AGRO METEOROLOGY

Meteorology

Greek word “Meteoro” means ‘above the earth’s surface’ (atmosphere) “logy” means ‘indicating science’. Branch of science dealing with that of atmosphere is known as meteorology. Lower atmosphere extending up to 20km from earth’s surface is where frequent physical process takes place.

Meteorology is a combination of both physics and geography Meteorology is a combination of both physics and geography. This science utilizes the principles of Physics to study the behaviour of air. It is concerned with the analysis of individual weather elements for a shorter period over a smaller area. In other words, the physical state of the atmosphere at a given place and time is referred to as “weather”. The study of weather is called ‘meteorology’. It is often quoted as the “physics of atmosphere”.

Weather: Physical state of the atmosphere at a given place and given time. Eg. Cloudy day

Climate: Long term regime of atmospheric variables of a given place or area. Eg. Cold season

Agricultural meteorology

1. A branch of applied meteorology which investigates the physical conditions of the environment of growing plants or animal organisms

2. An applied science which deals with the relationship between weather/climatic conditions and agricultural production.

3. A science concerned with the application of meteorology to the measurement and analysis of the physical environment in agricultural systems. The word ‘Agro meteorology’ is the abbreviated form of agricultural meteorology.

4. To study the interaction between meteorological and hydrological factors on the one hand and agriculture in the widest sense, including horticulture, animal husbandry and forestry on the other (WMO).

Meteorology Vs. Agricultural Meteorology

Meteorology	Agricultural meteorology
Branch of atmospheric physics	Branch of applied meteorology or a branch of agriculture as it deals with agriculture
It is a weather science	It is a product of agriculture and meteorology
It is a physical science	It is a biophysical science
It aims at weather forecasting	It aims at improving quantity and quality of crop production through meteorological skills
Weather service is the concern	Agro advisory service to the farmers is the concern based on weather forecast
It is a linking science to the society	It is a linking science to the farming community

IMPORTANCE TO CROP PRODUCTION

1. Helps in planning cropping patterns/systems.

2. Selection of sowing dates for optimum crop yields.

3. Cost effective ploughing, harrowing, weeding etc.

4. Reducing losses of applied chemicals and fertilizers.

5. Judicious irrigation to crops.

6. Efficient harvesting of all crops.

7. Reducing or eliminating outbreak of pests and diseases.

8. Efficient management of soils which are formed out of weather action.

9. Managing weather abnormalities like cyclones, heavy rainfall, floods, drought etc. This can be achieved by

(a) Protection: When rain is forecast avoid irrigation. But, when frost is forecast apply irrigation.

(b) Avoidance: Avoid fertilizer and chemical sprays when rain is forecast

(c) Mitigation: Use shelter belts against cold and heat waves.

10. Effective environmental protection.

11. Avoiding or minimizing losses due to forest fires.

FUTURE SCOPE

1. To study climatic resources of a given area for effective crop planning.

2. To evolve weather based effective farm operations.

3. To study crop weather relationships in all important crops and forecast crop yields based on agro climatic and spectral indices using remote sensing.

4. To study the relationship between weather factors and incidence of pests and diseases of various crops.

5. To delineate climatic/agro ecological/agro climatic zones for defining agro climatic analogues so as to make effective and fast transfer of technology for improving crop yields.

6. To prepare crop weather diagrams and crop weather calendars.

7. To develop crop growth simulation models for assessing/obtaining potential yields in different agro climatic zones.

8. To monitor agricultural droughts on crop-wise for effective drought management.

9. To develop weather based agro advisories to sustain crop production utilizing various types of weather forecast and seasonal climate forecast.

10. To investigate microclimatic aspects of crop canopy in order to modify them for increased crop growth

11. To study the influence of weather on soil environment on which the crop is grown

12. To investigate the influence of weather in protected environment (eg. Glass houses) for improving their design aiming at increasing crop production.

COORDINATES OF INDIA- ATMOSPHERE – COMPOSITION OF ATMOSPHERE - VERTICAL LAYERS OF ATMOSPHERE BASED ON TEMPERATURE DIFFERENCE / LAPSE RATE.

Coordinates of India

Lies between º N and º N latitude

ºE and º E longitude

Earth is elliptical in shape and has three spheres

Hydrosphere - the water portion

Lithosphere - the solid portion

Atmosphere - the gaseous portion

Atmosphere

The atmosphere is the colourless, odourless and tasteless physical mixture of gasses which surrounds earth on all sides. It is mobile, compressible and expandable. It contains huge number of solid and liquid particles called aerosol. Some gases are permanent atmospheric constituents in fixed proportions to the total gas volume. Others very from place and time to time. The lower atmosphere where the chemical composition of gas is uniform is called homosphere. At higher levels the chemical composition of air changes considerably and known as heterosphere.

Uses of atmosphere

1. Provides oxygen which is useful for respiration in crops
2. Provides carbon-dioxide to build biomass in photosynthesis.
3. Provides nitrogen which is essential for plant growth.
4. Acts as a medium for transportation of pollen.
5. Protects crops plants on earth from harmful U.V.rays.
6. Maintains warmth to plant life and
7. Provides rain to field crops as it is a source of water vapour, cloud, etc.

Composition of atmosphere

The following all the different gases that are present in percentage by volume approximately.

Nitrogen (N_2) = 78.08

Oxygen (O_2) = 20.95

Argon (Ar) =0.93 CO_2 =0.03

Neon (Ne) = 0.0018 Helium(He) =0.0005

Ozone(O_3) =0.00004 Hydrogen(H_2) =0.00006

Methane (CH_4) =0.00017

Vertical Layers of atmosphere based on temperature

On the basis of vertical temperature variation the atmosphere is divided into different spheres or layers.

A. Troposphere

1. The word “Trop” means mixing or turbulence and “sphere” means region.

2. The average height o this lower most layer of the atmosphere is about 14 km above the men sea level; at the equator it is 16 km and 7-8 km at the poles.

3. Under normal conditions the height of the troposphere changes from place to place and season to season.

4. Various types of clouds, thunderstorms, cyclone and anticyclones occur in this sphere because of the concentration of almost all the water vapour and aerosols in it. So, this layer is called as “seat of weather phenomena”.

5. The wind velocities increase with height and attain the maximum at the top of this layer.

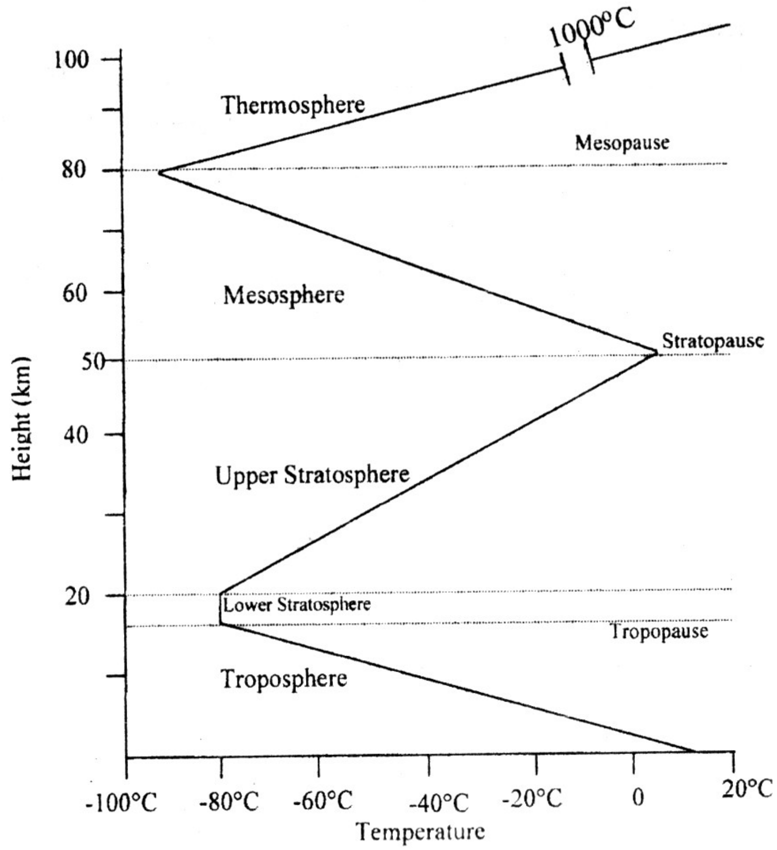
6. Another striking feature of the troposphere is that there is a decrease of temperature with increasing elevation at a mean lapse rate of about 6.5°C per km.

7. Most of the radiation received from the sun is absorbed by the earth’s surface. So, the troposphere is heated from below.

8. In this layer, about 75 per cent of total gases and most of the moisture and dust particles present.

9. A the top of the troposphere there is a shallow layer separating it from the stratosphere which is known as the “Tropopasue “.

10. The tropospause layer is thin and its height changes according to the latitudes and it is a transitional zone and distinctly characterized by no major movement of air.



TEMPERATURE BASED VERTICAL LAYERS OF ATMOSPHERE

B). Stratosphere

1). This layer exists above the tropopause (around 20 km onwards) and extends to altitudes of about 50-55 km.

2). This layer is called as “Seat of photochemical reactions”

3). The temperature remains practically constant at around 20 km and is characterized as isothermal because air is thin, clear, cold and dry near tropopause.

4). The temperature of this layer increases with height and also depends upon the troposphere because the troposphere is higher at the equator than at the poles.

5). In the upper parts of the stratosphere the temperatures are almost as high as those near the earth’s surface, which is due to the fact that the ultra-violet radiation from the sun is absorbed by ozone in this region. The air density is so much less that even limited absorption of solar radiation by the atmospheric constituents notably ozone produces a temperature increase.

6). Less convection takes place in the stratosphere because it is warm at the top and cold at the bottom.

7). There is also persistence of circulation patterns and high wind speeds.

8). The upper boundary of the stratosphere is called the stratopause.

C). Mesosphere/Ozonosphere

1. There is a maximum concentration of ozone between 30 and 60 km above the surface of the earth and this layer is known at the ozonosphere.

2. A property of the ozone is that it absorbs UV rays. Had there been no layer of the ozone in the atmosphere, the ultraviolet rays might have reached the surface of the earth and no life can exist.

3. Temperature of the ozonosphere is high (warm) due to selective absorption of U.V radiation by ozone.

4. Because of the preponderance of chemical process this sphere is called as the “chemosphere”

5. In this layer the temperature increases with height at the rate of 5°C per km.

6. According to some leading scientists the ionosphere is supposed to start at a height of 80 km above the earth’s surface. The layer between 50 and 80 km is called as “Mesosphere”. In this layer the temperature decreases with height. The upper boundary of this layer is called the “Mesospause”.

7. Mesosphere is the coldest region in the atmosphere with temperature reaching the lowest value of nearly -95°C at the mesopause (80km)

D). Thermosphere(Ionosphere)

1) The thermosphere layer lies beyond the ozonosphere (mesosphere) at a height of about 80 km above the earth’s surface and extends upto 400 km.

2) The atmosphere in the ionosphere is partly ionised enriched ion zones exist in the form of distinct ionised layers. So, this layer is called as the ionosphere.

3) Above the mesosphere the temperature increases again and is in the order of 1000°C.

4) The ionosphere reflects the radio waves because of one or multiple reflections of shortwave radio beams from the inoised shells. So, long distance radio communication is possible due to this layer.

E). Exosphere.

1) The outer most layer of the earth’s atmosphere is named as the exosphere and this layer lies between 400 and 1000 km.

2) At such a greater height the density of atoms in the atmosphere is extremely low.

3) Hydrogen and Helium gases predominate in this outer most region.

4) At an altitude of about 500 to 600 km the density of the atmosphere becomes so low that collisions between the natural particles become extremely rare.

Lapse rate

The decrease in air temperature with height is known as the normal / environmental lapse rate and it is 6.5°C/km.

Adiabatic lapse rate

The rate of change of temperature in an ascending or descending air mass through adiabatic process is called as adiabatic lapse rate. The thermodynamic transformation which occurs without exchange of heat between a system and its environment is known as adiabatic process. In adiabatic process, adiabatic cooling accompanies expansion, and adiabatic warming accompanies compression.

Monsoon Rainfall Variability

Indian continent receives its annual rainfall by the peculiar phenomenon known as monsoon. It consists of series of cyclones that arise in India Ocean. These travel in northeast direction and enter the Peninsular India along its west coast. The most important of these cyclones usually occur from June to September resulting in summer monsoon or southwest monsoon. This is followed by a second rainy season from October to December. A third and fourth rainy seasons occur from January to February and from March to May respectively. Of the four rainy seasons, southwest monsoon is the most important as it contribute 80 – 95% of the total rainfall of the country.

Two types of monsoon systems are a) South West Monsoon, b) North East Monsoon.

(a) South West Monsoon

Beginning of the year temperature of the Indian Peninsular rapidly rises under the increasing heat of the sun. A minimum barometric pressure is established in the interior parts of the Peninsular by the month of March. Westerly winds prevail on the west Kerala and south winds on the west of northern Circars, Orissa and Bengal. During April and May the region of high temperature is shifted to north viz., upper Sind, lower Punjab and Western Rajasthan. This area becomes the minimum barometric pressure area to which monsoon winds are directed.

The western branch of South West monsoon touches North Karnataka, Southern Maharashtra and then it make its way to Gujarat. When the South West Monsoon is fully operating on the Western India, another branch of the same is acting in the Bay of Bengal. It carries rains to Burma, Northern portions of the east coast of India, Bengal, Assam and the whole of North India in general.

b) North east Monsoon

During September end, the South West Monsoon penetrates to North Western India but stays on for a full month in Bengal. On account of the increase in barometric pressure in

Northern India, there is a shift of the barometric pressure to the South East and North Easterly winds begin to flow on the eastern coast. These changes bring on heavy and continuous rainfall to the Southern and South Eastern India.

c) Winter Rainfall

It is restricted more to Northern India and is received in the form of snow on the hills and as rains in the plains of Punjab, Rajasthan and central India. Western disturbance is a dominant factor for rainfall during these months in northwestern India.

d) Summer Rainfall

The summer Rainfall is received from March to May as local storms. It is mostly received in the South East of Peninsular and in Bengal. Western India does not generally receive these rains.

WEATHER AND CLIMATE, MICRO-CLIMATE

Weather

i) 'A state or condition of the atmosphere at a given place and at a given instant of time'.

ii) 'The daily or short term variations of different conditions of lower air in terms of temperature, pressure, wind, rainfall, etc'.

iii) State of atmosphere at a particular time as defined by the various meteorological elements. (WMO)

The aspects involved in weather include small areas and duration, expressed in numerical values, etc. The different weather elements are solar radiation, temperature, pressure, wind, humidity, rainfall evaporation, etc. is highly variable. It changes constantly sometimes from hour to hour and at other times from day to day.

Climate

i) 'The generalized weather or summation of weather conditions over a given region during comparatively longer period'.

ii) 'The sum of all statistical information of weather in a particular area during a specified interval of time, usually, a season or a year or even a decade'.

iii) Synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probabilities of extreme values, etc,) of the meteorological elements in that area. (WMO)

The aspects involved are larger areas like a zone, a state, a country and is described by normal. The climatic normals are generally worked out for a period of 30 years.

Differences between weather and climate:

Weather	**Climate**
1. A typical physical condition of the atmosphere.	1. Generalized condition of the atmosphere which represents and describes the

	characteristics of a region.
2. Changes from place to place even in a small locality	2. Different in different large region
3. Changes according to time (every moment)	3. Change requires longer (years) time.
4. Similar numerical values of weather of different places usually have same weather	4. Similar numerical values of climate of different places usually have different climates.
5. Crop growth, development and yield are decided by weather in a given season.	5. Selection of crops suitable for a place is decided based on climate of the region.
6. Under abnormal weather conditions planners can adopt a short-term contingent planning.	6. Helps in long-term agricultural planning.

Factors affecting climate

i) Latitude

The distance from the equator, either south or north, largely creates variations in the climate. Based on the latitude, the climate has been classified as

i) Tropical ii) Sub-tropical iii) Temperate & iv) Polar.

ii) Altitude (elevation)

The height from the MSL creates variation in climate. Even in the tropical regions, the high mountains have temperate climate. The temperature decreases by 6.5 ºC/Km from the sea level. Generally, there is also a decrease in pressure and increase in precipitation and wind velocity. The above factors alter the kind of vegetation, soil types and the crop production.

iii) Precipitation

The quantity and distribution of rainfall decides the nature of vegetation and the nature of the cultivated crops. The crop regions are classified on the basis of average rainfall which is as follow.

Rainfall(mm)	Name of the climatic region
Less than 500	Arid
500-750	Semi-arid
750-1000	Sub-arid
More than 1000	Humid

iv) Soil type

Soil is a product of climatic action on rocks as modified by landscape and vegetation over a long period of time. The colour of the soil surface affects the absorption, storage and re-radiation of heat. White colour reflects while black absorbs more radiation. Due to differential absorption of heat energy, variations in temperature are created at different places. In black soil areas, the climate is hot while in red soil areas, it is comparatively cooler due to lesser heat absorption.

v) Nearness to large water bodies

The presence of large water bodies like lakes and sea including its current affect the climate of the surrounding areas, eg: Islands and coastal areas. The movement of air from earth's surface and from water bodies to earth modifies the climate. The extreme variation in temperature during summer and winter is minimized in coastal areas and island.

vi) Topography

The surface of landscape (leveled or uneven surface areas) produces marked change in the climate. This involves the altitude of the place, steepness of the slope and exposure of the slope to light and wind.

vii) Vegetation

Kinds of vegetation characterize the nature of climate. Thick vegetation is found in tropical regions where temperature and precipitation are high. General types of vegetations present in a region indicate the nature of the climate of that region.

Scales of climate and their importance

i) Microclimate

Microclimate deals with the climatic features peculiar to small areas and with the physical processes that take place in the layer of air very near to the ground. Soil-ground conditions, character of vegetation cover, aspect of slopes, and state of the soil surface, relief forms – all these may create special local conditions of temperature, humidity, wind and radiation in the layer of air near the ground which differ sharply from general climatic conditions. One of the most important tasks of agricultural meteorology is to study the properties of air near the ground and surface layer of soil, which falls under the micro climate.

ii) Meso climate

The scale of meso climate falls between micro and macro climates. It is concerned with the study of climate over relatively smaller areas between 10 & 100 km across.

iii) Macro climate

Macro climate deals with the study of atmosphere over large areas of the earth and with the large scale atmospheric motions that cause weather. The scales of air motion in different climates are given in the Table below.

Type of climate	**Horizontal scale (km)**	**Vertical scale(km)**	**Time Scale(hrs)**
A. Macro climate			
1. Planetary scale	2000-5000 & more	10	200 to 400
2. Synoptic scale	500-2000	10	100
B. Meso climate	1 to 100	1-10	1-10

C. Micro climate	<100m	200 m	6-12 minutes

If any weather system develops under different types of climate, it persists longer periods under the macroclimate while smaller periods under micro climates.

CLIMATES OF INDIA AND TAMILNADU AND THEIR CHARACTERIZATION

Climate classification was tried by many scientists from beginning of 19th century using many parameters. Thornthwaite during 1931 and 1948 classified the climate using precipitation and evaporation /Potential evaporation and was subsequently modified by Mathur (1955) for the Moisture Index (Im) and is give below

Im = 100 [(P-PE)/PE]

Where P = Precipitation, PE = Potential evapo-transpiration

Using the moisture Index (**Im**) the following classification was made

Im Quantity	Climate classification
100 and above	Per humid
20 to 100	Humid
0 to 20	Moist sub humid
-33.3 to 0	Dry sub humid
-66.7 to -33.3	Semi arid
-100 to -66.7	Arid

Another classification by Troll (1965) based on number of humid months, said to be of more agricultural use was modified by ICRISAT for India. Humid month is one having mean rainfall exceeding the mean Potential evapo transpiration.

Climate	Number of humid months	% geographical area of India
Arid	<2.0	17.00
Semiarid-dry	2.0-4.5	57.17
Semiarid-wet	4.5-7.0	12.31
Humid	>7.0	1.10

The ICAR under All India Coordinated Research Project on Dryland Agriculture adopted classification based Moisture Deficit Index (MDI)

$$MDI = \frac{P - PET}{PET} \times 100$$

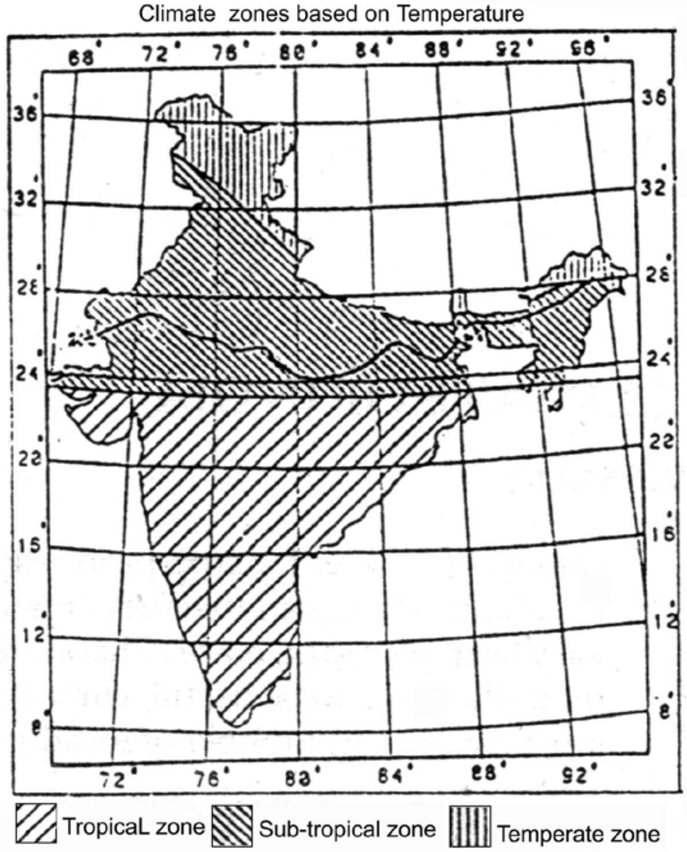
Where P is annual precipitation (cm) and PET is Potential Evapotranspiration. Based on MDI the climate is divided into three regions as below.

Type of climate	**MDI**
Subhumid	0.0 to 33.3
Semiarid	-33.3 to -66.6
Arid	> -66.6

Temperature based classification

The tropic of cancer, which passes through the middle of the country, divides it into two distinct climates. The tropical climate in the South where all the 12 months of the year have mean daily temperature exceeding 20°C; and in the North where a sub-tropical climate prevails. In sub-tropics during the winter months, it is cool to cold. Frosts occur sometime during the months of December and January. Some areas in the Northern India have a temperate climate. Here it snows during the winter months and freezing temperatures may extend to two months or more during the year. Three main climatic zones of India based on temperature are shown in the map below.

Climate zones based on Temperature



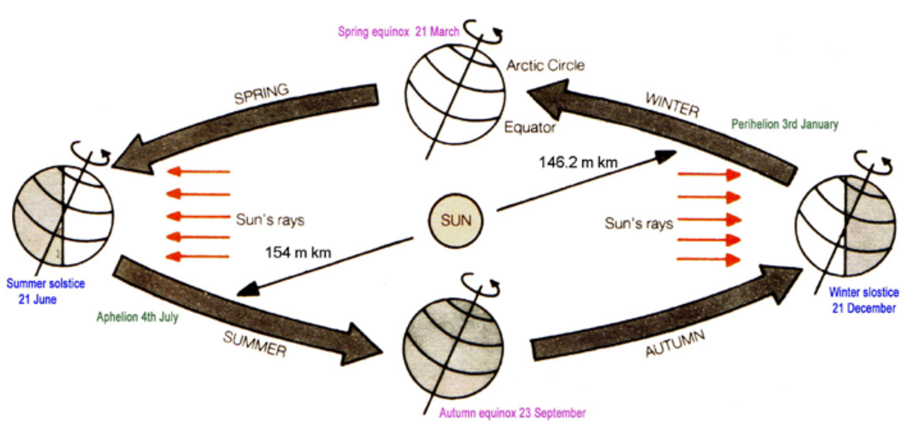
WEATHER ELEMENTS AND THEIR INFLUENCE ON DIFFERENT CROPS

The weather elements are solar radiation, temperature, soil temperature and light, radiation.

Solar radiation – Spectrum of radiation – Characteristics of different wave lengths and their effect on crop production.

Sun

- Sun is the prime source of energy
- Sun is the nearest star to the planet earth
- Diameter of the sun is 1.39 X 106 km
- It rotates on its axis about once every four weeks(27 days near equator & 30 days –polar)
- Sun is on an average 1.5 X 108 km away from the earth (149.64 M km deviation is 2.41 Mkm)
- Surface temperature of the sun is 5462° K
- Every minute, the sun radiates approximately 56 X 1026 calories of energy.
- The interior mass of the sun has a density of 80 to 100 times that of water.
- Energy is due to the fusion, Hydrogen is transformed to helium.
- 99% of the energy to biosphere is only from the sun and the rest one percent is from stars,lightning discharge, sun's radiation reflected from the moon, re-radiation from the earth etc.



Insolation

Electro magnetic energy radiated into the space by the sun

Factors affecting insolation

1. The solar constant which depends on

a. Energy output of the sun

b. Distance from earth to sun

2. Transparency of the atmosphere

3. Duration of daily sunlight period

4. Angle at which sun's noon rays strike the earth.

Transfer of heat

All mater, at a temperature above the absolute zero, imparts energy to the surrounding space. Three processes viz. conduction, convection and radiation are involved in heat flow or heat transfer.

Conduction

Heat transfer through matter without the actual movement of the substances or matter. Heat flows from the warmer to cooler part of the body so that the temperatures between them are equalized. Eg. The energy transmission through an iron rod which is made warmer at one end.

Convection

Processes of transmission of heat through actual movement of molecules of the medium. This is predominant form of energy transmission on the earth as all the weather related processes involve this process. Eg. Boiling of water in a beaker

Radiation.

Transfer of energy from one body to another without the aid of the material medium (solid, liquid or gas). Radiation is not heat, only when radiation is absorbed by surface of a body heat is produced. Eg. The energy transmission through space from the sun to the earth.

Solar radiation

The flux of radiant energy from the sun is solar radiation.

Heavenly bodies emit – short wave radiation

Near surfaces including earth emit - long wave radiation

Radiation flux

The amount of radiant energy emitted, received, transmitted across a particular area is known as radiant flux.

Radiant flux density

The radiant flux divided by the area across which the radiation is transmitted is called radiant flux density.

Emissive power

The radiant flux density emitted by a source is called its emissive power.

Energy measurement

Units Cal	**cm-2 min-1**	**J cm-2 mi-1**	**W cm-2**
Cal cm-2 min-1	1	4.1868	0.069
J cm-2 mi-1	0.238	1	0.00165
W cm-2	14.3	60.6	1

Spectrum of Radiation

Band	Spectrum	Wavelength (μ)	Importance
Ultra	Cosmic rays	< 0.005	Shorter wave lengths of spectrum & Chemically active, unless filtered there is danger of life on earth
	Gamma rays and X-rays	0.005 – 0.20	
	Ultraviolet rays	0.20 – 0.39	
Visible	Violet	0.39 – 0.42	Visible spectrum known as Light essential for all plant processes
	Blue	0.42 – 0.49	
	Green	0.49 – 0.54	
	Yellow	0.54 – 0.59	
	Orange	0.59 – 0.65	
	Red	0.65 – 0.76	
Infra red	Infrared rays	> 0.76	Essential for thermal energy of the plant (Source of heat)

Units of measurements of wavelength

Micron 1μ = 10-6 m = 10-4 cm

Milli micron 1 mμ = 10-9 m = 10-7 cm

Angstrom Å = 10-10 m = 10-8 cm

Solar radiation and crop plants

Crop production is exploitation of solar radiation

Three broad spectra

1. Shorter than visible range: Chemically very active

- When plants are exposed to this radiation the effects are detrimental.
- Atmosphere acts as regulator for this radiation and none of cosmic, Gamma and Xrays

  reaches to the earth.
- The UV rays of this segment reaching to the earth are very low and it is normally tolerated by the plants.

2. Higher than visible wavelength

- Referred to IR radiation
- It has thermal effect on plants

- In the presence of water vapour, this radiation does not harm plants, rather it supplies the necessary thermal energy to the plant environment.

3. Visible spectrum

- Between UV & IR radiation and also referred as light
- All plant parts are directly or indirectly influenced by the light
- Intensity, quality and duration are important for normal plant growth
- Poor light leads to plant abnormalities
- Light is indispensable to photosynthesis
- Light affect the production of tillers, the stability, strength and length of Culms

It affects the yield, total weight of plant structures, size of the leaves and root development.

Critical stages of plant growth for light

- Radiation intensity during the third month of Maize plant
- Rice – 25 days prior to flowering
- Barley – flowering period

Band	Wavelength(nm)	Specific effect on plant
1.	Radiation within 1000 and more	No specific effect on plant activity. Radiation absorbed by plants are transformed into heat. This radiation does not interfere with bio-chemical processes.
2.	1000-720	Radiation in this band helps in plant elongation, can be accepted as an adequate measure of plant elongation activity. The far red region (700-920 nm) has important role on photo-periodism, germination of seeds, flowering and colouration of fruits.
3.	720-510	In this spectral region light is strongly absorbed by chlorophylls. It generates strong photosynthetic and photo-periodic activity.
4.	610-510	This is green-yellow region. Absorption in this spectral region has low photosynthetic effectiveness and weak formative activity.
5.	510-400	It is the strongest chlorophyll and yellow pigment absorption region. In the blue-violet range, photosynthetic activity becomes very strong. This region has very strong effect on formation of tissues.
6.	400-315	Radiation in this band produces formative effects. It has dwarfing effect on plants and thickening effect on plant leaf.
7.	315-280	Radiation in this band has detrimental effect on most plants
8.	Less than 280	Lethal effect most of the plants get killed due to radiation in this band UV ranges have germicidal action.

Radiation balance – Solar constant – albedo – Sensible heat – Heat energy – Latent heat

A part of the incident radiation on the surface is absorbed, while a part is reflected and the remaining is transmitted.

Absorptivity

Absorptivity of a substance is defined as the ratio of the amount of radiant energy absorbed to the total amount incident upon that substance. The absorptivity of a blackbody is unity. Natural bodies like sun and earth are near perfect black bodies

Reflectivity

Reflectivity is defined as the ratio of the radiant energy reflected to the total incident radiation upon that surface. If it is expressed in percentage it becomes albedo.

Transmittivity

Transmittivity is defined as ratio of the transmitted radiation to the total incident radiation

upon the surface.

Emissivity

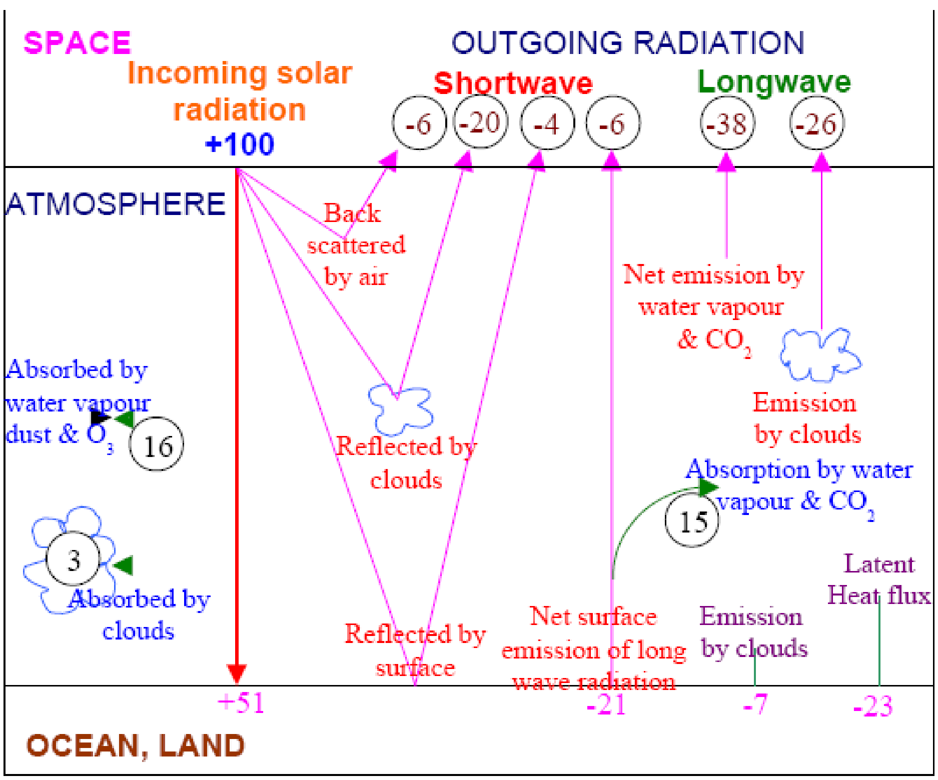
Emissivity is defined as the ratio of the radiant energy emitted by a given surface to the total heat energy emitted by a black body. The emissivity of a black body is unity.

Blackbody radiation

A Blackbody is defined as a body, which completely absorbs all the heat radiations falling on it without reflecting and transmitting any of it. It means reflectivity and transmittivity become zero. When such a black body is heated it emits radiation of all wavelengths depending upon its temp.

Radiation balance

The difference between all incoming and outgoing radiation at the earth's surface and top of the atmosphere is known as radiation balance at the earth's surface.



Solar constant

Solar constant is the energy received on a unit area at the outer most boundary of the earth (atmosphere) surface held perpendicular to the sun's direction, at the mean distance between the sun and the earth.

Solar constant is not a true constant. It fluctuates by as much as ± 3.5 % about its mean

value depending upon the distance of the earth from the sun.

Value is 2 cal / cm2 / min. (1.92 and 2.02) Recent measurements indicate value of 1.94

cal / cm2 / min (133 wm-2) [1 Langley = 1cal]

35% of the energy is contributed by U.V. and visible parts and 65% by Infra Red.

Albedo

It is the percentage of reflected radiation to the incident radiation. (Varies with colour and composition of the earth's surface, season, angle of the sun rays). Value is Highest in winter and at sunrise and sunset. Pure water – 5-20%, Vegetation 10-40%, Soils 15-50%, Earth 34-43% and clouds 55%. High albedo indicates that much of the incident solar radiation is reflected rather than absorbed.

Depends up on

1. Angle of incidence of radiation. Albedo increase with decreasing elevation of sun with minimum during noon.

2. Physical characteristics of surface

3. Season

4. Time of the day

For plant community albedo depends upon

1. Age of the crop

2. Percentage of ground cover

3. Colour and reflectivity of the foliage

Outgoing long wave radiation

After being heated by solar radiation, the earth becomes source of radiation.

Average temperature of the earth's surface 285º k (12º C)

99% of radiation is emitted in the farm of IR range (4 to 120 μ)

About 90% of the outgoing radiation is absorbed by the atmosphere.

Water vapour absorb in wavelengths of 5.3 to 7.7 μ and beyond 20μ.

Ozone 9.4 to 9.8 μ.

CO_2 – 13.1 to 16.9 μ

Clouds – in all wavelengths

Long wave radiation escapes to the space between 8.5 and 11 μ and this is known as the **atmospheric window.** Atmosphere for this spectrum acts as transparent medium instead of absorbing. This spectral region is used in microwave remote sensing to monitor the features of the sky in case of overcast sky.

A large part of the radiation absorbed by the atmosphere is sent back to the earth's surface as counter – radiation. This counter radiation prevents the earth's surface from excessive cooling at night.

Radiation laws

The direct transfer of heat from the sun to the earth through the space and atmosphere indicates that radiation of heat from one place to other occurs in the form of electromagnetic waves in the same manner and with same speed of as light. The wavelength of electromagnetic radiation is given by the equation

$$\lambda = \frac{C}{V}$$

Where λ = Wavelength (The shortest distance between consecutive crests in the wave trance)

C = Velocity of light (3x1010 cm sec-1)

V = Frequency means number of vibrations of cycles per second

Plank's law

Plank introduced the 'particle concept'. The electromagnetic radiation consists of a stream or flow of particles or quanta, each quantum having energy content E determined by of each quantum is proportional to the frequency given by the equation.

E= h v where

h= Plank's constant (6.62x10-34 J sec-1

V= Frequency

The law states that greater the frequency (shorter wave length) greater is the energy of quantum.

Kirchoff's law

A good absorber of radiation is a good emitter, in similar circumstances. This law states that the absorptivity 'a' of an object for radiation of a specific wavelength is equal to the emissivity 'e' for the same wavelength. The equation of the law is :

$$a (\lambda) = e (\lambda)$$

Stefan-Boltzmann's law

The intensity of radiation emitted (E) by a radiating body is directly proportional to the fourth power of the absolute temperature of that body. (Emissivity of black body = 1)

E = σ T4

Where,

T= (273+°C) because temperature is in Kelvins

= Stefan-Boltzmann's constant which is equal to 5.673 x 10-8 W m-2 K-4

Wein's Displacement laws

The wavelength of the maximum intensity of emission (λmax) from a radiating black body is inversely proportional to its absolute temperature

$$\lambda_{max} = 2897\ T^{-1}\ \mu = 2897/T\ \mu \text{ Where T is in °K}$$

If the temperature of a body is high, radiation maximum is displaced towards shorter wavelengths. For the sun's surface temperature of 5793°K, the λ_{max} is 0.5μ (2897/5793). The most intense solar radiation occurs in the blue-green range of visible light. The wavelength of maximum intensity of radiation for the earth's actual surface temperature of 14°C or 287°K is about 10.0 (2897/287) microns, which is in the infrared band.

Energy balance or heat balance

The net radiation is the difference between total incoming and outgoing radiations and is a measure of the energy available at the ground surface. It is the energy available at the earth's surface to drive the processes of evaporation, air and soil heat fluxes as well as other smaller energy consuming processes such as photosynthesis and respiration. The net radiation over crop is as follows.

$$Rn = G + H + LE + PS + M$$

Rn is net radiation, G is surface soil heat flux, H is sensible heat flux, LE is laten heat flux, PS and M are energy fixed in plants by photosynthesis and energy involved in respiration, respectively. The PS and M are assumed negligible due to their minor contribution (about 1-2% of Rn). The net radiation is the basic source of energy for evapotranspiration (LE), heating the air (H) and soil (S) and other miscellaneous M including photosynthesis.

Temperature

It is defined as the measure of the average speed of atoms and molecules

Kinetic energy

Energy of motion.

Heat

It is the aggregate internal energy of motion and molecules of a body. It is often defined as energy in the process of being transferred from one object to another because of the temperature between them.

Sensible heat

It is the heat that can be measured by a thermometer and thus sensed by humans. Normally measured in Celsius, Fahrenheit and Kelvin.

Latent heat

It is the energy required to change a substance to a higher state of matter. This same energy is released on the reverse process. Change of state through Evaporation and condensation is known as latent heat of evaporation and latent heat of condensation. From water to water vapour takes 600 calories and water to ice takes 80 calories.

Blue colour of the sky

If the circumference of the scattering particle is less than about 1/10 of the wavelength of the incident radiation, the scattering co-efficient is inversely proportional to the fourth power of the wavelength of the incident radiation. This is known as **Rayleigh scattering**. This is the primary cause of the blue colour of the sky. For larger particles with circumference >30 times of wavelength of the incident radiation, scattering is independent of the wavelength (i.e) white light is scattered. This is known as **Mei scaring**

Red Colour of the sky at sunset & sunrise.

It is because of increased path length in the atmosphere. % of solar energy in the visible part decreases. With in the visible part, the ratio of the blue to the red part decreases with increased path length.

Disposition of Solar radiation

a. 25% of solar radiation is reflected back to the space by clouds (more by middle and high latitudes and less in the sub tropics)

b. 6% reflected back by air, dust and water vapour.

c. 30% scatted downwards (more in the form of shorter wavelengths able) them that in longer wave length (red).

d. 17% of solar radiation is absorbed by the atmosphere. (Mostly by Oxygen, O3, CO2 & H2O

vapour).

O_2 – absorb the extreme UV wavelengths (0.12 to 0.6 μ)

O_3 – UV (0.2 to 0.32 μ) and Visible part of radiation (0.44 to 0.7 μ)

H_2O vapour – Near infra red (0.93, 1.13, 1.42 μ)

CO_2 - IR band 2.7 μ.

e. About 50% of solar radiation reaches earth's surface, after reflection, scattering and absorption.

LIGHT – EFFECT OF LIGHT INTENSITY, QUALITY, DIRECTION AND DURATION ON CROP PRODUCTION – AIR TEMPERATURE – FACTORS AFFECTING TEMPERATURE.

Light

Light is the visible portion of the solar spectrum with wavelength range is from 0.39 to 0.76μ. Light is one of the important climatic factors for many vital functions of the plant. It is essential for the synthesis of the most important pigment ie. Chlorophyll, Chlorophyll absorbs the radiant energy and converts it into potential energy of carbohydrate. The carbohydrate thus formed is the connecting link between solar energy and living world. In addition, it regulates the important physiological functions. The characteristics of light viz. intensity, quality, duration and direction are important for crops.

Light intensity

- The intensity of light is measured by comparing with a standard candle. The amount of light received at a distance of one metre from a standard candle is known as "Metre candle or Lux". The light intensity at one foot from a standard candle is called 'foot candle' or 10.764 luxes and the instrument used is called as lux metre.
- About one percent of the light energy is converted into biochemical energy.
- Very low light intensity reduces the rate of photosynthesis resulting in reduced growth.
- Similarly, very high intensity is detrimental to plant in many ways as below.
- It increases the rate of respiration.
- It also causes rapid loss of water (ie) increases the transpiration rate of water from the plants.
- The most harmful effect of high intensity light is that it oxidises the cell contents which is termed as 'Solarisation'. This oxidation is different from respiration and is called as photo-oxidation.
- Under field conditions the light is not spread evenly over the crop canopy but commonly passed by reflection and transmission through several layers of leaves.
- The intensity of light falls at exponential rate with path length through absorbing layers according to Beer's law. ie the relative radiation intensity decreases exponentially with increasing leaf area.
- At ground level the light intensity is below the light compensation point (The light intensity at which the gas exchange resulting from photosynthesis is equal to that resulting from respiration)

Based on the response to light intensities the plants are classified as follows.

(i) Sciophytes (shade loving plants): The plants grow better under partially shaded conditions. (eg) Betel vine, buck wheat etc.

(ii) Hetrophytes (Sun loving): Many species of plants produce maximum dry matter under high light intensities when the moisture is available at the optimum level. (eg) Maize, sorghum, rice etc.

Quality of Light

When a beam of white light is passed through a prism, it is dispersed into wavelengths of different colours. This is called the visible part of the solar spectrum. The different colours and their wave length are as follows:

Violet 400 – 435 m μ	Blue 435 – 490 m μ
Green 490 – 574 m μ	Yellow 574 – 595 m μ
Orange 595 – 626 m μ	Red 626 – 750 m μ

The principal wavelength absorbed and used in photosynthesis are in the violet – blue and the orange - red regions. Among this, short rays beyond violet such as X rays, gamma rays and larger rays beyond red such as infrared, are detrimental to plant growth. Red light is the most favourable light for growth followed by violet – blue. Ultra – violet and shorter wave lengths kill bacteria and many fungi.

c) Duration of light

The duration of light has greater influence than the intensity for canopy development and final yield. It has a considerable importance in the selection of crop varieties. The response of plants to the relative length of the day and night is known as phtoperiodism. The plants are classified based on the extent of response to day length which is as follows.

(i) Long day plants

The plants which develop and produce normally when the photoperiod is greater than the critical minimum (greater than 12 hours). eg. Potato, Sugarbeet, Wheat, Barley etc.

(ii) Short day plants

The plants which develop normally when the photoperiod is less than the critical maximum (less than 12 hours). Rice, Sorghum, cotton, Sunflower

(iii) Day neutral plants / Indeterminate

Those plants which are not affected by photoperiod.

(eg) Tomato, Maize

The photoperiodism influences the plant character such as floral initiation or development, bulb and rhizome production etc. In long day plant, during periods of short days, the growth of internodes are shortened and flowering is delayed till the long days come in the season. Similarly when short day plants are subjected to long day periods, there will be abnormal vegetative growth and there may not be any floral initiation.

Direction of light

- The direction of sunlight has a greater effect on the orientation of roots and leaves.
- In temperate regions, the southern slopes plants produce better growth than the northern slopes due to higher contribution of sunlight in the southern side.
- The change of position or orientation of organs of plants caused by light is usually called as phototropism ie the leaves are oriented at right angles to incidence of light to receive maximum light radiation.

Photomorphogenesis

Change in the morphology of plants due to light. This is mainly due to U.V and violet ray of the sun.

AIR TEMPERATURE

Temperature is defined as, “The measure of speed per molecule of all the molecules of a body”. Where as heat is, “the energy arising from random motion of all the molecules of a body'. (Degree of molecular activity). It is the intensity aspect of heat energy.

Conduction

Heat transfer when two bodies of unequal temperatures come into contact. Heat passes from point to point by means of adjacent molecules.

Convection

Transfer through movement of particles (part of mass) in fluids and gasses. These ar able to circulate internally and distribute heated part of the mass.

Radiation

It is the process of transmission of energy by electromagnetic waves between two bodies without the necessary aid of an intervening material medium.

Factors affecting air temperature

i. Latitude

ii. Altitude

iii. Distribution of land and water

iv. Ocean currents

v. Prevailing winds

vi. Cloudiness

vii. Mountain barriers

viii. Nature of surface

ix. Relief

x. Convection and turbulence etc.

1. Latitude

The time of occurrence of maximum monthly mean temperature and minimum monthly mean temperature also depends on latitude of a place. (eg.) The coldest month is January in northern regions of India while December in the south. Similarly, the warmest month is May in the south while June in the north across the country.

2. Altitude

The surface air temperature decreases with increasing altitude from the mean sea level as the density of air decreases. Since the density of air is less at higher altitudes, the absorbing capacity of air is relatively less with reference to earth's longwave radiation.

3. Distribution of land and water

Land and water surfaces react differently to the insolation. Because of the great contrasts between land and water surfaces their capacity for heating the atmosphere varies. Variations in air temperature are much greater over the land than over the water. The differential heating process between land and sea surfaces are due to their properties. It is one of the reasons for Indian monsoon.

4. Ocean currents

The energy received over the ocean surface carried away by the ocean currents from the warm areas to cool areas. This results in temperature contrast between the equator and poles. The occurrence of El-Nino is due to change in sea surface temperature between two oceanic regions over the globe.

5. Prevailing winds

Winds can moderate the surface temperature of the continents and oceans. In the absence of winds, we feel warm in hot climates. At the same time, the weather is pleasant if wind blows.

6. Cloudiness

The amount of cloudiness affects the temperature of the earth's surface and the atmosphere. A thick cloud reduces the amount of insolation received at a particular place and thus the day time temperature is low. At the same time, the lower layers in the atmosphere absorb earth's radiation. This results in increasing atmospheric temperature during night. That is why, cloudy nights are warmer. This is common in the humid tropical climates.

7. Mountain barriers

Air at the top of the mountain makes little contact with the ground and is therefore cold while in the valley at the foothills makes a great deal of contact and is therefore warm. That is, the lower region of the earth's atmosphere is relatively warmer when compared to hillocks.

Diurnal and seasonal variation of air temperature

- The minimum air temperature occurs at about sunrise, after which there is a constant

  rise till it reaches to maximum.
- The maximum air temperature is recorded between 1300 hrs and 1400 hrs although the

  maximum solar radiation is reaches at the moon.
- A steady fall in temperature till sunrise is noticed after is attains maximum. Thus the daily March displays one maximum and one minimum. The difference between the two is called the diurnal range of air temperature.
- The diurnal range of air temperature is more on clear days while cloudy weather sharply reduces daily amplitudes.
- The diurnal range of temperature is also influenced by soils and their coverage in addition to seasons.
- Addition of daily maximum and minimum temperature divided by two is nothing but daily mean / average temperature.
- In northern hemisphere winter minimum occurs in January and summer maximum in July.

Horizontal air temperature distribution

- The lines connecting points of equal temperature is called as **isotherm**
- It is largely depends latitude. A general decrease in temperature from equator towards poles is one of the most fundamental factors of climatology.
- Irregular distribution of land and water on earth's surface breaks the latitudinal variation in temperature.
- Land areas warm and cool rapidly than water bodies
- Mountain barriers influence horizontal distribution of temperature by restricting movement of air masses.
- On local scale topographic relief exerts an influence on temperature distribution.

Vertical air temperature distribution

Decrease in temperature with increase in height

Temperature inversion

- Occasionally at some altitude the temperature abruptly increases instead of decreasing. This condition in which this abrupt rise instead of fall in temperature occurs in the air is known as the temperature inversion. This may occurs under the following conditions.
- When the air near the ground cools off faster than the overlying layer, because of heat loss during cooling nights.
- When an actual warm layer passing over a lower cold layer
- Cold air from hill tops and slopes tend to flow downward and replaced by warm air.

Significance of Temperature inversion

- Cloud formation, precipitation and atmospheric visibility are greatly influenced by inversion phenomenon

- Fog formation may take place near the ground which may affect the visibility to both human beings and animals. Affects air navigation.
- Diurnal temperature is affected by temperature inversions.
- The incoming solar radiation and its conversion in to heat is affected.

Heat Units

- It is a measure of relative warmth of growing season of a given length. Normally it is indicated as Growing Degree Days (GDD). A heat unit is the departure from the mean daily temperature above the minimum threshold temperature.
- The minimum threshold temperature is the temperature below which no growth takes place.
- Usually ranges from 4.5 to 12.5 ºC for different crops (Most commonly used value is 6.0ºC)

Degree Day

A degree day is obtained by subtracting the threshold temperature from daily mean temperature. Summation of the daily values over the growth period gives degree days of the crops.

$$GDD = \Sigma \frac{T_{max} + T_{min}}{2} - T_b$$

Where

T_{max} – Maximum air temperature of the day

T_{min} – Minimum air temperature of the day

T_b - Base temperature of the crop

The base temperature is the threshold temperature.

Advantages / Importance of growing degree Day Concept

1. In guiding the agricultural operations and planting land use.
2. To forecast crop harvest dates, yield and quality

3. In forecasting labour required for agricultural operations

4. Introduction of new crops and new varieties in new areas

5. In predicting the likelihood of successful growth of a crop in an area.

HEAR INJURIES

'Thermal death point" – the temperature at which the plant cell gets killed when the temperature ranges from 50-60°C. This varies with plant species. The aquatic and shade loving plants are killed at comparatively lower temperature (40°C).

High temperature

- results in desiccation of plants
- disturbs the physiological activities like photosynthesis and respiration
- increases respiration leading to rapid depletion of reserve food.

Sun clad

Injury caused on the barks of stem by high temperature during day time and low temperature during the night time.

Stem griddle

The stem at ground level scorches around due to high soil temperature. It causes death of plant by destroying conductive tissues. Eg. This type of injury is very common in young seedlings of cotton in sandy soil when soil temperature exceeds 60°C.

COLD INJURY

(i) Chilling injury

Plants which are adapted to hot climate, if exposed to low temperature for sometime, are found to be killed or severely injured or development of chloratic condition (yellowing) (eg.) cholratic bands on the leaves of sugarcane, sorghum and maize in winter months when the night temperature is below 20°C.

(ii) Freezing injury

This type of injury is commonly observed in plants of temperate regions. When the plants are exposed to very low temperature, water freezes into ice crystals in the intercellular spaces of plants. The protoplasm of cell is dehydrated resulting in the death of cells. (eg.) Frost damage in potato, tea etc.

(iii) Suffocation

In temperature regions, usually during the winter season, the ice or snow forms a thick cover on the soil surface. As a result, the entry of oxygen is prevented and crop suffers for want of oxygen. Ice coming in contact with the root prevents the diffusion of CO_2 outside the root zone. This prevents the respiratory activities of roots leading to accumulation of harmful substances.

(iv) Heaving

This is a kind of injury caused by lifting up of the plants along with soil from its normal position. This type of injury is commonly seen in temperate regions. The presence of ice crystals increases the volume of soil. This causes mechanical lifting of the soil.

Role of temperature in crop production:

1. Temperature influences distribution of crop plants and vegetation.
2. The surface air temperature is one of the important variables, which influences all stages of crop during its growth development and reproductive phase.
3. Air temperature affects leaf production, expansion and flowering.
4. The diffusion rates of gases and liquid changes with temperature.
5. Solubility of different substances is dependent on temperature.
6. Biochemical reactions in crops (double or more with each 10°C rise) are influenced by air temperature.
7. Equilibrium of various systems and compounds is a function of temperature.
8. Temperature affects the stability of enzymatic systems in the plants.

9. Most of the higher plants grow between 0°C – 60°C and crop plants are further restricted from 10 – 40°C, however, maximum dry matter is produced between 20 and 30°C

10. At high temperature and high humidity, most of the crop plants are affected by pests and diseases.

11. High night temperature increases respiration and metabolism.

12. A short duration crop becomes medium duration or long duration crop depending upon its environmental temperature under which it is grown.

13. Most of the crops have upper and lower limits of temperature below or above which, they may not come up and an optimum temperature when the crop growth is maximum. These are known as cardinal temperatures and different crops have different temperatures.

Sl No	Crop	Minimum	Optimum	Maximum
1	Wheat and Barley	0 – 5	25 – 31	31 – 37
2	Sorghum	15 – 18	31 – 36	40 – 42

Thermo periodic response

Response of living organism to regular changes in temperature either day or night or seasonal is called thermoperiodism.

Soil temperature

The soil temperature is one of the most important factors that influence the crop growth. The sown seeds, plant roots and micro organisms live in the soil. The physio-chemical as well as life processes are directly affected by the temperature of the soil. Under the low soil temperature conditions signification is inhibited and the intake of water by roof is reduced. In a similar way extreme soil temperatures injures plant and its growth is effected.

Eg. On the sunny side, plants are likely to develop faster near a wall that stores and radiates heat. If shaded by the wall, however, the same variety may mature later. In such cases soil temperature is an important factor.

Importance of soil temperature on crop plants:

The soil temperature influences many process.

1. Governs uptake of water, nutrients etc needed for photosynthesis.

2. Controls soil microbial activities and the optimum range is 18-30°C.

3. Influences the germination of seeds and development of roots.

4. Plays a vital role in mineralization of organic forms of nitrogen.(inc with inc in temp)

5. Influences the presence of organic matter in the soil.(more under low soil temperature)

6. Affects the speed of reactions and consequently weathering of minerals.

7. Influences the soil structure (types of clay formed, the exchangeable ions present, etc.)

Factors affecting soil temperature:

Heat at ground surface is propagated downward in the form of waves. The amplitude deceases with depth. Both meteorological and soil factors contribute in bringing about changes of soil temperature.

I) Meteorological factors

1. Solar radiation

a) The amount of solar radiation available at any given location and point of time is directly proportional to soil temperature.

b) Even though a part of total net radiation available is utilised in evapotranspiration and heating the air by radiation (latent and sensible heat fluxes) a relatively substantial amount of solar radiation is utilized in heating up of soil (ground heat flux) depending up on the nature of surface.

c) Radiation from the sky contributes a large amount of heat to the soil in areas where the sun's rays have to penetrate the earth's atmosphere very obliquely.

2. Wind

Air convection or wind is necessary to heat up the soil by conduction from the atmosphere.

(eg.) The mountain and valley winds influence the soil temperature.

3. Evaporation and condensation

a) The greater the rate of evaporation the more the soil is cooled. This is the reason for coolness of moist soil in windy conditions.

b) On the other hand whenever water vapour from the atmosphere or from other soil depths condenses in the soil it heats up noticeably. Freezing of water generates heat.

4. Rainfall (Precipitation)

Depending on its temperature, precipitation can either cool or warm the soil.

II. Soil factors

1. Aspect and slope

a) In the middle and high latitudes of the northern hemisphere, the southern slopes receive more insolation per unit area than the northern exposure.

b) The south west slopes, are usually warmer than the south east slopes. The reason is that the direct beam of sunshine on the south east slope occur shortly after prolonged cooling at night, but the evaporation of dew in the morning also requires energy.

2. Soil texture

a) Because of lower heat capacity and poor thermal conductivity, sandy soils warm up more rapidly than clay soils. The energy received by it is concentrated mainly in a thin layer resulting in extraordinary rise in temperature.

b) Radiational cooling at night is greater in light soils than in heavy soils. In the top layer, sand has the greatest temperature range, followed by loam and clay.

c) The decrease of range with depth is more rapid in light soils than heavy soils when they are dry but slower when they are wet.

d) A soil with rough surface absorbs more solar radiation than one with a smooth surface.

3. Tillage and Tilth

a) By loosening the top soil and creating a mulch, tillage reduces the heat flow between the surface and the sub soil.

b) Since, the soil mulch has a greater exposure surface than the undisturbed soil and no capillary connection with moist layers below, the cultivated soil dries up quickly by evaporation, but the moisture in the sub-soil underneath the dry mulch is conserved.

c) In general soil warms up faster than air. The diurnal temperature wave of the cultivated soil has a much larger amplitude than that of the uncultivated soil.

d) The air 2-3 cm above the tilled soil is often hotter (10°C or above) than that over an untilled soil.

e) At night loosened ground is colder and more liable to frost than the uncultivated soil.

4. Organic matter:

a) The addition of organic matter to a soil reduces the heat capacity and thermal conductivity. But, the water holding capacity increases.

b) The absorbtivity of the soil increases because of the dark colour of the organic matter.

c) At night, the rapid flow of heat from sub-soil by radiation is reduced with the addition of organic matter because of its low thermal conductivity.

d) The darker the colour, the smaller the fraction of reflected radiation.

e) The dark soils and moist soils reflect less than the light coloured and dry soils.

5. Soil moisture

a) Moisture has an effect on heat capacity and heat conductivity.

b) Moisture at the soil surface cools the soil through evaporation.

c) Therefore, a moist soil will not heat up as much as a dry one.

d) Moist soil is more uniform in temperature throughout its depth as it is a better conductor of heat than the dry soil.

Variations in soil temperature:

There are two types of soil temperature variations; daily and seasonal variation of soil temperature

1. Daily variations of soil temperature:

a) These variations occur at the surface of the soil.

b) At 5 cm depth the change exceeds 10°C. At 20 cm the change is less and at 80 cm diurnal changes are practically nil.

c) On cooler days the changes are smaller due to increased heat capacity as the soils become wetter on these days.

d) On a clear sunny day a bare soil surface is hotter than the air temperature.

e) The time of the peak temperature of the soil reaches earlier than the air temperature due to the lag of the air temperature.

f) At around 20 cm in the soil the temperature in the ground reaches peak after the surface reaches its maximum due to more time the heat takes to penetrate the soil. The rate of penetration of heat wave within the soil takes around 3 hours to reach 10 cm depth.

g) The cooling period of the daily cycle of the soil surface temperature is almost double than the warming period.

h) Undesirable daily temperature variations can be minimised by scheduling irrigation.

2. Seasonal variations of soil temperature:

a) Seasonal variations occur much deeper into the soil.

b) When the plant canopy is fully developed the seasonal variations are smaller.

c) In winter, the depth to which the soil freezes depends on the duration and severeness of the winter.

d) In summer the soil temperature variations are much more than winter in tropics and sub tropics.

HUMIDITY –ABSOLUTE HUMIDITY – SPECIFIC HUMIDITY –RELATIVE HUMIDITY – MIXING RATIO, DEW POINT TEMPERATURE – VAPOUR PRESSURE DEFICIT – DIURNAL VARIATION IN RELATIVE HUMIDITY AND ITS EFFECT ON CROP PRODUCTION.

Humidity

The amount of water vapour that is present in atmosphere is known as atmospheric moisture or humidity.

Absolute humidity

The actual mass of water vapour present in a given volume of moist air. It is expressed as grams of water vapour per cubic meter or cubic feet.

Specific humidity

Weight of water vapour per unit weight of moist air. It is expressed as grams of water vapour per kilogram of air (g/kg).

Mixing ratio

The ratio of the mass of water vapour contained in a sample of moist air to the mass of dry air. It is expressed as gram of water vapour per kilogram dry air.

Relative Humidity

The ratio between the amount of water vapour present in a given volume of air and the amount of water vapour required for saturation under fixed temperature and pressure. There are no units and this is expressed as percentage. In other terms it is the ratio of the air's water vapour content to its maximum water vapour capacity at a given temperature expressed in percentage. The relative humidity gives only the degree of saturation of air. The relative humidity of saturated air is 100 per cent.

Dew Point temperature

The temperature to which a given parcel of air must be cooled in order to become saturation at constant pressure and water vapour content. In this case, the invisible water vapour begins to condense into visible form like water droplets.

Vapour Pressure deficit

The difference between the saturated vapour pressure (SVP) and actual vapour pressure (AVP) at a given temperature. This is an another measure of moisture in the atmosphere which is useful in crop growth studies. When air contains all the moisture that it can hold to its maximum limit, it is called as saturated air, otherwise it is unsaturated air, at that temperature. The vapour pressure created at this temperature under saturated conditions is vapour pressure or saturated vapour pressure (SVP).

Importance of Humidity on crop plants

The humidity is not an independent factor. It is closely related to rainfall, wind and temperature. It plays a significant role in crop production.

1. The humidity determines the crops grown in a given region.
2. It affects the internal water potential of plants.
3. It influences certain physiological phenomena in crop plants including transpiration
4. The humidity is a major determinant of potential evapotranspiration. So, it determines the water requirement of crops.
5. High humidity reduces irrigation water requirement of crops as the evapotranspiration losses from crops depends on atmospheric humidity.
6. High humidity can prolong the survival of crops under moisture stress. However, very high or very low relative humidity is not conducive to higher yields of crops.
7. There are harmful effects of high humidity. It enhances the growth of some saprophytic and parasitic fungi, bacteria and pests, the growth of which causes

extensive damage to crop plants. Eg: a. Blight disease on potato. b. The damage caused by thrips and jassids on several crops.

8. High humidity at grain filling reduces the crop yields.

9. A very high relative humidity is beneficial to maize, sorghum, sugarcane etc, while it is harmful to crops like sunflower and tobacco.

10. For almost all the crops, it is always safe to have a moderate relative humidity of above 40%.

Variation in Humidity:

1. Absolute humidity is highest at the equator and minimum at the poles.

2. Absolute humidity is minimum at sunrise and maximum in afternoon from 2 to 3 p.m. The diurnal variations are small in desert regions.

3. The relative humidity is maximum at about the sunrise and minimum between 2 to 3 p.m.

4. The behaviour of relative humidity differs a lot from absolute humidity. At the equator it is at a maximum of 80 per cent and around 85 per cent at the poles. But, near horse latitudes it is around 70 per cent.

MONSOON

Atmospheric pressure

The atmospheric pressure is the weight of the air, which lies vertically above a unit area centered at a point. The weight of the air presses down the earth with the pressure of 1.034 gm / cm2. It is expressed in millibar (mb) equal to 100 N/m2 or 1000 dynes/cm2. Unequal heating of the earth and its atmosphere by the sun and rotation of the earth bring about differences in atmospheric pressure.

Isobars

The distribution of pressure is represented on maps by 'isobars'. Isobars are defined as the imaginary lines drawn on a map to join places having the same atmospheric pressure.

Diurnal and seasonal variation

(a) Diurnal pressure variation

a. There is a definite rhythm in the rise and fall of the pressure in a day.

b. Radiational heating (air expansion) and radiational cooling (air contraction) are the main reasons for diurnal variation in the air pressure.

c. Diurnal variation is more prominent near the equator than at the mid latitudes.

d. The areas closer to sea level record relatively larger amount of variation than in land areas.

e. Equatorial regions absorbs more heat than it loses while the polar region gives up more heat than they receive

b) Seasonal pressure variation

a. Due to the effect caused by annual variation in the amount of insolation, distinct seasonal pressure variations occur.

b. These variations are larger in the tropical region than the mid latitude and polar regions.

c. Usually, high pressures are recorded over the continents during the cold season and over the oceans during the warm season.

Pressure systems of the world

The shape of the earth is not uniform and subjected to uneven distribution of solar radiation, when it revolves around the sun. The uneven distribution of solar radiation over different regions of the globe leads to contrast in surface air temperature. This results in variations of surface atmospheric pressure systems, which are known as standard atmospheric pressure systems / belts. There are altogether seven alternating low and high pressure belts on the earth's surface. They are as follows:

i. Equatorial trough of low pressure (between 5°N and 5°S)

ii. Subtropical high pressure belt (Northern hemisphere) (25° and 35°N)

iii. Subtropical high pressure belt (Southern hemisphere) (25° and 35°S)

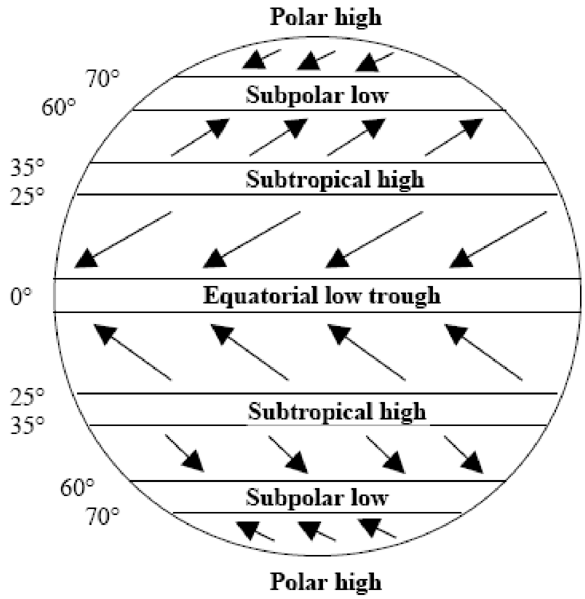
iv. Subpolar low pressure belt (Northern hemisphere) (60° and 70°N)

v. Subpolar low pressure belt (Southern hemisphere) (60° and 70°S)

vi. Polar high (Northern hemisphere)

vii. Polar high (Southern hemisphere)

The equatorial region receives more solar radiation and thus the surface air temperature is high, which creates lighter air near the ground compared to higher latitudes. The above condition leads to low atmospheric pressure over the equatorial region while sub tropical high pressure belts develop in both the hemispheres between 25 and 35 degree latitudes due to relatively low surface air temperature. It is due to low solar radiation received due to inclined sun's rays over the subtropical region when compared to the equatorial belt. Like wise alternate low and high atmospheric pressure belt systems are developed across the globe from the equator to the poles.



Causes of variation

The atmospheric pressure changes continuously due to several factors. The most important factors are changes with temperature, altitude, water vapour content and rotation of earth.

a) Temperature

Hot air expands and exerts low pressure. Cold air contracts and exerts high pressure. So the equator has a low pressure due to prevalence of high temperature but poles have a high pressure.

b) Altitude

At sea level, the air column exerts its full pressure, but when we stand on a hill or when we go in the upper layers of atmosphere, we leave a portion of air which cannot exert its full pressure. At sea level, a coastal town enjoys high pressure but on high altitude one will register a low pressure. For every 10 m of ascend, the pressure get reduced by 1 hPa.

c) Water vapour

The water vapour content is lighter in cold area than in air which is dry with the result that moist air of a high temperature exerts a less pressure when compared to cold air.

d) Rotation of the earth

On account of rotation of the earth, the pressure at 60-70°N and S becomes low. The rotation of the earth near sub-polar belts, makes the air to escape from these belts which move towards the horse latitude (30° - 35°N and 30 – 35°S). These latitudes absorb the air from sub polar belts making the pressure high. G.D.Coriolis (1844) a French Mathematician indicated that air is deflected towards right in the Northern Hemisphere and Left in the Southern hemisphere due to rotation of earth and this was termed after him as Coriolis force. Coriolis force is not actually a force but it is effect created by rotation of earth.

Low / Depression

When the isobars are circular or elliptical in shape, and the pressure is lowest at the centre, such a pressure system is called ‘Low’ or ‘Depression’ or ‘Cyclone’. The movement will be anti-clockwise in the Northern hemisphere while it is clockwise in the southern hemisphere. Wind spped hardly exceeds 40 km per hour.

Anticyclone

When isobars are circular, elliptical in shape and the pressure is highest at the centresuch a pressure system is called ‘High’ or ‘Anticyclone’. When the isobars are elliptical rather than circular the system is called as ‘Ridge’ or ‘Wedge’. The movement will be clockwise in the Northern hemisphere while it is anti-clockwise in the southern hemisphere.

Storm

Low pressure centre surrounded by winds having their velocities in the range of 40 to 120 km/hour. A more favourable atmosphere condition for their occurrence exists during the summer season. The Bay of Bengal and Arabian sea offer ideal condition for origin and growth of the storms. These storms produce heavy precipitation and bring about a change in the existing weather. It occurs very rarely. It causes wide spread damage.

Hurricane

A severe tropical cyclone with wind speed exceeding 120 km per hour. The name hurricane is given to the tropical cyclones in the North Atlantic and the eastern North Pacific Ocean. The tropical cyclones of Hurricane force in the western North pacific are known as typhoons. In Australia this type of storm is given the name willy-willy, whereas in the Indian Ocean they are called as Cyclones. Hurricanes are fueled by water vapour (i.e.) pushed up from the warm ocean surface, so they can last longer and sometimes move much further over water than over land. A combination of heat and moisture along with the right wind conditions can create a new hurricane.

Thunderstorms

Storms produced by cumulonimbus clouds and always accompanied by lightening and thunder. They are usually of short duration, seldom over 2 hours. They are also accompanied by strong wind gusts, heavy rain and sometimes hail.

Tornadoes

Defined as a violently rotating column of air attended by a funnel-shaped or tubular cloud extending downward from the base of cumulonimbus cloud. Tornadoes are the most violent storms of lower troposphere. They are very small in size and of short duration. They mostly occur during spring and early summer. They have been reported at widely scattered locations in the mid latitudes and tropics. Crop losses are heavy due to this event. Unknown in other parts of the world.

Waterspouts

It is column of violently rotating air over water having a similarity to a dust devil of tornado. In other words, tornadoes are weak visible vortices occurring over water are called waterspouts. They are formed over tropical and subtropical oceans.

Wind

Air in horizontal motion is known as wind. Vertical movement is noticed but negligibly small compared to horizontal movement as the height of the atmosphere is only for few kilometers. However vertical movement or uplift of air only causes significant weather changes in cloud formation and rain.

Wind systems of the world

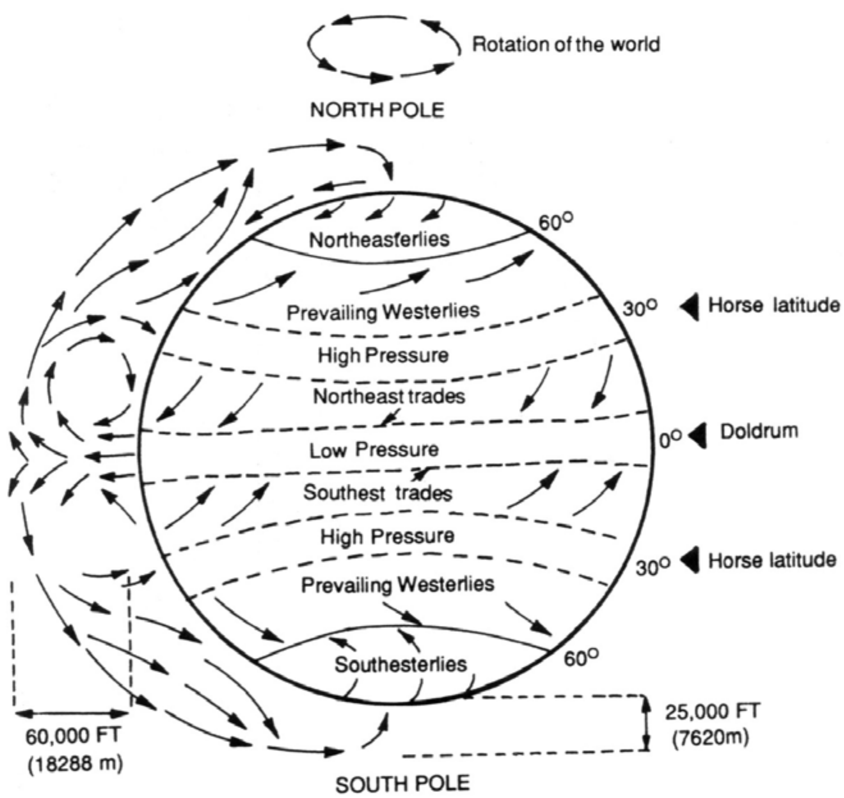
The wind belts found on earth's surface in each hemisphere are:

a. Doldrums

b. Trade wind belt

c. Prevailing westerlies

d. Polar easterlies



GLOBAL WIND CIRCULATION

1. Doldrums

Owing to continuous heating of the earth by insolation, pressures are low and winds converge and rise near the equator. This intertropical convergent zone is known as 'Doldrums'.

a) These are the equatorial belts of calms and variable winds.

b) The location is 5°S and 5°N latitudes.

c) Wind is light due to negligible pressure gradient.

d) Mostly, there are vertical movements in the atmosphere.

e) The atmosphere is hot and sticky.

2. Trade winds (Tropical Easterlies)

a) The regular high temperature at the equator results in a high pressure forming in the upper levels of the equator.

b) Then, the air is transferred to the northward and southward directions until 35° North and South in both the hemisphere.

c) Due to this reduction in surface pressure on the equator (doldrums) there is an increase in pressure at 35°N and 35°S which are known as horse latitude (sub-tropical high).

d) As a result, the winds flow from the horse latitude to the equatorial region.

e) While moving, these winds are deflected by Coriolis force to the right in northern hemisphere and to the left in southern hemisphere.

f) These winds flow from 35°N to the equator in NE direction in the northern hemisphere and from 35°S to the equator in SE direction in the southern hemisphere. These are known as 'Trade winds'. These are known as 'Tropical easterlies'.

g) These are most constant winds in force and direction and flow over nearly half the globe.

3. Anti-trade winds

a) This is a supplementary wind system of the earth which is effective at higher levels.

b) This system works in opposite direction to the surface winds.

c) The anti-trade winds mostly flow from land to ocean and brings no rain.

4. Prevailing Westerlies

a) The winds that flow from sub-tropical high to the low-pressure area about 60-70° latitudes in both the hemispheres are known as 'Prevailing westerlies'.

b) In the northern hemisphere the direction of Prevailing westerlies is SW and in southern hemisphere NW.

c) These winds are forceful and are irregular as compare to the trade winds in the tropical regions.

d) High precipitation zone

5. Polar Easterlies / Polar winds

b) A permanent high pressure exists on the poles.

c) From these high pressure polar regions, cold winds flow to areas at about 60-65° latitudes in both the hemispheres.

d) The winds flow in NE direction in the northern hemisphere and in SE direction in the southern hemisphere.

Mountain winds

a) Blows from mountain up slope to base

b) Occurs during night time

c) Cooling of air close to slope takes place

d) Adiabatic heating decreases this phenomenon

e) Also known as ‘Katabalic winds’

Valley winds

a) Blow from valley base to up slope.

b) Occurs during day time

c) Over heating of air adjacent to slope takes place

d) Adiabatic cooling decreases this phenomenon

e) Also known as ‘Anabatic winds’

Sea breeze

During the daytime, more so in summer, land is heated more than the adjacent body of water. As a result warmed air over the land expands producing an area of low pressure. The isobaric surfaces bend upward as a result of which the cooler air starts moving across the coast line from sea to land. This is the ‘Sea breeze; or ‘On shore breeze’.

Land breeze

At night because of nocturnal radiation land is colder than adjacent sea and the pressure gradient is directed from land to sea. There is a gentle flow of wind from land to sea. This ‘off-share’ wind is called ‘Land breeze’.

Sl.	Sea Breeze	Land Breeze
1.	Occurs in day time	Occurs in night time
2.	Flows from sea	Flows from land
3.	Have more moisture than land breeze	Do not have more moisture
4.	Occurrence depends on topography of Of coast to greater extent	Occurrence depends on on topography of land to little extent
5.	Modifies weather on hot summer afternoon	Produces cooler winters and warmer summers
6.	Stronger than land breeze	Weaker than sea breeze

Effect of wind on crop plants

1) Transports heat in either sensible or latent heat form from lower to higher altitudes

2) Wind affects the plant directly by increasing transpiration and the intake of CO_2 and also causes several types of mechanical damage.

3) Wind helps in pollination and dispersal of seeds.

4) Light and gentle winds are helpful for cleaning the agricultural produce.

5) Hot dry winds frequently do much damage to vegetation in the growing crops by promoting excessive water loss.

6) Wind has powerful effect on humidity.

7) Long, continued warm, dry winds injured blossoms by evaporating the secretion of the stigma.

8) Provides moisture which is necessary for precipitation

9) Wind prevents frost by disrupting atmospheric inversion

10) Causes soil erosion

Wind speed in different season

Winds represent air in motion. The primary cause of all winds is regional differences in temperature, producing regional differences in pressure. When these pressure differences persist for several hours, the rotation of the earth modifies the direction of motion, till the winds blow along lines of equal pressure. Wind direction and speed are modified frequently due to seasonal variation in solar radiation and differential heating of the earth's surface.

Wind Speed

The winds are generally measured over level, open terrain at 3 meters above ground. Yet, a general idea of the distribution of the mean daily wind speed, on an annual basis as well as on a monthly basis, would be useful. The mean daily wind speed is the value obtained by averaging the wind speed (irrespective of direction) for a whole day. This averaged for all the days of a month is the mean daily wind speed for that month. The daily values averaged for all the 365 days of the year is the annual mean daily wind speed.

Wind Direction

Winds are always named after the direction they come from. Thus, a wind from the south, blowing towards north is called south wind. The wind vane is an instrument used to find out the direction of the wind. Windward refers to the direction wind comes from, and leeward refers to the direction it blows to. When a wind blows more frequently from one direction than from any other, it is called a prevailing wind.

South West Monsoon wind direction

During South West Monsoon period of June to September, the westerly winds prevail on the west of Kerala and south winds on the west of northern Circars, Orissa and Bengal. During April and May the region of high temperature is shifted to north viz., upper Sind, lower Punjab and Western Rajasthan. This area becomes the minimum barometric pressure area to which monsoon winds are directed.

North East Monsoon wind direction

During North East Monsoon period of October to December, on account of the increase in barometric pressure in Northern India, there is a shift in the barometric pressure to the South East and North Easterly winds begin to flow on the eastern coast, by the end of September. These changes bring on heavy and continue rainfall to the Southern and South Eastern India.

Winter Rainfall

It is restricted more to Northern India and is received in the form of snow on the hills and as rains in the plains of Punjab, Rajasthan and central India. Western disturbance is a dominant factor for rainfall during these months in northwestern India.

Summer Rainfall

The summer Rainfall is received from March to May as local storms. It is mostly received in the South East of Peninsular and in Bengal. Western India does not generally receive these rains.

CLOUDS

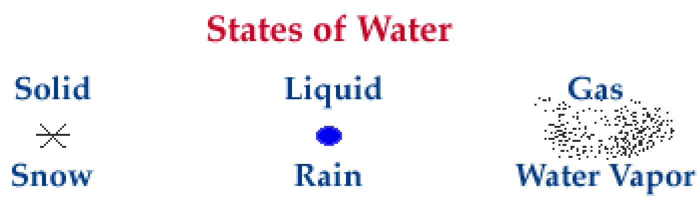
CLOUDS

"An aggregation of minute drops of water suspended in the air at higher altitudes" is called as cloud. A cloud is a visible aggregate of tiny water droplets and/or ice crystals suspended in the atmosphere and can exist in a variety of shapes and sizes. Some clouds are accompanied by precipitation; rain, snow, hail, sleet, even freezing rain. Clouds can occur at any level of the atmosphere wherever there is sufficient moisture to allow condensation to take place. The layer of the atmosphere where almost all cloud exists is the troposphere, although the tops of some severe thunderstorms occasionally pierce the tropopause.

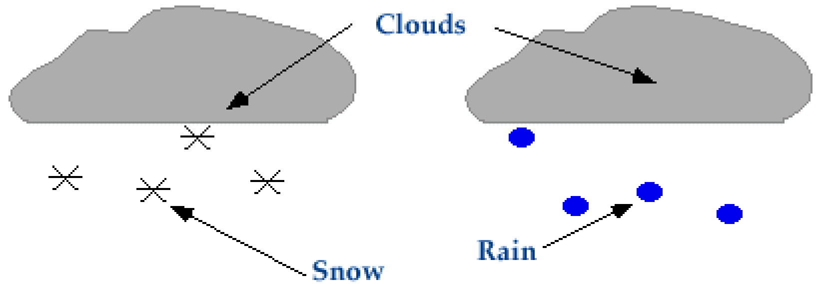
A cloud can be defined as hydrometeor consisting of minute particles of liquid water or ice, or of both, suspended in the free air and usually not touching the ground. It may also include larger particles of liquid water or ice as well as non-aqueous or solid particles such as those present in fumes, smoke or dust.

DEVELOPMENT OF CLOUDS

Water is known to exist in three different states; as a solid, liquid or gas.



Clouds, snow, and rain are all made of up of some form of water. A cloud is comprised of tiny water droplets and/or ice crystals, a snowflake is an aggregate of many ice crystals, and rain is just liquid water.



All of these are made of some form of water.

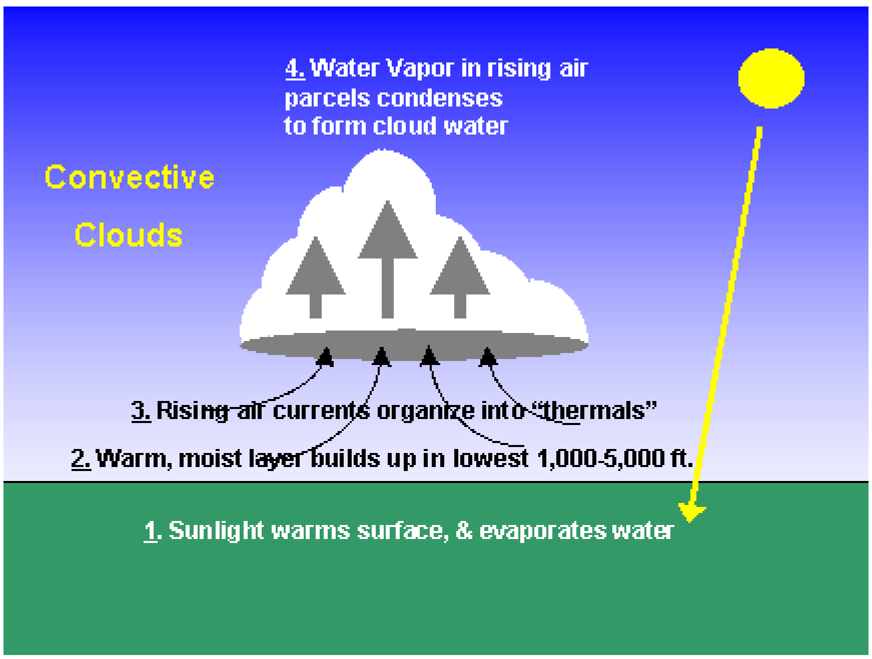
Water existing as a gas is called water vapor. When referring to the amount of moisture in the air, we are actually referring to the amount of water vapor. If the air is described as "moist", that means the air contains large amounts of water vapor. Moisture is a necessary ingredient for the production of clouds and precipitation

All clouds are a form of water. Clouds are condensed atmospheric moisture in the form of minute water droplets or ice crystals. The creation of a cloud begins at ground level. The sun heats the earth's surface, the warm ground heats the air, which rises. The air contains variable amounts of water, as vapor, that has evaporated from bodies of water and plants. Air at ground level is denser than air higher up, and as the warm air rises, it expands and becomes less dense.

Air rises for three main reasons

- Sunshine – heat from the sun or warm ground warms the air and makes it lighter. It therefore rises into the sky.
- The terrain – air may rise as it is forced upwards due to changes in the terrain (landscape). This often occurs when wind blows air either over mountains, or over cliffs onto land from the sea.
- A front – air can also rise at a weather front. At cold fronts, cold air is pushed under warm air, forcing it upwards and at a warm front, warm moist air is forced up and over the cold air.

Expansion cools the air and as the air cools, the water vapor that is present in the air, condenses into tiny microscopic droplets. Cloud formation depends on how much water is in the atmosphere, the temperature, the air current, and topography. If there is no water, no clouds can form. If condensation occurs below the freezing point, the cloud is made of ice crystals. Warm and cold air fronts, as well as topography can control how air rises. Clouds that form during vigorous uplift of air have a tall, stacked appearance and clouds formed by gentle uplift of air currents have a flat or stratified appearance. One can make short-term forecasts by observing clouds, as any change in the way a cloud looks indicates a change in the weather.



After cloud droplets (or ice crystals) form, then what happens to them? One of two things. Either they collide with each other and grow by joining together to such a large size that they fall to the ground as rain or snow, or they evaporate and change back into water vapor. It is estimated that, on average, about one-half of all cloud material eventually falls to the Earth as precipitation, while the other half re-evaporates back into water vapor.

DROP SIZE AND CLOUD APPEARANCE

The smaller the drops in a cloud the brighter the tops appear (and the darker the bases). Smaller droplets scatter more sunlight, while large drops allow more sunlight to pass through. This explains why the heavily raining part of a shower cloud or thunderstorm is usually brighter than just the cloudy part. The cloud droplets have combined into large raindrops, which allow more sunlight to pass through them.

CLOUD CLASSIFICATION

A) A scheme of distinguishing and grouping clouds according to their appearance, and, where possible, to their process of formation.

The one in general use, based on a classification system introduced by Luke Howard in 1803, is that adopted by the World Meteorological Organization and published in the International Cloud Atlas (1956). This classification is based on the determination:

1) genera - the main characteristic forms of clouds

2) species - the peculiarities in shape and differences in internal structure of clouds

3) varieties - special characteristics of arrangement and transparency of clouds

4) supplementary features and accessory clouds - appended and associated minor cloud forms and

5) mother-clouds - the origin of clouds if formed from other clouds.

- The ten cloud genera are cirrus, cirrocumulus, cirrostratus, altocumulus, altostratus, nimbostratus, stratocumulus, stratus, cumulus, and cumulonimbus.
- The fourteen cloud species are fibratus, uncinus, spissatus, castellanus, floccus, stratiform, nebulosus, lenticularis, fractus, humilis, mediocris, congestus, calvus, and capillatus.
- The nine cloud varieties are intortus, vertebratus, undulatus, radiatus, lacunosus, duplicatus, translucidus, perlucidus, and opacus.
- The nine supplementary features and accessory clouds are incus, mamma, virga, praecipitatio, arcus, tuba, pileus, velum, and pannus. (Note: Although these are Latin

words, it is proper convention to use only the singular endings, e.g., more than one cirrus cloud is cirrus, not cirri.)

B). A scheme of classifying clouds according to their usual altitudes.

Three classes are distinguished: high, middle, and low. High clouds include cirrus, cirrocumulus, cirrostratus, occasionally altostratus, and the tops of cumulonimbus. The middle clouds are altocumulus, altostratus, nimbostratus and portions of cumulus and cumulonimbus. The low clouds are stratocumulus, stratus and most cumulus and cumulonimbus bases, and sometimes nimbostratus.

C) A scheme of classifying clouds according to their particulate composition, namely, water clouds, ice-crystal clouds, and mixed clouds.

The first are composed entirely of water droplets (ordinary and/or supercooled), the second entirely of ice crystals, and the third a combination of the first two. Of the cloud genera, only cirrostratus and cirrus are always ice-crystal clouds; cirrocumulus can also be mixed; and only cumulonimbus is always mixed. Altostratus is nearly always mixed, but can occasionally be water. All the rest of the genera are usually water clouds, occasionally mixed; altocumulus, cumulus, nimbostratus, and stratocumulus.

WMO cloud classification

The World Meteorological Organisation (WMO) classified the clouds according to their height and appearance into 10 categories. From the height, clouds are grouped into 4 categories (viz., family A, B, C and D) as stated below and there are sub- categories in each of these main categories.

The 4 clouds families, which are in different heights of the troposphere are

High level clouds (altitudes of 5-13 km)

Medium level clouds (2-7 km)

Low level clouds (0-2 km) and

Clouds with large vertical extending (0-13 km)

Family A

The clouds in this category are high. The mean lower level is 7 kilometers and the mean upper level is 12 kilometers in tropics and sub-tropics. In this family there are three sub-categories.

1. Cirrus (Ci)

- In these clouds ice crystals are present.
- Looks like wispy and feathery. Delicate, desist, white fibrous, and silky appearance.
- Sun rays pass through these clouds and sunshine without shadow.
- Does not produce precipitation.

2. Cirrocumulus (Cc)

- Like cirrus clouds ice crystals are present in these clouds also.
- Looks like rippled sand or waves of the sea shore.
- White globular masses, transparent with no shading effect.
- Meckerel sky.

3. Cirrostratus (Cs)

- ❖ Like the above two clouds ice crystals are present in these clouds also.
- ❖ Looks like whitish veil and covers the entire sky with milky white appearance.
- ❖ Produces “Halo”.

CIRRUS AND CIRROSTRATUS

Cirrus clouds are higher level clouds that develop in filaments or patches. They are virtually brilliant white attributed to their ice crystal composition. However, they lack in contrast between the top and base. They occur in flat sheets with a low height to base ratio and are usually isolated with large breaks of sky. Cirrus also vary dramatically in 'shape' or patterns they portray but these represent the fluctuating wind flow at that level both in the horizontal and vertical direction.

Cirrostratus represent clouds that are more widespread than cirrus but containing some similar features. Like cirrus, they are brilliant white and lack in contrast. Sunlight can pass through cirrostratus but this again depends on the varying thickness of the clouds.

Both cirrus and cirrostratus clouds vary in thickness. The sun can easily be observed through both types of clouds although the intensity of light that is observed depends on the thickness of their layers. In their thickest form, cirrus and cirrostratus will allow a similar intensity of light to pass through to that of thin altostratus. They do not only develop in one complete layer. It may be difficult to observe because of the lack of contrast but these clouds can consist of several thin layers.

Cirrus and cirrostratus tend to move in the direction of the wind at that level which differ to that at the surface. The most common direction of motion of these clouds are from a westerly direction. This varies with factors such as the latitude, weather conditions and time of the year. Their apparent velocities are relatively slow as compared to lower clouds.

Both cirrus and cirrostratus can occur in conjunction with any of the other cloud types. Obviously, all the lower and middle level clouds will obscure the view of the higher level clouds, appear to move faster and appear less defined. They can only be observed above other clouds when breaks in the clouds occur. Any type of higher level clouds can develop simultaneously.

Cirrus clouds tend to develop on days with fine weather and lighter winds at the surface. cirrostratus can develop on days with light winds but normally increasing in strength. Although both cirrus and cirrostratus tend to develop in fine weather conditions, they also acts as a sign of approaching changes in the weather conditions. Such changes could include any of the various types of cold front situations, thunderstorms or developing and advancing troughs of low pressure, normally with preceding cloud masses.

Except in the latter case, cirrus and cirrostratus will typically precede any other types of clouds as part of a cloud band. In fact cirrus normally precedes cirrostratus. Nevertheless, the higher level clouds will persist until the actual change in the weather occurs. The higher clouds can develop from a few hours up to a few days before an actual change in the weather conditions occurs. They may develop during one afternoon and dissipate but redevelop the next day and so on until the actual change occurs. If the amount of moisture in the lower layers of the atmosphere increases, other lower clouds may also develop changing the appearance of the cirrus or the cirrostratus clouds as well as partially or totally hiding them from view. The same situation occurs in the case where cirrus develop ahead of thunderstorms. Cirrus normally precede cirrostratus which are then followed by the anvil of the approaching thunderstorm. In fact, cirrus and cirrostratus in this case are the remnants downwind of the weakening anvil.

Both cirrus and cirrostratus can develop and persist after a change has passed through a certain location. In this situation, cloud will decrease within a few hours up to a few days following the change. If it persists for longer periods, a jet stream cloud mass may be involved.

Another situation where cirrus and cirrostratus can be observed is when lower cloud breaks or clears during days with showers or rain. This case is far less common but can indicate a few situations. The higher clouds may be the remnants of the cloud mass that produced the actual wet weather. They can also be developing ahead of other cloud masses associated with another system, leading to the situation already discussed above. It all depends on the weather situation at that time but the observation of the movement of the higher level clouds can be critical in determining what weather may follow.

Cirrus generally does not produce precipitation except when it results from dissipating thunderstorms. Precipitation from such cirrus usually consists of larger droplets and the cloud normally dissipates and vanishes completely. cirrostratus does not produce precipitation.

Cirrus and cirrostratus can develop and persist at any time of the day despite the perception that it tends to occur during the day. This perception arises because it is much easier to observe cirrus during the day as compared to night time. The background darkness and the fact that the stars can easily be observed through cirrus and cirrostratus as thin layers allows them to camouflage from the view of the observer.

Cirrocumulus

Cirrocumulus is a higher level cloud that is brilliant white but with a spotty appearance created by the many small turrets. The turrets indicate vertical turbulence within the cloud. Despite this spotty appearance, cirrocumulus contains many features associated with cirrostratus discussed above. It moves in directions similar to that of the other higher clouds.

This cloud can develop in conjunction with any other clouds as well as with cirrostratus clouds. In Sydney, cirrocumulus is not as common as the other high clouds and mainly develops during the winter times with west to south westerly air streams. The development of cirrocumulus sometimes occurs in conditions similar to those associated with the development lenticular altocumulus. cirrocumulus clouds do not produce precipitation and are normally associated with fine weather.

Family B

The clouds in this category are middle clouds. Middle level clouds are those clouds that develop in the middle layers of the atmosphere. These clouds are brighter and less fragmented in appearance due to their distance from the ground and the higher composition of ice crystals. Middle level clouds vary in thickness from relatively flat sheets of cloud to a more cumuliform appearance. In fact, the sun (and moon) can be observed through some thin middle level clouds. The mean lower level is 2.5 kilometers and the mean upper level is 7 kilometers in tropics and sub-tropics.

Middle level clouds tend to have apparent speeds slower than the lower level clouds. They move in the direction of the wind at that level which does not necessarily be the same of that at the surface.

In this family there are 2 sub-categories as details below:

1. Altocumulus (Ac)

- In these clouds ice water is present.
- Greyish or bluish globular masses.
- Looks like sheep back and also known as flock clouds or wool packed clouds.

2. Alto-stratus (As)

- In these clouds water and ice are present separately.
- Looks like fibrous veil or sheet and grey or bluish in colour.
- Produces coronos and cast shadow.
- Rain occurs in middle and high latitudes.

Altocumulus

Altocumulus refers to the middle level cloud that exhibit to some extent the features normally associated with cumulus. This includes cumuliform tops and bases that are usually relatively darker than the tops. This cloud type can be widespread or patchy depending on the conditions. It can vary in appearance from broken to smooth, and vary in thickness.

Altocumulus can vary in its apparent movement (speed) depending on the wind and direction at that level. However, since altocumulus (like most other cloud types) represents an ever changing system, an observer must be careful in determining cloud motion. On some days, altocumulus continuously develop as it moves in the direction of the wind. Upstream, more altocumulus may develop giving the impression that the cloud is progressing slower than its actual speed. This process can occasionally create an illusion in terms of direction. Considering an example of altocumulus observed moving to the south east, because of development on the north and north-eastern side of the cloud band, the apparent direction may be more to the east. Altocumulus can develop in more than one layer and also in conjunction with other cloud types. The lower layer will obscure part or all of the higher altocumulus cloud layer. This situation also applies to higher level clouds. Higher level clouds will be obscured by the altocumulus. Lower level clouds, however, will obscure part or all of the altocumulus cloud layer.

ALTOSTRATUS

Altostratus refers to middle level cloud that appears as a flat, smooth dark grey sheet. These clouds are most often observed as large sheets rather than isolated areas. However, in the process of development, altostratus may develop in smaller filaments and rapidly develop to larger sheets. These types of clouds in certain conditions normally indicate an approaching cloud mass associated with a cold front, a trough system or a jet stream.

Altostratus can develop into a thick or thin layer. As a thin layer, the sun can be observed through the cloud. In its thinner form, the developing altostratus can sometimes be confused with approaching cirrostratus. In its thicker form, the sun can only occasionally be observed through the thinner sections if not at all. Obviously, the thicker the altostratus, the darker it becomes. When observed closely, it becomes apparent that altostratus is not just one complete layer but a composition of several thin layers.

Altostratus can produce precipitation. It will normally develop and then thicken. The precipitation is observed as relatively thick dark sections since precipitation cascades are very difficult to observe with the same colour in the background. In this situation, rain will develop as a light shower and gradually increase to showers, light rain or moderate rain.

Family C

The clouds in this category are lower clouds. The height of these clouds extends from ground to upper level of 2.5 kilometers in tropics and sub-tropics. Lower level clouds consist of those clouds in the lower layers of the atmosphere. Because of the relatively low temperatures at this level of the atmosphere, lower level clouds usually reflect lower amounts of light and therefore usually exhibit low contrast. The clouds at this level also appear not as well defined. When observed closely, it is easy to observe the turbulent motions and hence the ever-changing structure.

Being closer to the ground, lower level clouds appear to move or progress faster than other clouds. The clouds generally move in the direction of the wind very similar to the direction of the wind on the ground.

The most efficient method used to recognise lower clouds is when observed in conjunction with other clouds. The lower clouds will obscure part or all the view of the upper level clouds if they pass in between the observer's line of sight. In other words, all the observer can see is the lower clouds as well as parts of the higher level clouds through breaks of the lower clouds. In this family, like high clouds, there are 3 sub-categorises.

1. Strato cumulus (Sc)

- These clouds are composed of water.
- Looks soft and grey, large globular masses and darker than altocumuls.
- Long parallel rolls pushed together or broken masses.
- The air is smooth above these clouds but strong updrafts occur below.

2. Stratus (St)

- These clouds are also composed of water.
- Looks like for as these clouds resemble grayish white sheet covering the entire portion of the sky (cloud near the ground).
- Mainly seen in winter season and occasional drizzle occurs.

3. Nimbostratus (Ns)

- These clouds are composed of water or ice crystals.
- Looks thick dark, grey and uniform layer which reduces the day light effectively.
- Gives steady precipitation.
- Sometimes looks like irregular, broken and shapeless sheet like.

Stratocumulus

Stratocumulus are low clouds that generally move faster than cumulus and are not as well defined in appearance (recall the techniques of observing clouds). They tend to spread more horizontally rather than vertically.

Depending on the weather conditions, stratocumulus can appear like cumulus since stratocumulus can develop from cumulus. They may also appear as large flat areas of low, grey cloud. Sometimes stratocumulus appear in the form of rolling patches of cloud aligned parallel to each other. Stratocumulus can also appear in the form of broken clouds or globules. The sun, moon and generally the sky can be observed through the breaks in broken stratocumulus clouds. Of course, this depends on how large the breaks are, how high the clouds rise and the angle of elevation of the breaks with respect to the observer. This generally applies to all clouds but is more notable with clouds in broken form.

Stratocumulus mostly develop in wind streams moving in the direction of the wind similar to the direction of the wind at the surface. The friction created by the earth causes turbulence in the form of eddies. With sufficient moisture, condensation will occur in the lower layers of the atmosphere visible as clouds. The amount of stratocumulus covering the sky depends on the amount of moisture concentrated at that level of the atmosphere. The speed that the cloud moves varies according to the wind

Stratus

Stratus is defined as low cloud that appears fragmented and thin. It can also occur in the form of a layer or sheet. The sun, moon and generally the sky can usually be observed through stratus clouds, especially at a steep angle of elevation. Stratus lacks the vertical growth of cumulus and stratocumulus, and therefore lacks the contrast. This is more evident when observed as one layer as compared to patchy stratus. Being closest to the ground, stratus clouds normally move fairly rapidly in the direction of the wind depending of course on the wind speed.

❖

Like stratocumulus, stratus develops under several conditions or weather situations. Stratus mostly develop under the influence of wind streams where moisture condenses in the lower layers of the atmosphere. Wind changes during the summer months often lead to the development of stratus as the wind evaporates moisture from the ocean and condensing as turbulence mixes the surface air with the cooler air above. In these conditions, stratus develop in patches and gradually may become widespread forming into stratocumulus.

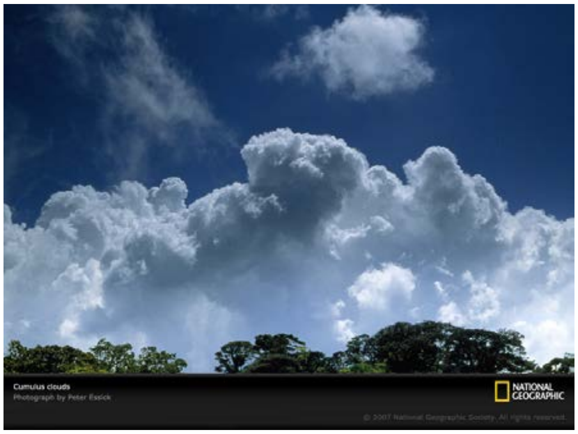
Family D

These clouds form due to vertical development i.e., due to convection. The mean low level is 0.5 and means upper level goes up to 16 kilometers.

In this family two sub-categories are present.

1. Cumulus (Cu)

- ❖ These clouds are composed of water with white majestic appearance with flat base.
- ❖ Irregular dome shaped and looks like cauliflower with wool pack and dark appearance below due to shadow.
- ❖ These clouds usually develop into cumuolo-nimbus clouds with flat base.



2. Cumulonimbus (Cb)

- ❖ The upper levels of these clouds possess ice and water is present at the lower levels.
- ❖ These clouds have thunder head with towering envil top and develop vertically.

- These clouds produce violent winds, thunder storms, hails and lightening, during summer.

Cumulus

Cumulus are cauliflower-shaped low level clouds with dark bases and bright tops. When observing cumulus, you are actually observing the condensation process of rising thermals or air bubbles at a certain level in the atmosphere known as the condensation level.

The air rising above this level condenses and cloud is observed. Since the height of this level is fairly constant at any particular time, then the bases of cumulus are usually flat.

PRECIPITATION

When cloud particles become too heavy to remain suspended in the air, they fall to the earth as precipitation. Precipitation occurs in a variety of forms; hail, rain, freezing rain, sleet or snow.

Rain

Rain develops when growing cloud droplets become too heavy to remain in the cloud and as a result, fall toward the surface as rain. Rain can also begin as ice crystals that collect each other to form large snowflakes. As the falling snow passes through the freezing level into warmer air, the flakes melt and collapse into rain drops. Rain is precipitation of liquid water particles either in the form of drops having diameter greater than 0.5 mm or in the form of smaller widely scattered drops. When the precipitation process is very active, the lower air is moist and the clouds are very deep, rainfall is in the form of heavy downpour. On occasions, falling raindrops completely evaporate before reaching the ground.

Drizzle: It is fairly uniform precipitation composed of fine drops of water having diameter less than 0.5 mm small and uniform size and seems to be floated in the air, it is referred as drizzle. If the drops in a drizzle completely evaporates before reaching the ground, the condition is referred to as 'mist'.

Hail

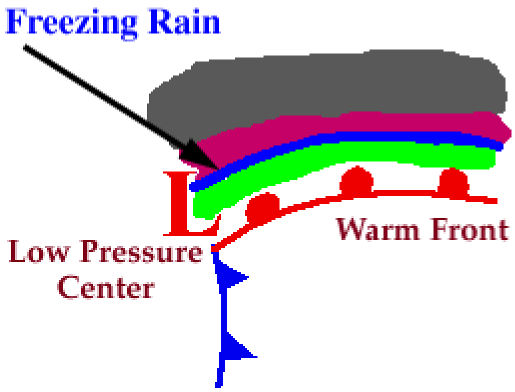
Hail is a large frozen raindrop produced by intense thunderstorms, where snow and rain can coexist in the central updraft. As the snowflakes fall, liquid water freezes onto them forming ice pellets that will continue to grow as more and more droplets are accumulated. Upon reaching the bottom of the cloud, some of the ice pellets are carried by the updraft back up to the top of the storm.

As the ice pellets once again fall through the cloud, another layer of ice is added and the hail stone grows even larger. Typically the stronger the updraft, the more times a hail stone repeats this cycle and consequently, the larger it grows. Once the hail stone becomes too heavy to be supported by the updraft, it falls out of the cloud toward the surface. The hail stone reaches the ground as ice since it is not in the warm air below the thunderstorm long enough to melt before reaching the ground.

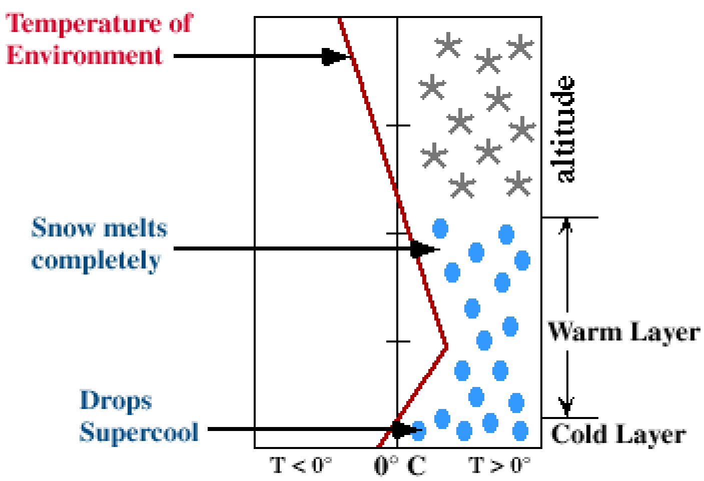
Freezing rain

Supercooled droplets freezing on impact

Ice storms can be the most devastating of winter weather phenomena and are often the cause of automobile accidents, power outages and personal injury. Ice storms result from the accumulation of freezing rain, which is rain that becomes supercooled and freezes upon impact with cold surfaces. Freezing rain is most commonly found in a narrow band on the cold side of a warm front, where surface temperatures are at or just below freezing.



The diagram below shows a typical temperature profile for freezing rain with the red line indicating the atmosphere's temperature at any given altitude. The vertical line in the center of the diagram is the freezing line. Temperatures to the left of this line are below freezing, while temperatures to the right are above freezing.



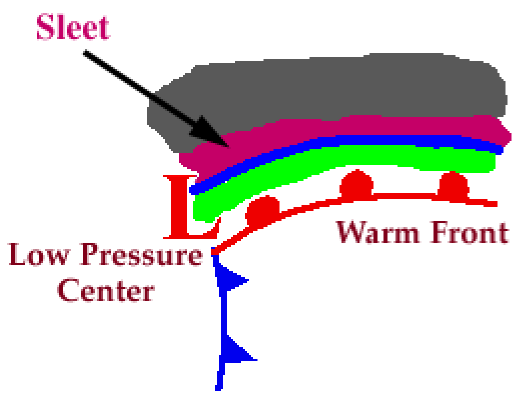
Freezing rain develops as falling snow encounters a layer of warm air deep enough for the snow to completely melt and become rain. As the rain continues to fall, it passes through a thin layer of cold air just above the surface and cools to a temperature below freezing. However, the drops themselves do not freeze, a phenomena called supercooling (or forming "supercooled drops"). When the supercooled drops strike the frozen ground (power lines, or tree branches), they instantly freeze, forming a thin film of ice, hence freezing rain.

Snow

It is the precipitation of white and opaque grains of ice. Snow is the precipitation of solid water mainly in the form of branched hexagonal crystals of stars. In winter, when temperatures are below freezing in the whole atmosphere, the ice crystals falling from the Altostratus do not melt and reach the ground as snow.

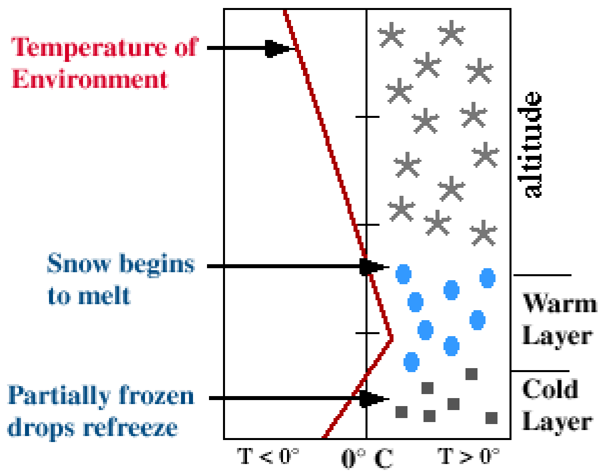
Sleet - frozen raindrops that bounce on impact with the ground

Progressing further ahead of the warm front, surface temperatures continue to decrease and the freezing rain eventually changes over to sleet. Areas of sleet are located on the colder side (typically north) of the freezing rain band.

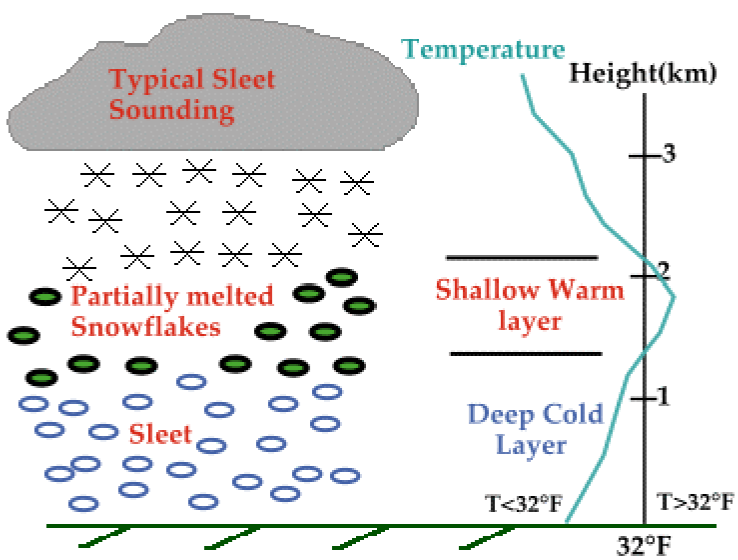


It refers to precipitation in the form of a mixture of rain and snow. It consists of small pellets of transparent ice, 5 mm or less in diameter. It refers to a frozen rain that forms when rain falling to the earth passing through a layer of cold air and freezes. This happens when temperature is very low. It is not commonly seen in India expect high ranges, that too in winter, in extreme north and northeast India.

Sleet is less prevalent than freezing rain and is defined as frozen raindrops that bounce on impact with the ground or other objects. The diagram below shows a typical temperature profile for sleet with the red line indicating the atmosphere's temperature at any given altitude. The vertical line in the center of the diagram is the freezing line. Temperatures to the left of this line are below freezing, while temperatures to the right are above freezing.

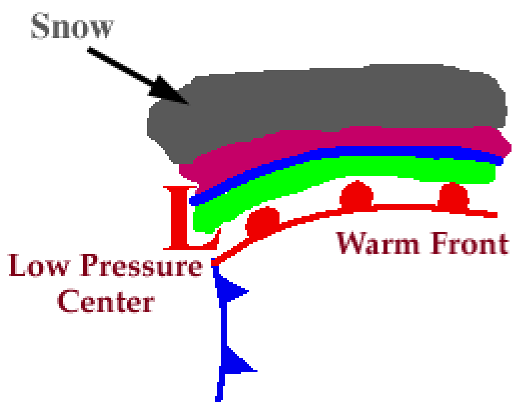


Sleet is more difficult to forecast than freezing rain because it develops under more specialized atmospheric conditions. It is very similar to freezing rain in that it causes surfaces to become very slick, but is different because its easily visible.

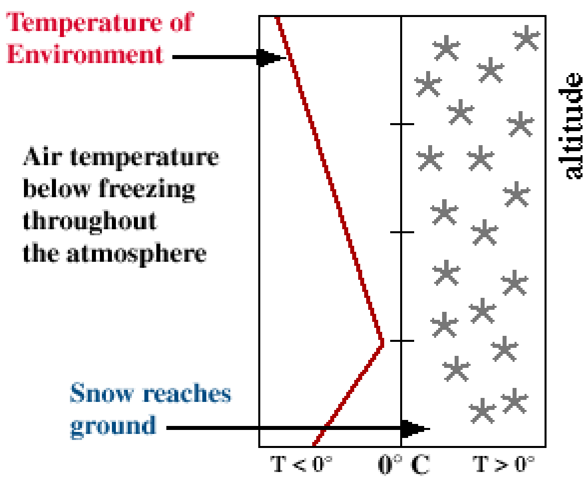


Snow - an aggregate of ice crystals

Progressing even further away from the warm front, surface temperatures continue to decrease and the sleet changes over to snow.



Snowflakes are simply aggregates of ice crystals that collect to each other as they fall toward the surface. The diagram below shows a typical temperature profile for snow with the red line indicating the atmosphere's temperature at any given altitude. The vertical line in the center of the diagram is the freezing line. Temperatures to the left of this line are below freezing, while temperatures to the right are above freezing.



Since the snowflakes do not pass through a layer of air warm enough to cause them to melt, they remain intact and reach the ground as snow.

Hail

Precipitation of small pieces of ice with diameter ranging from 5 to 50 mm or something more is known as hail. Hailstorms are frequent in tropics. In India, the period from March to May offers the ideal condition for hailstorms. It is the most dreaded and destructive form of precipitation produced in thunderstorms or cumulonimbus clouds.

Isohyets

Isohyets are the lines connecting various locations, having an equal amount of precipitation.

WEATHER ABERRATIONS

DROUGHT

The term drought can be defined by several ways.

1. The condition under which crops fail to mature because of insufficient supply of water through rains.

2. The situation in which the amount of water required for transpiration and evaporation by crop plants in a defined area exceeds the amount of available moisture in the soil.

3. A situation of no precipitation in a rainy season for more than 15 days continuously. Such length of non-rainy days can also be called as dry spells.

Classification of Drought

Droughts are broadly divided into 3 categories based on the nature of impact and spatial extent.

i. Meteorological Drought

If annual rainfall is significantly short of certain level (75 per cent) of the climatologically expected normal rainfall over a wide area, then the situation is called meteorological drought. In every state each region receives certain amount of normal rainfall. This is the basis for planning the cropping pattern of that region or area.

ii. Hydrological drought

This is a situation in which the hydrological resources like streams, rivers, reservoirs, lakes, wells etc dry up because of marked depletion of surface water. The ground water table also depletes. The industry, power generation and other income generating major sources are affected. If Meteorological drought is significantly prolonged, the hydrological drought sets in.

iii. Agricultural Drought

This is a situation, which is a result of inadequate rainfall and followed by soil moisture deficit. As a result, the soil moisture falls short to meet the demands of the crops during its growth. Since, the soil moisture available to a crops insufficient, it affects growth and finally results in the reduction of yield. This is further classified as early season drought, mid season drought and late season drought.

Flood

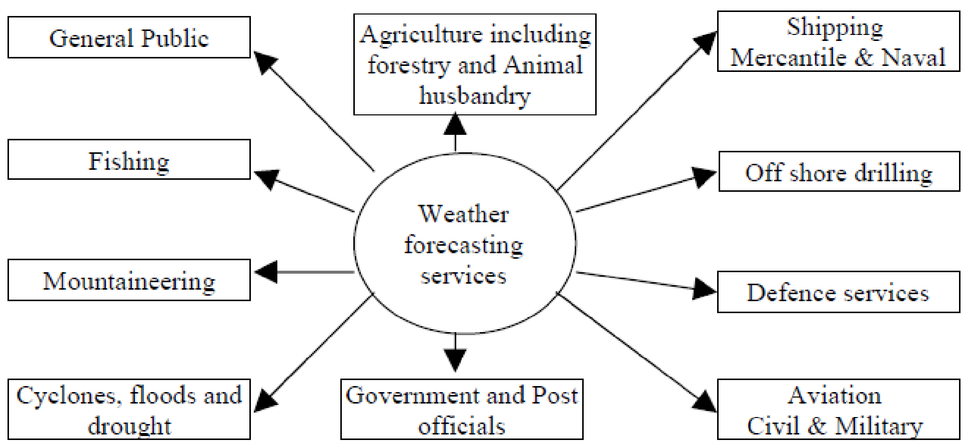
Years in which actual rainfall is ‘above’ the normal by twice the mean deviation or more is defined as years of floods or excessive rainfall. Like droughts, the definition of floods also varies one situation to another and form one region to other. Some of the flood years characterized based on the spatial damage due to high and intense rainfall in India are as follows.

India: 1878,1872,1917,1933,1942,1956,1959,1961,1970,1975,1983,1988.

WEATHER FORECASTING

Climatic normals

The climatic normals are the average value of 30 years of a particular weather element. The period may be week, month and year. The crop distribution, production and productivity depend on the climatic normals of a place. If the crops are selected for cultivation based on the optimum climatic requirements it is likely that the crop production can be maximized.



Weather forecast

The prediction of weather for the next few days to follow. The Figure below depicts different weather forecasting services normally practiced in a country.

NEED / IMPORTANCE OF FORECAST

- Basically weather has many social and economic impacts in a place.
- Among different factors that influence crop production, weather plays a decisive role as
- aberrations in it alone explains up to 50 per cent variations in crop production
- The rainfall is the most important among the required forecast, which decides the crop
- production in a region and ultimately the country's economy.

- The planning for moisture conservation under weak monsoon condition and for flood relief under strong monsoon condition is important in a region.
- A reliable weather forecasting when disseminated appropriately will pave way for the effective sustainability.
- One can minimize the damage, which may be caused directly or indirectly by unfavourable weather.
- The recurring crop losses can be minimized if reliable forecast on incidence of pest and
- diseases is given timely based on weather variables.
- Help in holding the food grain prices in check through buffer stock operations. This means that in good monsoon years when prices fall, the government may step in and buy and in bad years when price tend to rise, it may unload a part of what it had purchased.
- Judicious use of water can be planned in a region depending up on the forecast.

Type of weather forecast

Types of forecast	**Validity period**	**Main users**	**Predictions**
1. Short range a) Now casting	Up to 72 hours 0-2 hours	Farmers marine Agencies, general public	Rainfall distribution, heavy rainfall, heat and cold wave conditions, thunder storms etc.
b) Very short range	0-12 hours		
2. Medium range	Beyond 3 days and upto 10 days	Farmers	Occurrence of rainfall, temperature.
3. Long range	Beyond 10 days upto a month and a season.	Planners	This forecasting is provided for Indian monsoon rainfall. The out looks are usually expressed in the form of expected deviation from normal condition.

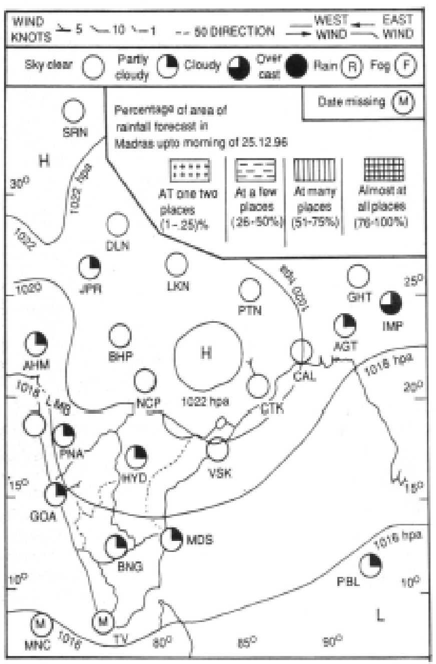
Synoptic charts

An enormous volume of meteorological data is being collected from all over the world continuously round the clock through various telecommunication channels. To assess, assimilate and analyse the vast data, they have to be suitably presented. For this purpose, the observations are plotted on maps instandard weather codes. These maps are called ‘Synoptic maps or charts’. Synoptic charts display the weather conditions at a specified time over a large geographical area. The surface synoptic charts plotted for different synoptic hours (00, 03, 06, 09, 12, 15, 18, 21 UTC) depict the distribution of pressure, temperature, dew point, clouds, winds, present and past weather. In place of GMT, UTC (Universal Time Co-ordinate) is used. The upper air charts are also prepared at the standard pressure levels of the atmosphere (different heights) of the atmosphere wherein the pressure, wind and temperature are plotted. The surface charts together with the upper air charts provide a composite three-dimensional weather picture pertaining to a given time. Thus it gives a birds eye view of the state of atmosphere at a time over a large area and is a important tool used by operational meteorologists and scientists. The surface synoptic charts are the most used charts. It contains the maximum number of observations with the largest number of parameters plotted and often forms the base on which the pressure level charts are built up. The pattern of the pressure distribution is brought out by drawing isobars, troughs, ridges, lows, highs, depressions, cyclones, cols, fronts and discontinuities. These systems are clearly marked and labeled using appropriate symbols and colours. In synoptic charts different weather phenomena and atmospheric characters are marked with different symbols as mentioned below.

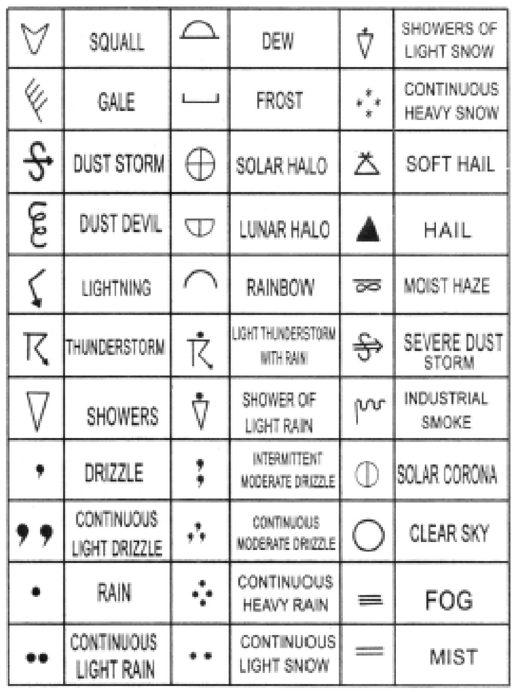
S.No	Symbols	Weather element/character/phenomenon

	Narrow black lines	Isobars
	Numbers at ends of isobars	Pressure values in hPa
	Shading	Precipitation
	Arrows	Wind direction
	Feathers in the arrows	Wind velocity
	Small circles with shading	Amount of clouds

In addition to the above, different symbols are used for recording weather phenomena.



Sample daily weather report



SYMBOLS FOR RECORDING WEATHER PHENOMENA

Weather calendar

In order to provide the farmers with an efficient weather service, it is essential that the weather forecaster should be familiar with the crops that are grown in a particular agroclimatic zone. The type of forewarnings to be given depend on the stages of the crop. In case of farmers, they should become familiar with weather bulletins and learn how to interpret. To meet the above requirement, the detailed information collected from the agricultural departments has been condensed by the IMD and presented in a pictorial form known as crop weather calendar. This calendar has three parts as follows.

a) Bottom part

b) Middle part

c) Top part

a) Bottom part provides the activities related to crop or information related to phenological stages of the crop and the months.

b) Middle part gives information regarding normal weather condition required for active crop growth. It is divided into different sections according to rainfall, rainy days, minimum temperature, maximum temperature, pan evaporation and sunshine hours.

c) Top part gives information related to the weather abnormalities or to take precautionary measures. Top part is divided into different sections according to dry spell length, high wind, heavy rainfall and cloudy weather.

Sample crop weather calendar prepared for cotton in Tamilnadu for South Arcot district

CROP WEATHER CALENDAR

STATE : TAMILNADU **CROP** : COTTON **VARIETY** : LRA-5166, MCU-7 **IRRIGATED**

DISTRICTS : SOUTH-ARCOT **DURATION** : 150 DAYS **SOIL** : RED LOAM

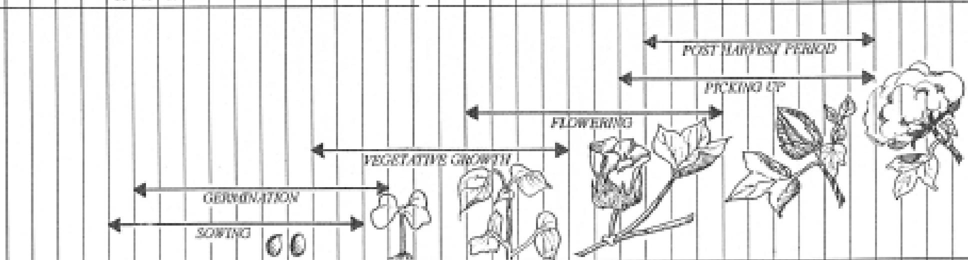
Weather warnings	Rain	> 100 MM/DAY		
	Duration of wet spell	> 30 MM FOR 10 DAYS		
	Cloudy weather			
	Drought	40 DAYS	35 DAYS	35 DAYS
	High winds			> 10 KM/HOUR
	Temperature			
	Hail storm			
Weather conditions favourable for incidence of pests and diseases	Pests	STEM WEEVIL, BOLL WORMS	STEM WEEVILS, BOLL WORMS	STEM WEEVILS, BOLL WORMS
	Weather			
	Diseases	WILT	WILT	
	Weather			

Normal phase wise water requirement (mm): 79.6 (standard weeks 1–5); 230.2 (weeks 6–13); 287.8 (weeks 14–19); 179.0 (weeks 20–25)

Weekly normal weather

Standard weeks	Rainfall (mm) total	Max. temp °C	Min. temp °C	Sunshine hours
47				
48				
49				
50	26.3	28.6	21.1	6.4
51	18.6	28.2	20.7	7.0
52	18.9	28.1	20.1	6.0
1	13.1	28.5	19.7	8.2
2	16.0	28.7	19.5	8.8
3	4.9	29.2	18.7	9.0
4	4.6	29.7	20.3	8.9
5	2.4	30.3	19.9	8.9
6	2.4	30.7	20.3	9.8
7	2.7	30.9	20.3	10.3
8	3.9	31.9	20.6	10.1
9	2.9	32.4	21.0	10.1
10	1.6	32.7	21.9	9.7
11	5.3	33.5	21.8	9.8
12	3.6	34.4	22.3	9.8
13	4.0	34.9	22.7	10.4
14	21.4	35.5	24.9	9.2
15	10.0	35.7	25.6	9.7
16	5.3	36.1	25.9	8.9
17	5.2	36.8	26.1	9.8
18	7.2	37.3	26.7	9.6
19	15.6	36.9	26.7	8.4
20	22.2	37.2	26.4	7.2
21	10.8	38.8	26.9	7.3
22	18.7	37.9	27.1	7.4
23	9.7	37.7	26.7	7.7
24	13.0	36.9	26.5	6.0
25	8.7	36.9	26.2	6.8
26	10.2	36.8	26.1	6.7
27	14.8	36.1	25.8	6.8
28				
29				
30				

Life history and mean dates of important epochs of crop growth



Months	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE

SSh → Sunshine hour; DUR → Duration,

WEATHER NORMALS FOR AGRICULTURAL CROPS

Sl. No.	Crops	Optimum Temperature ° C		Day length	Rainfall (mm)	Altitude above MSL (m)
		Germi nation	Growth stage			
1	Rice	Min 10 ° C	22-25 (flowering) 20-21(grain formn) 20-25(ripening)		1500	<3000
2	Maize	35-44 ° C				
3	Sorghum	7-10	25-30	Short day		
4	Pearl millet		28-32		400-750	
5	Finger millet				500-1000	
6	Kodo millet				400-500	
7	Wheat	20-22	16-22		250-1800	<3500
8	Barley		12-15 (growth) 30(reproduction)	Long day	400-500	
9	Oats	15-25			380-1140	
10	Ground nut	27-30	24-27		500-1250	
11	Sesame	25-27		Short day	500-650	<1250
12	Castor	20-26		Long day	500-600	<3000
13	Sunflower	20-25			500-700	<2500
14	Rape seed and Mustard	18-25		Long day	300-400	
15	Safflower	15-16	25-30	Day neutral	600-900	
16	Soybean	15-32	30-33		600-650	1200-2000
17	Pigeon pea	20-30				
18	Green gram	15	20-40	Short day	600-1000	
19	Black gram					1500
20	Cow pea	12-15	21-35	Short day	600	
21	Bengal gram		15-25		600-1000	
22	Cotton	18	21-27	Day neutral	500	
23	Jute		27-40	Short day	1500	
24	Tobacco	28	25-35		500-1000	
25	Sugar cane		24-30	Long day	2000-2500	
26	Sugar beet	12-15	22-30	Long day		
27	Potato	18-20	18-20			

WEATHER MODIFICATION – ARTIFICIAL RAIN MAKING AND CLOUD SEEDING

Weather modification refers to willful manipulation of the climate or local weather. Research done in this field goes back to as far as the early 1940s when the US military experimented with cloud seeding to stimulate rain. Today, private corporations have joined the weather modification research effort to protect people, cities and assets from the damage extreme weather brings.

Principles of rainmaking

Clouds are classified into warm and cold clouds based on cloud top temperature. If the cloud temperature is positive these clouds are called warm clouds and if it is negative they are called as cold clouds. The nucleus needed for precipitation differs with type of clouds. Hygroscopic materials are necessary as nucleus for warm clouds

History of Cloud Seeding

Cloud seeding experiments started with the work of a scientist from General Electric named Vincent Schaefer who discovered that ice crystals can induce precipitation. Since ice crystals are difficult to transport and spread over an area, silver iodide, a compound with similar properties, was used as a substitute. The experiments continued until the 1970's when the program was shelved because of lack of usable results.

Cloud seeding

Cloud seeding is one of the tools to mitigate the effects of drought. It is defined as a process in which the precipitation is encouraged by injecting artificial condensation nuclei through aircrafts or suitable mechanism to induce rain from rain bearing cloud. The raindrops are several times heavier than cloud droplets. These mechanisms are different for cold and warm clouds.

How it Works

Cloud seeding involves the use of water-absorbent materials to encourage the formation of clouds and rain so that there could be increased crop production in areas where there's little water. This practice has already been implemented in some areas like Texas and Utah, though not without its share of controversies. The effectiveness of cloud seeding cannot be proven and some worry that it may actually cause harm.

Cloud seeding useful in the following applications

Increasing Precipitation

The most common application of cloud seeding is to increase precipitation, possible with both warm and cold clouds. There are two primary methods employed to stimulate precipitation. One, hygroscopic seeding, affects warm cloud processes. The other, glaciogenic seeding initiates cold cloud processes.

Though occasionally both techniques may be helpful, in most cases one can be utilized more effectively than the other. In addition, either technology can be applied from the surface (ground-based) or from an aircraft. Weather Modification, Inc. can help you decide which method will be most effective.

Augmenting Snowfall

Glaciogenic seeding can also be used to increase precipitation from stratiform and orographic clouds. In such cases, seeding may be accomplished through either ground-based or airborne modes. By increasing snowpack and resultant spring runoff, subsequent water supplies for hydropower are increased. In addition to alleviating the need for alternative costly power supplies, cloud seeding increases the water availability for municipal, recreational, and environmental interests.

Enhancing Rainfall

Efforts to increase rainfall during the warm seasons are typically aimed at convective clouds. While it is theoretically possible to seed such clouds using ground-based equipment, targeting from aircraft is much more efficient and accurate. It is usually possible to affect the cloud through releases of a seeding agent in sub-cloud updrafts, or by dropping the seeding agents directly into the upper regions of the clouds. Warm season glaciogenic seeding is typically applied to treat supercooled cumulus congestus clouds, either by releasing the ice-forming (nucleating) seeding agent in the updraft beneath the actively-growing cumulus, or by dropping the nucleating agent directly into the supercooled cloud top. The seeding agents can produce ice at significantly warmer temperatures than the natural process. This is how glaciogenic seeding gives the treated cloud a head start in producing precipitation.

When clouds do not grow tall and cold enough to produce precipitation through the Bergeron process, it may be possible to stimulate precipitation growth by seeding these warm clouds with hygroscopic seeding agents. This approach can be quite successful through stimulation of the warm cloud precipitation processes. Hygroscopic seeding is normally done from aircraft flying in the sub-cloud updrafts, in order to affect the initial cloud droplet development which occurs in this zone.

Mitigating Hail Damage

Cloud seeding can be used as a tool to help mitigate hail damage and protect crop yields, homes and other property, thus reducing the economic harm from disastrous storm damage. Since hail is itself ice that is produced only by vigorous convective clouds, it is certain that such clouds are cold enough to be amenable to glaciogenic seeding techniques. Hail develops when excess supercooled liquid water develops within strong updrafts. However, if the excess might be induced to freeze into large numbers of small particles rather than much smaller numbers of large particles, the ice that does precipitate may melt during its transit through the warm sub-cloud layer, or if it doesn't it will reach the surface as much smaller, less-damaging, ice.

Dispersing Fog

Another useful application for cloud seeding is the treatment of ground-based clouds, also known as fog. Supercooled fogs, comprised of water droplets at temperatures cold enough to permit ice development, can easily be cleared by glaciogenic seeding. This can be done either from the ground or from airborne application. Your choice between the two will depend on characteristics such as local infrastructure, topography, and wind.

Seeding of cold clouds

This can be achieved by two ways (1. Dry ice seeding and 2. Silver Iodide seeding).

1. Dry ice seeding

- Dry ice (solid carbon-dioxide) has certain specific features. It remains as it is at –80^{o}C and evaporates, but does not melt. Dry ice is heavy and falls rapidly from top of cloud and has no persistent effects due to cloud seeding.
- Aircrafts are commonly used for cloud seeding with dry ice.
- Aircraft flies across the top of a cloud and 0.5 – 1.0 cm dry ice pellets are released in a steady stream.
- While falling through the cloud a sheet of ice crystals is formed.
- From these ice crystals rain occurs.
- This method is not economical as 250 kg of dry ice is required for seeding one cloud. To carry the heavy dry ice over the top of clouds special aircrafts are required, which is an expensive process.

2. Silver Iodide seeding

Minute crystals of silver iodide produced in the form of smoke acts as efficient ice-farming nuclei at temperatures below –5–C. When these nuclei are produced from the ground generators, these particles are fine enough to diffuse with air currents. Silver iodide is the most effective nucleating substance because; its atomic arrangement is similar to that of ice. The time for silver iodide smoke released from ground generator to reach the super cooled clouds was offer some hours, during which it would draft a long way and decay under the sun light. The appropriate procedure for seeding cold clouds would be to release silver iodide smoke into super cooled cloud from an aircraft. In seeding cold clouds silver iodide technique is more useful than dry ice techniques, because, very much less of silver iodide is required per cloud. There is no necessity to fly to the top of the cloud, if area to be covered is large.

Seeding of warm clouds

1) Water drop Technique

Coalescence process is mainly responsible for growth of rain drops in warm cloud. The basic assumption is that the presence of comparatively large water droplets is necessary to initiate the coalescence process. So, water droplets or large hygroscopic nuclei are introduced in to the cloud. Water drops of 25 mm are sprayed from aircraft at the rate of 30 gallons per seeding on warm clouds.

2) Common salt technique

Common salt is a suitable seeding material for seeding warm clouds. It is used either in the form of 10 per cent solution or solid. A mixture of salt and soap avoid practical problems. The spraying is done by power sprayers and air compressors or even from ground generators. The balloon burst technique is also beneficial. In this case gunpowder and sodium chloride are arranged to explode near cloud base dispersing salt particles.

REMOTE SENSING

Remote sensing is defined as the art and science of gathering information about objects or areas from a distance without having physical contact with objects area being investigated.

Uses: Remote sensing techniques are used in agricultural and allied fields.

1. Collection of basic data for monitoring of crop growth
2. Estimating the cropped area
3. Forecasting the crop production
4. Mapping of wastelands
5. Drought monitoring and its assessment
6. Flood mapping and damage assessment
7. Land use/cover mapping and area under forest coverage
8. Soil mapping
9. Assessing soil moisture condition, irrigation, drainage
10. Assessing outbreak of pest and disease
11. Ground water exploration

Remote Sensing platforms:

Three platforms are generally used for remote sensing techniques. They are ground based, air based and satellite based. Infrared thermometer, Spectral radiometer, Pilot-Balloons and Radars are some of the ground based remote sensing tools while aircrafts air based remote sensing tools. Since the ground based and air based platforms are very costly and have limited use, space based satellite technology has become handy for wider application of remote sensing techniques. The digital image processing, using powerful computers, is the key tool for analyzing and interpretation of remotely sensed data. The advantages of satellite remote sensing are:

Synoptic view ‑ Wide area can be covered by a single image/photo (One scene of Indian Remote Sensing Satellite IRS series cover about 148 x 178 sq.km area).

Receptivity ‑ Can get the data of any area repeatedly (IRS series cover the same area every 16- 22 days).

Coverage ‑ Inaccessible areas like mountains, swampy areas and thick forests are easily covered. Space based remote sensing is the process of obtaining information about the earth from the instruments mounted on the Earth Observation Satellites. The satellites are subdivided into two classes and the types of satellite are as follows:

Polar orbiting satellites

These satellites operate at an altitude between 550 and 1,600 km along an inclined circular plane over the poles. These satellites are used for remote sensing purposes. LANDSAT (USA), SPOT (FRANCE), and IRS (INDIA) are some of the Remote Sensing Satellites.

Geostationary satellite

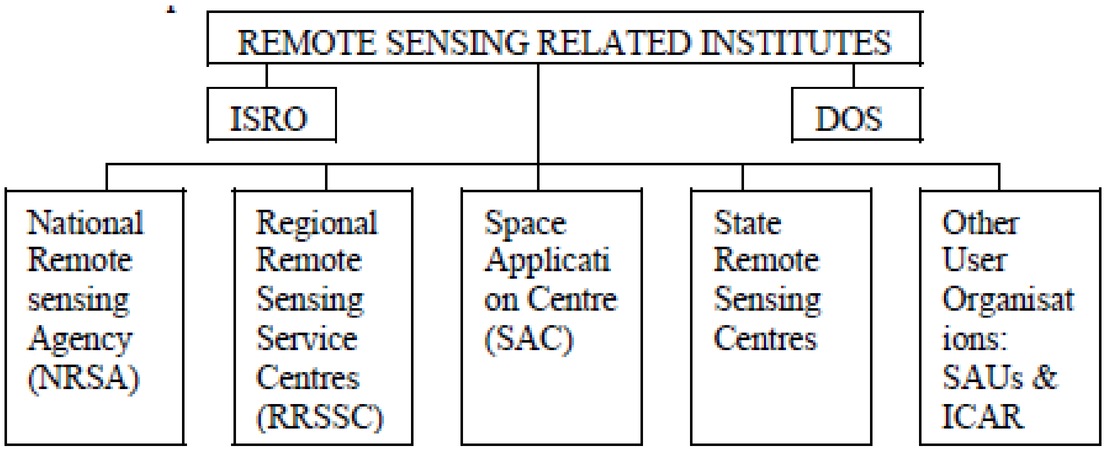
These have orbits around the equator at an altitude of 36,000 km and move with the same speed as the earth so as to view the same area on the earth continuously. They are used for telecommunication and weather forecasting purposes. INSAT series are launched from India for the above purposes. All these satellites have sensors on board operating in the visible and near infrared regions of the electromagnetic spectrum. INSAT-3A was launched on 10th April, 2003.

Role of Remote Sensing in agriculture

Agricultural resources are important renewable dynamic natural resources. In India, agriculture sector alone sustains the livelihood of around 70 percent of the population and contributes nearly 35 percent of the net national product. Increasing agricultural productivity has been the main concern since scope for increasing area under agriculture is rather limited. This demands judicious and optimal management of both land and water resources. Hence, comprehensive and reliable information on land use/cover, forest area, soils, geological information, extent of wastelands, agricultural crops, water resources both surface and underground and hazards/natural calamities like drought and floods is required. Season-wise information on crops, their acreage, vigour and production enables the country to adopt suitable measures to meet shortages, if any, and implement proper support and procurement policies. Remote Sensing systems, having capability of providing regular, synoptic, multi-temporal and multi-spectral coverage of the country, are playing an important role in providing such information. A large number of experiments have been carried out in developing techniques for extracting agriculture related information from ground borne, air borne and space borne data.

Indian Remote Sensing programme:

India, with the experience gained from its experimental remote sensing satellite missions BHASKARA-I and II, has now established satellite based operational remote sensing system in the country with the launch of Indian Remote Sensing Satellite IRS-IA in 1988, followed by IRS-IB (1992), IRS-IC (1995) and IRS-ID (1997). The Department of Space (DOS) / Indian Space Research Organisation (ISRO) as the nodal agency for establishing an operation remote sensing system in the country initiated efforts in the early 1970s for assessing the potentials of remotely sensed data through several means. In order to meet the user requirement of remote sensing data analysis and interpretation, ISRO/DOS has set up a system to launch remote sensing satellites once in three or four years to maintain the continuity in data collection. The remote sensing and some of its related institutes are depicted.



Crop weather modeling

Crop model

It is a representation of a crop through mathematical equations explaining the crops interaction with both above ground and below ground environment. The increase in dry matter of the crop is referred to as growth. The rate of growth of a healthy crop depends on the rate at which radiation is intercepted by foliage and / or on the rate at which water and nutrients are captured by root systems and therefore on the distribution of water and nutrients in the soil profile. The crop development is described in terms of various phenophases through which the crop completes its lifecycle. That is the progress of the crop from seeding or primordial initiation to maturity. Finally the yield of crop stand is expresses as a product of three components, viz., the period over which dry matter is accumulated (the length of the growing period), the mean rate at which dry matter is accumulated and the fraction of dry matter treated as yield when the crop is harvested. It is understood that the crop growth, development and yield depend upon the mean daily temperature (DTT), the length of the day and the amount of solar radiation (PAR) received by the crop.

$$\text{DTT} = \frac{\text{Max daily temperature} + \text{Min daily temperature}}{2} - \text{base temperature}$$

Where, DTT = Daily thermal time accumulation.

The time needed for the crop to reach a development stage depends upon temperature measured above a base value (DTT) and for photo periodically sensitive phases such as flowering, the day length above a fixed base. In the absence of stress, the harvest index does not vary much from year to year for a specified cultivar / variety. Therefore, crop weather modeling is based on the principles that govern the development of crop and its growing period based on temperature and / or day length. They are used to quantify the rate of crop growth in terms of radiation interception, water use and nutrient supply which moderate harvest index when the crops experience stress condition. The basic information required to be generated for crop weather modeling includes.

a) Crop phonology in relation to the temperature and day length

b) Water use by the crop during different phenophases of crop growth

c) The relationship between radiation interception, crop water use and total dry matter production

d) Partitioning of dry matter into various plant components as influenced by water and nutrient availability, and

e) The effect of weather parameters on biotic interference to crop growth.

Types of models

a) Statistical models

These models express the relationship between the yield or yield components and the weather parameters. The relationships are measured in a system using statistical techniques. Simple regression techniques explaining weather crop relationships are also considered as models.

b) Mechanistic model

These models explain not only the relationships between the weather parameters and the yield, but explain the relationship of influencing dependent variables.

c) Deterministic models

These models estimate the exact value of the yield or dependent variable. These models also have defined co-efficient.

d) Stochastic models

A probability element is attached to each output. For each set of inputs different outputs are given along with probabilities. These models define the yield or state of dependent variable at a given rate.

e) Dynamic models

Time is included as a variable. Both dependent and independent variables are having values which remain constant over a given period of time. Over a period of time these variables are changing due to change in rate of increment.

f) Static models

Time is not included as a variable. The dependent and independent variables having values remain constant over a given period of time.

g) Simulation models

Computer models in general, are a mathematical representation of a real world system. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. These models use one or more sets of differential equations over time, normally from planting until harvest maturity or final harvest.

h) Descriptive models

A descriptive model defines the behaviour of a system in a simple manner. The model reflects little or none of the mechanisms that are the causes of phenomena but consists of one or more mathematical equations. An example of such an equation is the one derived from successively measured weights quickly the weight of the crop where no observation was made.

i) Explanatory models

This model consists of quantitative description of the mechanisms and process that cause the behaviour of the system. To create this model, a system is analyzed and its process and mechanisms are quantified separately. The model is built by integrating these descriptions for the entire system. It contains descriptions of distinct processes such as leaf area expansion, tiller production etc. Crop growth is a consequence of these processes.

Climate change and variability

Climate change

Any permanent change in weather phenomena from the normals of a long period average is referred as climate change. Eg. The global temperature has increased by 2.0 to 3.0 C and increase in CO2 from 180ppm to 350ppm.

Climate variability

The temporal changes in weather phenomena which is part of general circulation of atmosphere and occurs on a yearly basis on a global scale. Climate change and climate variability are the concern of human kind in recent decades all over the world. The recurrent drought and desertification seriously threaten the livelihood of over 1-2 billion people who depend on the land for most of their needs. The weather related disasters viz. drought and floods, ice storms, dust storms, land slides, thunder clouds associated with lightening and forest fires are uncommon over one or other region of the world. The year 1998 was one of the recent weather related disaster years, which caused hurricane house in Central America and floods in China, India and Bangladesh. Canada and New England in the U.S. suffered heavily due to ice storm in January while Turkey, Argentina and Paraguay with floods in June 1998. Vast fires in Siberia burned over three million acres of forests. Human and crop losses are the worst phenomena in such weather disasters, affecting global economy to a considerable extent. The 1997-

’ 98 El-Nino events, the strongest of the last century is estimated to have affected 110 million people and cost the global economy nearly US $ 100 billion. Statistics compiled from insurance companies for the period 1950-1999. Show that major natural catastrophes which are mainly weather and climate related caused estimated economic losses of US $ 960 billion. Most of the losses were recorded in recent decades. Increase in aerosols due to emission of green house gases including black carbon and chlorofluorocarbons (CFCS), ozone depletion, UV-B filtered radiation, cold and heat waves, global cooling and warming and "human hand" in the form of deforestation and loss of wetlands in the process of imbalanced development for betterment of human kind may be caused factors for climate variability and climate change.

Causes of climatic variability

A. External causes

i) Solar output: An increase in solar output by 0.3%when compared to 1650 -1700AD data.

ii) Orbital variation:

1. Earth orbit varies form almost a complete circle to marked ellipse (Eccentricity).
2. Wobble of earth’s axis (Precession of equinox) 3. Tilt of the earth’s axis of rotation relative to the plane of the orbit varies between 21.8^{o} and 24.4^{o}.

B. Internal causes

i) Changes in the atmospheric composition. Change in the green house gases especially CO2

ii) Land surface changes particularly the afforestation and deforestation

iii) The internal dynamics of southern oscillation - changes in the sea surface temperature in western tropical Pacific (El-Nino/La-Nina) coupled with Southern

Oscillation Index, the Tahiti minus Darwin normalized pressure index leading to the ENSO phenomena

iv) Anthropogenic causes of climate variation in green house gases and aerosols.

Effects of climate change

1. The increase concentration of CO_2 and other green house gases are expected to increase the temperature of the earth.

2. Crop production is weather dependant and any change will have major effects on crop production and productivity.

3. Elevated CO_2 and temperature affects the biological process like respiration, photosynthesis, plant growth, reproduction, water use etc. Depending on the latitude the CO_2 may either offer beneficial effect or may behave otherwise also.

El-Nino and La-Nina

El-Nino is a Spanish word meaning "the boy child" ('Child Christ') because El-Nino occurs around Christmas time each year when the waters off the Peruvian coast warm slightly. In every three to six years, the waters become unusually warm. 'El Ni□' is now used more widely to refer to this abnormal warming of the ocean and the resulting effects on weather. 'El Nino' is often coupled with 'Southern Oscillation' as the acronym ENSO. 'La Nino' is used popularly to signify the opposite of El Nino occurring when the waters of the eastern Pacific are abnormally cold. La Nino episodes are associated with more rainfall over eastern Australia, and continuing drought in Peru. Peruvian meteorologists have objected to term La Nino-the Girl Child-because Christ is not known to have had a sister, and the term anti-ENSO is sometimes preferred. The El-Nino event is due to decrease in atmospheric pressure over the South East Pacific Ocean. At the same time, the atmospheric pressure over Indonesia and North Australia increases. Once the El-Nino event is over, the atmospheric pressure over the above regions swings back. This sea-saw pattern of atmospheric pressure is called Southern Oscillation. Since El-Nino and Southern Oscillation are linked they often termed as ENSO. It is most important one, which represents a tendency for high atmospheric pressure over the Pacific Ocean, represents to be associated with low pressure over the Indian Ocean and vice-versa. A measure of the monsoon low pressure is the Southern Oscillation Index (SOI) represented by the difference in sea level pressure over Tahiti, an Island in South central pacific and Darwin in North Australia, which represents the northern part of the Indian Ocean. The positive SOI denotes high pressure over the central pacific and low over Indonesia, North Australia and Northern Indian Ocean. Above average rainfall is expected over India, India and Indonesia and North Australia if the SOI is positive. Drought or deficit rainfall is expected in the above countries if the SOI is negative, indicating high atmospheric pressure over Indonesia and low in the central pacific.