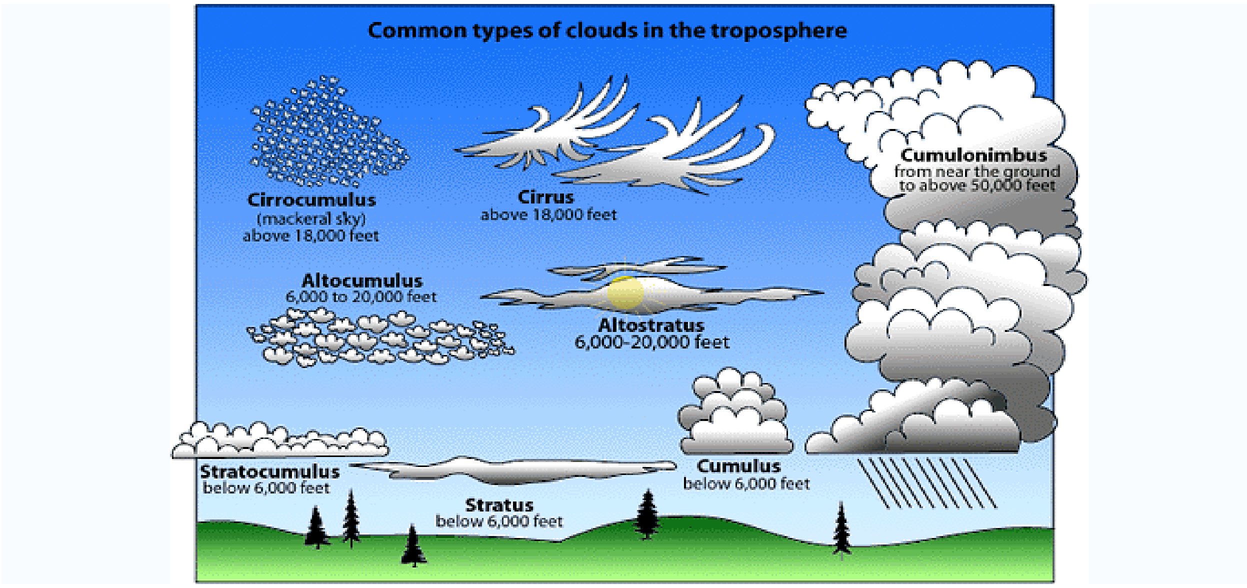
Clouds are nothing more than water vapour that condenses and accretes into a visible form. It may be defined as the visible aggregation of tinny water droplets or ice crystals or both condensed from air at higher levels above the ground. The usual mechanism is in which moisture-laden air near the Earth's surface to be raised higher into the atmosphere either by an encroaching air mass or topographical barrier in path or the heat of the sun. As the air is lifted, the pressure drops and the air is subsequently cooled and causes water vapour to condense in the form of cloud. Cloud is just like fog but it appears at higher levels in atmosphere. Cloud is an important form of condensation or sublimation that results from lifting of air. Presence of clouds affects the temperature of a place. Cloudy days are cooler in summer than the clear days. Cloudy nights in winter are warmer than clear nights.

Classification of clouds

Clouds are defined by their general appearance and level in the atmosphere. Luke Howard in 1803 first classified the clouds on the basis of their structure and named the different clouds with Latin words: Cirrus, cumulus, Nimbus and Stratus. The International Cloud Atlas published by World Meteorological Organization describes the ten main genera or types. The branch of meteorology in which clouds are studied is called nephology.

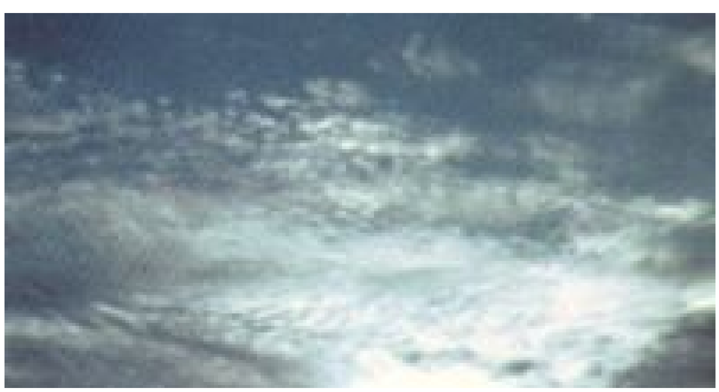
A) High clouds: The clouds which have their base at 6 km (20,000 feet) or above are termed as high clouds and since the temperatures are so cold at such high elevations; these clouds are primarily composed of ice crystals. High-level clouds are typically thin and white in appearance, but can appear in a magnificent array of colors when the sun is low on the horizon. They are denoted by the prefix *cirro-* or cirrus. These are:





1. Cirrus (Ci): These clouds are very high, wispy clouds made of ice. Detached fibrous white clouds are in the form of narrow bands. These look like feathers. Sun and moon produces halo through these clouds. Cirrus clouds are composed of ice crystals that originate from the freezing of super cooled water droplets. Cirrus generally occurs in fair weather and point in the direction of air movement at their elevation. No precipitation occurs from these clouds. When we see cirrus clouds, it usually indicates that a change in the weather will occur within 24 hours.

2. Cirrocumulus (Cc): This is white layer of clouds and composed of very small elements in the form of ripples. No shadow is caused by these clouds. This type looks like a patch of small globules arranged in small groups. Cirrocumulus clouds are usually seen in the winter and indicate fair, but cold weather. In tropical regions, they may indicate an approaching hurricane.



3. Cirrostratus (Cs): These are thin sheet like high clouds that often cover the entire sky and are relatively transparent, as the halo around the sun or the moon can easily be seen through them. This type of cloud gives a milky appearance to the sky. These clouds also do not cause shadow. Cirrostratus clouds usually come 12 to 24 hours before a rain or snow storm.


Cirrostratus **Cirrostratus with halo**

B) Medium clouds:

The clouds whose base lies at 2 km to 6 km (6,500 feet to 20,000 feet) are called medium clouds. These are denoted by the prefix *alto-*. They are composed primarily of water droplets; however, they can also be composed of ice crystals when temperatures are cold enough.

1. Altocumulus (Ac): These appear as parallel bands or rounded masses. Typically a portion of an altocumulus cloud is shaded, a characteristic which makes them distinguishable from the

high-level cirrocumulus. These clouds usually form by convection in an unstable layer aloft, which may result from the gradual lifting of air in advance of a cold front. They cause shadow on the ground. These clouds sometime referred to as 'sheep clouds' or wool pack clouds. The presence of altocumulus clouds on a warm & humid summer morning is commonly followed by thunderstorms later in the day. These clouds do not produce halos.

2. Altostratus (As): These are grey or blue grey mid level clouds composed of ice crystals and water droplets. These clouds usually cover partly or entire sky.

These clouds do not produce halo phenomena. Altostratus clouds often form ahead of storms with continuous rain or snow.

C) Low clouds: These are mostly composed of water droplets since their bases generally lie below 2 km (6,500 feet). However, when temperatures are cold enough, these clouds may also contain ice particles and snow.

1. Stratus (St): These are generally a grey cloud layer of uniform base. These types of cloud

may completely cover the sky. They may give precipitation in the form of drizzle or snow grains.

2. Stratocumulus (Sc): These are grey or white patches or both grey and white sheet of cloud and generally appear as rolls and round masses arranged in groups, lines or waves. Rain rarely occurs with stratocumulus clouds.

3. Cumulus (Cu): These are white, puffy clouds that look like pieces of floating cotton. Cumulus clouds are often fair weather clouds. The bases of each cloud is flat and the top of each cloud has rounded towers. The irregular patches of cumulus clouds are called fractocumulus. Cumulus clouds are generally found during day time over the land areas and dissipate during night. They produce light precipitation.

4. Cumulonimbus (Cb): These are heavy and dense cloud with considerable vertical extent, in the form of dome or huge tower. High winds can flatten the top of the cloud into an anvil-like shape. These types of clouds are associated with heavy rain, snow, hail, lightning, thunder storms and even tornadoes. These clouds are also called as vertical development clouds.

5. Nimbostratus (Ns): These are grey or dark, low-level clouds accompanied by light to moderate continuous rain and snow. This type of clouds can never accompanied by thunder and hail storms. Streaks of rain or snow failing from these clouds but not reaching the ground are called virga.

Cloud Measurement

The measurement of the height of a cloud is done by using a device which is called ceilometer. It is photoelectric instrument for ascertaining the cloud height. It is a device using a laser or other light source to determine the height of a cloud base.

Laser Ceilometer

The **Laser Ceilometer** measures cloud height and thickness, in addition to vertical visibility, detecting up to four cloud layers simultaneously to a distance of 30,000 vertical feet. A laser pulse is emitted into the atmosphere and backscatter analyzed. Using the speed of light, the altitude of each cloud base and top is determined. Due to poorly defined borders or a sparse composition, some clouds are much more difficult to measure. Depending on the current and historical sky conditions, an adaptive algorithm determines the number of returns needed to maintain accuracy. Accurate measurement of cloud height and thickness in all weather conditions, including heavy precipitation and low clouds, can cause serious errors.

Ceiling: The height to the lowest cloud layer which creates brown, over cast or obscured sky cover is termed as ceiling. It is especially useful in airport operation.

Cloud height: The distance between ground and base of cloud is called cloud height.

Isohyet: It is line joining the places having equal precipitation.

9. MONSOONS

Monsoon is a wind pattern that reverses direction with the seasons. The term was originally applied to seasonal winds in the Indian Ocean and Arabian Sea. The word is also used more specifically for the season in which this wind blows from the Southwest in India and adjacent areas that is characterized by very heavy rainfall associated with this wind. Every summer, southern Asia and especially India, is drenched by rain that comes from moist air masses that move in from the Indian Ocean to the south. These rains, and the air masses that bring them, are known as monsoons. Smaller monsoons also take place in equatorial Africa, northern Australia, and, to a lesser extent, in the southwestern United States (Figure 9.1).

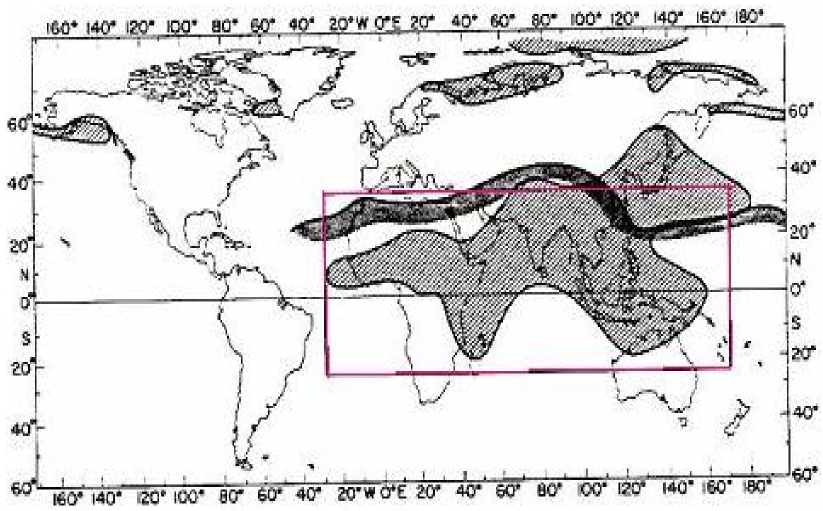


Figure 9.1. World Monsoon Regions

Etymologically, the English **word '***monsoon***' comes from the** Dutch ***monssoen*, from the** Portuguese ***monçao*,** from the Arabic ***mawsim*,** from the Malayan word '***monsin***' which means '**season**'. The word monsoon is applied to such a circulation which reverses its direction every six months i.e. from winter to summer and vice-versa.

In terms of total precipitation, total area covered and the total number of people affected, the monsoon affecting the Indian Subcontinent dwarfs the North American monsoon (also called the "Mexican", "Southwest", "Desert", or "Arizona" monsoon).

Monsoon Systems

As monsoons have become better understood, the term monsoon has been broadened to include almost all phenomena associated with the annual weather cycle within the tropical and subtropical land regions of the earth. Monsoons are caused by the larger amplitude of the seasonal cycle of temperature over land as compared to the adjacent oceans. This differential warming results from the fact that heat in the ocean is mixed vertically through a "mixed layer" that may be 50 meters deep, through the action of wind and buoyancy-generated turbulence, whereas the land surface conducts heat slowly, with the seasonal signal penetrating perhaps a meter or so. Additionally, the specific heat of liquid water is significantly higher than that of most materials that make up land. Together, these factors mean that the heat capacity of the layer participating in the seasonal cycle is much larger over the oceans than over land, with the consequence that land warms faster and reaches a higher temperature than the ocean. The hot air over the land tends to rise, creating an area of low pressure. This creates a steady wind blowing toward the land, bringing the moist near-surface air over the oceans with it. Associated rainfall is caused by the moist ocean air being lifted upward by mountains, surface heating/convection currents, convergence at the surface, divergence aloft, or from storm-produced outflows at the surface. However, the lifting occurs, the air cools due to adiabatic expansion, which in turn produces condensation.

In winter, the land cools off quickly, but the ocean retains heat for longer. The hot air over the ocean rises, creating a low pressure area and a breeze from land to ocean while a large area of high pressure is formed over the land, intensified by wintertime radiational cooling. Monsoons are similar to sea breezes, a term usually referring to the localized, diurnal (daily) cycle of circulation near coastlines everywhere, but monsoons are much larger in scale, stronger and seasonal. The wind pattern in summer and winter seasons has been depicted in Figure 9.2.

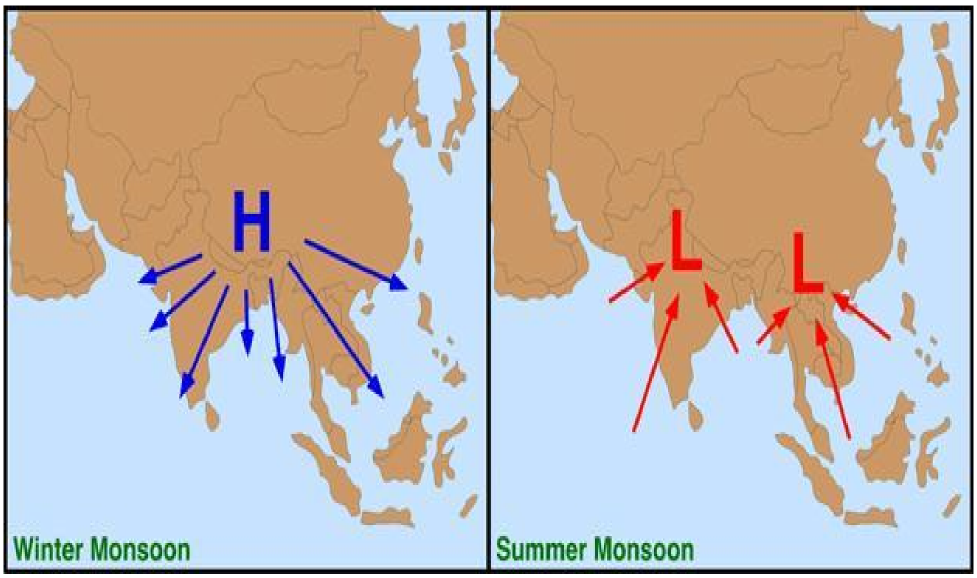


Figure 9.2. Monsoon wind pattern in Southeast Asia

i) Northeast Winter Monsoon (Asia)

In Asia, the northeastern winter monsoons take place from December to early March. The lower temperature over central Asia, creates a zone of high pressure there. The jet stream in this region splits into the southern subtropical jet and the polar jet. The subtropical flow directs northeasterly winds to blow across south Asia, creating dry air streams which produce clear skies over India from the months of November to May.

Meanwhile, a low pressure system develops over northern Australia and winds are directed toward Australia. During the Northeast Winter Monsoon, Australia and Southeast Asia receive large amounts of rainfall.

ii) Southwest Summer Monsoon

The Southwestern Summer Monsoons occur from June to August, and are drawn towards the Himalayas, creating winds blowing rain clouds towards India, some areas of which receive up to 1000 cm of rain.

iii) North American Monsoon

The North American Monsoon (NAM) occurs from late May or early June into September, originating over Mexico and spreading into the southwest United States by mid July. It affects Mexico along the Sierra Madre Occidental as well as Arizona, New Mexico, Nevada, Utah, Colorado, West Texas, and California. It pushes as far west as the Peninsular Ranges and Transverse Ranges of southern California but rarely reaches the coastal strip (a wall of desert thunderstorms only a half-hour's drive away is a common summer sight from the sunny skies along the coast during the monsoon). The North American Monsoon is known to many as the *Summer*, *Southwest*, *Mexican* or *Arizona* monsoon or *Desert Monsoon* as a large part of the affected area is desert.

iv) Indian Monsoons

The term arose in the 16th century during the rise in navigation across the Indian Ocean, because the monsoonal winds were so critical to sail. The monsoon has always been of critical importance to the people of India since crops all over the country are dependent on the monsoon rains for irrigation and livelihood. But environmental degradation has weakened or changed the monsoon system prevalent for many centuries. The southwest monsoon is generally expected to begin around the middle of June and dies down by September. It begins first in the coastal state of Kerala and moves upwards at a rate of roughly 1-2 weeks per state. The monsoon accounts for 80 percent of the rainfall in the country. Indian agriculture (which accounts for 25 percent of the GDP and employs 70 percent of the population) is heavily dependent on the rains, especially crops like cotton, rice, oilseeds and coarse grains. A delay of a few days in the arrival of the monsoon can, and does, badly affect the economy, as evidenced in the numerous droughts in India in the 90s.

1. Summer Monsoon (Southwest Monsoon)

During the hot, dry season (April-May) when temperature rises rapidly and pressures over land decrease, the warm and moist air form over the adjacent seas starts blowing, towards the above-mentioned low pressure centre. However, in the beginning the maritime air masses are drawn only from a short distance. But by the end of May or the first week of June, when the low pressure centre has fully developed, the pressure - gradient is steepened so that even the trade winds from southern hemisphere are drawn towards the thermal low positioned in north-western region of the sub-continent. The southerly trade winds on crossing the equator are deflected to their right in accordance with Ferrell's Law. Now, the originally south-east trade winds become south-westerly blowing towards north-east. In India, the onset of the southwest monsoon (when the rain bringing dominant winds become established) for a particular area is expected in June or July, depending on its location (Figure 9.3). The normal rainfall during this season over India is about 88.0 cm.

South-westerly on-shore winds blowing towards the centre of low pressure over northern India traverse thousand of miles over the warm tropical ocean. They are, therefore, full of moisture and have a great potential for heavy precipitation. The south-west monsoon, as it is called in this region, is split into two branches by the shape of Peninsular India. They are known as:

i. The Arabian Sea branch

ii. The Bay of Bengal branch.

***i)* Arabian Sea branch**

The Arabian sea branch strikes the elevated Western Ghats of India at almost right angles. The windward slopes of Western Ghats receive heavy orographic precipitation. However, the westerly current from the Arabian Sea continues its journey across the Indian Peninsula, but the amount of rainfall on the leeward side goes on diminishing with increasing distance from the sea cost. The Western Ghats have 100-250 cm of rainfall on their windward slopes, while there is a well-marked rain-shadow to the leeward. Towards the north, where Western Ghats are not very high, the difference in the amount of rainfall between the windward and leeward side is rather negligible. Some of the air currents from the Arabian Sea branch manage to proceed towards Chhota Nagpur Plateau through the Narmada and Tapti gaps. These air currents ultimately unite with the Bay of Bengal Branch (Figure 9.3).

***ii)* Bay of Bengal branch**

One current of the Bay of Bengal branch, which is more southerly, moves towards Assam where Masaynram (near Cherrapunji), situated on the southern slope of Khasi hills, has the unique distinction of recording the highest annual average precipitation (965 cm) in the world. This is because of its peculiar geographical location. A current of the Bay of Bengal branch recurves westward and advances upto the Gangetic plain towards the Punjab. It may be mentioned that the westward movement of monsoon current takes place around the eastern end of a trough of low pressure developed over northern India. The movement of winds is, of course, parallel to the Himalayan Ranges. The rainfall occurring in the Gangetic Plain is partly controlled by the relief, and partly by the cyclonic storms or monsoon depressions which followed the track of low relief and low

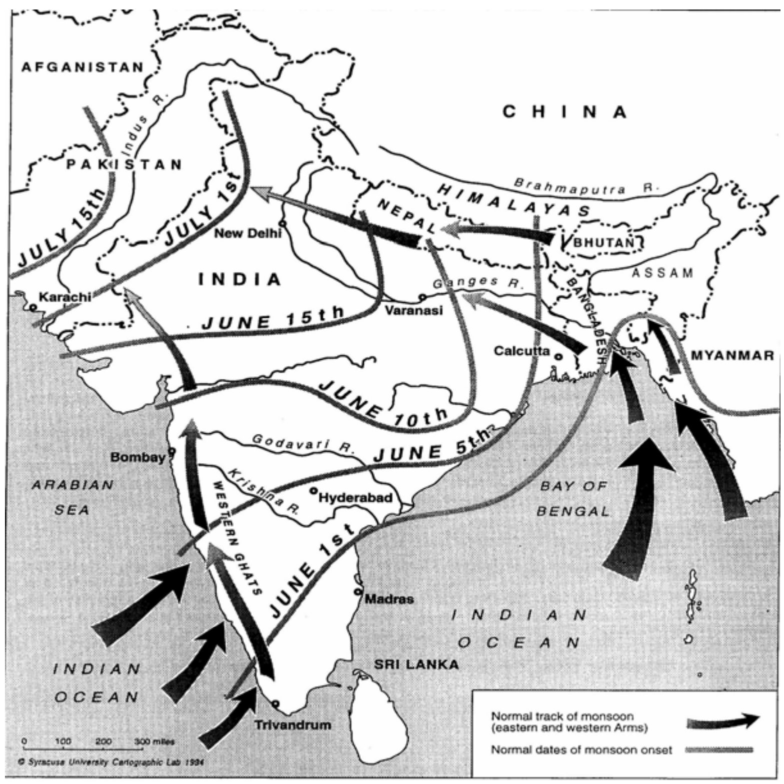


Figure 9.3. Branches of Southwest Monsoon over India

pressure along southern fringe of the plains. It is to be noted that in this region the monsoon current blows from a southeasterly direction. The rainfall decreases from east to west and from north to south. The main reason why the amount of rainfall decreases westwards is the increasing distance from the source of moisture. The southward decrease in rainfall is due to the increasing distance form the Himalayas which cause the forced ascent of rain-bearing air currents.

2. Winter Monsoon (Northeast Monsoon)

A secondary high pressure system develops over Kashmir and the Punjab in winter. The high pressure area controls the prevailing wind direction over the rest of the subcontinent. Contrary to the pressure condition over land, there are low pressure centers formed over the Indian Ocean, the Arabian Sea, and northern part of Australia. In the cool season, therefore, there is pressure gradient from land to sea as a result of which winds begin to move from land to sea. These are the Northeast or winter monsoons of northern hemisphere. The southern part of Indian Peninsula receives rainfall from Northeast monsoon currents. These currents while traveling over the Bay of Bengal pick up moisture from warm ocean surface. The amount of winter rainfall on the eastern side of the peninsula is much heavier than that on the other side. Tamilnadu receives maximum rainfall in this season. It is also known as retreating monsoon. The normal rainfall during this monsoon is around 12 cm.

Aberrations in rainfall

Aberration means the deviation from the normal behavior of the rainfall. As we all know the principal source of water for dry land crops is rain, a major portion of which is received during the monsoon period. Bursts of rain alternated with "Breaks" are not un common. There are at least four important aberrations in the rainfall behavior.

1. The commencement of rains may be quite early or considerably delayed.
2. There may be prolonged breaks during the cropping season (Intermittent droughts).
3. The rains may terminate considerably early (early cessation of rain) or continue for longer periods.
4. There may be spatial and or temporal aberrations.

Early or delayed onset of monsoon

To quantify the aberrations in the onset of monsoon, 50 years of data has to be analyzed for the onset dates of monsoon (Fig. 9.4) for different regions of the country. It has been seen that the normal date of onset of monsoon in the Madhya Pradesh and Maharashtra region is 10th June. But, in 8 per cent of the years onset of monsoon occurred during last week of May (May 28th in 1925) and in 10 per cent of the years it was delayed as beyond 21st June).

Breaks in the monsoon rains (Intermittent drought)

The breaks can be of different durations. Breaks of shorter duration (5-7 days) may not be of serious concern, but breaks of longer duration of 2-3 weeks or even more, lead to plant-water stress causing reduction in production. These breaks or intermittent droughts can be of different magnitude and severity and effect different crops in varying degrees. The yield of many drought resistant crops is not seriously affected, but in several sensitive crops the yield reduction was reported to be very heavy.

Early withdrawal of monsoon

The normal withdrawal of SW monsoon in Rayalaseema region is between 25th September and October 15th. But monsoon in 4 per cent of the years out of 55 years monsoon withdrew during first fortnight of September and in 10 per cent of the years withdrew during the month of December.

Uneven distribution of monsoon rains, in space and time over different parts of the country

Such situations are encountered almost every year in one or another part of the country during monsoon period leading to periodical drought and flood situations.

High variability of rainfall (or more precisely the soil-water) is the single factor which influences the high fluctuations in the crop yields in the different parts of the country.

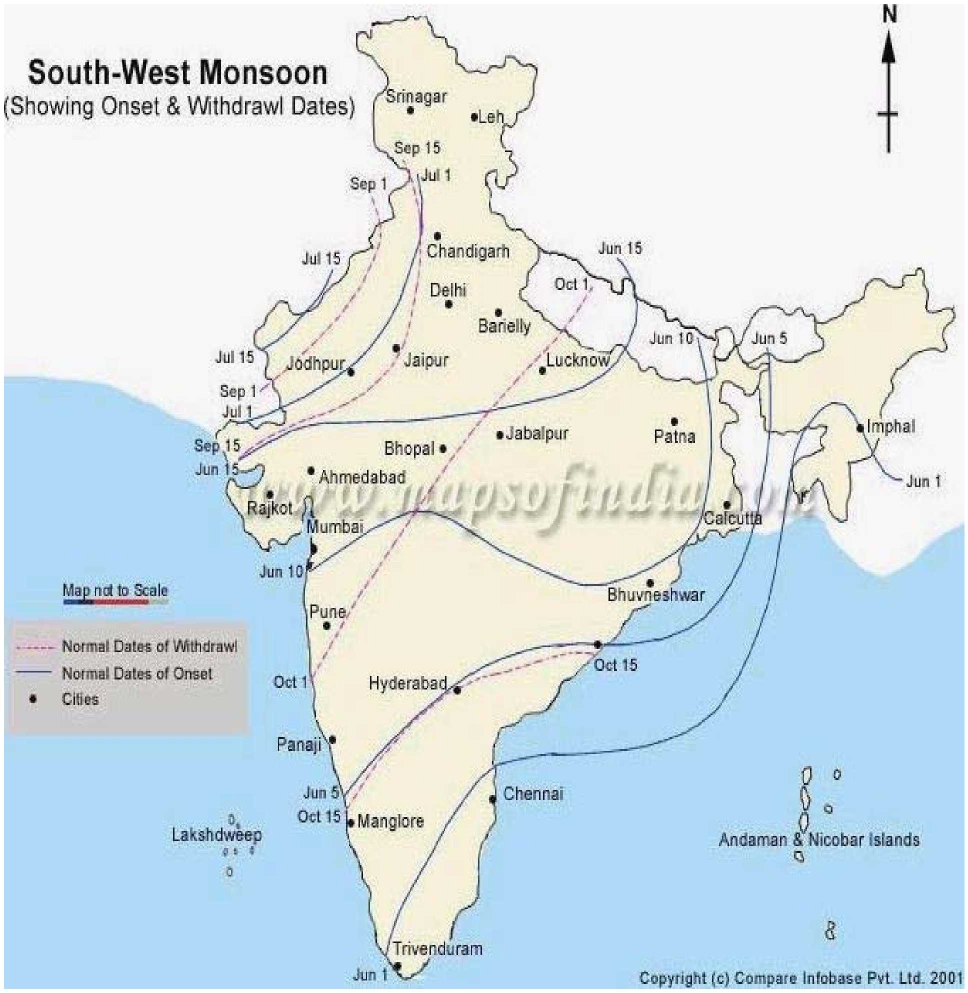


Figure 9.4. Normal dates of onset and withdrawal of SW Monsoon

Recent Development in Monsoon Forecast e.g. during 2008

India Meteorological Department (IMD) follows a two-stage forecast strategy for long range forecasts of the south-west monsoon rainfall over the country as a whole. The first long range forecast for the south-west monsoon season (June-September) rainfall is issued in April and the forecast update is issued in June.

Last year (2007), IMD introduced the following new statistical models for forecasting south-west monsoon rainfall (June – September) for the country as a whole:

A 5- parameter statistical ensemble forecasting system requiring data up to March, for the first forecast in April.

A 6- parameter statistical ensemble forecasting system requiring data up to May for the forecast update in June.

The same forecasting system was used for preparing the forecast for the 2008 South-west monsoon rainfall.

Operational Statistical Forecast System

In the IMD's Ensemble Statistical Forecasting system, the following 8 predictors are used, out of which the first 5 predictors are used for the April forecast.

S.No	Predictor (Period)	Used for the forecasts in
1	North Atlantic Sea Surface Temperature (SST) (December + January)	April and June
2	Equatorial South Indian Ocean SST (February + March)	April and June
3	East Asia Mean Sea Level Pressure (February + March)	April and June
4	NW Europe Land Surface Air Temperature (January)	April
5	Equatorial Pacific Warm Water Volume (February+March)	April
6	Central Pacific (Nino 3.4) Sea Surface Temperature Tendency (MAM-DJF)	June
7	North Atlantic Mean Sea Level Pressure (May)	June
8	North Central Pacific Wind at 1.5 Km above sea level (May)	June

The model errors of the April and June forecasting systems are ±5% and ±4% respectively.

Experimental Forecasts

As a part of ongoing efforts to improve the long range forecast capabilities, experimental forecast for the 2008 south-west monsoon rainfall based on the IMD's dynamical forecast system was also generated. For this purpose, observed sea surface temperature data of March have been used.

In addition, IMD has also taken into account the experimental forecasts prepared by the national institutes like Indian Institute of Tropical Meteorology, Pune, Indian Institute of Science, Bangalore, Space Applications Centre, Ahmedabad, National Aerospace Laboratories (NAL), Bangalore and Centre for Mathematical Modelling and Computer Simulation (CMMACS), Bangalore, National Centre for Medium Range Weather Forecasting (NCMRWF), Noida and operational/experimental forecasts prepared by international institutes like the National Centers for Environmental Prediction (NCEP), USA, International Research Institute for Climate and Society (IRI), USA, Meteorological Office, UK, the European Center for Medium Range Weather Forecasts(ECMWF), UK and the Experimental Climate Prediction Center (ECPC), USA.

La Nina Conditions over the equatorial Pacific

During August 2007, La Nina conditions were developed over the equatorial Pacific with colder than normal Sea Surface Temperatures (SST). However, during the recent weeks, negative SST anomalies weakened across the central and east-central equatorial Pacific. During March 2008, La Nina conditions declined to moderate-strength. The recent dynamical and statistical SST forecasts indicate La Nina will become weak and persist during the next three months. Thereafter, there is considerable spread and uncertainty in the forecasts of La Nina conditions.

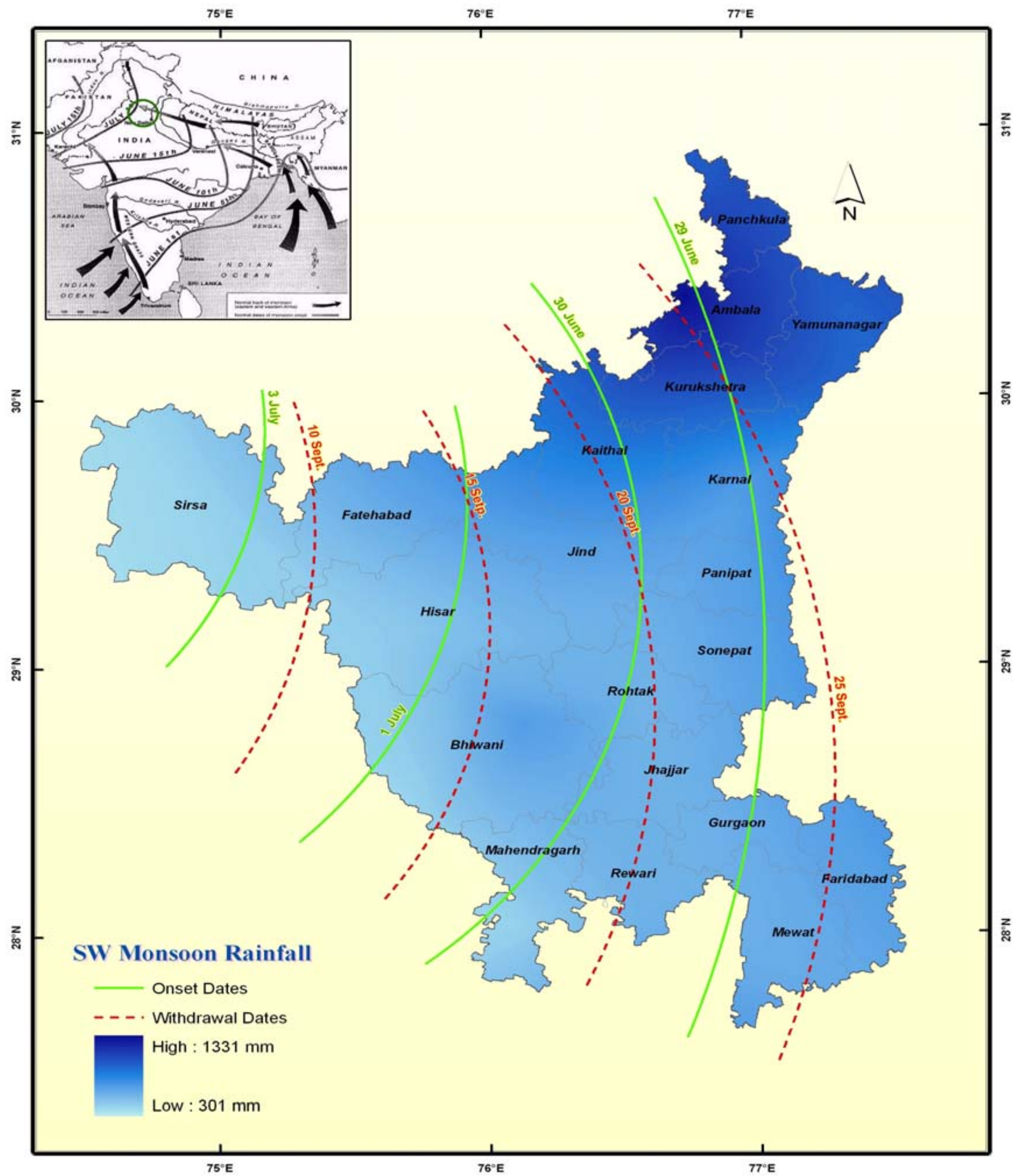
Forecast for the 2008 South-west monsoon rainfall

IMD's long range forecast for the 2008 south-west monsoon season (June to September) is that the rainfall for the country as a whole is likely to be Near Normal.

Quantitatively, monsoon season rainfall is likely to be 99% of the long period average with a model error of ± 5%. The Long period average rainfall over the country as a whole for the period 1941-1990 is 89 cm.

IMD will update the above forecast in June 2008 as a part of the second stage forecasts. Separate forecasts for the July rainfall over the country as a whole and seasonal (June-September) rainfall over the four geographical regions of India will also be issued.

SW Monsoon
Normal Onset/Withdrawal Dates over Haryana & India



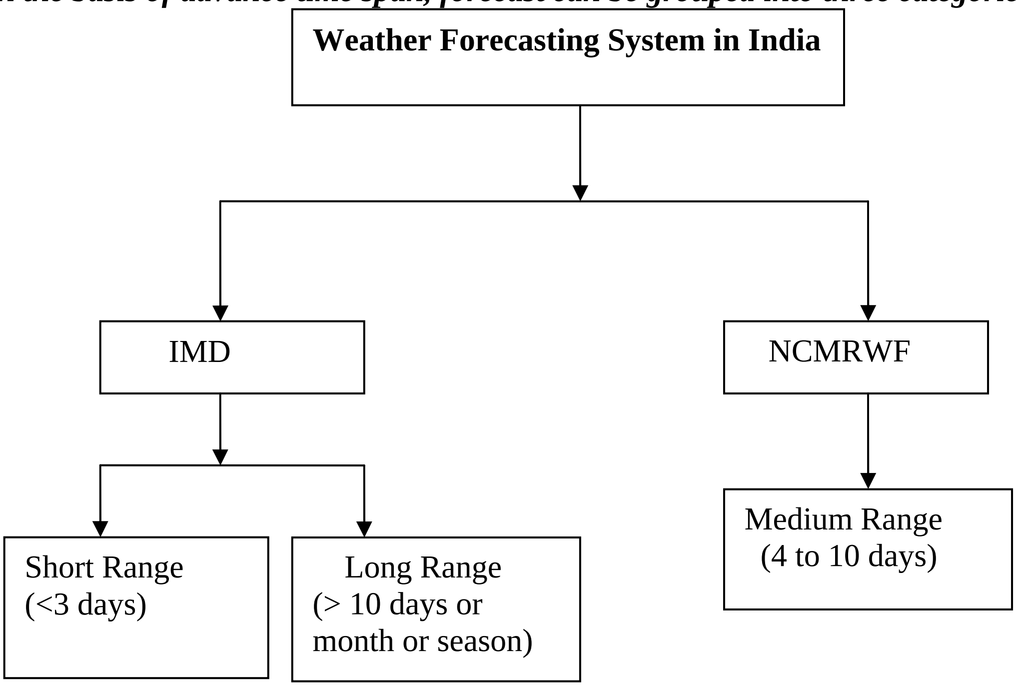
10. WEATHER FORECASTING FOR AGRICULTURE

Weather controls the crop production and affects agricultural operations through its effects on soil, plant growth and development. The variation in crop production is attributed to aberration in weather. In India, the losses of crop production are quite high due to abnormal weather conditions. Aberrant weather includes floods, hail stones, thunder storms, dust storms, high winds, heat wave, cold wave and frost etc. The losses due to aberrant weather can be minimized to a considerable extent by suitable adjustment of the farming operations according to the probable weather conditions through accurate weather forecasting. Weather forecasting is foretelling the coming weather in advance. It may be defined as advance information about the probable weather conditions for few days to follow. So the time for which weather forecast is made is also important. We also termed it as lead time. The accuracy of a forecast decreases with increasing lead period and decreasing area under forecast. Different weather phenomena can be forecasted with different lead time.

Weather phenomena	**Lead time**
Hail	<12 hours
Flash floats	<12 hours
Heavy rainfall	24 hours
Thunder storms	24 hours
Wind speed	36 hours
Rainfall amount	36 hours
Change in temperature	5 days
Temperature and rainfall departure from normal	3 months

Types of weather forecasts

On the basis of advance time span, forecast can be grouped into three categories:



I. Short range weather forecast

Forecasting of coming weather for 2 to 3 days in advance is called short range weather forecasting. Weather phenomena for which forecast are issued under this type is:

- Rise and fall in temperature
- Speed and direction of wind
- Cloudiness
- Rainfall amount

This type of weather forecast is issued by India Meteorological Department, Delhi for different regions throughout the country. The error in forecast ranges from 20-30 per cent.

II. Medium range forecast

Forecasting of weather 4-10 days in advance is termed as medium range forecasting. Presently, medium range weather forecasting for 4 days in advance is issued by National Centre for Medium Range Weather Forecasting (NCMRWF) situated in NOIDA, U.P. This forecast is issued twice in a week i.e. on Tuesday and Friday forecast error ranges from 30 to 40 per cent. Weather phenomena on which weather forecast is issued are as under:

- Increase or decrease in maximum and minimum temperature
- Cloudiness
- Speed and direction of wind
- Precipitation amount

III. Long range weather forecast

Forecasting of coming weather for more than 10 days or a month or a season in advance is called as long range weather forecasting. It may also be categorized as monthly forecast or seasonal forecast depending on the lead time. Long range forecasting is issued by India Meteorological Department, New Delhi for south west monsoon rains, first in April and then the forecast is updated in July. This forecast is issued region wise i.e. country is divided in four zones: (1) North eastern region (2) Central region (3) North Western Region (4) Peninsular region. The forecast error varied around 40 per cent.

The weather parameters on which forecast have been issued as under:

- Onset of monsoon rains
- Deviation of rainfall amount from long period average (LPA) rainfall

Methods of weather forecasting

1. Synoptic method: This is the oldest method of forecasting of a weather system. The data of meteorological elements such as atmospheric pressure, temperature, humidity, rainfall, wind, clouds, visibility, weather phenomena and waves are recorded at surface and various heights above the earth surface at various meteorological stations situated throughout the country and its surrounding at synoptic hours i.e. 0000, 0300, 0600, 1200 and 1800 hrs. These data from different meteorological stations are sent to main centre (IMD) through electro-magnetic signals. A large volume of meteorological observations from surface and aloft obtained from a dense network of stations are depicted in pictorial and coded form on the weather maps or charts by drawing isopleths, i.e. lines joining places with equal numerical value of the weather element. The inferences on expected movement of weather system are drawn using the previous and present synoptic charts. In addition to this the satellite pictures (Visible and infrared) are also needed for accurate weather forecast. Visible pictures enable to know cloud formation and wind velocity through cloud movement. Infrared pictures helps in determining earth surface temperature, cloud temperature and its height. The satellite pictures thus received at shorter intervals provide information on cloud development and movement; thereby wind velocity, cloud type and height. Then weather forecast is made with greater accuracy by superimposing synoptic charts and cloud pictures.

This method of forecast is mainly used for short range weather forecasting by IMD, New Delhi.

2. Analogue method: This method is defined as any particular type of system if it is present in the past also, it is assumed that the present system is likely to behave in the same way as the previous one. There are a number of limitations on the success of this method. First, it is difficult to select right analogue, and second, even if we succeed in picking up the right ones, there is no guarantee that they will evolve in the same way. It has been suggested that analogue should be used in conjunction with other methods, either as an aid or a check on pressure pattern prognosis. The success of forecast depends upon the knowledge and the experience of the forecaster.

3. Persistence method: Persistence Method is the simplest way of producing a forecast among the different methods of forecasting. It assumes that the conditions at the time of the forecast will not change and yesterday's weather may continue to behave in same manner for today also.Often summarized as "*Tomorrow equals today*". For example, if it is sunny and 37°C today, the persistence method predicts that it will be sunny and 37°C tomorrow. The method a forecaster chooses depends upon the experience of the forecaster, the amount of information available to the forecaster and the degree of accuracy or confidence needed in the forecast. It may also appear that the persistence method would work only for short-term forecasts (e.g. a forecast for a day or two), but actually one of the most useful roles of the persistence forecast is predicting long range weather conditions or making climate forecasts. For example, it is often the case that one hot and dry month will be followed by another hot and dry month.

4. Climatological Method: Climatology is the main theme with which we can study the present weather systems. The Climatology method is another simple way of producing a forecast. This method involves historical weather data over long periods of time (years) to predict conditions on a given date. The weather statistics accumulated over many years has been averaged to make the weather forecast. For example, if you were using the climatology method to forecast for temperature and precipitation for Hisar on September 4^{th}, you would go through the temperature and precipitation data that has been recorded for every September 4^{th} and take an average. If these averages were 35°C with 25 mm of rain, then the weather forecast would be 35°C temperature and 25 mm of rain for Hisar on September 4^{th}. The climatology method only works well when the weather pattern is similar to that expected for the chosen time of year. If the pattern is quite unusual for the given time of year, the climatology method will often fail.

5. Statistical methods: This method is based on statistical approaches such as regression and auto regressive integrated moving average techniques. The regression equations are used to predict weather parameters. Knowledge of correlation coefficient will also help to access effect of one parameter over the other. This method is used for long range forecasting of Indian monsoon rainfall. The forecast is issued region wise i.e. north eastern region, central region, north western region and peninsular region using power regression model. This method is used for forecasting Indian Monsoon rainfall based on 16 atmospheric land-oceanic parameters (Table 1). It is introduced operationally by IMD in 1988 as 16 Parameters Power Regression Model. Weather forecast to be made available at the end of May each year by IMD up to the year 2000. A minor modification was made to this model in 2000, involving the replacement of four parameters, as with time they had lost their correlation as described in Table 1. The year 2002 turned out to be an all India drought year with an overall rainfall deficiency of 19 per cent, while IMD had predicted a normal monsoon, resulting in a more attention being focused on forecasting system of IMD.

Table 1. **Comparison of 16 parameter model (1988) and the changes for the year 2000 model**

Original 16 Parameters Power Regression Model	**Revised 16 Parameters Power Regression model**
1.50 hPa East-west wind (Jan-Feb)	**1**.50 hPa East-west wind (Jan-Feb)
2.10 hPa Zonal wind (Jan)	**2**.Arabian sea surface temperature (Jan-Feb)
3.East coast India temperature (Mar)	**3.**East coast India temperature (Mar)
4.Central India temperature (May)	**4.**Central India temperature (May)
5.Northern hemisphere temperature (Jan-Feb)	**5**.Northern hemisphere temperature (Jan-Feb)
6.North India minimum temperature (Mar)	**6.**Northern hemisphere temperature (Jan-Feb)
7.Northern hemisphere pressure (Jan-Apr)	**7**.Northern hemisphere pressure (Jan-Apr)
8. Darwin pressure (Spring)	**8**.Darwin pressure tendency (Jan-Apr)
9. Argentina pressure (Apr)	**9.**Argentina pressure (Apr)
10. 500 hPa Ridge (Apr)	**10**.South Indian ocean SST (Feb-Mar)
11.Equatorial Indian ocean pressure (Jan-May)	**11**.Equatorial Indian ocean pressure (Jan-May)
12.Southern oscillation index (Mar-May)	**12**.Southern Oscillation Index (Mar-May)
13. El Nino (Same year)	**13**.El Nino (Same year)
14. El Nino (Previous year)	**14**.El Nino (Previous year)
15. Himalayan snow cover (Jan-Mar)	**15**.Himalayan snow cover (Jan-Mar)
16.Eurasian snow cover (Dec)	**16**.Eurasian snow cover (Dec)

Table 2. Comparison of 8 parameters and 10 parameters Power Regression Model

8 Parameters Power regression model	**10 Parameters Power regression model**
Model parameters (Month for data)	*Model parameters (Month for data)*
1.El Nino previous year (Jly, Aug, Sep)	**1**.El Nino previous year (Jly, Aug, Sep)
2.Eurasian snow cover (Dec)	**2**.Eurasian snow cover (Dec)
3.North west Europe temperature (Jan)	**3**.North west Europe temperature (Jan)
4.Europe pressure gradient (Jan)	**4**.Europe pressure gradient (Jan)
5.50 hPa Wind pattern (Jan, Feb)	**5.**50 hPa Wind pattern (Jan, Feb)
6.Arabian sea SST(Jan, Feb)	**6**.Arabian sea SST(Jan, Feb)
7.East Asia pressure (Feb, Mar)	**7**.East Asia pressure (Feb, Mar)
8.South India Ocean temperature (Mar)	**8**.South India ocean temperature (Mar)
	9.El Nino (3+4) temperature (Apr, May, Jun and Jan, Feb and Mar)
	10.South Indian Ocean 850 hPa Z wind (Jun)

In 2003, IMD reviewed the forecast models and attempted to develop new credible models which come closer to requirement of users. The above power regression models were modified to power regression and probabilistic models with 8 and 10 parameters (Table 2). From 2003, IMD adopted a two stage long range forecast strategy. In the first stage, forecast for south west monsoon season rainfall (June-September) for the country as a whole is issued in April using the 8 parameters power regression and probabilistic models. In the second stage, update forecast for the seasonal rainfall over the country as a whole is issued by the first week of July using 2 more parameters.

6. Numerical weather prediction methods: Numerical Weather Prediction (NWP) is the methodology to predict the future state of the atmospheric circulation and weather from knowledge of its present state, using known physical and hydrodynamic laws of atmospheric motions. The physical processes are modeled in terms of differential equations using these physical laws. Motion of atmosphere is governed by a set of non-linear differential equations which involves variation of weather parameters. Though, there is difficulty in solving non-linear equations, some approximations are made and these equations are solved. Numerical Weather Prediction (NWP) method is extensively used after advent of fast computer. Complex computer programs or forecast models run on supercomputers and give the predictions on many meteorological parameters such as temperature, pressure, wind and rainfall. The NWP method is flawed in that the equations used by the models to simulate the atmosphere are not precise. This leads to some error in the predictions. In addition, they are many gaps in the initial data since we do not receive many weather observations from areas in the mountains or over the ocean. If the initial state is not completely known, the computer's prediction of how that initial state will evolve will not be entirely accurate. Despite these flaws, the NWP method is probably the best of forecasting methods for the day-to-day weather changes.

Weather Service Organizations

India Meteorological Department: Government of India established the India Meteorological Department as a national agency, bringing all meteorological work in the country in 1875. Mr. H. F. Blanford was appointed the first imperial meteorological reporter to the Government of India. The headquarter of IMD was Calcutta. In 1905, IMD headquarters shifted to Simla and the Calcutta office was given the status of a branch office. The transfer of IMD offices from Simla to Pune in 1926 and finally to New Delhi in 1976. IMD maintains a countrywide network of observational stations viz. 559 surface meteorological observatories, 701 hydrometeorological observatories, 65 pilot balloon stations, 35 radiosonde/rawinsonde observatories, 219 agrometeorological stations, 45 radiation observatories from where weather reports are received at Pune through the Regional Telecommunication Hub based at New Delhi. With the help of these reports and other observations from the globe, IMD issues the weather forecasts for the entire country by the forecasting offices at its 6 Regional Meteorological Centres i.e. Mumbai, Chennai, New Delhi, Calcutta, Nagpur and Guwahati and Meteorological Centres at the State capitals. In addition, warnings bulletins for tropical storms and other severe weather systems affecting the Indian coastal and other marine activities over the Indian seas issued by IMD's Area Cyclone Warning Centres at Chennai, Calcutta and Mumbai and Cyclone Warning Centres at Ahmedabad, Bhubaneshwar and Visakhapatnam. Agrometeorological Advisory Bulletins for farmers are issued by 17 IMD Centres in various states. IMD has strong international linkages with World Meteorological Organization (WMO). IMD has been participating in all the Antarctic expeditions and carries out regular meteorological observations at India's station at Maitri.

National Center for Medium Range Weather Forecasting: The National Center for Medium Range Weather Forecasting (NCMRWF) is premier institution provide medium range weather forecasting through deterministic methods and render Agro Advisory services to the farmers. It was established in December 1988 by the Government of India as a mission mode project under Department of Science & Technology mandated to develop operational Numerical Weather Prediction (NWP) system for forecasting weather in the medium range (3-10 days in advance) scale and setting up of Agro-meteorological Advisory Service (AAS) units in the 127 agro-climatic zones spread all over India to inform and guide the farmers in advance to undertake various farming activities based on the expected weather. Headquarter of NCMRWF is at NOIDA (UP). Currently, the NCMRWF functions under the Ministry of Earth Sciences, Government of India. The Centre maintains high-end computing resource and regularly upgrades it to meet the objectives.

The NCMRWF strives to improve the accuracy, and consistency of its operational forecasts. A number of global, regional and meso-scale numerical forecast models are being run in real time by the Centre. These are global modes T-80/L18 - horizontal resolution of 150 km, T-170/L28 with 75 km horizontal resolution, Embedded Regional Spectral Model with 50 km grid resolution and Meso-scale Models MM5 with 30 and 10 km resolution and ETA Model with 48 km resolution. At present, NCMRWF has established AAS units in 107 agro climatic zones. Agromet Advisory Bulletins comprising of expert advice on crop, soils and weather are made available to the farming community through media and direct contact. The location specific forecasts valid for 4 days comprising of six meteorological variables, viz., total precipitation, average cloudiness, average wind speed, predominant wind direction, maximum temperature and minimum temperature are derived NWP model outputs. These forecasts of weather elements are subjected to fine tuning through statistical and synoptic techniques to obtain final location specific weather forecast. They are disseminated biweekly to AAS units on every Tuesday and Friday over Telephone, Fax or Internet system.

Indian Institute of Tropical Meteorology: The Indian Institute of Tropical Meteorology (IITM) was established on 17th November 1962 as Institute of Tropical Meteorology (ITM) at Pune as a distinct unit of India Meteorological Department for the study of the fundamental atmospheric problems in the tropical region. The Institute was transferred into an autonomous organisation on 1st April 1971 under the name Indian Institute of Tropical Meteorology. Currently, the IITM functions under the Department of Science and Technology, Government of India. The IITM has developed techniques and expertise in specialized area of research such as studies on weather forecasting, climatology, monsoon studies, climate modeling, hydrometeorology, weather modification, atmospheric chemistry, atmospheric electricity, cloud physics and instrumentation for observational studies. The IITM has been playing important role in the international activities such as Inter Governmental Panel on Climate Change (IPCC), International Geosphere Biosphere Programme (IGBP), Indian Climate Research Programme (ICRP) and several research programmes of the World Meteorological Organisation (WMO).

CSIR Centre for Mathematical Modelling and Computer Simulation (C-MMACS)

The Council of Scientific and Industrial Research (CSIR) established in 1988 the "CSIR Center for Mathematical Modelling and Computer Simulation", briefly called *C-MMACS*. The Centre is located in National Aerospace Laboratories (NAL), Bangalore. In another program, the initial evolutionary features of cyclones have been studied in the context of those originating in the Bay of Bengal. The first results indicate the possibility of developing viable Mathematical Models for early warning of cyclones. The centre also prepares the experimental forecasts of All India summer Monsoon rainfall by using mathematical simulation models.

Significance of weather forecasting in agriculture

Agriculture is mainly dependent of weather. If the weather is favourable, then crop production will be higher. But if the weather is not under optimum/favourable range, then it will cause losses to crop production depending upon its intensity of abnormality. Such type of weather is termed as aberrant weather or abnormal weather. However the losses due to aberrant weather can be minimized if it is forecasted accurately. Rather it is impracticable to avoid crop losses due to aberrant weather but it is possible to minimize crop losses to some extent, if weather forecast is accurate and in time.

The input cost can be minimized by avoiding wastage of inputs through short term adjustment of input applications with coming weather. The applications of forecasting also depend upon the lead time of forecasting. So the applications can be grouped with the type of forecasting:

A) Short range applications:

i) Adjustment of day to day field operation
ii) Scheduling of irrigation and application of agro-chemicals
iii) Protection of field crops & livestock from frost/cold wave & heat wave
iv) Efficient use of labour

B) Medium range applications:

i) Sowing and planting of crops
ii) Management of labour, irrigation water and agro-chemicals
iii) Protection measures again frost/cold wave and heat wave
iv) Management of inputs and products of livestock
v) Transportation of farm products

C) Long range applications:

i) Selection of crops, varieties and breeds
ii) Management of water resources
iii) Management of farm inputs such as labour, machinery, seeds, agro-chemicals etc.
iv) Management of dry and green fodder and feeds for livestock

Generally in the month of March, the weather in Haryana is highly variable and the wheat crop is approaching maturity. If the farmers of the state are informed about anticipated heavy rains and strong surface winds in advance for two to three days and also advised to withhold the irrigation, it can save the wheat crop from lodging which can cause a great loss in final yield. During April there are frequent thunderstorms and squalls which carry away considerable quantities of the crop during harvesting operations. If the farmers are informed about dust storms/ thunderstorms well in advance then farmers stop their harvesting operation of rabi crops and can collect and make the bundle of harvested crop well in time to save the crops being blown away.

The losses in seed, diesel, labour and time can also be minimized by not sowing the crops if anticipated weather is not favourable for sowing. The loss of chemical fertilizers in the State may be minimized if the farmers are informed well in time that the coming weather may not be suitable for application of agri-chemicals. Timely application of agricultural chemicals is economical and efficient as it minimizes the losses due to unfavourable weather. Forecast on wind speed helps in determining suitable time for spraying of agri-chemicals. Temperature determines the effectiveness of spraying, whereas precipitation immediately following applications can dilute or wash out the chemicals. The severe cold waves during winter adversely affect the mustard crops and vegetables as frost injury. This type of loss can be minimized if the farmers are informed well in time about the frost occurrence and suggest the measures to prevent frost injury.

It clearly showed that the weather forecast play a vital role in agricultural production. It helps in enhancing economic gains by suitable adjustment of farming according to anticipated weather conditions. The gain can be either through reducing input costs for farm management or through increasing production or through minimizing the losses.

11. CLIMATE AND CROP PRODUCTION

India is a land of many rivers and mountains. Its geographical area of about 329 Mha is criss crossed by a large number of small and big rivers, some of them figuring amongst the mighty rivers of the world. The rivers and mountains have a greater significance in the history of Indian cultural development, religious and spiritual life. It may not be an exaggeration to say that the rivers are the heart and soul of Indian life.

Climate

The presence of the great mountain mass formed by the Himalayas and its spurs on the North and of the ocean on the South is the two major influences operating on the climate of India. The first poses an impenetrable barrier to the influence of cold winds from central Asia, and gives the sub-continent the elements of tropical type of climate. The second, which is the source of cool moisture-laden winds reaching India, gives it the elements of the oceanic type of climate. India has a very great diversity and variety of climate and an even greater variety of weather conditions. The climate ranges from continental to oceanic, from extremes of heat to extremes of cold, from extreme aridity and negligible rainfall to excessive humidity and torrential rainfall. It is, therefore, necessary to avoid any generalization as to the prevalence of any particular kind of climate, not only over the country as a whole but over major areas in it. The climatic condition influences to a great extent the water resources utilization of the country.

1. **Rainfall**

Rainfall in India is dependent in differing degrees on the Southwest and Northeast monsoons, on shallow cyclonic depressions and disturbances and on violent local storms which form regions where cool humid winds of the sea meet hot dry winds from the land and occasionally reach cyclonic dimension. Most of the rainfall in India takes place under the influence of Southwest monsoon between June to September except in Tamilnadu, where, it is under the influence of Northeast monsoon during October and November. The rainfall in India shows

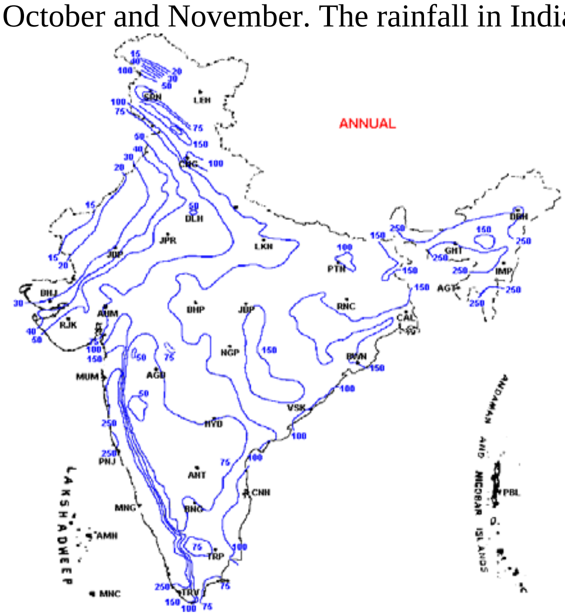


Figure 11 a: Annual rainfall climatology over India

great variations, unequal seasonal distribution, still more unequal geographical distribution (Fig. 11 a to 11d) and the frequent departures from the normal. It generally exceeds 100 cm in areas to the East of Longitude 78°. It extends to 250 cm along almost the entire West Coast and Western

Ghats and over most of Assam and Sub-Himalayan West Bengal. On the West of the line joining Porbandar to Delhi and then to Ferozpur the rainfall diminishes rapidly from 50 cm to less than 15 cm in the extreme west. The Peninsula has large areas of rainfall less than 60 cm with pockets of even 50 cm.

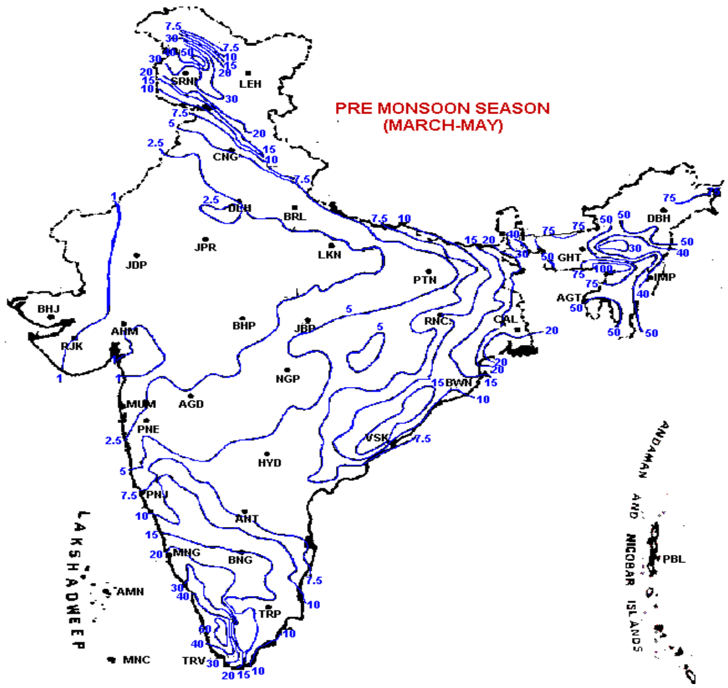


Figure 11 b: Pre Monsoon rainfall climatology over India

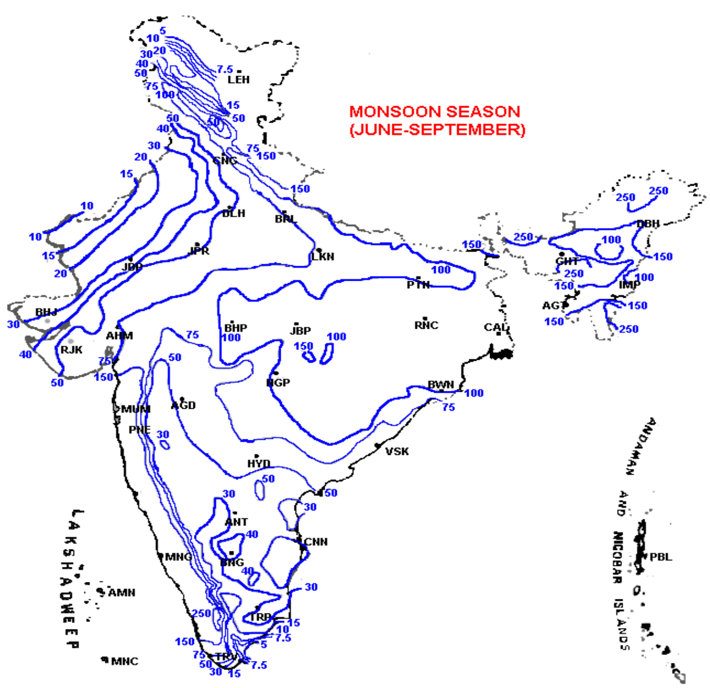


Figure 11 c: Monsoon rainfall climatology over India

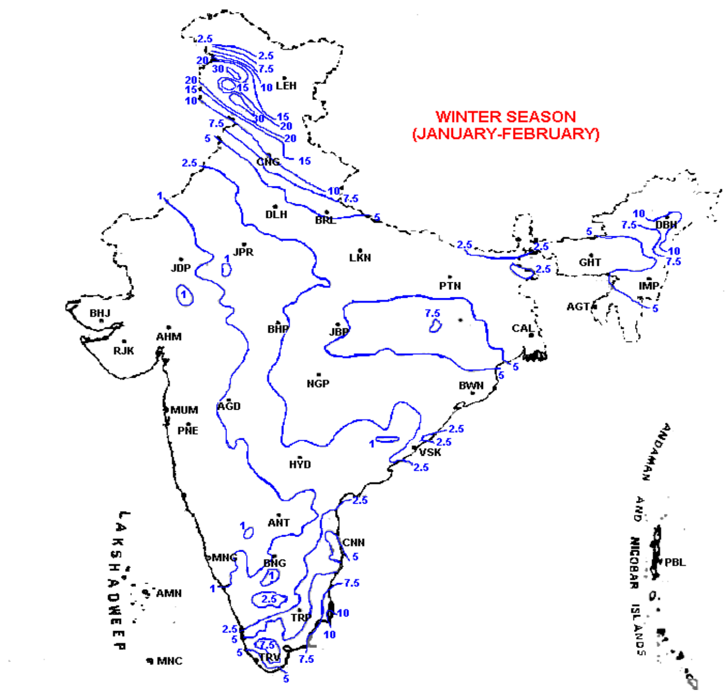


Figure 11 d: Winter rainfall climatology over India

2. Temperature

The variations in temperature are also marked over the Indian sub-continent during different periods (Figure 11.1 a & b). During the winter seasons from November to February, due to the effect of continental winds over most of the country, the temperature decreases from South to North. The mean maximum temperature during the coldest months of December and January varies from 29°C in some part of the peninsula to about 18°C in the North, whereas the mean minimum varies from about 24°C in the extreme South to below 5°C in the North. From March to May is usually a period of continuous and rapid rise of temperature. The highest temperature occurs in North India, particularly in the desert regions of the North-West where the maximum may exceed 48°C, whereas on the same day maximum temperature of 22 °C is recorded at Gulmerg. The minimum temperature may fall below -20°C in Kargil and Dras areas, while on the same day, it has been around 24°C at Madras. With the advent of Southwest Monsoon in June, there is a rapid fall in the maximum temperature in the central region of the country. The temperature is almost uniform over the area covering two thirds of the country which gets good rain. There is a marked fall in temperature when the monsoon retreats from North India in September. In Northwest India, in the month of November, the mean maximum temperature is below 38°C and the mean minimum below 10°C. In the extreme North, temperature drops below freezing point.

3. Evaporation

Evaporation rates closely follow the climatic seasons, and reach their peak in the summer months of April and May and the central areas of the country display the highest evaporation rates during this period. With the onset of monsoon, there is a marked fall in the rate of evaporation. The annual potential evaporation ranges between 150 to 250 cm over most parts of the country. Monthly potential evaporation over the Peninsula increases from 15 cm in December to 40 cm in May. In the North-East, it varies from 6 cm in December to 20 cm in May. It rises to 40 cm in June in West Rajasthan. After the onset of monsoon potential evaporation decreases generally all over the country.

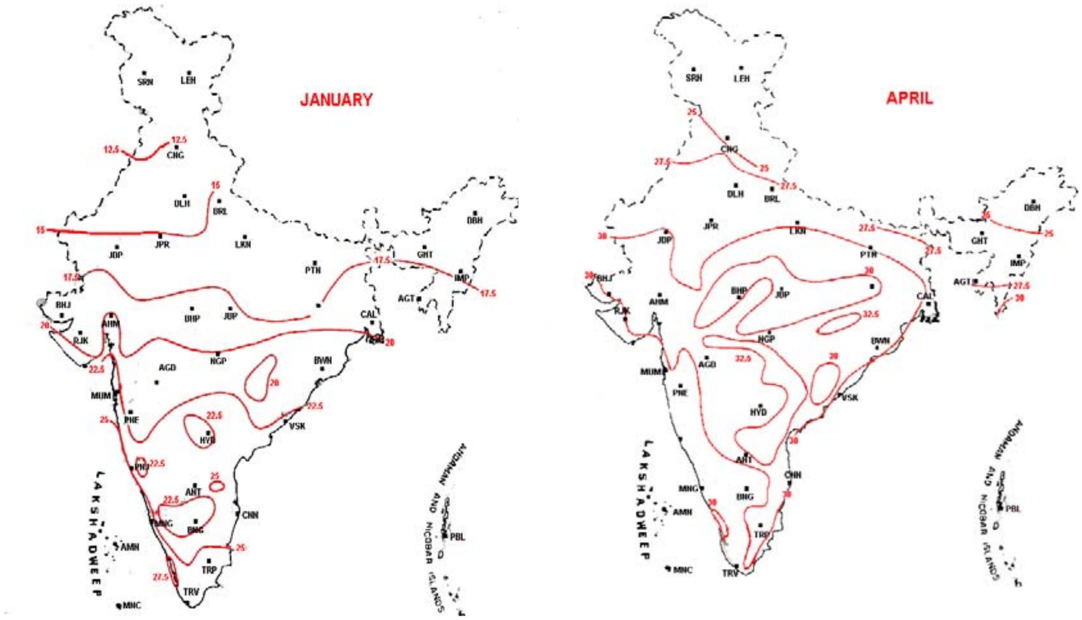


Figure 11.1 a. Average temperatures during January & April over India

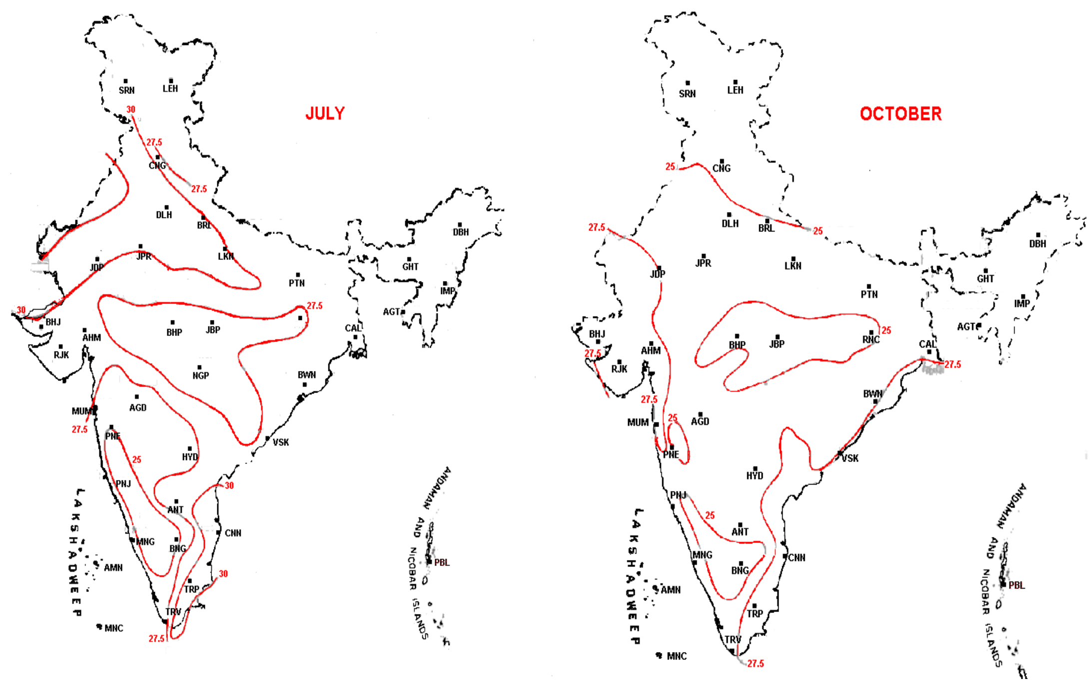


Figure 11.1 b. Average temperatures during July & October over India

Haryana

Haryana is located in the northwest part of the country and the climate is arid to semi arid with average rainfall of 455 mm. Around 80 per cent rainfall is received during the month from July to September and the remaining rainfall is received during December to February. There are two agro climatic zones in the state delineated by NARP (Figure 11.2). The north eastern part is suitable for paddy, wheat, vegetable and temperate fruits and the south western part is suitable for cotton, wheat, mustard, pulses, tropical fruits, exotic vegetables and herbal and medicinal plants. The state of Haryana extends between 27°39' to 30°55'N latitude and 74°27' to 77°36'E longitude. The altitude in the state ranges between 200 to 300 meters above mean sea level (except the hilly ranges of Shivaliks in the north and Aravallis in the south). It is one of the smaller states in the country with an area of 42,222 sq km and is land locked from all sides and mostly covers the Indo-Gangetic plains.

Figure 11.2. Agroclimatic Zones of Haryana

Climate

The geographical location of Haryana in the north-west of Indian sub-continent, over 1600 km away from the bay of Bengal, and between western Himalayas in the north and thar desert in the south, mainly determines its climatic conditions. Climate is one of the important agricultural resources which have not been exploited to its full for increasing the productivity. Year to year variations in climate and sudden departure from normal weather features have deleterious effects on crops and keep the food production highly fluctuating. Scanty rains, excess and untimely rains, heat waves, cold waves, high and hot winds during summer (locally known as 'loo'), dust storms, fog, frost and hails are important weather abnormalities occurring in the state and adversely affect the crop production. The climate of Haryana is strongly influenced by north-westerly cold and south-westerly monsoon winds. Only tails of summer monsoon depressions are received during months from July to September.

i) Western Zone of Haryana

The rainfall during the monsoon season is very erratic and limited (250-500 mm) in 10-20 rainy days, prolonged dry spell, delayed onset and early withdrawal. The coefficient of variation is about 50 per cent in kharif and nearly 100 per cent in *rabi* season. Moisture stresses of varying degrees in both seasons. Potential evapotranspiration is around 1500-1650 mm per annum with Aridity index > 0.66.

ii) Eastern Zone of Haryana

The Rainfall during the monsoon season varies between 500-1200 mm in 40-45 days. Excess moisture in kharif but severe moisture stress in *rabi* crops. Potential evapotranspiration is around 1250-1350 mm per annum.

1. Rainfall

Normal annual rainfall features (Figure 11.3 a to c) show that amount of annual rainfall in the state ranges between below 400 mm (south-western parts) to 1200 mm (northern parts-Shivalik foothills) with 25 to 45 per cent coefficient of variation. Above 80 per cent of this rainfall is received during monsoon season (July to September) which coincides with the growing season of *Kharif* crops. On an average around 300 mm of rains are received during this period in the south-western (SW) region and above 750 mm in the northern most region with coefficient of variation ranging between 45 to 55 per cent. Only 10 to 15 per cent of the annual rainfall is received during October to March period coinciding with the growing season of *rabi* crops. Rainfed agriculture is mostly practiced during

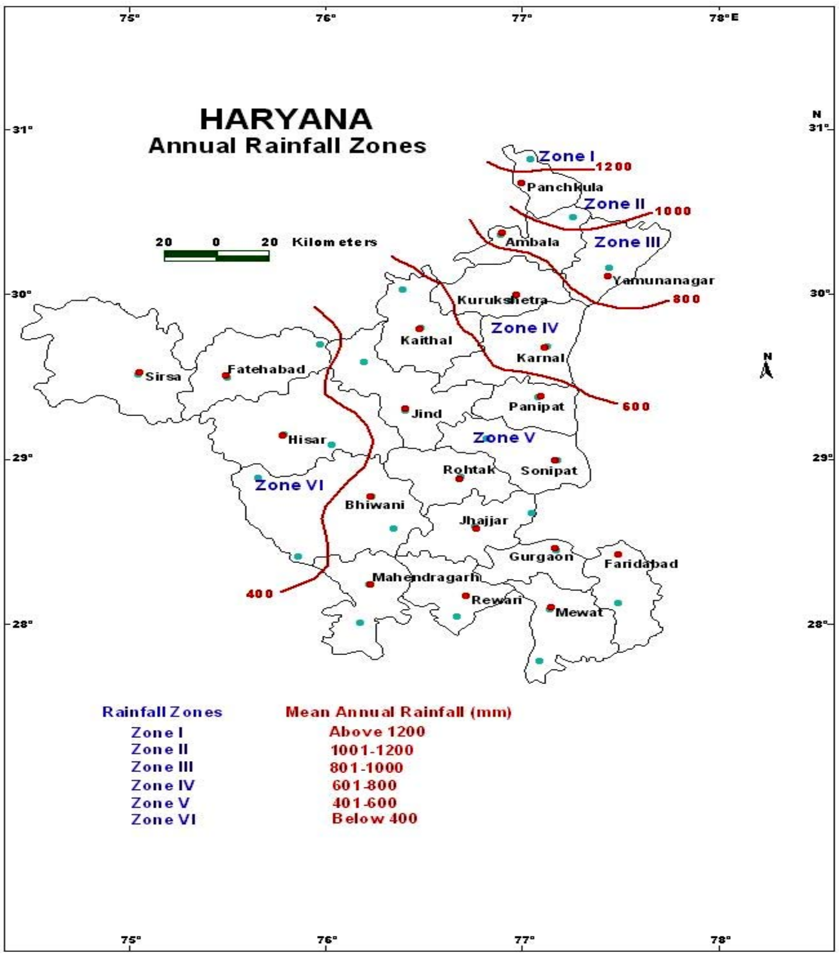


Figure 11.3 a. Annual rainfall zones in Haryana

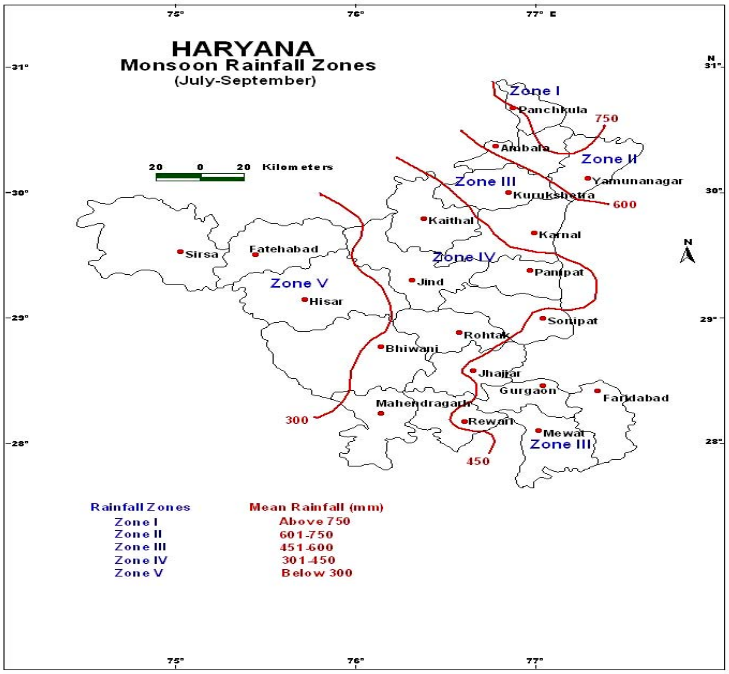


Figure 11.3 b. Rainfall Climatology of Haryana during monsoon season

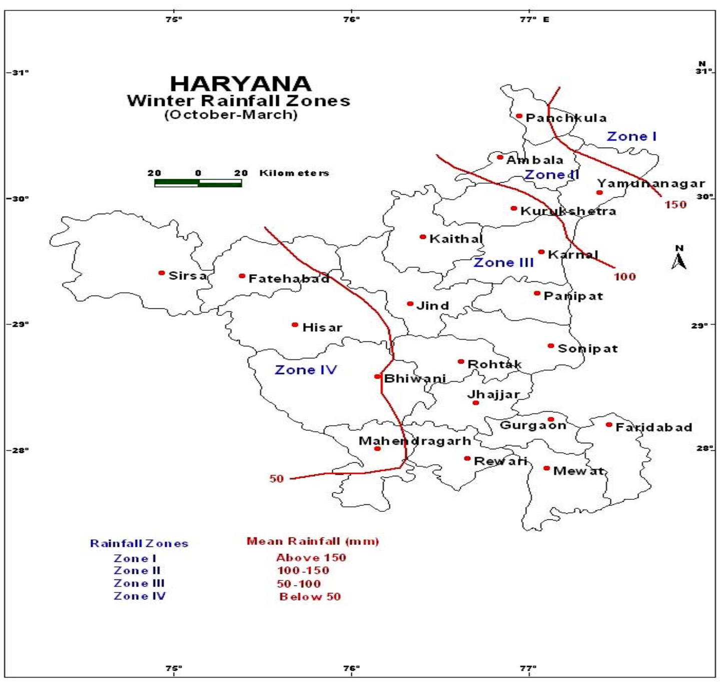


Figure 11.3 c. Rainfall Climatology of Haryana during winter season

the monsoon season with possibility of *rabi* crop sowing in areas where abundant soil moisture conservation is possible with receipt of good rains during later monsoon season.

2. Temperature

Mean temperature during *Kharif* season in SW region is around 32°C and decreases to 29°C in the northern parts. However, during *Rabi* season the mean temperature of 15°C in the northern parts with an increase towards the south-western upto 20°C is observed. Day temperature of 48°C during summer (May/June) and night temperature below 0°C during winter (December to February) are not uncommon to the state. Haryana state has arid, semi-arid climate in the south-west and dry sub-humid environment in the remaining parts. Annually, air temperature below 24°C, 24 - 25°C and above 25°C prevails in Zone I, Zone II and Zone III, respectively (Figure 11.4).

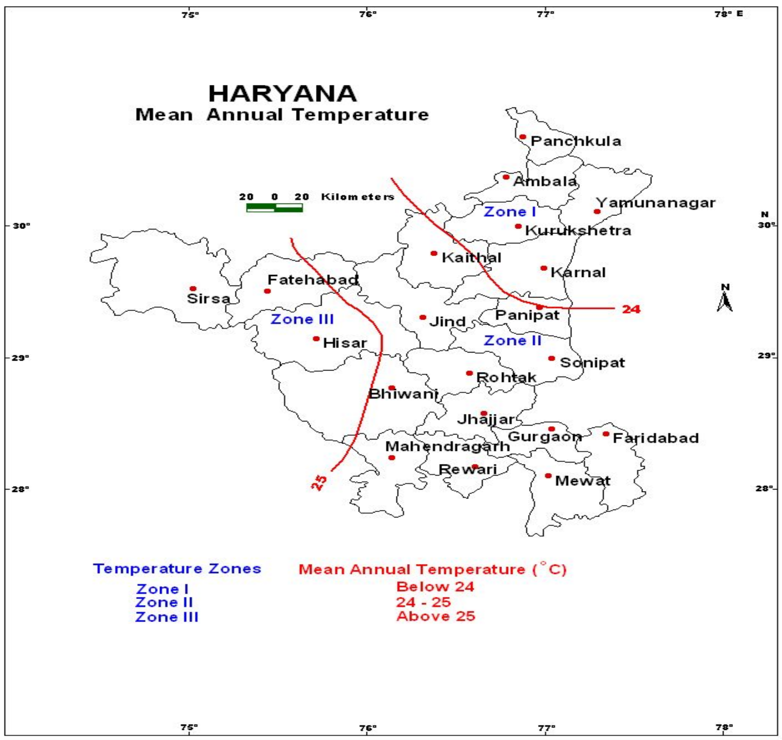


Figure 11.4. Annual temperatures in Haryana

3. Sunshine and radiation

Abundant sunshine (6 to 10 hrs/day) and solar radiation of sufficient intensity available in the state throughout the year except few occasions of abnormal weather. Multiple cropping with two or more cereals or four to five vegetable crops can be cultivated if moisture is not the limiting factor.

Importance of weather elements in crop production

Each phase of agricultural activity from preparatory tillage to plant growth, harvest and storage is influenced by weather elements (Rainfall, temperature, humidity, sunshine & radiation and wind etc.) directly or indirectly. The healthy growth and yield of crops depend upon certain optimum conditions of weather. The important elements of weather which influence the cropping pattern, plant suitability, adaptability, growth and final yield etc are given below.

1. Rainfall

The most important climatic element for agriculture in the tropics is the rainfall. The rainfall received during the SW monsoon season is the most important as the country's agricultural production is dependent on its quantum and distribution. In agriculture, rainfall largely manifests itself through its influence on the edaphic factors, viz., soil moisture, and soil temperature and aeration. In area with winter rains the winter - annuals germinate quickly and smother in the slow germinating annuals.

Similarly, winter annuals are suppressed in area of summer rains. There is adverse effect of denial of rainfall in rainy months of July and August on cane yield in spite of adequate irrigation. Flowering of a number of tropical plants including coffee is induced by rain.

Rain occurring during flowering period is harmful. Rainfall within six hours of foliar sprays adversely effect the efficiency of chemicals. Excessive rains can cause mineral deficiency in plants. Rain causing regular wetting of leaves encourage growth of bacteria on leaf surfaces. Dry weather is obligatory for ripening of a wide range of crops. Excessive rainfall occurring during vegetative and flowering phase may delay tillering and reduce yields.

2. Temperature

Due to the latitudinal extent from near equatorial to sub-tropical. The country experiences wide range of temperature conditions from North to South and East to West. The mean annual temperature across the country varies from <10°C in the extreme north to more than 28°C in south. The temperature starts to increase over the country from March onwards and reaches a peak in May and June. By May, many parts of India record mean daily maximum temperature above 40°C. On individual days temperature can be over 46 to 49°C. During winter northern states experience minimum temperature less than 10°C. These states are prone to occasional frost during the *rabi* season.

The influence of temperature are conditioned by its effects on the plant activities that regulate mechanisms of hormones, genes etc. Temperature effects from sowing of crops to final yields with various degrees. Low temperatures effects are on both roots and shoots. The worst trouble is in fruit and flowers.

Regardless of how favorable light and moisture conditions may be plant growth ceases when the temperature drop below a certain minimum value or exceeds a certain maximum value. Between these limits, there is an optimum temperature at which growth proceeds with great rapidity.

Influence of temperature on chemical processes is more pronounced than on physical processes of crop plants. Generally speaking, active growth of commercial crops is confined to the temperature range of 5° to 40°C. Within this range the cardinal temperatures and the optimum temperature range vary from species to species.

Role of temperature on net photosynthesis (photosynthesis - respiration) is of vital concern in crops. Photosynthesis consists of dark enzymatic reactions as well as light driven reactions. Available evidence suggests that at lower temperature range enzymatic reactions are limiting. On other hand respiration increases exponentially with temperature. Therefore, higher temperature can be expected to have a more deleterious effect on net photosynthesis than lower temperatures, leading to decreased production of photosynthates above a certain temperature.

In considering role of temperature on crop production not only mean temperature but temperature during night and day time periods must be considered. If days are warm, increased respiratory loss might, to some extent, be made good by photosynthesis. However, if nights are warm, loss by respiration is high. Unfavorable temperature conditions leads to slow development of leaf surface in young seedling stage and will have permanent deleterious effect on total foliage area even if subsequent condition turn to be favorable. However, if conditions are congenial in early stages of crop, occurrence of unfavorable temperature in later stage of crop are not that harmful.

Further, a considerable fraction of dry matter in the grains of crops arises from photosynthesis in the ears, thus influence of temperature during the flowering period becomes important. Temperature often exerts a modifying influence on the control of flowering by photoperiods. Too high or too low temperature in photo induction period may partly or wholly offset the influence of photoperiod on flowering. Ordinarily higher temperature in this period hasten flowering.

3. Sunshine and radiation

Solar radiation is the primary source of energy for various agricultural purposes. Out of the total spectrum, the visible part of the spectrum (0.4 to 0.7 µ) constitutes about 45 per cent of total global radiation, which affects a number of plant functions and regulates the plant growth and development. Agriculture is infact an exploitation of solar radiation, made possible by an adequate supply of water and nutrients to maintain plant growth. Intercrops are greatly benefited as prolonged periods of radiation are available for photosynthesis in most part of the country. Light quality, duration & intensity affect plant development and plant- processes to varying degree in different plants.

i) Quality: Quality of light refers to the wavelength of the radiation. Full range of visible spectrum of light is required for the normal growth and development. Flowering in the case of long day plant is inhibited by red light with 0.66 µ. Germination of the seeds is also inhibited when exposed to green, blue and infra-red portion of the spectrum. Red portion of the light induces germination. Stem elongation is promoted by far red. Phototropism, the process of orientation of shoots in the direction of light is enhanced by blue light with wavelength 0.45 µ, it increases with red to blue part but declines in th UV portion. UV rays, however, kill microorganisms, disinfect soil, and eradicate diseases, influence germination and quality of seeds.

ii) Duration: Based on flowering behavior to the photoperiod, plants are classed as 'long day', 'short day' and 'day neutral' types. It has been demonstrated that even a brief interruption of dark period by a flash of light can offset the effects of the duration of day.

Since photoperiodic reaction processes can proceed at very low intensity, the entire duration from sun rise to sunset constitutes the photoperiod duration. Weakness of moonlight in red wave length, most effective wavelength for photoperiodism, restricts its role as flowering factor to some kinds of plants only.

Photoperiod, in addition to its effect on flowering, may a) exerts other effects like inculcation and breaking of bud dormancy and winter hardiness, and b) influence i) elongation and branching of stem ii) shape, size, succulence and abscission of leaves iii) formation of tubers, tuberous roots and bulbs iv) fruit setting v) sex expression vi) germination.

iii) Intensity: Light intensity influences growth through its effect on photosynthesis. Two points on the light intensity scale assume importance, which are ‘compensation point' and 'saturation light intensity'. Compensation point is the minimum light intensity at which respiration equals photosynthesis rate. Rates of photosynthesis of tropical crops (sugarcane, maize, sorghum) are often twice as great as temperate species (wheat, oats, beans, cotton etc.) because of different methods of CO_2 fixation. Light saturation point is higher for tropical crops/plant species than for temperate species. Higher the temperature the higher is compensation point.

If there is no limiting factor, the rate of photosynthesis increases logarithmically with the increasing light intensity. But there occurs a point at which further increase in light intensity fails to accelerate photosynthesis. This intensity is known as light-saturation intensity and varies considerably with plant species.

Weather hazards and their impact on crops

1. Rainfall

- ***** *Excessive rainfall* (> 75 mm/day or 50 mm/h)
  Effects: Devastation of Crops
  Management: Construction of dams, planned afforestation, growing flood obstructing crops.
- ***** *Scanty Rainfall:* Droughts or insufficient rains/monsoon breaks
  Effects: Wilting, drying of crops, no growth, yield loss
  Management: Conservation of rains, reduction in runoff, thinning, weeding etc
- ***** *Untimely Rains:* Too early, too late or rains during flowering periods etc
  Effects: Poor fertilization, pest attacks, loss of harvestable products,
  Management: Follow the weather forecast, operation of contingency plans
- ***** *Storm/Cyclones/Depressions/Thunderstorms/Hails/Tornado*
  Effects: Damage or destruction of the crops
  Management: Hail, lightening suppression, cloud seeding

2. Temperature

- * *Cold wave:* Frost, chilling injury, advection frost, radiation frost
  Effects: Plants yellowing in chilling, plants are mostly killed in frost, mechanical injury, cell destruction, crop-diseases attack
  Management: Wind breaks for chilling or frost management, overhead sprinklers, heaters, wind machines use, irrigation etc.
- * *Heat Wave*
  Effects: Desiccating winds cause stress to the plants, shedding of leaves, flowers, fruits, shriveling of milk stage, wilt and plants may die
  Management: Heat evasion, heat trapping, shelter belts, wind breaks etc.

3. Radiation

- * *Defective Insolation:* Too excessive or defective due to cloudy weather
  Effects: Affect crop quality and yield, cloudy weather retard growth, affects pollination, cause disease and pest incidence Intense and bright solar radiation causes pollen burst or flower drop
  Management: Proper site selection, hormone sprays, pruning of orchards.

12. CLIMATIC REQUIREMENTS OF DIFFERENT CROPS

Weather or climate is the basic input in crop production. The external environment is the climate which regulates and determines the growth and development of crop plants and animals. The excess or deficiency of climatic elements exerts a negative influence on the life cycle of plants. The genetic yielding potentials of the improved or hybrid crop varieties can only be expressed under favorable weather. Under unfavorable weather, every thing including inputs, pesticides, weedicides, labor cost etc. cannot contribute in increasing yield and may go in waste. Every crop requires certain set of optimum conditions relating temperature, photoperiod, light intensity and water for maximum possible yield. In this chapter climatic requirements of few important crops have been given.

1. Rice (*Oryza sativa L.*)

Rice cultivation in India extends from 8 to 35°N latitude and from sea level to as high as 3000 meters. Rice crop needs a hot and humid climate. It is best suited to regions, which have high humidity, prolonged sunshine and an assured supply of water. Rice is a heat loving crop. Rice-growing seasons vary in different parts of India, depending upon temperature, rainfall and other climatic conditions. In parts of eastern region and Peninsular India, the mean temperatures throughout the year are favorable for rice cultivation and hence two or three crops of rice are taken in a year. In northern and western parts of the country where winter temperatures are fairly low only one crop of rice is taken during Kharif Season. Photo periodically, rice is a short-day plant. However, there are varieties, which are non-sensitive to photoperiodic conditions.

The average temperature required throughout the life period of the crop ranges from 21 to 37°C. At the time of tillering, the crop requires a higher temperature than for growth. The optimum temperature range for germination is 22-31°C. The optimum temperature required for flowering is 22 to 23°C. At the time of ripening the temperature should be between 20 – 25°C. If the temperature is high at grain filling stages, the respiration rate is accelerated and grain filling period is reduced. The crop tolerates day temperatures upto 40°C, provided water is not a limiting factor. If the night temperatures drop lower than 15°C towards the vegetative phase, even the flower primodia initiation fails to take place. The rice yield is greatly reduced by formation of sterile spikelets, which are induced by low temperatures. On an average the critical low temperature for inducing sterility is 15-17°C. The base or lower threshold temperature is 10°C. Total growing period ranges 90-150 days. Its mean thermal requirement is 1872 day°C for transplanting to maturity. For flowering its photoperiodic requirement is short day to day neutral. Short day length decreases the rice plant growth period.

Water Requirement: It requires abundant moisture. Crop is generally grown in regions with rainfall about 1250 mm. Its seasonal water requirement ranges 750-2500 mm. A heavy rainfall of 125 cm is required during its vegetative period. There should be a monthly rainfall of 200 mm to grow lowland rice and 100mm to grow upland rice successfully. The feet of the plant should remain submerged in water from time of sprouting to the milk stage of the grain. Its water utilization efficiency for getting harvested yield is 0.7 to 1.1 kg per m^3 of water.

2. Wheat (*Triticum aestivum*)

Wheat crop has wide adaptability. It can be grown not only in the tropical and sub-tropical zones but also in the temperate zone and the cold tracts of the far north, beyond even 60 degree latitude. The best wheat is produced in areas favored with cool, moist weather during the major portion of the growing period followed by dry, warm weather to enable the grain to ripe properly. It can be cultivated from sea level to as high as 3300 meters. Wheat is mainly a rabi (winter) season crop in India. Wheat can tolerate severe cold and snow and resume growth with the setting in of warm weather in spring.

Wheat is cold loving crop. Minimum, optimum and maximum cardinal temperatures for the germination of wheat crop are 3-4°C, 25°C and 30-32°C, respectively. Optimum temperature requirement for growth and development of wheat is 15-20°C. It can survive at temperature -8 to -10°C in the spring during the early periods of its vegetative growth. High temperature significantly reduced tillering in wheat. During the heading and flowering stages, excessively high or low temperatures and drought are harmful to wheat. Cloudy weather, with high humidity and low temperatures are conducive for rust attack. Higher temperatures of about 30- 35°C have detrimental effects on growth. High temperatures during winter accelerate growth, force early maturity and finally reducing the yields. The temperature conditions at the time of grain filling development are very crucial for yield. Temperatures above 25°C during this period tend to depress grain weight. When temperatures are high, too much energy is lost through the process of transpirations by the plants and the reduced residual energy results in poorer grain formation and lower yields. Higher temperature 30- 35°C have in general detrimental effects on the wheat crop. The base temperature is 5°C. Wheat is quantitative long day plant. Shading or cloudy days greatly reduces wheat grain yields. Decrease in day length increases growing period of all varieties.

Water Requirement: Wheat is grown in regions with rainfall 500-875 mm. Its moisture requirements ranges 450-650 mm. 350 to 400 mm of well distributed rainfall in the entire crop season or four irrigations one at crown root initiation and subsequently three at 40 to 45 days interval produce the best yields for the crop. Its water use efficiency for harvested product is 0.8 to 1.0 kg/m^3 of water. Its daily water requirement increases from 1.6 mm per day to 4 to 5.0 mm per day during heading or flowering. Soil moisture stress at any stage decreases grain yield.

3. Cotton (*Gossypium spp*)

Cotton is a heat loving crop. Generally cotton requires abundant sunshine, adequate soil moisture and fairly high temperature. Cotton plant cannot stand frost and hence its cultivation is restricted to an altitude of 1000 meters only. A frostless season of 180 to 240 days is required in north India for successful cotton cultivation.

Soil temperature is the most important factor affecting either the extent or speed of establishment of the initial crop stand. The maximum and minimum soil temperature limits are 14°C and 40°C. Soil temperature of 10°C or below increases seedling mortality due to pathogenic infection The minimum, optimum and maximum cardinal temperatures for the germination and growth of seedling of cotton crop are 16°C, 34°C and 39°C, respectively. The minimum, optimum and maximum cardinal temperatures for cotton growth are 15-20°C, 25-30°C and 35-40°C, respectively. Air temperature less than 16°C or greater than 38°C are not conducive for good vegetative development. A day time temperature of 26-32°C with cooler night temperatures is optimum for fruiting. A mean temperature of 22-27°C is optimum for boll and fibre maturation. Optimum temperature requirement of cotton for the growth is 15-20°C. A daily minimum temperature of 16°C is required for germination and 21-22°C for proper vegetative growth. It can tolerate temperatures as high as 43°C but does not do well if the temperature falls below 21°C. During fruiting phase, the day temperature ranging from 27 to 32°C and cool nights are needed. If during the fruiting period heavy showers of rain occur or heavy irrigation is applied, shedding of the flowers and young bolls may result. Low temperatures of 15-20°C retard growth and reduce fruiting. High temperatures 30-40°C and above have detrimental effects on growth and fiber quality. Cold nights and hot days favour the cotton aphid or cotton louse. Cotton is a short day plant for flowering. Sunshine affects cotton growth during bloom. Cloudiness prolongs vegetative growth. Abundant sunshine during the period of boll maturation and harvesting is essential to obtain a good quality produce.

Water Requirement: Cotton is grown in regions having 550-750 mm/season rainfall. The minimum rainfall limit for cotton is 500 to 650 cm. Heavy rainfalls, during sowing and early stage is undesirable. Excessive rainfall at later stage may cause the shedding of leaves, squares, blooms and bolls. Its water requirement ranges 700- 1300 mm. Its sensitivity to water supply is medium to low. Its water use efficiency is 0.4 -0.6 kg/m^3 of water. Shedding is closely related with water supply of the plant. Heavy continuous rains also result in shedding. Continuous rains during flowering cause improper pollination and bad quality fiber in boll developed.

4. Sugarcane (*Saccharum spp*)

Sugarcane is a tropical plant. It grows most successfully in those areas where the climate is more or less tropical, but it can grow in sub-tropics too like in north India. Under warm and humid condition it can continue its growth, unless terminated by flowering. The minimum soil temperature for the germination of sugarcane setts is in the range of 19-21°C. The optimum range is from 27-38°C, while temperatures above 38°C are not conducive. No root development occurs below 12°C.The minimum threshold temperature for cane growth is 16°C.Tillering is maximum at 30°C. Maximum temperature above 35°C and minimum temperature less than 18°C during tillering phase decrease cane yield. Optimum day and night temperatures for elongation are 31°C and 20°C, respectively. Maximum temperature above 37°C inhibits growth and growth also stops below 7°C. Growth and yield both fails with low temperature 0°C during winter nights. During ripening cool (10-20°C), dry sunny weather is required. Longer nights and shorter days, bright sunshine, and low humidity are conductive to effective dehydration and rapid accumulation of sucrose. The yield of the crop is reduced to one half if sunshine is reduced to half of its normal value.

Moisture: Crop requires 125-165cm of rainfall in a year. Its water requirement ranges 1500-2500 mm. Its sensitivity to water supply is high. For harvesting and handling it requires comparatively dry conditions.

5. Mustard (*Brassica* spp)

Mustard is the crop of tropical as well as temperate zones and requires somewhat cool and dry weather for satisfactory growth. The mean air temperature of 25°C is better for germination. They require a fair supply of moisture during the growing period and a dry clear weather at the time of maturity. These crops are not drought tolerant. They require an annual precipitation of 25-35 cm. Higher temperatures during shorter days markedly reduced the height of plants, developed a large number of leaves on the main stem and suppressed flowering. High temperatures and absence of rain during flowering periods decrease seed yields. This combination also disrupts the biosynthesis of fat and fatty acid content in the seeds. They require a fair supply of soil moisture during the growing period and daily clear weather at the time of maturity. Cool temperature, clear dry weather with plentiful of bright sunshine accompanied with adequate soil moisture increases the oil yield. In India, it is grown in *rabi* season from September-October and in February-March. Toria is more liable to suffer from frost and cold and is, therefore, usually sown earlier and harvested before the onset of frost. Rapeseed and mustard are long day in periodic response. These crops are not drought tolerant.

6. Pearlmillet (*Pennisetum glacum*)

Millets are heat-loving plants, mostly distributed in sub-humid and semi-arid climates. For germination, the minimum temperature required is 8 to 10°C. The plants are not frost-resistant; when temperatures fall below 1°C, the young leaves of plant are damaged and growth is retarded. A temperature of 35 to 40°C is normally tolerated by them. The optimum temperature for the growth of millets is difficult to define. However, best yields have been obtained where the mean temperature during the growth period is 26 to 29°C. High yields are rarely obtained below a mean air temperature of 24°C.

Millets have low moisture requirements and are highly drought-resistant. The transpiration coefficient of millets is very small and is about one-half to one-third that of wheat. They have an exceptionally high capacity for soil water uptake through their root system. Plants become dormant during drought periods, but revert to normalcy subsequently. A minimum of 28 to 35 cm rain fall is needed for the crop to be successful. During a 5-week period, from flowering to seed setting, a minimum of 2-5 mm of water a day for normal growth and 3.7 mm for higher yields, is required.

7. Chikpea (*Cicer aeritinum*):

Chickpea is a winter legume withstanding temperature between 8°C minimum and 22°C maximum during the coldest month. During the flowering period the average minimum temperatures 10-14°C and average maximum temperature between 25-31°C are considered optimum for hybridization and seed setting in most cultivars. Chickpea is Sensitive to both light and temperatures. It requires long days and cool temperatures. Average around 20°C with warm days (20°- 25°C) and cool (5°-10°C) or even cold frosty nights (-1° to 0°C). The optimum soil temperature for establishment of desi chickpea in India has been reported to be between 25-30°C.

Water requirements:

Chickpea uses 100 to 450 mm of water and is generally grown under rainfed conditions in India but gives good results in irrigated conditions as well. Heavier rainfall seasons (over 750 mm. annually) show reduced yields due to disease outbreaks and stem lodging problems from the excessive vegetative growth. Areas with lighter, well distributed rainfall patterns have produced the highest yield and quality chickpea seed. They produce good yields in drier conditions because of their deep tap root.

8. Guar (*Cymposis tetragonoloba*):

Guar has been characterized as a warm weather, drought tolerant, deep rooted, summer annual legume adapted to semi-arid climates. The ability of guar to endure high temperatures and soil water deficit may be due to the crop ability to deplete soil water deep within the profile and to a thick foliar epidermis that may reduce the transpiration losses. The soil temperature of 21°C or higher is necessary for guar seed germination. Optimum temperature fro guar growth and development is in the range of 24-30°C

13. CLIMATE CHANGE

The atmosphere covers the earth. It is a thin layer of mixed gases which make up the air we breathe. This thin layer also helps the earth from becoming too hot or too cold, much like clothing does for us. The biosphere is that part of Earth's atmosphere, land, oceans that supports any living plant, animal, or organism. It is the place where plants and animals, including humans, live. Large quantities of carbon dioxide are exchanged between the land based biosphere and the atmosphere as plants take in carbon dioxide and give off oxygen, and animals inhale oxygen and exhale carbon dioxide. Weather systems, which develop in the lower atmosphere, are driven by heat from the sun, the rotation of the earth, and variations in the earth's surface. The earth has been warming since 1910, with a temperature maximum reached in the 1990s. And the four warmest years of the 20th century all happened in the 1990s. Periods of increased heat from the sun may have helped make the Earth warmer. But many of the world's leading climatologists think that the greenhouse gases people produce are making the

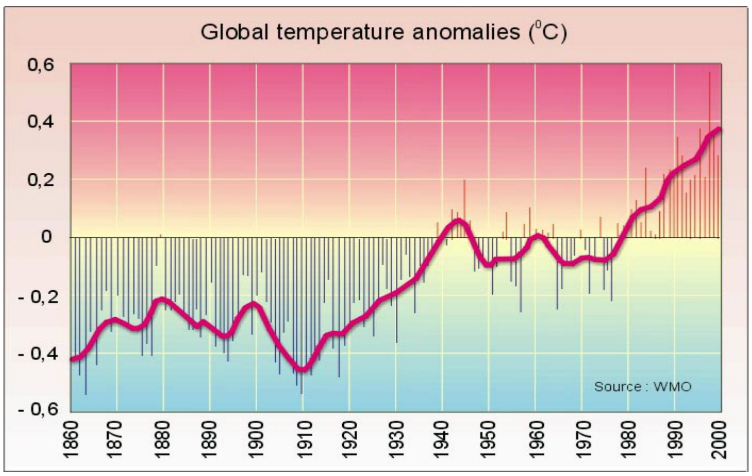


Figure 13.1. Global temperature anomalies during 1860-2000

earth warmer, too. Once, all climate changes occurred naturally. However, during the Industrial Revolution, we began altering our climate and environment through agricultural and industrial practices. The Industrial Revolution was a time when people began using machines to make life easier. It started more than 200 years ago and changed the way humans live. Before the Industrial Revolution, human activity released very few gases into the atmosphere, but now through population growth, fossil fuel burning, and deforestation, we are affecting the mixture of gases in the atmosphere.

Since the Industrial Revolution, the need for energy to run machines has steadily increased. Some energy, like the energy we need to do our homework, comes from the food we eat. But other energy, like the energy that makes cars run and much of the energy used to light and heat our homes, comes from fuels like coal and oil – fossil fuels. Burning these fuels releases greenhouse gases. This has caused an increase in global temperatures, a phenomenon known as *global warming*. If the amount of carbon dioxide were doubled instantaneously, with everything else remaining the same, the outgoing infrared radiation would be reduced by about 4 Wm^{-2}. In other words, the radiative forcing corresponding to a doubling of the CO_2 concentration would be 4 Wm^{-2}. To counteract this imbalance, the temperature of the surface-troposphere system

would have to increase by 1.2°C (with an accuracy of ±10%), in the absence of other changes. In reality, due to feedbacks, the response of the climate system is much more complex.
Weather observations indicate that the global average surface temperature has increased by 0.6^{o} C (IPCC 2001) since the 19th century (Fig.13.1). The rate of warming is faster than that at any other time during the past 1,000 years, which is attributed to the increase in the proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century. Observations also indicate that all the warmest years across the globe during the past century occurred during the last two decades (1981-1990 and 1991-2000).

The Greenhouse Effect

The Greenhouse Effect is the natural phenomenon that warms the Earth, enabling it to support life (Fig. 13.2). The sun's warmth passes easily through the blanket of gases around the Earth to reach the Earth's surface. However, instead of this heat being lost back to space when it is radiated by the Earth's surface, certain gases in the atmosphere (called greenhouse gases viz., Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Halocarbons block this heat. Greenhouse gases are a natural part of the atmosphere and without them we could not live on Earth. However, the problem we now face is that human actions, particularly the burning of fossil fuels, are increasing the concentration of these gases. This is believed to be raising the Earth's temperature, creating the prospect of global climate change. This is the Enhanced Greenhouse Effect.

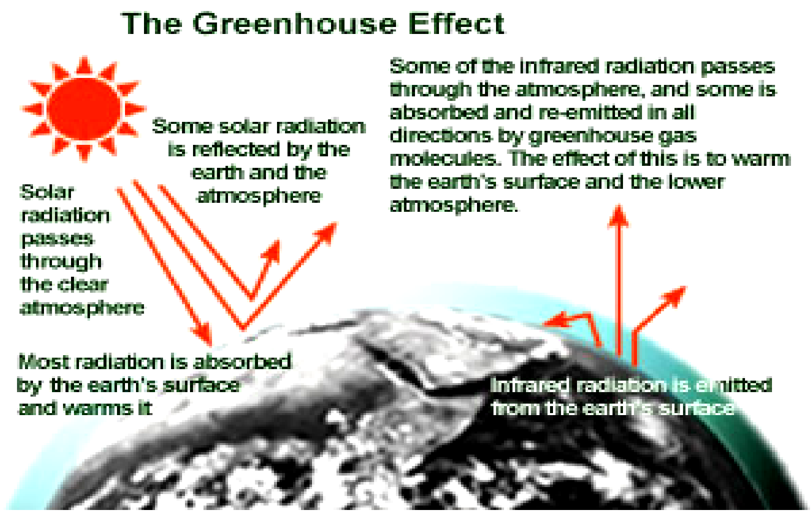


Figure 13.2. The Greenhouse Effect

Anticipated Warming

Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Scientists expect that the average global surface temperature could rise 0.6 to 2.5°C in the next fifty years, and 1.4 to 5.8°C by the end of century (Fig.13.3), with significant regional variation including a 2.7–4.3 °C increase over India by the 2080s. There are predictions of an increase in rainfall over the sub-continent by 6–8 per cent and that sea level would rise up to 88 centimeters by 2100. Local climate change will affect the region in various ways. In India, rainfall patterns are also set to change. Western and central areas could have up to 15 more dry days each year, while in contrast, the north and north-east are predicted to have five to ten more days of rain annually. In other words, dry areas will get drier and wet areas wetter. Extreme events, such as droughts, torrential rain, flash floods, cyclones and forest fires, could become more common. Changing rainfall patterns are likely to affect food security. Rising sea levels could threaten coastal mangrove and wetland systems, and increase the flood risk faced by the quarter of India's population that lives on the coast. The scientific conclusion reached is that warming is real. Carbon dioxide has been rising since the time of James Watt (1736 - 1819), inventor of the auto-controlled steam engine that helped in jump-start the industrial revolution. Since then, coal, oil and natural gas have powered our economies. Hydro-power and nuclear power are comparatively minor contributors to energy needs (excepting certain countries such as Norway and France).

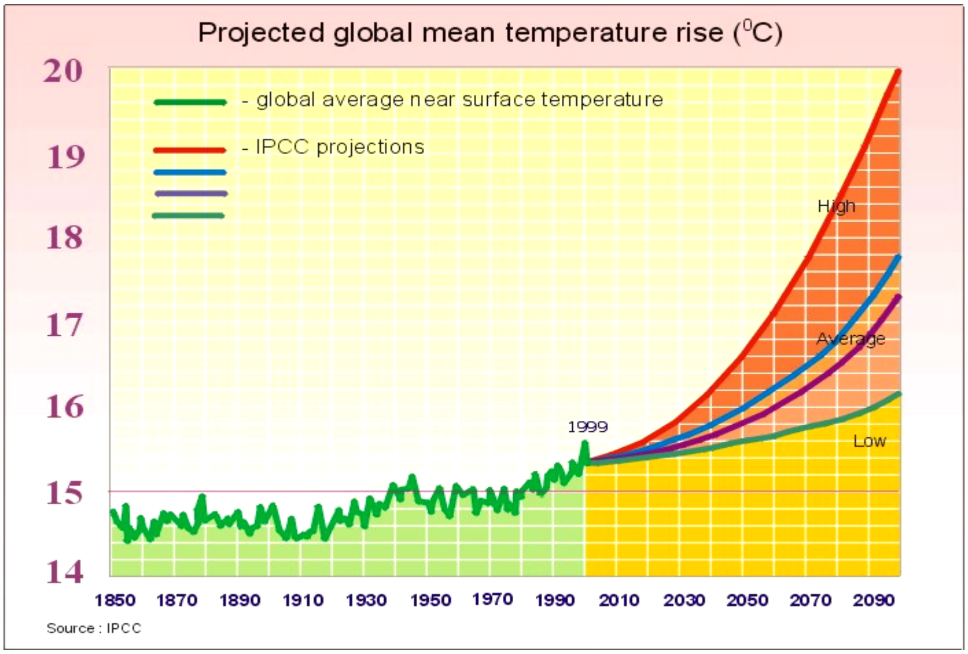


Figure 13.3. Anticipated global mean temperature rise (^{o}C)

Weather is the most important cause of year-to-year variability in crop production, even in high-yield and high-technology environments. There is strong evidence that change is an ongoing feature of the global climate system on various time scales. The global climate system is a consequence of and a link between the atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere. Any change to this system produced by forcing agents - results in climate change. Climate variations, both in the mean state and in other statistics such as, for example, the occurrence of extreme events, may result from radiative forcing–an imposed perturbation of the Earth's energy balance. While climate variability involves relatively short-term changes and can occur as a result of natural alterations in some aspect of the climate system, climate change represents longer-term trends that occur over many decades or centuries due to changes in atmospheric composition.

Impacts of Climate Change on Crop Production

People's ability to grow enough to feed themselves and their animals is determined to a large extent by the weather - by temperature, light and water. Short or long-term fluctuations in weather patterns - climate variability and climate change - can have extreme impacts on agricultural production, slashing crop yields and forcing farmers to adopt new agricultural practices in response to altered conditions. Climate, therefore, has a direct impact on food security.

Plants grow through the well-known process of *photosynthesis*, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose the *carbohydrates* that are the foundations of the entire food chain. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to a physiological class (called *C3 plants*) that respond readily to increased CO_2 levels. Corn, sorghum, sugarcane, and millet are *C4 plants* that follow a different pathway. The *C4 plants*, though more efficient photosynthetically than *C3* crops at present levels of CO_2, tend to be less responsive to enriched concentrations.

Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as *stomata* through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed. At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on crop physiology.

Higher concentrations of CO_2 generally result in higher photosynthesis rates and may also reduce water losses from plants. Photosynthesis is enhanced when additional carbon is available for assimilation and so crop yields generally rise. The actual response to increased CO_2 differs among crops. Most commercial crops including wheat, rice, barley, oats, potatoes, and most vegetable crops, tend to respond favorably to increased CO_2, with a doubling of atmospheric CO_2, concentration leading to yield increases in the range of 15-20 per cent. The crop models used in this assessment assume a CO_2 fertilization effect in this range, and also assume that sufficient nutrients and water will be available to support these increases. Other crops including corn, sorghum, sugar cane, and many tropical grasses, are less responsive to increases in CO_2, with a doubling of its concentration leading to yield increases of about 5 per cent. In situations where crop yields are severely limited by factors such as nutrient availability, an enduring CO_2 fertilization effect is very likely to be of only minor importance.

In middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. Crop-producing areas may expand poleward in countries such as Canada and Russia, although yields in higher latitudes will likely be lower due to the less fertile soils that lie there. Many crops have become adapted to the growing-season day-lengths of the middle and lower latitudes and may not respond well to the much longer days of the high latitude summers. In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO_2 in the process of *respiration*, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If nighttime temperature minima rise more than do daytime maxima--as is expected from greenhouse warming projections--heat stress during the day may be less severe than otherwise, but increased nighttime respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield.

Extreme meteorological events, such as spells of high temperature, heavy storms, or droughts, disrupt crop production. Recent studies have considered possible changes in the variability as well as in the mean values of climatic variables. Where certain varieties of crops are grown near their limits of maximum temperature tolerance, such as rice in Southern Asia, heat spells can be particularly detrimental. Similarly, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration. Global warming will affect the scheduling of the cropping season, as well as the duration of the growing period of the crop in all the major crop producing areas.

In India, while the wheat crop is found to be sensitive to an increase in maximum temperature, the rice crop is vulnerable to an increase in minimum temperature. The adverse impacts of likely water shortage on wheat productivity could be minimized to a certain extent under elevated CO_2 levels. They would largely be maintained for rice crop, resulting in a net decline in rice yields. Acute water shortage conditions combined with thermal stress should adversely affect both wheat and, more severely, rice productivity in northwest India, even under the positive effects of elevated CO_2 in the future.

Climate change over the long-term, in particular global warming, could affect agriculture in a number of ways - the majority of which would threaten food security for the world's most vulnerable people:

- The overall predictability of weather and climate would decrease, making planning of farm operations more difficult.
- Climate variability might increase - putting additional stress on fragile farming systems.
- Climate extremes - which are almost impossible to plan for - might become more frequent.
- The sea-level would rise, threatening valuable coastal agricultural land, particularly in low-lying small islands.
- Biological diversity would be reduced in some of the world's most fragile environments, such as mangroves and tropical forests.
- Climatic and agro-ecological zones would shift, forcing farmers to adopt, as well as threatening natural vegetation and fauna.
- The current imbalance of food production between cool and temperate regions and tropical and subtropical regions could worsen.
- Distribution and quantities of fish and sea foods could change dramatically, wreaking havoc in established national fishery activities.
- Pests and vector-borne diseases would spread into areas where they were previously unknown.

If climate changes and temperatures rise, there are a number of potential effects on agriculture. The timing and length of growing seasons might shift geographically, which would alter planting and harvesting dates and likely result in a need to change crop varieties currently used in a particular area. Seasonal precipitation patterns and amounts could change. With warmer temperatures, evapotranspiration rates would rise, which would call for much greater efficiency of water use. Weed and insect pest ranges could shift. Perhaps most important of all, there is general agreement that in addition to changing climate, there would likely be increased variability in weather, which might mean more frequent extreme events such as heat waves, droughts, and floods.

14. AGROECOLOGICAL CLASSIFICATION

Climate is the average condition of the atmosphere near the earth's surface at a certain place on earth. It is the long-term weather of that area (at least 30 years). This includes the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are air temperature and precipitation.

World biomes are controlled by climate. The climate of a region will determine what plants will grow there, and what animals will inhabit it. All three components, climate, plants and animals are interwoven to create the fabric of a biome.

The climatic classification in general and agroclimatic classification in particular are of great importance for the introduction of plants, their species and annual types from one area to the other of analogous climatic conditions. Agroclimatic classification attempts for the evaluation of potential productivity of crops and for improving of productivity of crops for which a number of simple as well as complex climatic/agroclimatic indices have been developed.

I. Climatic classification

Greeks were first to divide the earth into three climatic zones viz. tropical climate having mean monthly temperature above 18ºC, Temperate/middle latitude climate having temperature between 10-18ºC and Polar climate having mean monthly temperature below 10ºC.

1. Koppen's classificastion:

The Koppen climate classification system is the most widely used for classifying the world climates. Most classification systems used today are based on the one introduced in 1900 by the Russian-German climatologist Wladimir Koppen. Koppen (1936) classified the climate based on annual rainfall/ precipitation and mean monthly temperature into five main climatic types (Figure14):

Climatic types		**Mean temperature (^{0}C)**	
		Coldest month	**Warmest month**
A	Tropical rainy climate	>18	---
B	Dry climate	Mean annual temperature >18ºC and evaporation > precipitation	
C	Meso thermal climates	>-3 and <18	>10
D	Micro thermal climates	<-3	>10
E	Arctic climate	---	<10

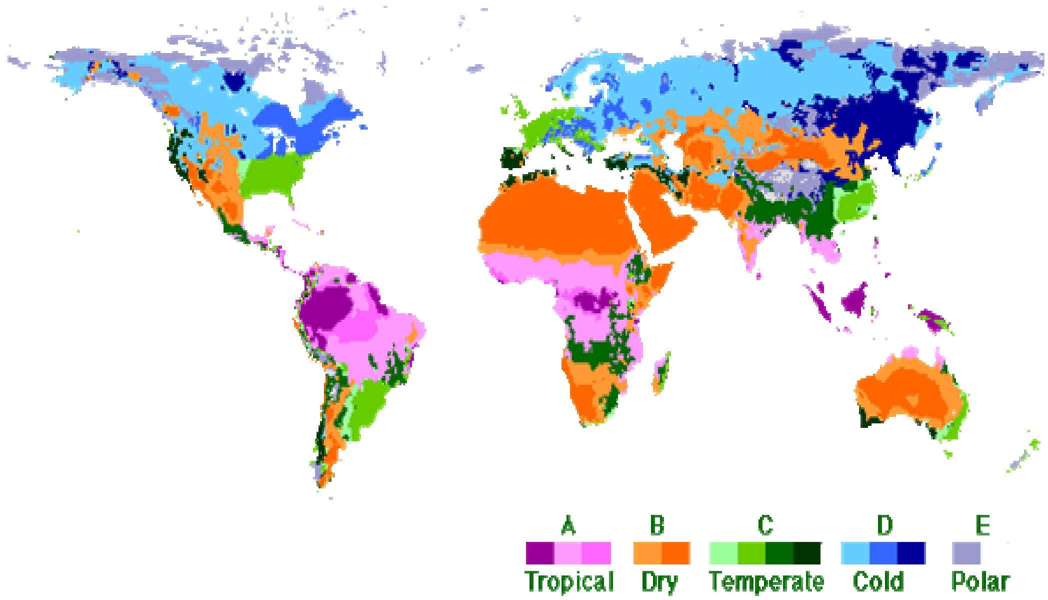


Figure.14. World climate types by *Koppen's* classification

2. Thornthwaite classification:

Thornthwaite (1948) proposed a rational classification of climates based on the concept of potential evapotranspiration and water balance. On the basis of moisture index (Im), climate is classified into nine climatic types:

$$\mathrm{Im} = \frac{S - D}{PE} \times 100$$

Where,

S = Annual water surplus, D = Annual water deficiency

PE = Annual potential evapotranspiration

	Climatic types	Moisture index
A	Per humid	>100
B4	Humid	80 to 100
B3	Humid	60 to 80
B2	Humid	40 to 60
B1	Humid	20 to 40
C2	Moist sub humid	0 to 20
C1	Dry sub humid	-20 to 0
D	Semi arid	-40 to -20
E	Arid	-60 to -40

Thornthwaite and Mathor (1955) revised the moisture index and they classified 9 climatic type based on the value of moisture index expressed as:

$$\text{Im} = \frac{P - P\ E}{PE} \times 100$$

Where, *P* is precipitation/rainfall

	Climatic types	Moisture index
A	Per humid	>100
B4	Humid	80 to 100
B3	Humid	60 to 80
B2	Humid	40 to 60
B1	Humid	20 to 40
C2	Moist sub humid	0 to 20
C1	Dry sub humid	-33.3 to 0
D	Semi arid	-66.7 to -33.3
E	Arid	-100 to -66.7

II. Agroclimatic classification

A. Agroecological zones of India

Planning Commission has demarcated the geographical area of India into 15 agro-climatic zones based on rainfall, soils, cropping systems and water resources (Figure 14.1). These are further divided into more homogenous 72 sub-zones. The 15 agro-climatic zones are as given below:

Agroclimatic zone	Regions
1. Western Himalaya	J&K, HP, UP, Uttranchal
2. Eastern Himalaya	Assam Sikkim, W.Bangal & all North-Eastern states
3. Lower Gangetic Plains	West Bangal
4. Middle Gangetic Plains	UP, Bihar
5. Upper Gangetic Plains	UP
6. Trans-Gangetic Plains	Panjab, Haryana, Delhi and Rajasthan
7. Eastern Plateau and Hills	Maharastra, UP, Orissa and West Bangal
8. Central Plateau and Hills	MP, Rajasthan, UP
9. Western Plateau and Hills	Maharastra, MP & Rajasthan
10. Southern Plateau and Hills	AP, Karnatak, Tamil Nadu
11. East Coast Plains and Hills	Orissa, AP, TN,& Pondicheri
12. West Coast Plains and Ghat	TN, Keral, Goa, Karnatka and Maharastra
13. Gujarat Plains and Hills	Gujrat
14. Western Dry	Rajasthan
15. The Islands	Andeman & Nicaobar and Lakshya Deep

The ICAR has broadly divided the whole country into 127 agroclimatic zones under the National Agricultural Research Project in 1980s.

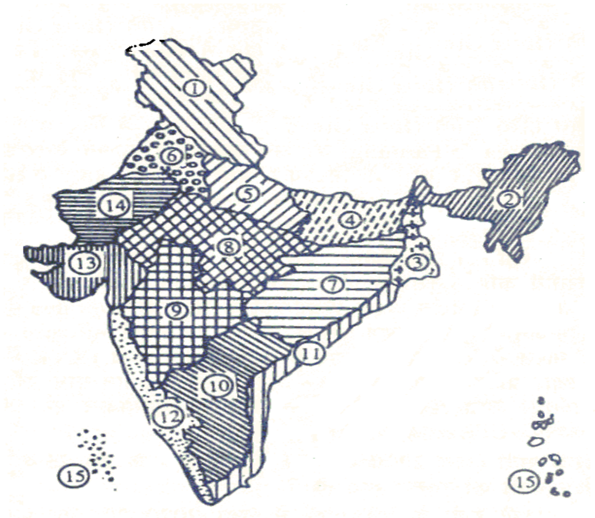


Figure 14.1: Agro-climatic zones of India

B. Climatic zones of Haryana

Based on *Thornthwaite's* classification Haryana state can be broadly divided into three climatic zones namely arid, semi-arid and dry sub-humid (Fig. 14.2).

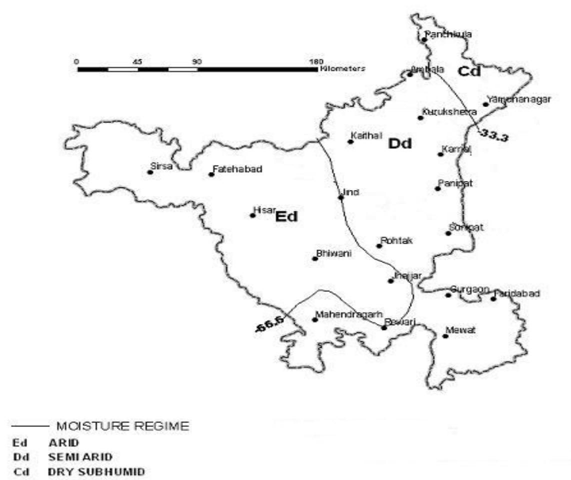


Figure 14.2: Climatic zones of Haryana.

	Climatic zone	Moisture index
1.	Arid	< -66.6
2.	Semi arid	-66.6 to -33.3
3.	Dry sub humid	-33.3 to 0

1. Arid zone comprises southwestern parts of Haryana covering districts of Sirsa, Fatehabad, Hisar, Bhiwani and parts of Rohtak, Jhajjar and Mahendragarh. This zone is deficient in precipitation against the high evapotranspiration rates. Variation in rainfall is also highest.

2. Semi-arid zone covers the districts of Jind, Kaithal, Karnal, Kurukshetra, Panipat, Sonepat, Gurgoan, Faridabad and parts of Ambala, Rohtak, Jhajjar and Mahedragarh.

3. Dry sub-humid zone comprises districts of Panchkula, Yamunanagar and northern parts of Ambala. This zone receives good amount of rainfall to meet out the water requirements of the atmosphere.

C. Soil Climatic Zones

Krishnan and Singh (1968) demarcated the soil climatic zones by superimposing the moisture index and mean temperature on the soil map of India showing major soil types. Based on the moisture and temperature belts entire Haryana could be divided into 5 major soil climatic zones.

1. Extremely dry zone: This zone consisted of south-western part of Hisar, Sirsa, Loharu, Siwani, Tosham, Dabawali and Baraguda.

2. Dry zone: This comprised most of the area of the state and included Fatehabad, Hisar, Hansi, Bhiwani, districts of Rohtak, Jhajjar, Sonepat, Kaithal, Gurgoan, Faridabad, Rewari, Mahederagarh and Jind.

3. Semi-dry zone: This zone extended from district Kaithal, Panipat, Karnal and south western portion of Ambala.

4. Slightly dry zone: It covered Jagadhari, Dadupur, Kalka, Barara, south Naraingarh, Chhachhrauli and Bilaspur.

5. Slightly moist zone: This zone comprises north Nariangarh and Raipur Rani areas.

III. Agro-ecological classification

The climatic classification based on standard climatic indices may not take into consideration other important factors of soil productivity and cropping system. For this reason, their utility decreases in large areas where such factors become increasingly varied. The agroecological zones to a large extent provide the factfile of related variables to explain cropping systems.

National Bureau of Soil Survey and land use planning (1992) on the basis of physiography, soil, bioclimate and length of growing period has divided the country into twenty agro-ecological region and the criteria followed is as under:

Physiograpahy

A	Western Himalyas	C	Eastern Himlayas
D	North Eastern Hills	E	Western Ghats
H	Eastern Ghats & Tamilnadu uplands	I	Central High land
J	Eastern Plateau	K	Decan Plateau
M	Western Plains	N	Northern Plains
O	Eastern Plains	Q	Asam and Bengal
S	Eastern Coastal Plain	T	Islands

Soil types

1. Red loamy soils	**2.** Red laterite soils
3. Red and yellow soils	**4.** Shallow and medium black soils
5. Medium and deep black soils	**6**. Red and black soils
7. Coastal alluvium derived soils	**8.** Alluvium derived soils
9. Desert and saline soils	**10.** Brown and red hill soils
11. Shallow skeletal soils	**12**. Brown forest and podzoic soils

Climate types

A	Per humid	B	Humid
C	Sub humid	D	Semi arid
E	Arid	F	Island

Length of growing period

1. 90 days	2. 90 – 150 days
3. 150 – 180 days	4. 180-210 days
5. 210 days	

Each zone has a code consisting of a first letter (represents physiogrpahy), a numeral (represents soil type), a second letter (represents climatic type) and a numeral (represents length of growing period). The code K4E1 zone indicates:

K Decan Plateau
4 Shallow and medium black soils
E Arid
1 Growing period of 90 days

Eight eco-systems were demarcated namely

1. Arid eco-system
2. Semi arid eco-system
3. Sub-humid eco-system
4. Humid eco-system
5. Per humid eco-system
6. Coastal eco-system
7. Island eco-system

The 20 agro-ecological zones of India have been demarcated on the basis of physiography, soil, bioclimate and length of growing period as depicted in Figure 14.3. Detail characteristics of these agroecological zones are presented in Table 1.

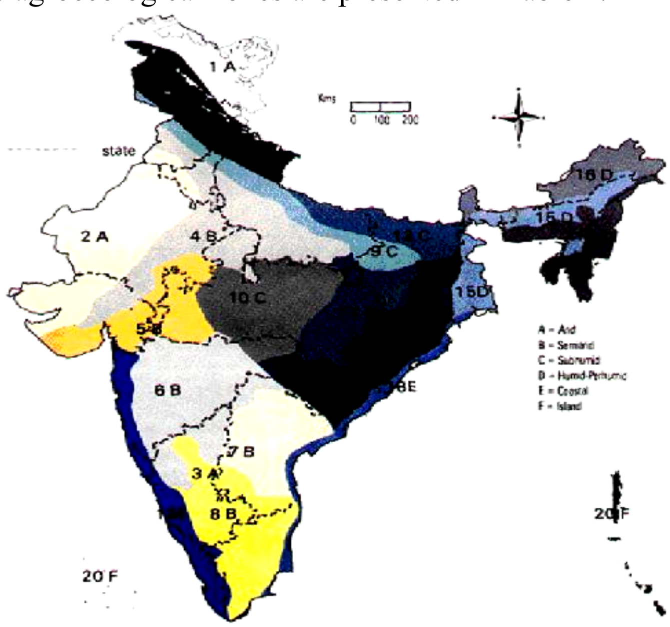


Figure 14.3: Agro-ecological region of India

Table 1: Agro-Ecological regions of India

Region No.	Map unit	Physiography	Soil	Climate	Precip. (mm)	PET (mm)	Growing period (days)
1.	A13E1	Western Himalaya	Shallow, sandy to loamy, skeletal soils with low AWC	Cold Arid	<150	<800	<90
2.	M9E1	Western Plain and Kachchha Penisula	Deep, sandy and coarse loamy, desert soils with low AWC; deep, loamy, saline and alkali soils with medium AWC	Hot Arid	<300	1500-2000	<90
3.	K6E1	Deccan Plateau	Deep, loamy red soils and clayey, black soils with medium and high AWC	Hot Arid	400-500	1800-1900	90-150
4.	N8D2	Northern plain and Central High Lands including parts of Gujarat Plains	Deep, loamy, alluvium derived soils with medium AWC and shallow to medium, sandy to loamy, gray brown soils with low to medium AWC	Hot semi-arid	500-800	1400-1900	
5.	I5D2	Central (Malwa) Highlands, Gujarat Plains and Kathiawar Peninula	Medium and deep, fine loamy and clayey, black soils with medium and high AWC	Hot semi-arid	500-1000	1600-1200	90-150
6.	K4D2	Deccan Plateau	Shallow and medium, loamy to clayey, black soils with low and medium AWC; inclusion of deep, clayey, black soils with high AWC	Hot semi-arid	600-1000	1600-1000	90-150
7.	K6D2	Deccan (Telagana) Plateau and Eastern Ghats	Medium, red loamy soils with low and medium AWC and deep, clayey, black soils with medium and high AWC	Hot semi-arid	600-1000	1600-1700	90-150
8.	H1D2	Eastern Ghats (TN Uplands) and Deccan Plateanu (Karnataka)	Shallow to deep, loamy, red soils with low to medium AWC; inclusion of deep clayey black soils with high AWC	Hot semi-arid	800-1000	1300-1600	90-150
9.	N8C3	Northern Plain	Deep, loamy, alluvium derived soils with medium and high AWC	Hot semi-humid	1000-1200	1400-1800	150-180

Region No.	Map unit	Physiography	Soil	Climate	Precip. (mm)	PET (mm)	Growing period (days)
10.	I6C3	Central Highlands (Malwa & Bundekhand)	Medium and deep, clayey, black soils with medium and high AWC and clayey red soils with low AWC	Hot sub-humid	1000-1500	1300-1500	150-180
11.	J3C3	Eastern Plateau (Chhatisgarh region)	Medium and deep, loamy, red and yellow soils with medium AWC	Hot sub-humid	1200-1600	1400-1500	150-180
12.	J2C3/4	Eastern (Chhota Nagpur) Plateau and Eastern Ghats	Shallow and medium, loamy, red soils and deep, loany, lateritic soils with low and medium AWC	Hot sub-humid	1000-1600	1400-1700	150-180
13.	O8C4	Eastern plain	Deep, loamy, alluviu-derived soils with medium and high AWC	Hot sub-humid	1400-1600	1300-1500	180-210
14.	A15 C/B/A 4/5	Western Himalayas	Shallow and medium, loamy, brown forest and podzolic soils with low and medium AWC; and deep loamy tarai soils with high AWC	Warm sub-humid to humid and per-humid	1600-2000	800-1300	180-210
15.	08BA/C5 & O8C/ BA5	Bengal Basin and Assam plain	Deep, loamy, alluvium derived soils with medium and high AWC	Hot sub-humid to per humid	1400-2000	1000-1400	>210
16.	C11A5	Eastern Himalayas	Shallow and medium brown red hill soils with low AWC	Warm per-humid	2000-4000	<1000	>210
17.	D2A5	North-Easter Hills	Shallow and medium, loamy red, yellow and lateritic soils with low AWC	Warm to hot per-humid	1600-2600	100-1100	>210
18.	S7 CD2-5	Eastern Coastal Plain	Deep, loamy, coastal and deltaic alluvial soils with medium and high AWC	Hot semiarid to sub humid	900-1600	1200-1900	>210
19.	E2B/A5	Western Ghats and Coastal Plain	Shallow and medium, loamy, red and lateritic soils with low AWC and deep coastal alluvial soils with high AWC	Hot humid per-humid	2000-3200	1400-1600	>210
20.	T1B/A5 & T1A/B5	Islands of Andaman and Nicobar and Lakshadeep	Medium and deep, red, loamy and sandy soils with very low to medium AWC	Hot per-humid	1600-3000	1400-1600	>210

With consideration to three dominant factors i.e. soil, rainfall and quality of underground water, Haryana can be divided into 7 agroecological zones (Figure 14.4).

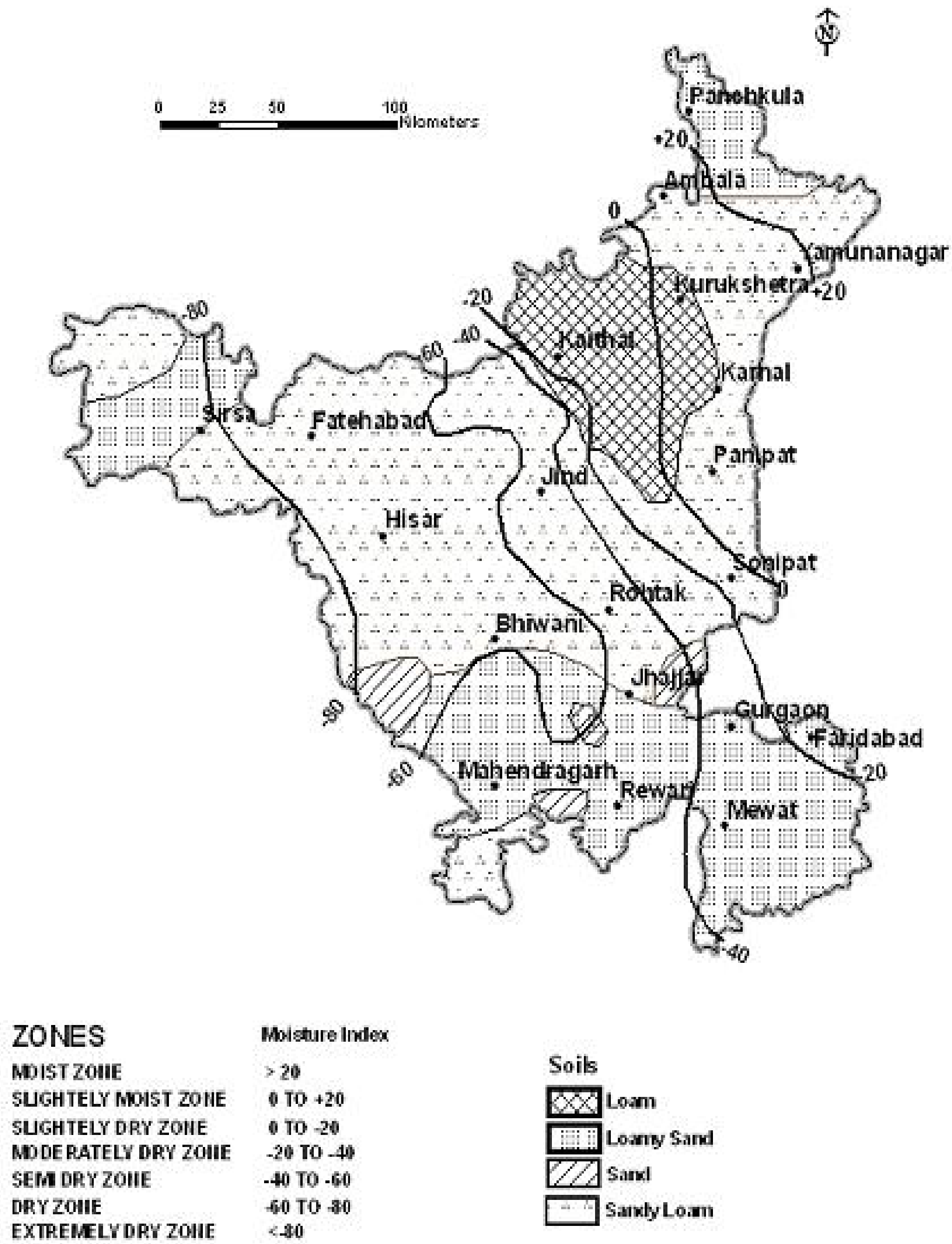


Figure 14.4: Agro ecological zones of Haryana

1. **Moist zone:** This zone comprises Siwalik Hilly region with high rainfall and covers Kalka, Nariangarh and Chhachharauli areas. In this zone wheat and paddy are grown under irrigated conditions whereas, maize, gram and wheat under rainfed conditions.
2. **Slightly moist zone:** This zone covers Jagadhri, Ambala, Karnal, Panipat, Asand, Thanesar, Kaithal, Guhla, Pehwa, Sonipat, Safidon and Jind areas and crops grown are rice, wheat, sugarcane, rapeseed & mustard and barseem.
3. **Slightly dry zone:** The areas under this zone are Rohtak, Bahadurgarh, Gohana and Ganour. The crops grown under irrigated conditions are wheat, rice, sugarcane, rapeseed & mustard and cotton. Under rainfed conditions pearl millet, sorghum, gram, guar and barley are grown.
4. **Moderately dry zone:** This zone comprises areas of Palwal, Ballabgarh, Hathin, Nuh, Gurgoan, Ferozpur-zhirka and Pataudi. Rice, wheat, barley, sugarcane and rapeseed & mustard crops are grown in irrigated situation and in rainfed situation the crops grown are pearl millet, sorghum, guar, gram and rapeseed & mustard.
5. **Semi dry zone:** This zone covers parts of Sirsa, Fatehabad and Hisar along with Hansi, Tohana and Narwana. Irrigated crops of this zone are cotton, wheat and rapeseed & mustard and rainfed crops are pearl millet, gram and guar.
6. **Dry zone:** The zone covers the parts of Dabwali, Sirsa, Fatehabad and Hisar along with areas of Jhajjar, Meham, Kosli, Bhiwani, Dadri, Bawani Khera, Mahindergarh, Narnaul, Rewari and Bawal. Cotton, wheat and barley are the crops under irrigated conditions, whereas, pearl millet, sorghum, gram, guar and rapeseed & mustard are rainfed crops.
7. **Extremely dry zone:** This zone covers parts of Dabwali. Sirsa and Hisar along with Siwani and Loharu. Cotton and wheat are the irrigated crops. Under rainfed situation the crops grown are pearl millet, guar, gram and rapeseed & mustard.

Significance of Agroecological zoning

- It enables to get potential yield of genotypes.
- Efficient utilization of soil and bioclimatic resources can be achieved.
- Helps in transfer of technology from one region to another.
- It helps in double cropping.
- It enables to introduce new genotypes in a region.
- Constraints to maximize crop production can be identified.

SAMPLE QUESTIONS

Type A: Tick (√) the correct answer of the following

1. Decrease in temperature with altitude is termed as

a) Inversion b) Lapse rate c) Isothermal lapse rate d) None

2. Reflectivity of solar radiation is called as

a) Solar constant b) Albedo c) Insolation d) Scattering

3. Isotherm may be defined as

a) Line joining places having equal temperature

b) Line joining places having equal air pressure

c) Both of these d) None of these

4. Solar constant is equal to

a) 1.0 cal/cm^2/minute b) 2.0 cal/cm^2/minute

c) 2.5 cal/cm^2/second d) None of these

5. Air in horizontal motion is termed as

a) Wind b) Storm c) Tornado d) Hurricane

6. The altitude of tropopause at equator is about

a) 18.0 km b) 8 km c) 25 km d) 10 km

7. Scale used for temperature measurement are

a) Celsius b) Fahrenheit c) Kelvin d) All of these

8. Increase in temperature with increase in height in troposphere is called

a) Isobar b) Inversion c) Isotherm d) Lapse

9. In northern hemisphere, due to coriolis force wind turns

a) Left b) Right c) Back d) None of these

10. Relative humidity is measured in

a) ^oC b) g/cc c) Per cent d) None of these

11. The term precipitation is used for

a) Rainfall b) Fog c) Dew d) All of these

12. Humidity is a measure of

a) Air pressure b) Wind direction

c) Atmospheric moisture d) None of these

13. Specific humidity is expressed in

a) ml b)Per cent c) g/cm^3 d) None of these

14. Frost is the form of

a) Precipitation b) Radiation c) Condensation d) None

15. Solar radiation ranges between

a) 0.15-0.40 μm b) 15-40 μm c) 8-14 μm d) 0.4-0.7 μm

16. Local dry and warm wind in Haryana during the months of May and June is called

a) Chinook b) Loo c) Simoon d) None of these

17. Valley wind moves from

a) Mountain to valley b) Valley to mountain

c) Valley to valley d) None of these

18. Long wave radiation wavelength is

a) > 4.0 μm b) < 4.0 μm c) >0.4 μm d) None

19. Pressure of air at saturation is called

a) Actual vapour pressure b) Saturated vapour pressure

c) Partial vapour pressure d) None of these

20. Relative humidity is the ratio of

a) Humidity and temperature b) Sensible and latent heat

c) Actual and saturated vapour pressure d) None of these

21. Water loss in vapour form from water surface is called

a) Respiration b) Transpiration c) Evaporation d) Condensation

22. Presence of water vapours in air is treated as

a) Rain b) Fog c) Mist d) Humidity

23. In lower most layer of atmosphere, fall of temperature is known as

a) Isotherm b) Lapse rate c) Inversion d) Isohyte

24. Horizontal movement of air is named as

a) Gale b) Wind c) Storm d) Cyclone

25. Specific humidity is measured in

a) g/kg b) Unit of volume c) Degree Celsius d) Centimeter

26. Term Precipitation is used for

a) Hailstorm b) Snowfall c) Rainfall d) All of these

27. Western disturbances commonly occur in

a) Summer b) Winter c) Autumn d) Spring

28. Burst of monsoon takes place in Haryana during

a) June-July b) September-October

c) January-February d) March-April

29. Annual rainfall in general, in Haryana State, increases as we move in a direction

a) South-West to North-East b) South to North

c) West to East d) All of these

30. Over a large continent, annual range of temperature is likely to be

a) Large b) Small c) Constant d) None of these

31. On a hot, humid & cloudy day diurnal (daily) range of temp would be

a) Normal b) Big c) Constant d) None of these

32. National Centre for Medium Range Weather forecasting (NCMRWF) is located at

a) Pune b) Kolkata c) Noida d) Mumbai

33. The emissivity and absorptivity is equal for all black bodies at a given wavelength. It is known as

a) Vant Hoff's law b) Plank's law

c) Kirchoff's law d) Boyle's law

34. The solar constant is the flux of solar radiation at the outer boundary of the earth's atmosphere received on a surface held___ to the sun's direction at the mean distance between the sun and earth

a) Angular b) Horizontal c) Perpendicular d) Parallel

35. The sum of direct solar radiation reaching to the earth and sky diffused radiation is

a) 25 % b) 45 % c) 60 % d) 99 %

36. Standard atmospheric pressure corresponds to the value of acceleration due to gravity as

a) 979.543 cm/sec^2 b) 980.665 cm/sec^2

c) 981.621 cm/sec^2 d) 982.270 cm/sec^2

37. In alluvial plains of Haryana with coarse textured soils & low rainfall, the annual rainfall is

a) 150-300 mm b) 300 –500 mm c) 500 – 600 mm d) 600 –900 mm

38. During monsoon rainy season, the moisture adequacy index in the northern and north-eastern parts of the Haryana State is

a) 0.50 b) 1.00 c) 1.20 d) 1.50

39. The mass of water vapour contained in unit volume of air is called as

a) Relative humidity b) Specific humidity

c) Absolute humidity d) Specific density

40. Following is a type of high clouds

a) Alto-cumulus b) Strato-cumulus
c) Cirro-cumulus d) Cumulo-nimbus

41. Which region in Haryana receives the highest average rainfall during the monsoon season

a) North-west b) North-east c) South-west d) South-east

42. The part of solar radiation which helps in photosynthesis is

a) X-rays b) Ultra-violet c) Visible d) Infra-red

43. Human hair is used as sensor in an instrument used for measuring the following weather parameter

a) Precipitation b) Air Pressure c) Evaporation d) Humidity

44. Areas near the equator are also known as

a) Horse latitudes b) Sub-tropics c) Roaring latitudes d) Doldrum

45. On an average, the highest values of annual total solar radiation at the surface in the northern hemisphere are obtained between the following latitudinal belts

a) 0-20 deg. N b) 20-40 deg. N c) 50-70 deg. N d) 70-90 deg. N

46. The value of solar constant (in calories/sq cm/min) is about

a) 0.2 b) 2.0 c) 0.5 d) 5.0

47. Cloudiness is measured in terms of

a) Pentads b) Octas c) Deciles d) Percentiles

48. The atmosphere is divided into different vertical layers based on the increase/decrease of the following

a) Air temperature b) Air pressure c) Air humidity d) Air density

49. Density of air in the atmosphere decreases with height in the

a) Stratosphere b) Mesosphere c) Thermosphere d) All of these

50. The height of homosphere is

a) 40 km b) 80 km c) 400 km d) 60 km

Write 'T' for true or 'F' for false statements

51. The temperature increases with altitude in troposphere

52. The normal lapse rate of atmosphere in troposphere is 3.5^{o}F/1000 feet

53. Relative humidity is affected by vapour pressure in the air

54. Instaneous state of atmosphere is defined as Climate

55. Height of troposphere is more at equator than poles.

56. Air density increases continuously with height in the atmosphere.

57. Wheat is a heat loving plant.

58. Wind moves from low pressure to high pressure area.

59. The process of conversion of vapours into liquid is known as inversion.

60. Cumulonimbus clouds are rain bearing clouds.

61. Bajra is important crop of north-eastern region of Haryana.

62. Land breeze prevails during night in costal region.

63. Western disturbances give rainfall during winter season in northern India.

64. Rice can be successfully grown in arid region.

65. Radiation intensity decreases with increase in latitude.

66. Temperature increases as we move towards poles.

67. Hail storms in Haryana are most common during south west monsoon season.

68. Extreme climate are commonly found near sea.

69. In mountaneous region the orrographic rainfall is most common.

70. Cyclone is a high pressure system.

71. Extremes of elements like temperatures as well as others are treated under the head weather.

72. Relative humidity is in relation to actual and maximum water holding capacity of air at same temperature.

73. Troposphere is highest at equator and lowest at either of the poles.

74. High clouds cause more rainfall than low clouds.

75. Moderate climates are found surrounded by water on all sides.

76. Damage caused by hailstorm, in Haryana, is most often before or at the time of harvest of *rabi* crops.

77. Extremes of climate are found on a small island.

78. Density of atmosphere decreases as we ascend from the surface of the earth.

79. Moist air is lighter than dry air.

80. Wheat, gram and barley are *kharif* crops.

81. Wet bulb depression increase, shows decline in relative humidity.

82. The artificial simulation of precipitation can be caused by Silver Iodide spraying in the atmosphere over cloud elements.

83. The presence of Ozone layer in the stratosphere is essential for well-beings of human and animal life on the earth.

84. During the day time there is land breeze while during the night there is sea breeze.

85. Any process in which no heat is supplied to or withdrawn from is to be non-adiabatic.

86. The conversion of water vapour into the ice is called crystallization while the conversion of ice into water vapour is called as sublimation.

87. Any process in which an accumulation of water vapour molecules into the exceedingly small droplets take place is called the condensation process.

88. Nimbostratus is a dense, shapeless and raged layer of low clouds from which precipitation does not fall.

89. The amount of incoming solar radiation varies strongly with latitude and depends essentially upon the altitude of sun.

90. The horizontal exchange of heat between the oceans and continents exerts a strong moderating influence on the annual range of temperature.

Fill in the blanks with appropriate word:

91. Atmospheric pressure at mean sea level is ……………..

92. Isotherm is the line joining the places having ….. ……….temperature.

93. In southern hemisphere isotherms are more or less………….

94. Albedo of field crops varies between………… per cent.

95. The height of tropopause over poles is………… kilometers

96. About……… per cent solar radiation is confined between 0.15 and 4.0 μm.

97. An average height of mesosphere is …………… km

98. In mesosphere temperature…………… with height.

99. UV-radiations are absorbed by………………. gas layer present in stratosphere.

100. During day time in coastal region, prevails……………..breeze.

101. ………percent of total rainfall in Haryana is received by south-west monsoon.

102. Shimla is ….. …………than Delhi.

103. The process of conversion of vapours into liquid is called………..

104. Climate of sub mountaineous region of Haryana is …………

105. Albedo of coniferous forests lies between………. and ……….per cent.

106. Time period of medium range weather forecasting is …….in advance.

107. Increase in air temperature in atmosphere is called as …………

108. The solar radiation between 0.4 to 7.0 μm wavelength is called………..

109. Air pressure in atmosphere………… with increase in altitude.

110. Lower part of thermosphere is called as…………..

111. Pressure of air is measured in…. …..by India Meteorological Department.

112. Lapse rate of temperature in upper troposphere is ………...than in its lower portion.

113. About four fifths of weight of atmosphere is confined to height of ………..Km.

114. Mean sea level air pressure is normally…………..milibars.

115. A wind speed of one KNOT is equal to …………. metre per second.

116. 50 degree celsius temperature equals to ………….degree Fahrenheit.

117. Germination and growth of wheat is restricted below…………..temperature.

118. Length of plant cycle decreases with …………….in altitude.

119. Light is essential for absorption of CO_2 and …………….in plants.

120. Specific day length requires by plants to produce flowers is called …………

121. The mean vertical variations in atmospheric pressure is about ……………

122. Knots is the unit of …………….

123. Winds which blow constantly throughout the year in a particular direction from high pressure to low pressure area are called as ……………..

124. The angular distance of a place from the equator is called as …………….

125. In some parts of the troposphere there is a shallow layer in which the temperature increases with height. Such a layer is called as …………..

126. The ratio of the mass of water vapour to the mass of moist air is called as …………….

127. The surface wind usually varies rapidly and continuously, and the variations are irregular both in period and time. This property of the wind is referred to as the ……………….

128. The total amount of water lost due to evapotranspiration and that used by the plant for its metabolic activities is called…………….

129. Haryana state is divided into …………….agro climatic zones.

130. When an air mass moves over a warmer surface it absorbs heat from below and becomes unstable resulting in……………….

131. A wind speed of one Knot is equal to ……………km per hour.

132. Milibar (mb) is a unit of ……………..

133. 45 degree Celsius is equal to ……………. degree F.

134. Boiling point of water in Kelvin (absolute) scales is ….. ……. K.

135. Precipitation is measured in ………………

136. Specific heat of pure water is ……………..

137. Valley winds are also known as…………winds.

138. Alto-cumulus is a type of ……………...height clouds.

139. Diameter of US Class A Open Pan Evaporimeter is ……………….

140. Trade winds blow from ………to …….. in the southern hemisphere.

KEY TO ANSWERS

Que	Ans	Que	Ans	Que	Ans	Que	Ans	Que	Ans
1	b	**31.**	d	**61.**	False	**91.**	1013 mb	**121.**	1 cm/100 meter
2	b	**32.**	c	**62.**	True	**92.**	Equal	**122.**	Wind
3	a	**33.**	c	**63.**	True	**93.**	Parallel	**123.**	Permanent wind
4	b	**34.**	c	**64.**	False	**94.**	15 and 25	**124.**	Latitude
5	a	**35.**	b	**65.**	False	**95.**	About 8 km	**125.**	Inversion layer
6	a	**36.**	b	**66.**	False	**96.**	99	**126.**	Specific humidity
7	d	**37.**	b	**67.**	False	**97.**	80	**127.**	Local
8	b	**38.**	b	**68.**	False	**98.**	Decreases	**128.**	Consumptive use
9	b	**39.**	c	**69.**	True	**99.**	Ozone	**129.**	Two
10.	c	**40.**	c	**70.**	False	**100.**	Sea	**130.**	Precipitation
11.	a	**41.**	b	**71.**	True	**101.**	80	**131.**	1.854
12.	b	**42.**	c	**72.**	True	**102.**	Colder	**132.**	Pressure
13.	d	**43.**	d	**73.**	True	**103.**	Condensation	**133.**	113
14.	c	**44.**	d	**74.**	False	**104.**	Dry sub-humid	**134.**	373
15.	a	**45.**	a	**75.**	True	**105.**	10 and 15	**135.**	mm
16.	b	**46.**	b	**76.**	False	**106.**	3-10 days	**136.**	1 cal/gm
17.	b	**47.**	b	**77.**	False	**107.**	Inversion	**137.**	Anabatic
18.	a	**48.**	a	**78.**	True	**108.**	Visible radiations	**138.**	Medium
19.	b	**49.**	d	**79.**	True	**109.**	Decrease	**139.**	122 cm
20.	c	**50.**	d	**80.**	False	**110.**	Ionosphere	**140.**	SE to NW
21.	c	**51.**	False	**81.**	True	**111.**	Millibar		
22.	d	**52.**	True	**82.**	True	**112.**	Greater		
23.	b	**53.**	True	**83.**	True	**113.**	18		
24.	b	**54.**	False	**84.**	False	**114.**	1013		
25.	a	**55**	True	**85.**	False	**115.**	0.5148		
26.	d	**56.**	False	**86.**	True	**116.**	122		
27.	b	**57.**	False	**87.**	True	**117.**	5^oC		
28.	a	**58.**	False	**88.**	False	**118.**	Increase		
29.	a	**59.**	False	**89.**	True	**119.**	Photosynthesis		
30.	a	**60.**	True	**90.**	True	**120.**	Threshold photoperiod		