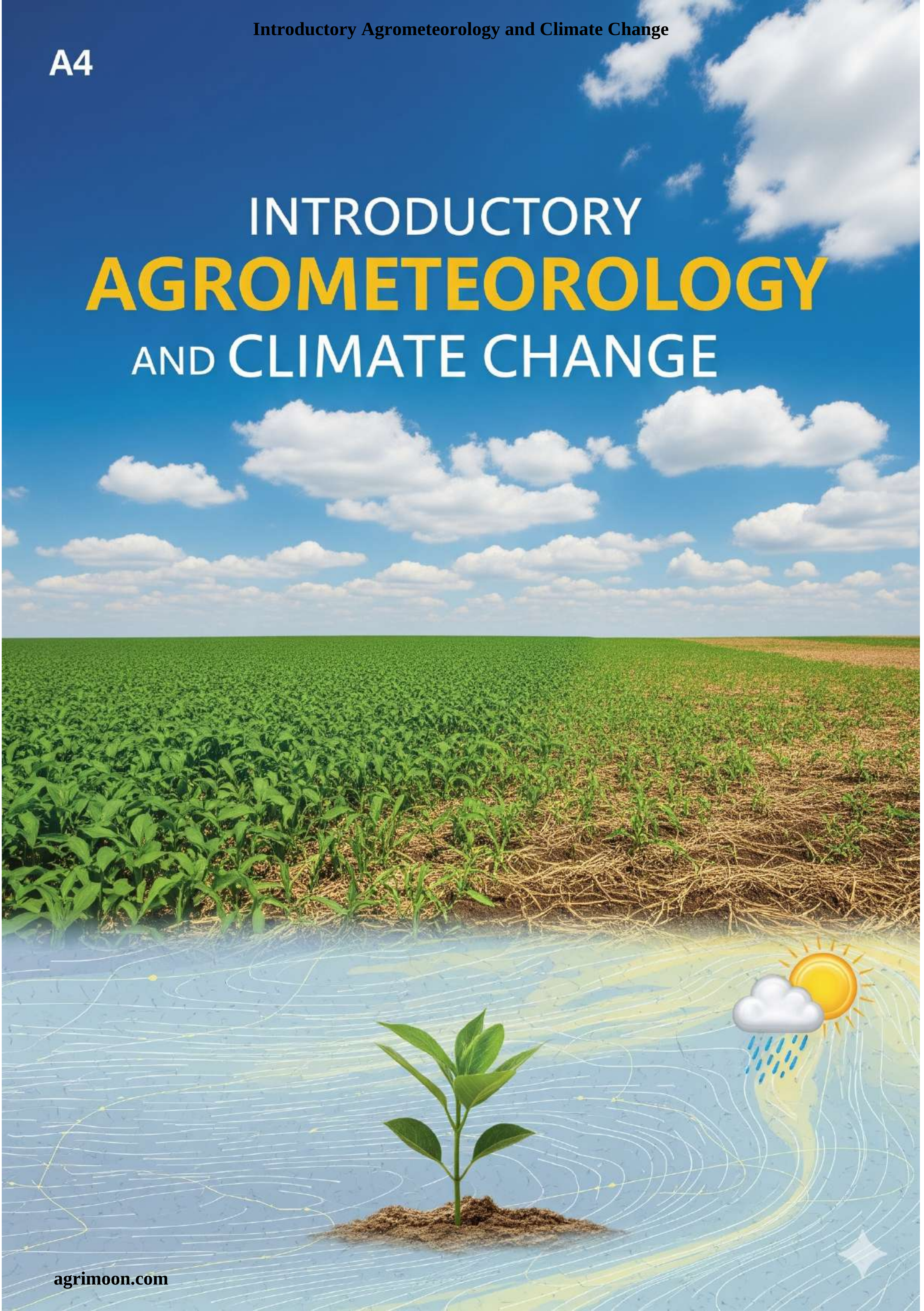

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Introductory Agrometeorology and Climate Change

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Chapter 1

AGRICULTURAL METEOROLOGY

Agricultural meteorology is the branch of applied meteorology which deals with the response of crops and animals to the physical environment. It is the study of physical process of the atmosphere that produces weather in relation to agricultural production.

It is the science investigating the meteorological, climatological and hydrological conditions which are significant for agriculture owing to their interaction with the objects and process of agricultural production.

Scope of Agricultural Meteorology

- To study climatic resources of given area for effective production.
- To quantify favourable weather normal for effective farm operations.
- To develop crop/animal weather relationships for estimation of animal/crops productivity.
- To study weather- crop pest and disease relationships.
- To modify micro climatic for increasing agricultural productivity.
- To delineate agro-ecological zones for efficient use of resources and fast transfer of technology.
- To prepare crop weather diagrams and crop weather calendars for timely operations by farmers.
- To develop crop/animal growth simulation models for prediction of productivity in advance and also obtaining potential yield in different agro- ecological zones.
- To determine and monitor drought for effective drought management.
- To prepare value added weather based agro-advisory and its real time dissemination to farmers for reducing input cost and increasing productivity.

Weather and Climate:

Weather:

The state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure. It describes the atmospheric conditions at a specific place at a specific point in time. Weather generally refers to day-to-day temperature and precipitation activity refers to day-to-day temperature and precipitation activity

Climate:

Climate originated from ancient Greek word *klima*, meaning inclination. It is commonly defined as the weather averaged over a long period and for a large area. It describes the average conditions expected at a specific place at a given time. A region's climate is generated by the climate system, which has five components: atmosphere, hydrosphere, cryosphere, land surface, and biosphere.

Differences between Climate and Weather:

	Climate	**Weather**
Definition	Describes the average conditions expected at a specific place at a given time. A region's climate is generated by the climate system, which has five components: atmosphere, hydrosphere, cryosphere, land surface, and biosphere.	Describes the atmospheric conditions at a specific place at a specific point in time. Weather generally refers to day-to-day temperature and precipitation activity refers to day-to-day temperature and precipitation activity
Components	Climate may include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms over a long period of time.	Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, excessive heat, heat waves and more
Forecast	By aggregates of weather statistics over periods of 30 years	By collecting meteorological data, like air temperature, pressure, humidity, solar radiation, wind speeds and direction etc.
Determining factors	Aggregating weather statistics over periods of 30 years (climate normal).	Real-time measurements of atmospheric pressure, temperature, wind speed and direction, humidity, precipitation, cloud cover, and other variables
About	Climate is defined as statistical weather information that describes the variation of weather at a given place for a specified interval.	Weather is the day-to-day state of the atmosphere, and its short-term (minutes to weeks) variation
Time period	Measured over a long period	Measured for short term
Study	Climatology	Meteorology

Weather variables/elements:

There are several variables/elements that make up the weather and climate of a place. The major of these elements are five: temperature, pressure, wind, humidity, and rain. Analysis of these elements can provide the basis for forecasting weather and defining its climate. These same elements make also the basis of climatology study, of course, within a longer time scale rather than it does in meteorology.

- Temperature is how hot or cold the atmosphere is, how many degrees it is above or below freezing. Temperature is a very important factor in determining the weather because it influences or controls other elements of the weather, such as precipitation, humidity, clouds and atmospheric pressure.
- Humidity is the amount of water vapor in the atmosphere.
- Precipitation is the product of a rapid condensation process (if this process is slow, it only causes cloudy skies). It may include snow, hail, sleet, drizzle, fog, mist and rain.
- Atmospheric pressure (or air pressure) is the weight of air resting on the earth's surface. Pressure is shown on a weather map, often with lines called isobars.
- Wind is the movement of air masses, especially on the Earth's surface.

Earth’s Atmosphere:

Definition: The atmosphere is a thick gaseous envelop which surrounds the earth from all sides and is attached to the earth‘s surface by gravitational force.

Composition:

(1)Gases: The gases nitrogen and oxygen together make up about 99% of the volume of the dry atmosphere. The remaining 1% is comprised of a number different gases of which ozone, carbon dioxide, nitrous oxide, and methane are the most important to life on the Earth. Ozone is concentrated in a layer that extends from 15 to 55 kilometers above the Earth's surface. Ozone is important to life because it absorbs harmful ultraviolet radiation from the Sun. Recent investigations of the ozone layer have discovered areas of severe thinning located primarily at the South Pole. Researchers have determined that this thinning is caused by the emission of the artificially produced chemical chlorofluorocarbon into our atmosphere.

Table 1: Average composition of the atmosphere up to an altitude of 25 km

Gas Name	Chemical Formula	Percent Volume
Nitrogen	N2	78.08%
Oxygen	O2	20.95%
*Water	H2O	0 to 4%
Argon	Ar	0.93%
*Carbon Dioxide	CO2	0.0360%
Neon	Ne	0.0018%

Helium	He	0.0005%
*Methane	CH_4	0.00017%
Hydrogen	H_2	0.00005%
*Nitrous Oxide	N_2O	0.00003%
*Ozone	O_3	0.000004%

(2)Water vapour: The vapour content in the atmosphere ranges between zero to 5 % by volume. Vapour depends upon temperature therefore decreases from eqator to poleward in response to decreasing temperature towards the pole. The content of vapour decreases upward. More than 90 % of the total atmospheric vapour is found up to the height of 5 km. It helps in heating the earth‘s surface and lower portion of the atmosphere because it absorbs terrestrial radiation.

(3)Particulate matter: The solid particles present in the atmosphere include dust particle, salt particles, pollen, smoke, volcanic ashes etc. They are kept in suspension in the atmosphere. Sky appears blue in colour due to selective scattering of solar radiation by dust particles. Salt particles become hygroscopic nuclei and thus help in the formation of water drops, clouds and various forms of condensation and precipitation.

Structure of earth’s atmosphere:

Troposphere: The Troposphere is the lowest layer of the atmosphere, and makes up about 75-80% of Earth‘s atmosphere. In the Troposphere all of weather phenomena occurs. The higher we go up the Troposphere, the colder it gets. Temperature decreases at the rate of 6.5 ^{0}C/ 1000 m as we go upward and is called **Normal Lapse Rate**. The air also gets thinner as we travel upward in the Troposphere because nearly all of the water vapour and dust particles of the atmosphere are in the Troposphere. At the top of the Troposphere, there is a place called the Tropopause, which is boundary between Troposphere and Stratosphere. The troposphere is the lowest layer of Earth's atmosphere. It extends from Earth's surface to an average height of about 12 km, although this altitude actually varies from about 9 km at the poles to 17 km at the equator, with some variation due to weather. The troposphere is bounded above by the tropopause, a boundary marked in most places by a temperature inversion (i.e. a layer of relatively warm air above a colder one), and in others by a zone which is isothermal with height.

Although variations do occur, the temperature usually declines with increasing altitude in the troposphere because the troposphere is mostly heated through energy transfer from the surface. Thus, the lowest part of the troposphere (i.e. Earth's surface) is typically the warmest section of the troposphere. This promotes vertical mixing (hence the origin of its name in the Greek word *tropos*, meaning "turn"). The troposphere contains roughly 80% of the mass of Earth's atmosphere. The troposphere is denser than all its overlying atmospheric layers because a larger atmospheric weight sits on top of the troposphere and causes it to be most severely compressed. Fifty percent of the total mass of the atmosphere is located in the lower 5.6 km of the troposphere.

Nearly all atmospheric water vapour or moisture is found in the troposphere, so it is the layer where most of Earth's weather takes place. It has basically all the weather-associated cloud genus types generated by active wind circulation, although very tall cumulonimbus thunder clouds can penetrate the tropopause from below and rise into the lower part of the stratosphere. Most conventional aviation activity takes place in the troposphere, and it is the only layer that can be accessed by propeller-driven aircraft.

Stratosphere: The stratosphere is the second-lowest layer of Earth's atmosphere. It lies above the troposphere and is separated from it by the tropopause. This layer extends from the top of the troposphere at roughly 12 km above Earth's surface to the stratopause at an altitude of about 50 to 55 km.

The atmospheric pressure at the top of the stratosphere is roughly 1/1000 the pressure at sea level. It contains the ozone layer, which is the part of Earth's atmosphere that contains relatively high concentrations of that gas. The stratosphere defines a layer in which temperatures rise with increasing altitude. This rise in temperature is caused by the absorption of ultraviolet radiation (UV) radiation from the Sun by the ozone layer, which restricts turbulence and mixing. Although the temperature may be −60 °C at the tropopause, the top of the stratosphere is much warmer, and may be near 0 °C.

The stratospheric temperature profile creates very stable atmospheric conditions, so the stratosphere lacks the weather-producing air turbulence that is so prevalent in the troposphere. Consequently, the stratosphere is almost completely free of clouds and other forms of weather. However, polar stratospheric or nacreous clouds are occasionally seen in the lower part of this layer of the atmosphere where the air is coldest. This is the highest layer that can be accessed by jet-powered aircraft.

The Stratosphere is the layer in Earth‘s atmosphere, which contains the Ozone Layer. The Stratosphere‘s Ozone Layer absorbs ultraviolet light from the sun. In the Stratosphere, as we move up, temperature increases, which is the exact opposite of what happens in the Troposphere. The Stratosphere is the second lowest of the out of all top layer of Earth‘s atmospheric layers.

Mesosphere: The Mesosphere is the third lowest layer in Earth‘s atmosphere, and this is where meteorites burn up, before they reach Earth. As we go up in this layer, temperature decreases. Mesosphere is located on top of the Stratosphere. The mesosphere is the third highest layer of Earth's atmosphere, occupying the region above the stratosphere and below the thermosphere. It extends from the stratopause at an altitude of about 50 km to the mesopause at 80–85 km above sea level. Temperatures drop with increasing altitude to the mesopause that marks the top of this middle layer of the atmosphere. It is the coldest place on Earth and has an average temperature around −85 °C. Just below the mesopause, the air is so cold that even the very scarce water vapour at this altitude can be sublimated into polar-mesospheric noctilucent clouds. These are the highest clouds in the atmosphere and may be visible to the naked eye if sunlight reflects off them about an hour or two after sunset or a similar length of time before sunrise. They are most readily visible when the Sun is around 4 to 16 degrees below the horizon. A type of lightning referred to as either sprites or ELVES, occasionally form far above tropospheric thunderclouds. The mesosphere is also the layer where most meteors burn up upon atmospheric entrance. It is too high above Earth to be accessible to jet-powered aircraft and balloons, and too low to permit orbital spacecraft. The mesosphere is mainly accessed by sounding rockets and rocket-powered aircraft.

Thermosphere: The Thermosphere is one of the upper layer s of the atmosphere. It also includes the **exosphere,** and **ionosphere**. The exosphere is above it, and the ionosphere is below. **Aurora Borealis** occurs in the Thermosphere, charged particles emit photons of light which forms the aurora. Temperatures climb sharply in the lower portion of the Thermosphere. Since, it is the outermost layer in the Earth‘s atmosphere. It extends from the mesopause (which separates it from the mesosphere) at an altitude of about 80 km up to the thermopause at an altitude range of 500–1000 km. The height of the thermopause varies considerably due to changes in solar activity. Because the thermopause lies at the lower boundary of the exosphere, it is also referred to as the exobase. The lower part of the thermosphere, from 80 to 550 kilometres above Earth's surface, contains the **ionosphere.**

The temperature of the thermosphere gradually increases with height. The temperature of this layer can rise as high as 1500 °C, though the gas molecules are so far apart that its temperature in the usual sense is not very meaningful. The air is so rarefied that an individual molecule (of oxygen, for example) travels an average of 1 kilometre between collisions with other molecules. Although the thermosphere has a high proportion of molecules with high energy, it would not feel hot to a human in direct contact, because its density is too low to conduct a significant amount of energy to or from the skin. This layer is completely cloudless and free of water vapour. However non-hydro meteorological phenomena such as the aurora borealis and aurora australis are occasionally seen in the thermosphere. The **International Space Station** orbits in this layer, between 350 and 420 km.

Exosphere is the outermost layer of Earth's atmosphere (i.e. the upper limit of the atmosphere). It extends from the exobase, which is located at the top of the thermosphere at an altitude of about 700 km above sea level, to about 10,000 km, where it merges into the solar wind. This layer is mainly composed of extremely low densities of hydrogen, helium and several heavier molecules including nitrogen, oxygen and carbon dioxide closer to the exobase. The atoms and molecules are so far apart that they can travel hundreds of kilometres without colliding with one another. Thus, the exosphere no longer behaves like a gas, and the particles constantly escape into space. These free-moving particles follow ballistic trajectories and may migrate in and out of the magnetosphere or the solar wind. The exosphere is located too far above Earth for any meteorological phenomena to be possible. However, the **aurora borealis** and **aurora australis** sometimes occur in the lower part of the exosphere, where they overlap into the thermosphere. The exosphere contains most of the satellites orbiting Earth.

Chapter 2

ATMOSPHERIC PRESSURE

Atmospheric p r e s s u r e , sometimes also called **barometric pressure**, is the pressure exerted by the weight of air in the atmosphere of Earth (or that of another planet). In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point. Low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Likewise, as elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing elevation. On average, a column of air one square centimetre in cross-section, measured from sea level to the top of the atmosphere, has a mass of about 1.03 kg and weight of about 10.1 N. That force over one square centimetre is a pressure of 10.1 N/cm^2 or 101000 N/m^2.

The mean sea level pressure (MSLP) is the atmospheric pressure at sea level. This is the atmospheric pressure normally given in weather reports on radio, television, and newspapers or on the Internet. When barometers in the home are set to match the local weather reports, they measure pressure adjusted to sea level, not the actual local atmospheric pressure. Average sea-level pressure is 101.325 kPa (1013.25 hPa or mbar) or 29.92 inches (inHg) or 760 millimetres of mercury (mmHg).

Wind:

Wind can be simply defined as air in motion. Air moves above the Earth's surface because of spatial differences in the density of the atmosphere. Newton's laws of motion suggest that wind should blow from areas of high density to areas of low density. We can measure the density of the air through atmospheric pressure.

Factors affecting Wind:

Pressure gradient: The speed of wind is controlled by pressure gradient force. Pressure gradient force can be simply described as the rate of pressure change (pressure gradient) over space. Once in motion air is influenced by a number of forces.

Rotation of the Earth: The rotation of the Earth causes medium and large scale movements of air to be deflected from their intended path. The magnitude of this force, known as **Coriolis force,** is controlled by the latitude of the location and the speed of the wind.

Centripetal Force: Another force that acts on wind is centripetal force. This force is active when wind is flowing around curved paths, and high or low pressure centres.

Friction: The final force that can influence moving air is friction. However, friction only acts on wind that is flowing near the surface of the Earth.

Types of Wind:

1. Planetary Winds:
The winds blowing throughout the year from one latitude to another in response to latitudinal differences in air pressure are called ―planetary or prevailing winds‖. They involve large areas of the globe. Two most important prevailing winds are trade winds and westerly winds.

2. Trade Winds:
These are extremely steady winds blowing from sub-tropical high pressure areas (30°N and S) towards the equatorial low pressure belt. These winds should have blown from the north to south in Northern Hemisphere and south to north in Southern Hemisphere, but, they get deflected to the right in Northern Hemisphere and to the left in Southern Hemisphere due to Coriolis effect and Ferrel‘s law. Thus, they blow as north eastern trades in Northern Hemisphere and south eastern trades in Southern Hemisphere. They are also known as tropical easterlies, and they blow steadily in the same direction. They are noted for consistency in both force and direction.

3. The Westerlies:
These winds blow from sub-tropical high pressure belts towards sub-polar low pressure belts. The westerlies of Southern Hemisphere are stronger and constant in direction than Northern Hemisphere. These winds develop between 40° and 65°S latitudes and these latitudes are known as Roaring Forties, Furious Fifties and Shrieking Sixties.

4. Periodic Winds:
Periodic winds change their direction periodically with the change in season, e.g., Monsoons, Land and Sea Breezes, Mountain and Valley Breezes.

a. Monsoon Winds: These winds are seasonal winds and refer to wind systems that have a pronounced, seasonal reversal of direction. According to ‗Flohn‘, monsoon is a seasonal modification of general Planetary Wind System.

b. Land and Sea Breeze:

Land Breeze: At night, the land cools off faster than the ocean due to differences in their heat capacity, which forces the dying of the daytime sea breeze as the temperature of the land approaches that of the ocean. If the land becomes cooler than the adjacent sea surface temperature, the air pressure over the water will be lower than that of the land, setting up a **land breeze** blowing from the land to the sea, as long as the environmental surface wind pattern is not strong enough to oppose it. If there is sufficient moisture and instability available, the land breeze can cause showers, or even thunderstorms, over the water. Overnight thunderstorm development offshore due to the land breeze can be a good predictor for the activity on land the following day, as long as there are no expected changes to the weather pattern over the following 12–24 hours. This is mainly because the strength of the land breeze is weaker than the sea breeze. The land breeze will die once the land warms up again the next morning.

Sea Breeze: A **sea breeze** or **onshore breeze** is any wind that blows from a large body of water toward or onto a landmass; it develops due to differences in air pressure created by the differing heat capacities of water and dry land. As such, sea breezes are more localised than prevailing winds. Because land absorbs solar radiation far more quickly than water, a sea breeze is a common occurrence along coasts after sunrise. The sea has a greater heat capacity than land, so the surface of the sea warms up more slowly than the land's. As the temperature of the surface of the land rises, the land heats the air above it by conduction. The warming air expands and becomes less dense, decreasing the pressure over the land near the coast. The air above the sea has a relatively higher pressure, causing air near the coast to flow towards the lower pressure over land. The strength of the sea breeze is directly proportional

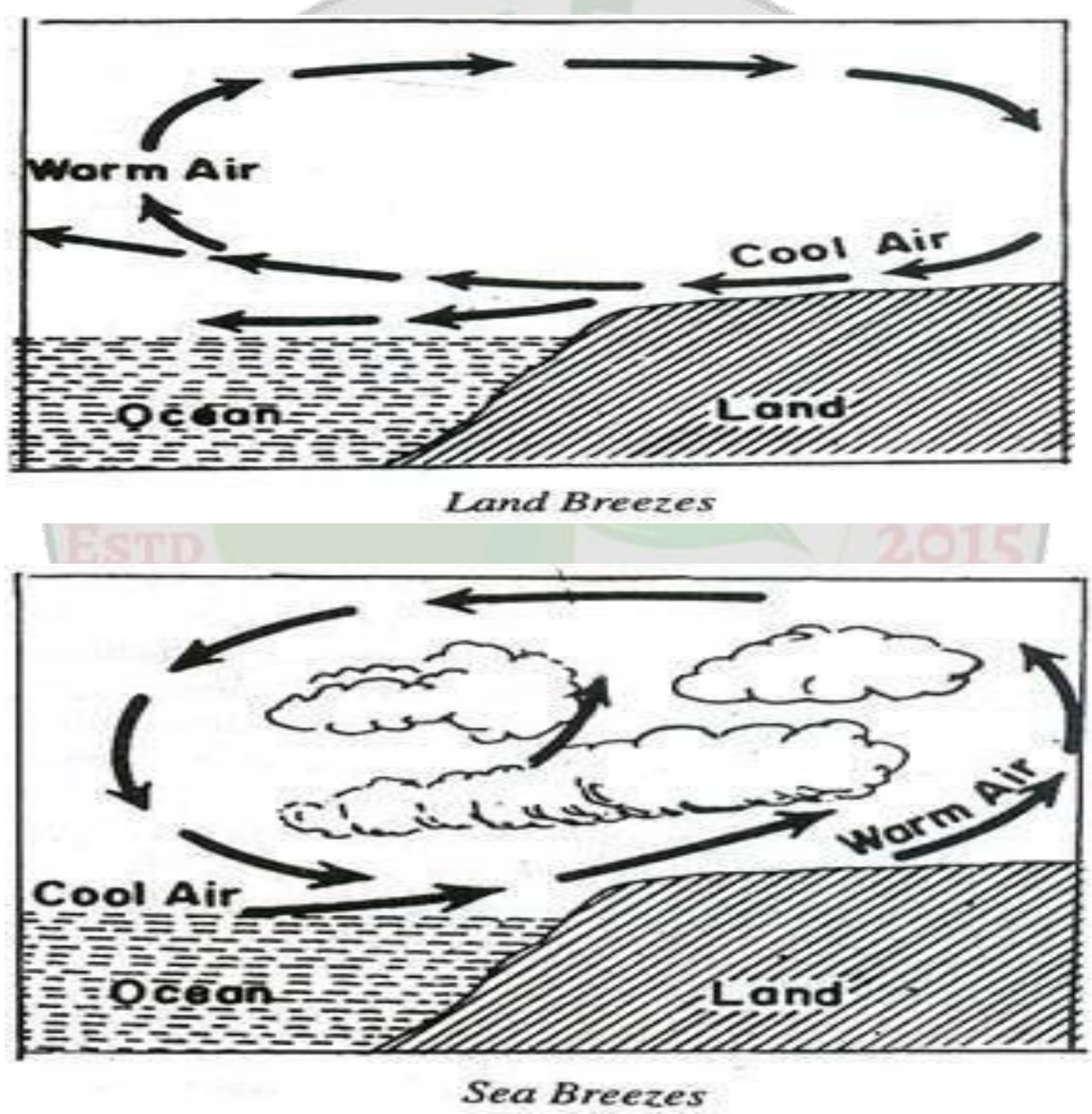


Fig 1: (a) Land Breeze and (**b)** Sea Breeze

to the temperature difference between the land and the sea. If a strong offshore wind is present (that is, a wind greater than (15 km/h)) and opposing the direction of a possible sea breeze, the sea breeze is not likely to develop.

c. Mountain and Valley Breezes:

A diurnal wind occurs in mountainous regions which are similar to Land and Sea Breezes. During the day the slopes of mountains are hot and air from valley flows up the slopes. This is known as ―Valley Breeze‖. After sunset the pattern is reversed and cold air slides from mountain to valley and is called ―mountain breeze‖.

5. Local Winds:

The local difference in temperature and pressure causes local winds. It is of four types: hot, cold, convectional and slope.

Important Local Winds

Local Wind	*Area/Place of Blowing*
Chinook or Snoweather	U.S.A. and Canada
Foehn	The Alps and Switzerland
Samun	Iran
Norwester	New Zealand
Bergs	South Africa
Santa Anas	California (U.S.A.)
Sirocco	Sahara
Salano	Southern Spain
Khamsin	Egypt
Simoon	Arabia
Gibli	Tunisia
Leveche	Sahara
Chili	Sahara
Brickfielder	Victoria (Australia)
Zonda	Argentina
Harmattan	Western Africa
Mistral	France
Bora	Former Yugoslavia
Tramontana	Northern Italy
Pampero	Argentina
Gregale	Sicily
Norther	Texas (U.S.A.)
Norta	Mexico
Papagayo	Mexico
Loo	Northern India and Pakistan

Fig 2: Important local winds

Cyclones:

A cyclone is a large scale air mass that rotates around a strong centre of low pressure. They are usually characterized by inward spiralling winds that rotate counter-clockwise in the Northern Hemisphere and clockwise in the southern hemisphere. Distinctive weather patterns tend to be associated with both cyclones and anticyclones. Cyclones (commonly known as lows) generally are indicators of rain, clouds, and other forms of bad weather.

Winds in a cyclone blow counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. In cyclones, air close to the ground is forced inward toward the center of the cyclone, where pressure is lowest. It then begins to rise upward, expanding and cooling in the process. This cooling increases the humidity of the rising air, which results in cloudiness and high humidity in the cyclone.

Structure of the cyclone:

A cyclone's centre (often known in a mature tropical cyclone as the eye), is the area of lowest atmospheric pressure in the region. Near the centre, the pressure gradient force (from the pressure in the centre of the cyclone compared to the pressure outside the cyclone) and the force from the Coriolis effect must be in an approximate balance, or the cyclone would collapse on itself as a result of the difference in pressure.

Because of the Coriolis effect, the wind flow around a large cyclone is counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. In the Northern Hemisphere, the fastest winds relative to the surface of the Earth therefore occur on the eastern side of a northward-moving cyclone and on the northern side of a westward-moving one; the opposite occurs in the Southern Hemisphere. In contrast to low pressure systems, the wind flow around high pressure systems are clockwise (anticyclonic) in the northern hemisphere, and counter-clockwise in the southern hemisphere.

Tropical Cyclone:

Tropical cyclones form due to latent heat driven by significant thunderstorm activity, and are warm core. Cyclones can transition between extratropical, subtropical, and tropical phases. Mesocyclones form as warm core cyclones over land, and can lead to tornado formation. Waterspouts can also form from mesocyclones, but more often develop from environments of high instability and low vertical wind shear. In the Atlantic and the northeastern Pacific oceans, a tropical cyclone is generally referred to as a hurricane (from the name of the ancient Central American deity of wind, Huracan), in the Indian and south Pacific oceans it is called a cyclone, and in the northwestern Pacific it is called a typhoon.

Formation of tropical cyclone: Tropical cyclones form as a result of significant convective activity, and are warm core. Mesocyclones form as warm core cyclones over land, and can lead to tornado formation. Waterspouts can also form from mesocyclones, but more often develop from environments of high instability and low vertical wind shear. A surface low can form in a variety of ways. Topography can create a surface low. Mesoscale convective systems can spawn surface lows that are initially warm core. The disturbance can grow into a wave-like formation along the front and the low will be positioned at the crest. Around the low, the flow will become cyclonic. This rotational flow will move polar air will equatorward on the west side of the low, while warm air will move poleward on the east side. A cold front will appear on the west side, while a warm front will form on the east side. Usually the cold front will move at a quicker pace than the warm front and will "catch up" with it due to the slow erosion of higher density air mass located out ahead of the cyclone. In addition, the higher density air mass sweeping in behind the cyclone strengthens the higher pressure, denser cold air mass. The cold front over takes the warm front, and reduces the length of the warm front. At this point an occluded front forms where the warm air mass is pushed upwards into a trough of warm air aloft, which is also known as a trowal

Tropical cyclogenesis, the development of a warm-core cyclone, begins with significant convection in a favorable atmospheric environment. There are six main requirements for tropical cyclogenesis:

1. sufficiently warm sea surface temperatures,
2. atmospheric instability,
3. high humidity in the lower to middle levels of the troposphere
4. enough Coriolis force to develop a low-pressure centre
5. a pre-existing low-level focus or disturbance
6. Low vertical wind shear.

Extra tropical/Temperate cyclone:

Extratropical cyclones, sometimes called **mid-latitude cyclones** or **wave cyclones**, are low pressure zones, which along with the anticyclones of high pressure zones, drive the weather over much of the Earth. Extratropical cyclones are capable of producing anything from cloudiness and mild showers to heavy gales and thunderstorms. These types of cyclones are defined as large scale (synoptic) low pressure weather systems that occur in the middle latitudes of the Earth. In contrast with tropical cyclones, they produce rapid changes in temperature and dew point along broad lines about the center of the cyclone called fronts. Extratropical cyclones begin as waves along weather fronts before occluding later in their life cycle as cold-core systems. However, some intense extratropical cyclones can become warm-core systems when a warm seclusion occurs.

Extratropical cyclones form anywhere within the extratropical regions of the Earth (usually between 30° and 60° latitude from the equator), either through cyclogenesis or extratropical transition. A study in the Northern Hemisphere suggests that approximately 234 significant extratropical cyclones form each winter.

Formation of extratropical cyclone: Extratropical cyclones form along linear bands of temperature/dew point gradient with significant vertical wind shear, and are thus classified as baroclinic cyclones. Initially, cyclogenesis, or low pressure formation, occurs along frontal zones near a favourable quadrant of a maximum in the upper level jet stream known as a jet streak. The favourable quadrants are usually at the right rear and left front quadrants, where divergence ensues. The divergence causes air to rush out from the top of the air column. This in turn forces convergence in the low-level wind field and increased upward motion within the column. The increased upward motion causes atmospheric pressure at ground level to lower. This is because the upward air motion counteracts gravity, lessening the weight of the atmosphere in that location. The lowered pressure strengthens the cyclone (a low pressure system). As the cyclone strengthens, the cold front sweeps towards the equator and moves around the back of the cyclone. Meanwhile, its associated warm front progresses more slowly, as the cooler air ahead of the system is denser, and therefore more difficult to dislodge. Later, the cyclones occlude as the poleward portion of the cold front overtakes a section of the warm front, forcing a tongue, or trowal, of warm air aloft. Eventually, the cyclone will become barotropically cold and begin to weaken.

Atmospheric pressure can fall very rapidly when there are strong upper level forces on the system. When pressures fall more than 1 millibar (0.030 in Hg) per hour, the process is called explosive cyclogenesis, and the cyclone can be described as a (weather) bomb. These bombs rapidly drop in pressure to below 980 millibars (28.94 inHg) under favorable conditions such as near a natural temperature gradient like the Gulf Stream, or at a preferred quadrant of an upper level jet streak, where upper level divergence is best. The stronger the upper level divergence over the cyclone, the deeper the cyclone can become.

The windfield of an extratropical cyclone constricts with distance in relation to surface level pressure, with the lowest pressure being found near the center, and the highest winds typically just on the cold/poleward side of warm fronts, occlusions, and cold fronts, where the pressure gradient force is highest. The area poleward and west of the cold and warm fronts connected to extratropical cyclones is known as the cold sector, while the area equatorward and east of its associated cold and warm fronts is known as the warm sector.

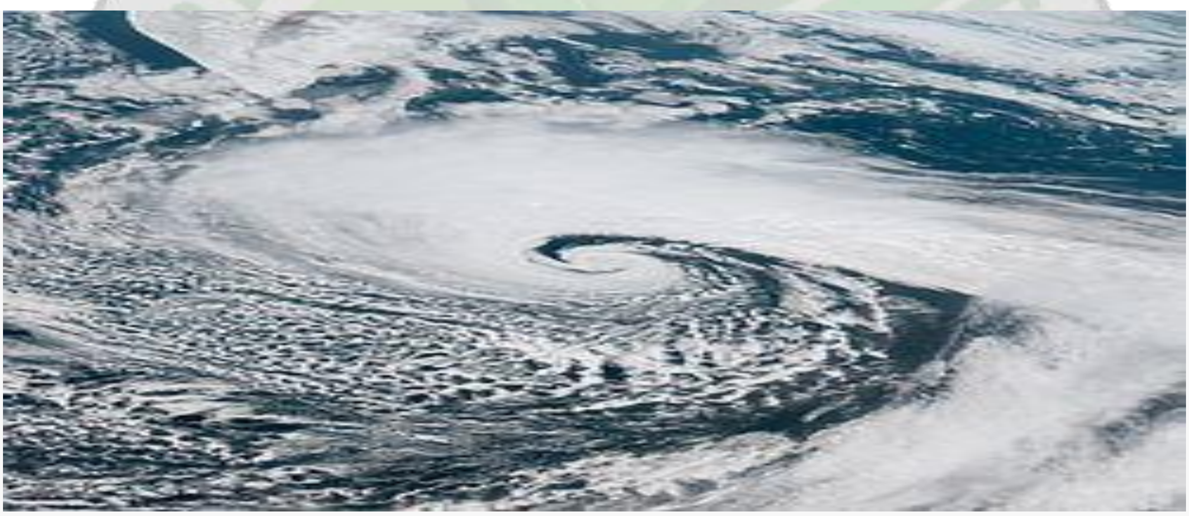


Fig 3: A counter-clockwise spinning extratropical cyclone south of the Kamchatka Peninsula, in the Northern Hemisphere.

The wind flow around an extratropical cyclone is counter-clockwise in the northern hemisphere, and clockwise in the southern hemisphere, due to the Coriolis effect (this manner of rotation is generally referred to as *cyclonic*). Near this center, the pressure gradient force (from the pressure at the center of the cyclone compared to the pressure outside the cyclone) and the Coriolis force must be in an approximate balance for the cyclone to avoid collapsing in on itself as a result of the difference in pressure. The central pressure of the cyclone will lower with increasing maturity, while outside of the cyclone, the sea-level pressure is about average. In most extratropical cyclones, the part of the cold front ahead of the cyclone will develop into a warm front, giving the frontal zone (as drawn on surface weather maps) a wave-like shape. Due to their appearance on satellite images, extratropical cyclones can also be referred to as frontal waves early in their life cycle. In the United States, an old name for such a system is "warm wave".

In the northern hemisphere, once a cyclone occludes, a **tr**ough **o**f **w**arm air **al**oft—or "trowal" for short—will be caused by strong southerly winds on its eastern periphery rotating aloft around its northeast, and ultimately into its north-western periphery (also known as the warm conveyor belt), forcing a surface trough to continue into the cold sector on a similar curve to the occluded front. The trowal creates the portion of an occluded cyclone known as its **comma head**, due to the comma-like shape of the mid-tropospheric cloudiness that accompanies the feature. It can also be the focus of locally heavy precipitation, with thunderstorms possible if the atmosphere along the trowal is unstable enough for convection.

Vertical Structure: Extratropical cyclones slant back into colder air masses and strengthen with height, sometimes exceeding 30,000 feet (approximately 9 km) in depth. Above the surface of the earth, the air temperature near the centre of the cyclone is increasingly colder than the surrounding environment. These characteristics are the direct opposite of those found in their counterparts, tropical cyclones; thus, they are sometimes called "cold-core lows".

Anticyclone:

An anticyclone is a system of winds that rotates around a center of high atmospheric pressure. Anticyclones (commonly known as highs) are predictors of fair weather. Winds in an anticyclone blow just the opposite of the cyclone. In anticyclones, the situation is reversed of cyclone. Air at the centre of an anticyclone is forced away from the high pressure that occurs there. That air is replaced in the center by a downward draft of air from higher altitudes. As this air moves downward, it is compressed and warmed. This warming reduces the humidity of the descending air, which results in few clouds and low humidity in the anticyclone.

Fig 4: Image of Hurricane Diana at its strongest on September 11,1984. The hurricane was just off the coast of South and North Carolina at the time, and winds within it were 130 miles per hour (210 kilometers per hour).

Formation of Anticyclone: The development of anticyclones aloft occurs in warm core cyclones such as tropical cyclones when latent heat caused by the formation of clouds is released aloft increasing the air temperature; the resultant thickness of the atmospheric layer increases high pressure aloft which evacuates their outflow.

Weather Condition during anticyclone: High-pressure systems are frequently associated with light winds at the surface and subsidence through the higher portion of the troposphere. Subsidence will generally dry out an air mass by adiabatic (compressional) heating. Thus, high pressure typically brings clear skies. Because no clouds are present to reflect sunlight during the day, there is more incoming shortwave solar radiation and temperatures rise. At night, the absence of clouds means that outgoing longwave radiation (i.e. heat energy from the surface) is not absorbed, giving cooler diurnal low temperatures in all seasons. When surface winds become light, the subsidence produced directly under a high-pressure system can lead to a buildup of particulates in urban areas under the ridge, leading to widespread haze. If the low level relative humidity rises towards 100 percent overnight, fog can form.

Strong but vertically shallow high-pressure systems moving from higher latitudes to lower latitudes in the northern hemisphere are associated with continental arctic air masses.[12] The low, sharp inversion can lead to areas of persistent stratocumulus or stratus cloud, colloquially known as anticyclonic gloom. The type of weather brought about by an anticyclone depends on its origin. For example, extensions of the Azores high pressure may bring about anticyclonic gloom during the winter because they are warmed at the base and trap moisture as they move over the warmer oceans. High pressures that build to the north and extend southwards often bring clear weather because they are cooled at the base (as opposed to warmed) which helps prevent clouds from forming.

Chapter 3

SOLAR RADIATION

Solar radiation is the prime source of energy on earth and life depends on it. Solar radiation is defined as ―the flux of radiant energy from the sun‖. All matter at a temperature above the absolute zero emits energy from the surrounding space. This energy is transformed by green plants in the process of photosynthesis into the potential energy of organic material. In the organic bodies the rays absorbed are used in heating. The variations of the total radiation flux from one site to another on the surface of the earth are enormous and the distribution of plants and animals responds to this variation.

Sun

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 M km). 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, reradiation from the earth etc.

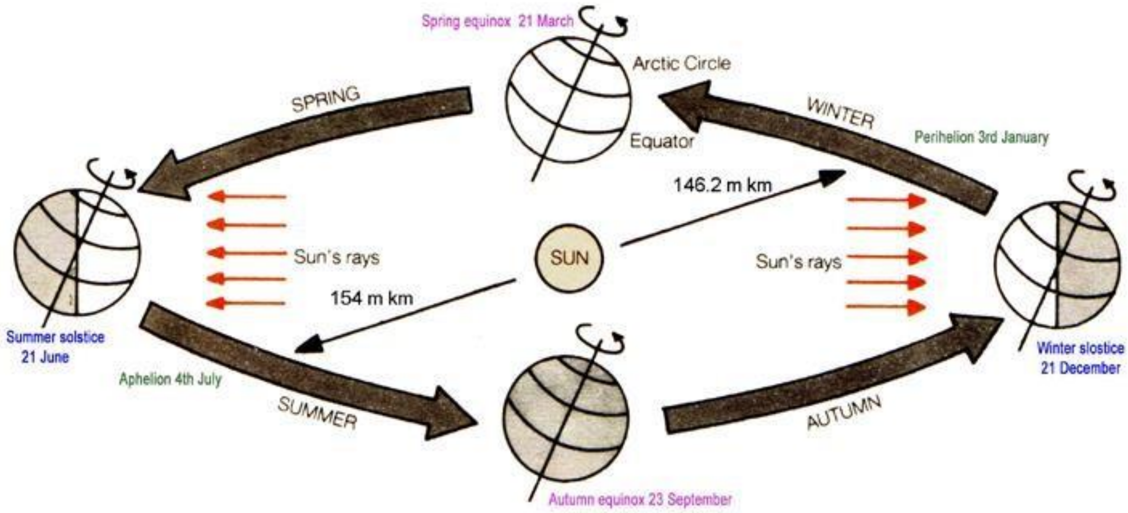


Fig. Movement of earth around sun

Insolation

Electromagnetic 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

Solar radiation is the set of electromagnetic radiation emitted by the Sun. The solar radiation ranges goes from infrared to ultraviolet.

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 $cm^2 min^{-1}$**	**W cm^2**
Cal $cm^2 min^{-1}$	1	4.1868	0.0669
J $cm^2 min^{-1}$	0.238	1	0.00165
W cm^2	14.3	60.6	1

Solar spectrum-

Radiant energy is transmitted in the form of electromagnetic waves by the sun. The energy from the sun is spread over a very broad band of wavelengths known as solar spectrum. It is also known as electromagnetic spectrum. The spectrum does not constitute only one band but a combination of different waves which are characterized individually.

Band	**Spectrum**	**Wavelength (μ)**	**Importance**

Ultra	Cosmic rays	<0.005	Shorter wavelengths of spectrum and chemically active, unless filtered there is danger of life on earth
	Gamma and X-rays	0.005-0.20	
	Ultraviolet rays	0.20-0.39	
Visible (Light)	Violet	0.39-0.42	Visible spectrum known as light essential for all plant processes
	Indigo	0.42-0.45	
	Blue	0.45-0.49	
	Green	0.49-0.54	
	Yellow	0.54-0.59	
	Orange	0.59-0.65	
	Red	0.65-0.76	
Infrared	Infrared rays	>0.76	Essential for thermal energy of plant (source of heat)

The energy contains between the 200 and 390 nm (0.20-0.39 µ) wavelengths and it is divided into ultraviolet radiation, visible light and infrared radiation.

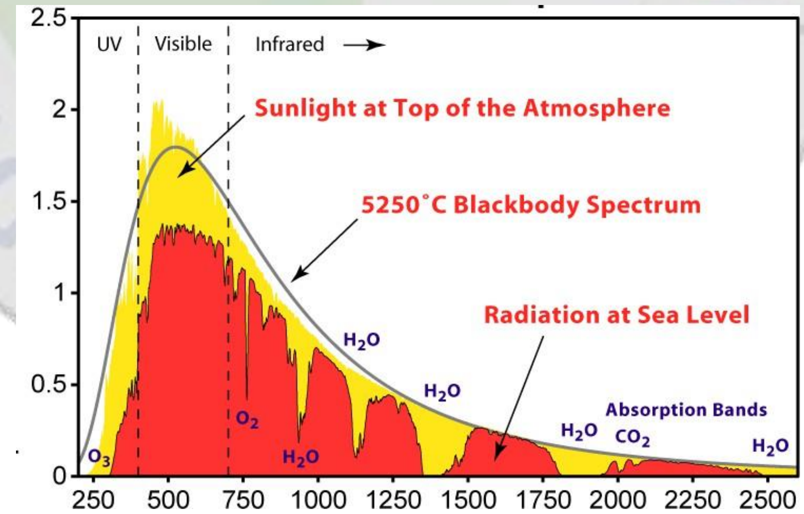
Ultraviolet radiation: Consists of the shorter wavelengths band (360 nm), it has a lot of energy and interacts with the molecular bonds. These waves are absorbed by the upper atmosphere, especially by the ozone layer.

Visible Light: This radiation band corresponds to the visible area with wavelengths between 360 nm (violet) and 760 nm (red), it has a great influence on living beings.

Infrared radiation: Consists of wavelengths between 760 and 4000 nm, it corresponds to the longer wavelengths and it has little energy associated with it. Its absorption increases molecular agitation, causing the increase of temperature.

Solar spectrum

Spectral irradiance (W/m^2/nm)



Wavelength (nm)

Fig. Spectrum of solar radiation above the atmosphere and sea level.

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 X-rays 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	Wavelengths (nm)	Specific effect on plants
1	Radiation within 1000 and more	No specific effect on plant activity. Radiation absorbed by plants are transformed into heat. The radiation does not interfere with biochemical processes.
2	1000-720	Radiation in the band helps in plant elongation, can be accepted as an adequate measure of plant elongation activity. The far red region (700-900nm) has important role on photoperiodism, germination of seedsflowering and colouration of fruits.
3	720-510	In this spectral region light is strongly absorbed by chlorophylls. It generates strong photosynthetic and photoperiodic activity.
4	610-510	Green-yellow region. Absorption in the spectral region has

		low photosynthetic effectiveness and weak formative activity.
5	510-400	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 of plants.
8	Less than 280	Lethal effect on most of the plants get killed due to reduction in the 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.

Earth’s energy budget-

Not all the radiation reaches Earth's surface, because the ultraviolet wavelengths, that are the shorter wavelengths, are absorbed by gases in the atmosphere, primarily by ozone. The atmosphere acts as a filter to the bands of solar spectrum, and at its different layers as solar radiation passes through it to the Earth's surface, so that only a fraction of it reaches the surface. The atmosphere absorbs part of the radiation reflects and scatters the rest some directly back to space, and some to the Earth, and then it is irradiated. All of this produce a thermal balance, resulting in radiant equilibrium cycle.

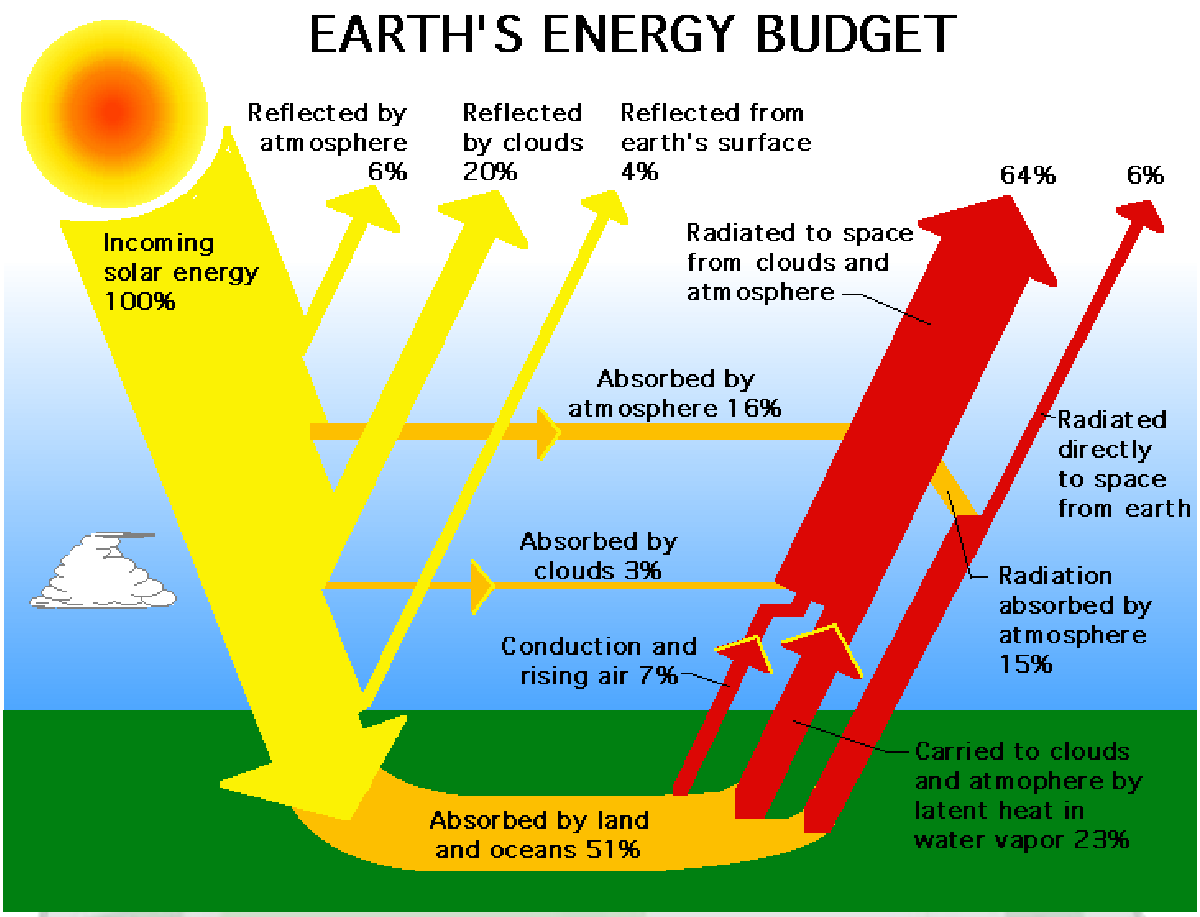
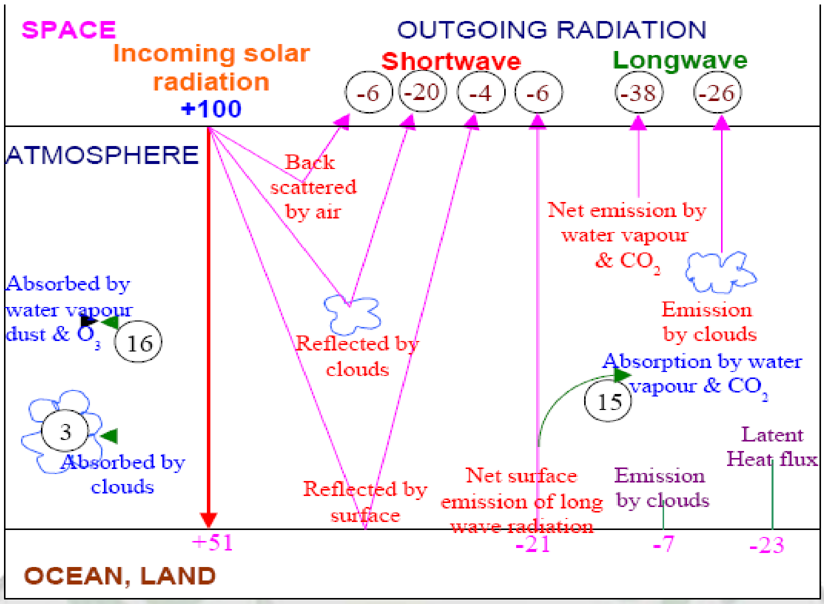


Fig. Effects of clouds on the Earth's Energy Budget.

Depending on the type of radiation, it is known that the 324 Wm-2 reaching the Earth in the upper atmosphere (1400 Wm-2 is the solar constant), 236 Wm-2 are reissued into space infrared radiation, 86 Wm-2 are reflected by the clouds and 20 Wm-2 are reflected by the ground as short-wave radiation. But part of the re-emitted energy is absorbed by the atmosphere and returned to the earth surface, causing the "greenhouse effect". The average energy that reaches the outside edge of the atmosphere from the sun is a fixed amount, called solar constant.

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 Infrared.

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%

Clouds: 55%.

High albedo indicates that much of the incident solar radiation is reflected rather than absorbed.

Depends 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 f—or 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

$$\lambda = c/v$$

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

C = Velocity of light ($3x10^{10}$ 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)

$$E = \sigma T4$$

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

$$\lambda max = 2897\ T^{-1}\ \mu = 2897/T\ \mu$$

Where T is in ºK
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 λmax 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. Within 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, O_3, CO_2 & H_2O 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 infrared (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

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 are 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 UV and violet ray of the sun.

Chapter 4

AIR TEMPERATURE

Temperature is defined as, ―The measure of speed per molecule of all the molecules of a body‖. Whereas 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 are 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 Temperature Distribution

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.

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.

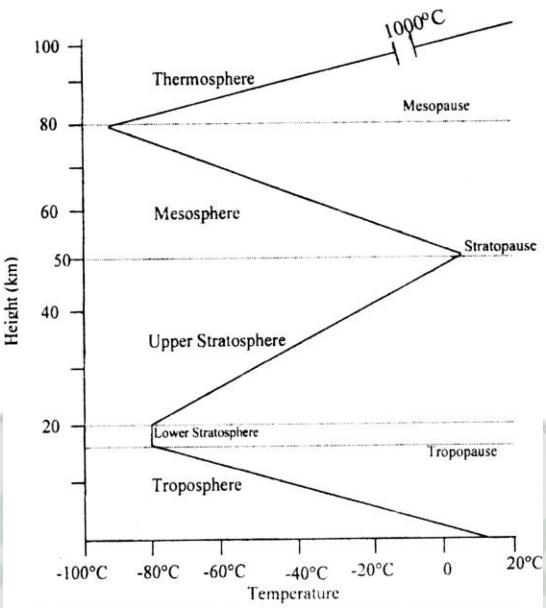
4). The temperature of this layer increases with height and also depends upon the troposphere because the troposphere is higher at the equator than at the poles.

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.



TEMPERATURE BASED VERTICAL LAYERS OF ATMOSPHERE

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 and Adiabatic Processes

First, we need to understand what a lapse rate is. The atmospheric lapse rate is the change in temperature with height. For example, on average the temperature cools 6.5 C for every kilometer. Of course, this varies from location to location. We can use observations to determine the lapse rate of a particular location. The observations are gathered from a miniature weather-monitoring station (smaller than a shoe box) that is attached to a balloon and released into the air twice a day at various sites throughout the world (a radiosonde).

The value of the lapse rate is strongly dependent on the amount of water vapor in the air. Dry air cools at about 10 C/km (the 'dry adiabatic lapse rate'), while moist air usually cools at less than 6 C/km ('moist adiabatic lapse rate'). The word adiabatic means that no outside heat is involved in the warming or cooling of the air parcels.

Why are the two lapse rates different? Remember that water vapor in a rising parcel of air will condense when the air becomes cold enough. The phase change from gas to liquid takes a little work from the water molecules. As they are working, they release heat. The heat decreases the cooling that occurs in the air parcel. Therefore, a rising parcel of dry air cools faster than a moist parcel of air. And conversely, a sinking parcel of dry air warms faster than a sinking parcel of moist air.

Now apply these concepts to mountains. Moist air that reaches a mountain range is forced to rise. The rising air cools at the moist adiabatic lapse rate and eventually some or all of the water vapor will condense. If the conditions are right, a cloud will form and it will either rain or snow. The air continues to flow over the mountain range and eventually descends on the other side. The sinking air warms. Since the air has lost much of its moisture through precipitation, it warms at the dry adiabatic lapse rate, which is greater than the moist adiabatic lapse rate. This means the air is now drier and warmer than it was before it encountered the mountain range.

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.

$$GDD = \Sigma \frac{Tmax + Tmin}{2} - Tb$$

Where

Tmax – Maximum air temperature of the day

Tmin – Minimum air temperature of the day

Tb - 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.

HEAT 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 CO2 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 microorganisms live in the soil. The physiochemical 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 affected. 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 southeast 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 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 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.

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

Kinetic energy is form of energy that an object or a particle has by reason of its motion. If work, which transfers energy, is done on an object by applying a net force, the object speeds up and thereby gains kinetic energy. Kinetic energy is a property of a moving object or particle and depends not only on its motion but also on its mass. Translational kinetic energy of a body is equal to one-half the product of its mass, *m*, and the square of its velocity, *v*, or $1/2mv^2$.

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 it is 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. Within 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 & H_2O 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 infrared (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.

Chapter 5

HUMIDITY

Humidity is the general term which describes the invisible amount of water vapour present in the air. It is a highly variable climatic factor which forms only a small proportion (varying from zero to four per cent and averaging around 2% in the atmosphere.) Humidity is measured by an instrument called hygrometer.

Water vapour in the atmosphere comes through evaporation from the oceans, lakes, rivers, ice-fields and glaciers, through transpiration from plants and respiration from animals.

Significance of Atmospheric Moisture:

1. The water vapour present in rain-bearing clouds is responsible for all kinds of precipitation, and the amount of water vapour present in a given volume of air indicates the atmosphere‘s potential capacity for precipitation.

2. Water vapour absorbs radiation—both incoming and terrestrial. It thus plays a crucial role in the earth‘s heat budget.

3. The amount of water vapour present decides the quantity of latent energy stored up in the atmosphere for development of storms and cyclones.

4. The atmospheric moisture affects the human body‘s rate of cooling by influencing the sensible temperature.

Humidity is a general term and can be expressed quantitatively in different ways.

Absolute Humidity:

It is the weight of actual amount of water vapour present in a unit volume of air. It is usually expressed as grams per cubic metre of air. Absolute humidity of the atmosphere changes from place to place and from time to time. The ability of air to hold water vapour depends entirely on its temperature. Warm air can hold more moisture than cold air. For instance, at a temperature of 10°C, one cubic metre of air can hold 11.4 grams of water vapour.

The same volume of air can hold 22.2 grams of water vapour, once the temperature rises to 21°C. Thus, a rise in the temperature of air increases its capacity to retain water vapour, whereas a fall in temperature decreases it. However, it is not a very reliable index because changes in temperature and pressure cause changes in the volume of air and consequently the absolute humidity.

Relative Humidity

It is a more practical measure of atmospheric moisture. It is the ratio of the air‘s actual water vapour content to its water vapour capacity at a given temperature. This relationship between absolute humidity and the maximum moisture holding capacity of air at a particular temperature is always expressed in percentage.

Since, the relative humidity is based on the air's water vapour content as well as on its capacity, it can be changed in either of the two ways:

(i) If moisture is added by evaporation, the relative humidity will increase.

(ii) A decrease in temperature (hence, decrease in moisture-holding capacity) will cause an increase in relative humidity.

The relative humidity determines the amount and rate of evaporation and hence it is an important climatic factor. Air containing moisture to its full capacity at a given temperature is said to be _saturated‘. At this temperature, the air cannot hold any additional amount of moisture. Thus, relative humidity of the saturated air is 100%. If it has half the amount of moisture that it can carry, the air is unsaturated and its relative humidity is only 50%.

A given sample of air becomes saturated without any actual change in its moisture content, provided its temperature falls or it cools to the required extent. The temperature at which saturation occurs in a given sample of air or water vapour begins to change into water is known as the dew point.

Specific Humidity

It is expressed as the weight of water vapour per unit weight of air, or the proportion of the mass of water vapour to the total mass of air. Since it is measured in units of weight (usually grams per kilogram), the specific humidity is not affected by changes in pressure or temperature.

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.

Concept of saturation

When we think of air as being saturated with moisture we often say that the air is "holding all the moisture it can". This implies that once the air has reached saturation it won't "accept" anymore water by evaporation. This is wrong. So long as there is water available evaporation will continue even when the air is fully saturated. Let's examine the concept of saturation in more detail.

Imagine a beaker filled halfway with water. Let's put a top on it to constrain the movement of water molecules and eliminate the influence of wind on evaporation. As the water absorbs heat it begins to change phase and enter the air as water vapor. Above the surface, water vapor molecules dart about suspended in the air. However, near the surface water molecules are attaching themselves back the surface, thus changing back into liquid water (condensation) (A). As evaporation occurs the water level in the beaker decreases (B). This occurs because evaporation exceeds condensation of water back onto the surface. After some time, the amount of water entering the air from evaporation is equal to that condensing (C). When this occurs the air is said to be saturated.

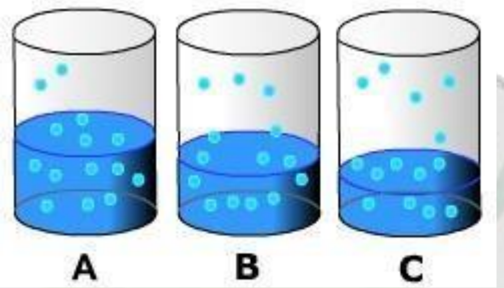


Figure: Evaporation and condensation in an enclosed beaker of water.

The saturation level of the air is directly related to the air's temperature. As air temperature increases, more water can remain in a gas phase. As temperature decreases, water molecules slow down and there is a greater chance for them to condense on to surfaces. The graph below shows the relationship between air temperature and vapor pressure, a measure of the humidity, at saturation.

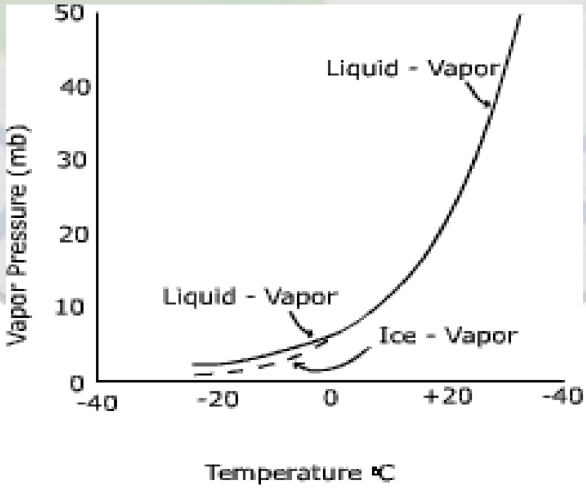


Fig.: Relationship between Air Temperature and Vapour Pressure

Note that below zero degrees Celsius the curve splits, one for the saturation point above a liquid surface (liquid-vapor) and one for a surface of ice (ice - vapor). The first thing you might be wondering is how water can exist as a liquid below the freezing point. Water that is not frozen below 0^o C is called "super-cooled water". For water to freeze, the molecules must become properly aligned to attach to one another. This is less likely to occur especially with small amounts of water, like cloud droplets. Thus in clouds where temperatures are below freezing it is common to find both super-cooled liquid water and ice crystals.

Notice that the saturation vapour pressure at -20^o C is lower for ice than for a liquid surface. Why would this be so? You may recall that to convert water from a liquid to a gas requires about 600 calories per gram. To convert water from a solid to a gas requires about 680 calories, hence it is more difficult to "liberate" a molecule of water from ice than water. Therefore, when the air is saturated, there are more molecules above a water surface (i.e. more vapor pressure) than an ice surface (i.e. less vapour pressure).

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).

Distribution of Water Vapour

Latitudinally, the atmospheric moisture decreases from the equator towards the poles in an irregular manner with the latitudinal temperature gradient. The marine air may be saturated to the extent of 80%, while the continental air may be only saturated up to 20%. With altitude, the capacity of air to hold moisture decreases because the temperature also decreases. Looking at the diurnal variation, the absolute humidity is high during the afternoon and comes down as the temperature comes down. The relative humidity is the lowest during early morning, especially after long, calm, clear nights due to low capacity of the air to hold moisture at a low temperature.

Condensation:

Condensation is the process of change of state from gaseous to liquid or solid state. When moist air is cooled, it may reach a level when its capacity to hold water vapour is exceeded by the actual amount present in it. Then, the excess water vapour condenses into a liquid or solid form depending upon the temperature. In free air, condensation results from cooling around very small particles termed _condensation nuclei‘. Particles of dust, smoke and salt from the oceans are particularly good nuclei because they absorb water. These particles are termed ―hygroscopic (water-seeking) nuclei‘.

Condensation in air itself can only take place if the air temperature is reduced to below the dew point. As the dew point of any mass of air is its saturation point, when its relative humidity is 100%, a little more cooling will bring the point to the level where condensation takes place, i.e. when water vapour changes into clouds or rain. In contrast, when the relative humidity is low, a large amount of cooling is required to first reach the dew point and then the condensation. Condensation, therefore, depends upon—(i) the amount of cooling and (ii) relative humidity of the air.

Condensation occurs under varying conditions which, in some way or the other, are associated with change in any of these variables—air volume, temperature, pressure and humidity.

Thus condensation takes place:

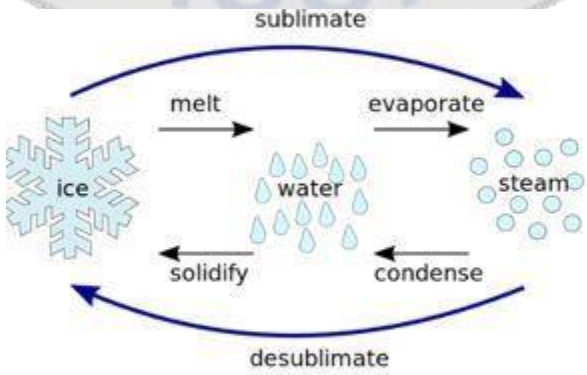
(i) When the temperature of the air is reduced but its volume remains constant and the air is cooled below the dew point; (ii) if the volume of the air is increased without addition of heat;

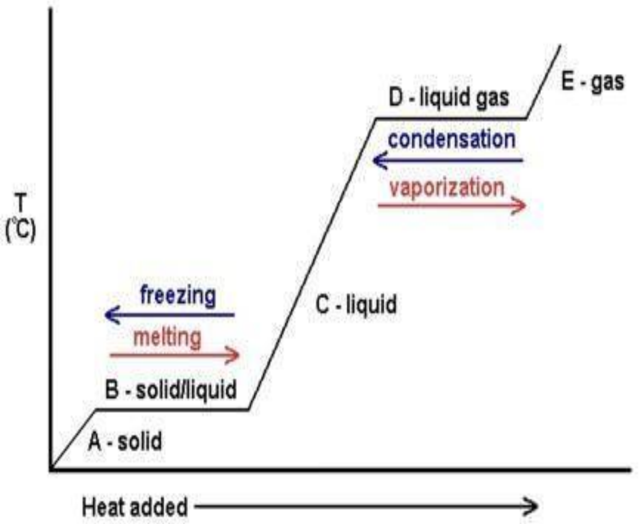
(iii) When the joint change of temperature and volume reduces the moisture holding capacity of the air below its existing moisture content; –

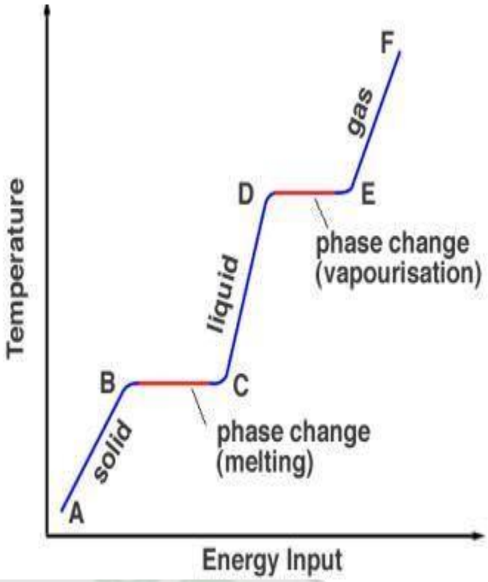
(iv) By evaporation adding moisture to the air. The most common circumstances favourable for condensation are those producing a drop in air temperature. .

Process of condensation

- ✓ The transformation of **water vapour into water** is called **condensation**.
- ✓ Condensation is caused by the **loss of heat** (**latent heat of condensation, opposite of latent heat of vaporization).**
- ✓ When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases (Saturation Point = 100% Relative Humidity = Dew Point reached). Then, the excess water vapour condenses into liquid form. If it directly condenses into solid form, it is known as **sublimation**.







- ✓ In free air, condensation results from cooling around very small particles termed as **hygroscopic condensation nuclei**. Particles of **dust, smoke, pollen** and **salt** from the ocean are particularly good nuclei because they absorb water.
- ✓ Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the **dew point.**
- ✓ Condensation, therefore, depends upon the **amount of cooling** and the **relative humidity** of the air.
- ✓ Condensation takes place:

1. when the temperature of the air is **reduced to dew point** with its volume remaining constant (**adiabatically**),
2. when both the volume and the temperature are reduced,
3. when moisture is added to the air through evaporation,

- ✓ After condensation the water vapour or the moisture in the atmosphere takes one of the following forms — **dew, frost, fog and clouds**.
- ✓ **Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.**

Processes of Cooling for Producing Condensation

- ✓ These processes can be studied under the‖ headings, **adiabatic and non-adiabatic.**

Adiabatic Temperature Changes

- ✓ When the air rises, it expands. Thus, heat available per unit volume is reduced and, therefore, the temperature is also reduced. Such a temperature change which does not involve any subtraction of heat, and cooling of air takes place only by ascent and expansion, is termed _adiabatic change‘.

- ✓ The vertical displacement of the air is the major cause of **adiabatic and katabatic** (cold, dense air flowing down a slope) temperature changes.
- ✓ Near the earth‘s surface, most processes of change are **non-adiabatic** because horizontal movements often produce mixing of air and modify its characteristics.

Non-Adiabatic Temperature Changes

- ✓ Non-adiabatic processes include cooling by **radiation, conduction or mixing** with colder air. The air may be cooled due to loss of heat by radiation.
- ✓ In case there is direct radiation from moist air, the cooling produces **fog or clouds**, subject to presence of hygroscopic nuclei in the air.
- ✓ Cooling by contact with a cold surface produces **dew, frost or fog** depending on other atmospheric conditions.
- ✓ But the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere.
- ✓ The non-adiabatic processes of cooling produce only dew, fog or frost. They are **incapable** of producing a substantial amount of precipitation.

Forms of Condensation

- ✓ The forms of condensation can be classified on the basis of temperature at which the dew point is reached.
- ✓ Condensation can take place when the dew point is
- ✓ **Lower than the freezing point,**
- ✓ **Higher than the freezing point.**
- ✓ **White frost, snow and some clouds (cirrus clouds)** are produced when the temperature is lower than the freezing point.
- ✓ **Dew, fog and clouds** result even when the temperature is higher than the freezing point.
- ✓ Forms of condensation may also be classified on the basis of their location, i.e. at or near the earth‘s surface and in free air.
- ✓ **Dew, white frost, fog and mist** come in the first category, whereas **clouds** are in the second category.

Dew

- ✓ When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as dew.
- ✓ The ideal conditions for its formation are **clear sky, calm air, high relative humidity**, and **cold and long nights**.
- ✓ For the formation of dew, it is necessary that the **dew point is above the freezing point.**

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

White Frost

- Frost forms on cold surfaces when condensation takes place **below freezing point (0° C)**, i.e. the **dew point** is at or below the freezing point.
- The excess moisture is deposited in the form of **minute ice crystals** instead of water droplets.
- The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the **air temperature must be at or below the freezing point.**

Fog

- When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden, condensation takes place within itself on fine dust particles.

- ✓ So, the fog is a **cloud with its base at or very near to the ground**. Because of the **fog and mist**, the visibility becomes poor to zero.
- ✓ In urban and industrial centers smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke, is described as **smog (will be discussed in detail in next post).** [Related Question Asked in Mains 2015: ***Mumbai, Delhi and Kolkata are the three mega cities of the country but the air pollution is much more serious problem in Delhi as compared to the other two. Why is this so?]***
- ✓ **Radiation fog** results from radiation, cooling of the ground and adjacent air. These fogs are **not very thick**. Usual in winters.
- ✓ Fogs formed by condensation of warm air when it moves horizontally over a cold surface, are known as **advectional fog**. These fogs are **thick and persistent**. Occurs over warm and cold water mixing zones in oceans.
- ✓ **Frontal or precipitation fog** is produced due to convergence of warm and cold air masses where warm air mass is pushed under by the heavier cold air mass.
- ✓ Precipitation in the warm air mass condenses to produce fog at the boundary of the two air masses. These are called **frontal or precipitation fog.**
- ✓ **In fog visibility is less than one kilometer**.

Mist

- ✓ The difference between the mist and fog is that mist contains more moisture than fog.
- ✓ In mist each nuclei contains a thicker layer of moisture.

- ✓ Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface.
- ✓ Mist is also formed by water droplets, but with less merging or coalescing. This means mist is less dense and quicker to dissipate.
- ✓ Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents.
- ✓ **In mist visibility is more than one kilometer but less than two kilometres.**

Haze

- ✓ Haze is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky (No condensation. Smog is similar to haze but there is condensation in smog).

- ✓ Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires.

Smog

- ✓ Smog = smoke + fog (smoky fog) caused by the burning of large amounts of coal, vehicular emission and industrial fumes (Primary pollutants).

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:

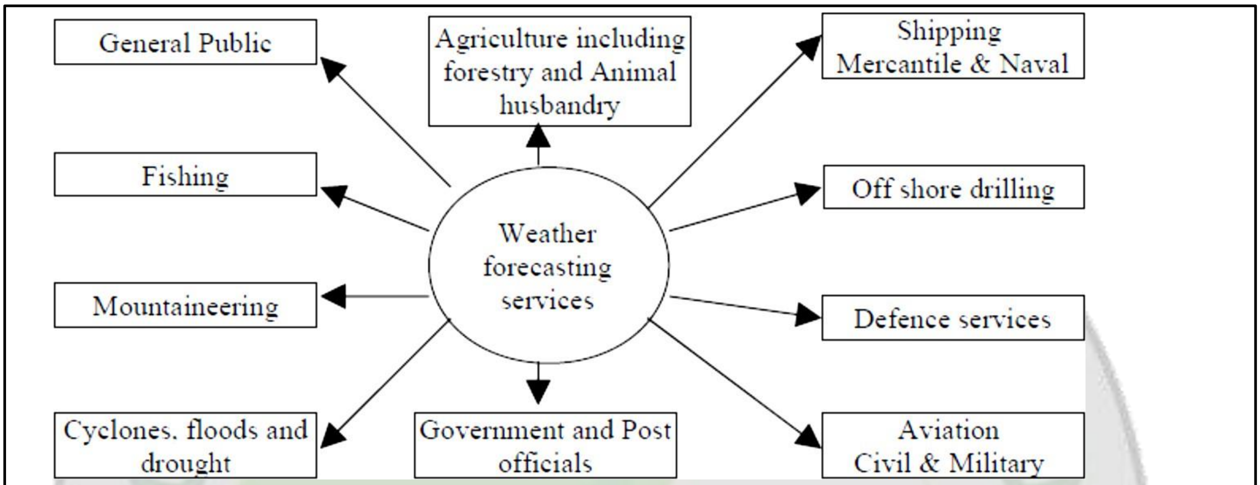
1. Absolute humidity is highest at the equator and minimum at the poles.
2. Absolute humidity is minimum at sunrise and maximum in afternoon from 2 to 3 p.m. The diurnal variations are small in desert regions.
3. The relative humidity is maximum at about the sunrise and minimum between 2 to 3 p.m.
4. 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.

Chapter 6

WEATHER FORECASTING

Climatic Normal

The climatic normal is 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 normal 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 the season is called weather forecast. The Table 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

- Nowcast : A short-time weather forecast issued generally for the next few hours
- Short range forecast: A short term weather forecast issued for 24 hours with an outlook for another 24 hours
- Medium range forecast: A weather forecast issued for a period extending from about three days to seven / ten days in advance.
- Long range forecast: A weather forecast issued for a period greater than seven days in advance and up to a season of more than three months.
- Seasonal climate Forecast: A weather forecast issued for a season especially for rain for taking farm decisions (Response farming)

Types of forecast	**Validity period**	**Main users**	**Predictions**
1. Short range a) Now casting	Upto 72 hours 0 -2 hours	Farmers, marine agencies, general public	Rainfall distribution, heavy rainfall, heat and cold wave, thunder storms
b) Very short range	0-12 hours		
2. Medium range	Beyond 3 days and up to 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 outlooks are usually expressed in the form of expected deviation from normal condition.

Name of the Weather forecast	**Issued by**	**Forecasted Weather elements**	**Methods used in India**	**Lead time**	**Accuracy (%)**
Now casting	IMD	Thunder storm, dust storm Cold and heat waves	Synoptic and weather map	One to two hours earlier	90-98
Short range	IMD	Cloud spread, rainfall, temperature, cyclone warning	Synoptic and weather map, NWP	One day	80-90
Medium range	IMD	Rainfall, temperature, RH, wind speed, wind direction and cloud cover	GNWPM, RCM	3- 10 days	70- 75
Long range	IMD	Seasonal rainfall	Statistical regression like ARIMA model	30 to 40 days	60

Methods of weather forecasting

Methods of forecasting	Characters
Synoptic method	Using weather elements observations at surface level and upper level,(synoptic) made from different locations, chart is prepared to indicate present status of atmosphere. Present weather and past weather chart + satellite information of the present + analogue analysis
Statistical method	Multiple regression, ARIMA
Numerical weather prediction	Equations drawn from Coriolis force, frictional force pressure gradient force and gravitational force are integrated in to multiple equations and it becomes model. Model is run from present to future. Initial condition is very important.

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 types 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.

Climate change and Global Warming

Climate change is any significant long-term change in the expected patterns of average weather of region (or the whole Earth) over a significant period of time. It is about non-normal variations to the climate, and the effects of these variations on other parts of the Earth. These changes may take tens, hundreds or perhaps millions of year. But increased in anthropogenic activities such as industrialization, urbanization, deforestation, agriculture, change in land use pattern etc. leads to emission of greenhouse gases due to which the rate of climate change is much faster. Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. There are three ways in which the Greenhouse Effect may be important for agriculture. First, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO_2-induced changes of climate may alter levels of temperature, rainfall and sunshine that can influence plant and animal productivity. Finally, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in coastal areas. The greenhouse effect is a natural process that plays a major part in shaping the earth‘s climate. It produces the relatively warm and hospitable environment near the earth‘s surface where humans and other life-forms have been able to develop and prosper. However, the increased level of greenhouse gases (GHGs) (carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) etc) due to anthropogenic activities has contributed to an overall increase of the earth‘s temperature, leading to a global warming. The average global surface temperature have increased by 0.74 ^oC since the late 19th Century and is expected to increase by 1.4 ^oC - 5.8 ^oC by 2100 AD with significant regional variations (IPCC, 2007). The atmospheric CO_2 concentration has increased from 280 ppm to 395 ppm, CH_4 concentration increased from 715 ppb to 1882 ppb and N_2O concentration from 227 ppb to 323 ppb from the year 1750 and 2012. The Global Warming Potential (GWP) of these gases i.e, CO_2, CH_4 and N_2O are 1, 25 and 310 respectively.

	Weather	**Climate**
Definition	Weather is the state of the atmosphere on a current day at a current time. It changes day to day.	Climate is the average conditions that are expected at a certain place over a number of years.
Components	Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, excessive heat, heat waves and more.	Climate may include precipitation, temperature, humidity, sunshine, and wind velocity, phenomena such as fog, frost, and hail storms over a long period of time.
Forecast	Day to day forecast can be done depending on the air pressure, temperature and other similar factors.	Climate forecast can only be done over longer periods of time, such as 30 years. The average of weather over 30 years helps determine the climate of a certain area.
Determined by	Real-time measurements of atmospheric pressure, temperature, wind speed and direction, humidity, precipitation, could cover, etc.	Aggregating weather statistics over periods of 30 years
Study	Meteorology	Climatology

Climate variability

The temporal changes in weather phenomena, which is part of general circulation of atmosphere and occur 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, landslides, thunder clouds associated with lightening and forest fires are uncommon over one or other region of the world.

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 from 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 greenhouse gases especially CO_2

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 greenhouse gases and aerosols.

Effects of climate change

1. The increase concentration of CO_2 and other greenhouse 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.

Detecting climate trends is complicated by the fact that there are many natural variations in temperature, precipitation, and other climate variables. These natural variations are caused by many different processes that can occur across a wide range of timescales— from a particularly warm summer or snowy winter to changes over many millions of years. Among the most well-known short-term climatic fluctuations are El Niño and La Niña, which are periods of natural warming and cooling in the tropical Pacific Ocean. Strong El Niño and La Niña events are associated with significant year-to-year changes in temperature and rainfall patterns across many parts of the planet, including the United States. These events have been linked to a number of extreme weather events, such as the 1992 flooding in midwestern states and the severe droughts in south-eastern states in 2006 and 2007. Globally, temperatures tend to be higher during El Niño periods, such as 1998, and lower during La Niña years, such as 2008. However, these up-and-down fluctuations are smaller than the 20th century warming trend; 2008 was still quite a warm year in the long-term record. Natural climate variations can also be forced by slow changes in the Earth‘s orbit around the Sun that affect the solar energy received by Earth, as is the case with the Ice Age cycle or by short- term changes in the amount of volcanic aerosols in the atmosphere. Major eruptions, like that of Mount Pinatubo in 1991, spew huge amounts of particles into the stratosphere that cool Earth. However, surface temperatures typically rebound in 2-5 years as the particles settle out of the atmosphere. The short-term cooling effects of several large volcanic eruptions can be seen in the 20th century temperature record, as can the global temperature variations associated with several strong El Niño and La Niña events, but an overall warming trend is still evident. In order to put El Niño and La Niña events and other short-term natural fluctuations into perspective, climate scientists examine trends over several decades or longer when assessing the human influence on the climate system. Based on a rigorous assessment of available temperature records, climate forcing estimates, and sources of natural climate variability, scientists have concluded that there is a more than 90% chance that most of the observed global warming trend over the past 50 to 60 years can be attributed to emissions from the burning of fossil fuels and other human activities. Scientists have used models to simulate what would have happened if humans had not modified Earth's climate during the 20th century—that is, how global temperatures would have evolved if only natural factors (volcanoes, the Sun, and internal climate variability) were influencing the climate system. These ―undisturbed Earth‖ simulations predict that, in the absence of human activities, there would have been negligible warming, or even a slight cooling, over the 20th century. When greenhouse gas emissions and other activities are included in the models, however, the resulting surface temperature changes more closely resemble the observed changes.

Climate change – mitigation and adaptation in agriculture

1. Assist farmers in coping with current climatic risks by providing value-added weather services to farmers. Farmers can adapt to climate changes to some degree by shifting planting dates, choosing varieties with different growth duration, or changing crop rotations.
2. An Early warning system should be put in place to monitor changes in pest and disease outbreaks. The overall pest control strategy should be based on integrated pest management because it takes care of multiple pests in a given climatic scenario.
3. Participatory and formal plant breeding to develop climate-resilient crop varieties that can tolerate higher temperatures, drought and salinity.
4. Developing short-duration crop varieties that can mature before the peak heat phase set in.
5. Selecting genotype in crops that have a higher per day yield potential to counter yield loss from heat-induced reduction in growing periods.
6. Preventive measures for drought that include on-farm reservoirs in medium lands, growing of pulses and oilseeds instead of rice in uplands, ridges and furrow system in cotton crops, growing of intercrops in place of pure crops in uplands, land grading and leveling, stabilization of field bunds by stone and grasses, graded line bunds, contour trenching for runoff collection, conservation furrows, mulching and more application of Farm yard manure (FYM).
7. Efficient water use such as frequent but shallow irrigation, drip and sprinkler irrigation for high value crops, irrigation at critical stages.
8. Efficient fertilizer use such as optimum fertilizer dose, split application of nitrogenous and potassium fertilizers, deep placement, use of *neem*, *karanja* products and other such nitrification inhibitors, liming of acid soils, use of micronutrients such as zinc and boron, use of sulphur in oilseed crops, integrated nutrient management.
9. Seasonal weather forecasts could be used as a supportive measure to optimize planting and irrigation patterns.
10. Provide greater coverage of weather linked agriculture-insurance.
11. Intensify the food production system by improving the technology and input delivery system.
12. Adopt resource conservation technologies such as no-tillage, laser land leveling, direct seeding of rice and crop diversification which will help in reducing in the global warming potential. Crop diversification can be done by growing non-paddy crops in rain fed uplands to perform better under prolonged soil moisture stress in kharif.
13. Develop a long-term land use plan for ensuring food security and climatic resilience.
14. National grid grain storages at the household/ community level to the district level must be established to ensure local food security and stabilize.

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