LECTURE 1

MEANING AND SCOPE OF AGRICULTURAL METEOROLOGY

Successful crop production requires suitable combinations of several factors like climate, soil, water, crop species etc. Between these, climate is prime importance. It is often rightly said that 50 per cent of the variations in crop yields are due to climatic conditions alone. Since every farmer has to live with the local climatic conditions and he cannot exercise any control over them, therefore, it is essential to study the climate as science.

Every growth phases of a plant is influenced by the prevailing weather conditions. Each crop has its own weather requirement for the expression of its full yield potential. It is known fact that the occurrence of pests and diseases in crop plants is closely related to weather conditions. So, knowledge of weather parameters and their effects on growth and yield of crops is essential in successful crop production.

Meteorology: The word meteorology has been derived from the greek words **"Meteoros"** means "things up, above" or "lower atmosphere" and **"Logus"** means "study or science" hence the meaning of meteorology is **the study of things up above the earth or the study of lower atmosphere.**

Meaning of the word meteorology was given by Aristotle (384-322 B.C.).He has defined meteorology as a study of lower atmosphere (Meteoros = Lower atmosphere and logus means science / study). Human interest in weather is , therefore, inevitable.

DEFINITIONS OF METEOROLOGY

1. Meteorology is the science dealing with physics of atmosphere.
2. Meteorology is defined as the science of atmosphere.
3. Aristotle defined meteorology as a study of lower atmosphere.
4. Meteorology is a branch of physics of the earth dealing with physical processes in the atmosphere that produce water.
5. Meteorology is defined as the science of atmosphere and its phenomena, especially those phenomena which we call collectively as weather and climate.
6. Meteorology can be defined as the science of atmosphere which deals with physics, chemistry and dynamics of the atmosphere and also their direct and indirect effects on the earth surface and thereby on the life.

SCOPE OF METEOROLOGY IN GENERAL

Almost all social, industrial, agricultural, commercial, transport etc. activities are directly or indirectly affected by weather and climate. The atmosphere affects and sustains human life, animal life, micro-organisms, insects, pests, plants, trees, forests, and marine culture at all times during every stage of growth and development. Therefore, meteorology has the greatest scope on every human enterprise in the modern life. The early knowledge / foreknowledge of any adverse weather, through meteorological forecast is most useful for human activity and can save the loss of human life and property by undertaking suitable safety measures, against such adversities in the weather.

The specific fields of applications to illustrate the scope of meteorology :

1. **Safe navigation**: For safe navigation on sea, the knowledge of adverse weather i.e. large tidal waves, ocean waves, high speed wind, cyclonic storms etc. is needed which is provided through weather forecast from meteorology.
2. **Safe aviation**: For transport through air, the pilots need en-route information about atmospheric conditions such as electrical lightening, high turbulence, thunder storms, foggy atmosphere, line squalls etc. for safe aviation. so pilot can go safely. For this purpose, accurate forecasts are needed and are only possible from meteorology.
3. **Industrial planning**: Many industries for their raw material depend on agricultural produce and accordingly location of industry is decided, so it is necessary to consider the weather and climate. The first cotton mill in India was set up in Bombay because of hot and humid climate which is most suitable for this industry.
4. **Animal production**: Beef, poultry and milk production also depend on weather and meteorology provides the information for successful animal production and animal husbandry.
5. **Fishery industry**: Fishermen need information of atmospheric and oceanic changes before they proceed on sea for fishing so that they can take precautions if necessary and this is possible from meteorological knowledge.
6. **Irrigation and water resources**: Meteorological and hydrological information assist in planning the location, size and storage capacities of dams to ensure water supply for irrigation and domestic needs. When to irrigate and how much to irrigate is also decided from the meteorological information.
7. **Land use planning**: The meteorological data supplemented with soil and topographic information help to plan the sites for the specific land use for crop production, forests, urban residence, industry etc.
8. **Human life :** Human being tries to acclimatize himself with the prevailing weather conditions, for this they manage for type of clothing, housing, food habit etc.
   - **8.1 Clothing :** Warm clothes during winter and thin cloth during summer are used.
   - **8.**2 **Housing :** Direction of windows, doors for proper ventilation ,roofing-plain in low rainfall region whereas, slanting roof in the areas where rainfall is more and frequent in occurrence.
   - **8.3 Food habits :** Heavy diet during winter season is recommended whereas, during summer season more quantum of water consumption is needed.
9. **Public and civil agencies**: The agencies like Z.P.(Zilla parishad), Panchayat Samitee requires weather information for various purposes for planning and protective measures against disaster e.g. floods, droughts, cyclones, thunder storms, hails etc.
10. **Human health**: If any sudden change in the climatic conditions is experienced, it results into different epidemics.Asthma patient suffers more during cloudy conditions.

10. Commerce : Trading of any item is made according to need of the people in relation to weather prevailing e.g. Gum shoes, umbrella and raincoats are generally traded in rainy season only. Woolen cloths in winter season and white cotton cloths, cold drinks etc. are in more demand in summer season.

Thus, meteorology has wide scope and applications in various services. The final practical aim of meteorology is to describe,interpret and predict the weather for the service of mankind.

AGRICULTURAL METEOROLOGY OR AGROMETEOROLOGY

Agriculture meteorology or agrometeorology is an applied science which uses the principles of the science of meteorology for betterment of agriculture science. The aim of agricultural meteorology is to make use of the science of meteorology in the interest of food production. Agriculture deals with three most complex entities *viz*., soil, plant and atmosphere and their interactions. Among these three, atmosphere is the most complex entity over the other two.

DEFINITIONS

1. J.W. Smith (1916) has defined Agricultural meteorology as “meteorology in its relation to agriculture”.
2. It is the study of those aspects of meteorology that have direct relevance to agriculture.
3. Agricultural meteorology is an applied science which deals with relationship between weather/climatic conditions and agricultural production.
4. Agricultural meteorology is the applied branch of meteorology aiming to make use of the science of meteorology in the interest of Agricultural production (food production).
5. Agrometeorology is the science of meteorology to the service of agriculture in its various forms and fact to help the sensible use of land accelerate production of food and to avoid irreversible abuse of land resources.
6. It can be defined as the science investigating meteorology, climates and hydrologic conditions which are significant to agriculture owing to their interaction with the objects and processes of agriculture.
7. In short, Agricultural Meteorology is the applied branch of meteorology which deals with the relationship between climate s, weather and life and growth of the cultivated plants and animals.

SCOPE OF AGRICULTURAL METEOROLOGY IN AGRICULTURE

The science of meteorology has a wide scope in agriculture to improve use of land to increase agricultural production. The weather and climate is the natural resource and considered as basic input for agriculture. Every plant process related with growth, development and yield of crop is affected by weather. Similarly, every farm operations such as ploughing, harrowing, land preparation, sowing, weeding, irrigation, manuring, spraying, dusting, harvesting, threshing, storage and transport of farm produce are affected by weather.

The field of interest of agro meteorology extends from the soil surface layer to depth up to which tree roots penetrate. In the atmosphere, it is interested in the air layer near the ground in which crops and higher organisms grow and animals live, to the highest levels in the atmosphere through which the transport of seeds, spores, pollen and insects may takes place. Most of the meteorological phenomena like rain, cloud, winds, thunder, lightening etc. take place within the height of 30-35 km, therefore, the meteorologist may consider this height with special interest.

The scope of agricultural meteorology is to make use of the knowledge of meteorology for developing a stable and sustained agricultural production system and can be illustrated through the following few applications.

1. **Characterization of agricultural climate for determining crop growing season:**
   Solar radiation, air temperature, precipitation, wind, humidity etc. are important climatic factors on which the growth, development and yield of a crop depends. The study and effect of these elements can be used for planning, stability and management of the crops on weather basis. The agricultural operations can be arranged by studying the concepts of effect of weather elements. According to climatic condition, agricultural year can be divided into three seasons i.e.*kharif* , *rabi* and summer.
2. **Crop planning for stability in production :**
   To reduce risk of crop failure on climatic part (due to climatic factor), so as to get stabilized yields even under weather adversity, suitable crops / cropping patterns / contingent crop planning can be selected by considering water requirement of crop, effective rainfall and available soil moisture. Stability can be further increased by selecting short duration crops with low water requirement, drought resistance or tolerance etc. Contingent crop planning, in case of late start or early start of monsoon as well as for long dry spells can also be done.
3. **Crop management on weather basis :**
   Management of crop involves various farm operations such as sowing, inter-Culturing operations, fertilizer application, plant protection, irrigation scheduling, harvesting etc. can be carried out on the basis of specially tailored weather report. For this the use of operational forecasts available from agromet advisories is made e.g. a) Sowing of crops can be carried out on the basis of past normal climatic data. b) Interculturing operations are undertaken during dry spell forecasted. c) Fertilizer application is advised when rainfall is less than 1mm / day and wind speed is < 30km/hr and soil moisture is between 30 to 80%. d) Spraying / dusting is undertaken when there is no rainfall and wind speed is < 25km /hr.
4. **Crop monitoring :**
   To check crop health and growth performance, suitable meteorological tools such as crop growth models, water balance technique or remote sensing etc. can be used.
5. **Crop modeling and yield forecasting :**
   A model is a mathematical equation giving growth and yield as a function of climatic parameters or other relevant parameters. Suitable crop models devised for the purpose can provide information or predict the results about the growth and yield when the current and past weather data are used.

6. **Research in crop-climate relationship:**
   Agrometeorology can help to understand crop-climate relationship so as to resolve complexities of plant process in relation to its microclimate. It also develops suitable techniques of modification of microclimate.
7. **Climatic extremities and management strategies :**
   Climatic extremities such as frost, floods, droughts, high winds, and hail storms can be forecasted. The loss in production can then be prevented / protected by arranging suitable strategies such as –
   a) **Avoidance** : e.g. Give up or No spraying if heavy rains are forecasted.
   b) **Protection** : e.g. Give irrigation to crop when frost is forecasted.
   c) **Mitigation** : e.g. small fire in garden when fog is forecasted. Mulching, interculturing operations if drought is forecasted.
8. **Climate as a tool to diagnose soil moisture stress :**
   Soil moisture can be exactly determined from climatic water balance method which is used to diagnose the soil moisture stress, drought and necessary protective measures such as irrigation, mulching, application of antitranspirants, defoliation, thinning etc. can be undertaken.
9. **Livestock production :**
   Livestock production is a part of agriculture. The set of favorable and unfavorable weather conditions for growth, development and production of livestock is studied in Agricultural meteorology. Thus to optimize milk production and poultry production the climatic normals are worked out and on that basis the suitable breeds can be evolved or otherwise can provide the congenial conditions for the existing breeds.
10. **Soil formation :**
    Soil formation process depends on climatic factors like temperature, precipitation, humidity and wind etc. Thus climate is a major factor in soil formation and development.
11. **Forest production and fire prevention :**
    Meteorological information is needed to conserve forest wealth. Natural forest fire destroying this valuable wealth can be forecasted well in advance from weather information.
12. **Agrometeorological services :**
    In many countries agro meteorological services have been established to help the farmer in his job. These services release weather bulletins for farmers. Operational forecasts for various farm operations are also framed and released.

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LECTURE 2

EARTH'S ATMOSPHERE - ITS COMPOSITION, EXTENT AND STRUCTURE ; ATMOSPHERIC WEATHER VARIABLES

The earth is elliptical in shape. It has three spheres.
They are as follows –

1. Atmosphere – the gaseous portion
2. Hydrosphere – The water portion
3. Lithosphere – The solid portion

DEFINITIONS OF ATMOSPHERE

1. The colourless, odourless and tasteless physical mixture of gases which surrounds the earth on all sides called atmosphere.
2. The dynamic layer surrounding the earth above its surface containing various gases, moisture, aerosols etc. is called atmosphere.
3. Atmosphere can be defined as the gaseous envelope surrounding the earth.
4. Atmosphere is a shallow gaseous envelope surrounding the earth of which thickness is less than 1% of the earth radius (Earth radius is 6371 km).
5. Atmosphere can be defined as a grand body from the earth surface to the outer space and composed of number of gases.

The present form of atmosphere and composition evolved at least 400 million years ago. The estimated mass of the atmosphere is 56 x 10^{14} metric tonnes and it extends over about 400 km in height (variable) and meteorological events and effects occur in it. Earth's atmosphere contains air which is a mechanical mixture of gases. Mean sea level temperature and pressure (45^0N latitude) of the atmosphere are 15^0C and 1013.250 mb, respectively.

USEFULNESS OF THE ATMOSPHERE

1. It fulfills the biological oxygen demand (BOD) of the animal life.
2. It supplies the necessary precipitation or moisture required for plants, animals etc.
3. It protect the biological life on the planet from harmful extra-terrestrial radiations like UV, by absorbing it through ozone.
4. It maintains warmth of the planet through its green house effect, avoiding the temperature to falls to too extreme limits.[The earth's temperature in absence of atmosphere would have been +95^{o}C (day) and–145^{o}C (night)].Therefore, acts as both greenhouse and protective thermal blanket for earth.
5. It provides the necessary CO_2 which is basic input required to run photosynthesis process in plants to build biomass.
6. It provides the necessary medium for the transport of pollens, seeds, spores, insects, and conducts sound.
7. Many physical, chemical and hydrological processes responsible for weather and climate occur in atmosphere only.

8. Atmosphere is a big reservoir of nitrogen. Some plants and microbes can fix this nitrogen for plant growth e.g. Azolla, Pinata, *Azotobacter*

COMPOSITION OF THE ATMOSPHERE

Atmosphere is a huge envelope of mixture of gases extending several hundreds of kilometers from earth surface.

The various constituents/ components of the atmosphere can be divided into following three categories.

1. Gases 2. Moisture and 3. Solid impurities or Aerosols.

1. **Gases :** The atmosphere is a mixture of many gases. Nitrogen (78%) and oxygen (21%) make up approximately 99% gases constitution and 1% by other gases. Four gases *viz*., nitrogen, oxygen, argon and carbon dioxide accounts for 99.98% of the dry air by volume. Some gases of the atmosphere remains constant at surface of globe up to the height of 80 to 88 km. These gases are called **Non-variable components/permanent gases.**They are nitrogen, oxygen, argon, neon, helium, krypton, xenon and radon. Some gases or components of the atmosphere changes with change in time, space, season etc. these components are called as **Variable components**. They are carbon dioxide, carbon monoxide, nitrous oxide, sulphur dioxide, nitrogen dioxide, ozone, hydrogen, methane and ammonia.
2. **Moisture :** Moisture in the form of water vapour exist in the atmosphere. It is released through the process of evaporation from open water bodies like sea, ocean, lake, river, etc. and also released by plants through transpiration. Water vapour comprises up to 4% of the atmosphere by volume (about 3% by weight) near the surface, but it is almost absent above 10 to 12 km. Water vapour plays a large role in absorption of long wave radiation. It is also a important component of hydrological cycle (precipitation). The proportion of water vapour in the atmosphere always changes according to space and time.
3. **Solid impurities or Aerosols :** These are suspended solid particles of dust, salt, and carbon also some liquid particles like water droplets. These particles are dispersed in the atmosphere and are known as **aerosols**. Aerosols enter the atmosphere by man made pollution and by agricultural practices as well as through forest fires, wind raised dust, sea spray and volcanic activity. Bacteria, spores, pollens, seeds, smokes are also present in the atmosphere. They are also called as **aerosols**.

Non variable and variable components in Atmosphere :

1. **Non variable components :**

Some gases in the atmosphere remain constant at surface of globe up to the height of 80 to 88 km. This is due to transport of gases on continental level , diffusion of gases, turbulent mixing and convection.

Table 1: Category wise average components of dry atmosphere

Gases	Moisture	Solid impurities or Aerosols

1. Nitrogen (N_2)	Water vapour	1. Dust particles
2. Oxygen (O_2)		2. Salt particles
3. Argon (Ar)		3. Carbon particles
4. Carbon dioxide (CO_2)		4. Water droplets and ice crystals
5. Ozone (O_3)		5. Spores
6. Sulphur dioxide (SO_2)		6. Pollen grains
7. Nitrogen dioxide (NO_2)		7. Smoke
8. Ammonia (NH_3)		8. Bacteria
9. Carbon monoxide (CO_2)		9. Sulphuric acid Particles
10. Neon (Ne)		10. Nitric acid particles

Table 2 : Non variable components :

Sr.No.	Component / Constituent	Symbol	Percentage by volume
1.	Nitrogen	N_2	78.084
2.	Oxygen	O_2	20.946
3.	Argon	Ar	0.934
4.	Carbon dioxide	CO_2	0.032
5.	Neon	Ne	$18.18x10^{-4}$
6.	Helium	He	$5.24x10^{-4}$
7.	Crypton	Kr	$1.14x10^{-4}$
8.	Xenon	Xe	$0.087x10^{-4}$
9.	Hydrogen	H_2	$0.5x10^{-4}$
10.	Methane	CH_4	$1.5x10^{-4}$
11.	Nitrous oxide	N_2O	$0.5x10^{-4}$
12.	Radon	Rn	$6x10^{-18}$

2. Variable components :

Some gases or components of the atmosphere changes with change in time, place, season etc. These components are called as variable components.

Table 3 : Variable components :

Sr.No.	Component / Constituent	Symbol	Percentage by volume
1.	Water vapour	H_2O	<4
2.	Ozone	O_3	$<0.07x10^{-4}$
3.	Sulphur dioxide	SO_2	$<1x10^{-4}$
4.	Nitrogen dioxide	NO_2	$<0.02x10^{-4}$
5.	Ammonia	NH_3	trace
6.	Carbon monoxide	CO	$0.2x10^{-4}$(0.00002)
7.	Dust (Salt to soil)	Kr	$<10^{-3}$(0.000)
8.	Water (Liquid and solid)	Xe	

EXTENT AND STRUCTURE OF THE ATMOSPHERE

The atmosphere can be divided into two spheres on the basis of its chemical composition occurring with height i.e. (1) Homosphere and (2) Heterosphere.

1) **Homosphere :** In the lower region up to the height of 88 km the various gases are thoroughly mixed and are homogeneous by the processes of turbulant mixing and diffusion. This sphere is called as Homosphere. The gases composition in this sphere remains normally constant.

2) **Heterosphere :** In Heterosphere, gaseous composition changes and various gases form separate compositional layering individually. Satellite data has shown the presence of different Chemospheres as follow :

   a) Nitrogen and oxygen layer - From 88 to 115 km
   b) Atomic oxygen layer - 115 to 965 km
   c) Helium layer - 965 to 2400 km
   d) Hydrogen layer - 2400 to 10,000 km.

   The distribution of the gases is governed by the earth's gravitational field. Thus, heavier gases sink downward while the lighter gases like hydrogen remain at higher altitude.

   Extent of the atmosphere : Since the gases in the atmosphere are free to expand, there is no sharp boundary between the air and extra terrestrial space. It is difficult to ascertain the height of the atmosphere. Half of the total gas exists below a height of 5.5km. It is thought that up to a height of 400 km air exists in perceptible quantity.

STRATIFICATION OF ATMOSPHERE or LAYERING OF ATMOSPHERE or PHYSICAL STRUCTURE OF ATMOSPHERE

On the basis of the vertical temperature difference, the atmosphere can be divided into four horizontal layers or shells, namely –

1. Troposphere } Lower Atmosphere
2. Stratosphere }
3. Mesosphere } Upper Atmosphere
4. Thermosphere }

A) Lower atmosphere :

1. **Troposphere** : The word "tropo" means mixing or turbulence and "sphere" means region. The lowest layer of the atmosphere is called the troposphere. The altitude of the troposphere changes according to latitude. It has an elevation of about 16 km at the equator and only 8 km at the poles. Its average altitude is about 11km. In this layer about 75% of the gaseous mass of the total atmosphere, water vapour and aerosols are present. It is the realm of clouds, storms, cyclones, anticyclones and convective motion. Because of these atmospheric activities occurs in this layer, the layer is called as "Seat of weather phenomena". The outstanding characteristic of the troposphere is that there is a decrease of temperature with increase in altitude (height) at mean lapse rate of about 6.5^{o} C/km or 3.6^{o}F/1000ft until minimum temperature of

-50^{0}C to -60^0 C is reached. (The temperature decrease with increase in height is called as lapse rate of temperature (LRT).)

Thermal convection is better developed in tropics and hence the troposphere has higher altitude at equator. Because of thermal convection, the height of troposphere is more in summer than in winter.

At the top of the troposphere there is a shallow layer separating it from the stratosphere which is “tropopause”. The thermal layer marking the end of temperature decrease is called ‘tropopause’ and it separates troposphere and stratosphere. Tropopause acts as a lid at the top of the troposphere. Height of the tropopause is not constant, either in space or time. The temperature in the tropopause is almost constant (about -57 ^{o}C). As the temperature is constant, the lapse rate in tropopause is zero. This layer contains relatively warm air at the top of troposphere. The atmospheric pressure in the troposphere at earth surface (mean sea level) is 1013.25 mb and it is decreases with height.

2. **Stratosphere** : This is the second atmospheric layer above tropopause which extends upwards from tropopause to about 50 km (30 miles). The stratosphere contains much of the total atmospheric ozone. The density of the ozone is maximum at 22 to 24.5 km approximately. In stratosphere temperature increases with increase in height. The atmospheric pressure decreases from 110 mb to 1mb. The ozone at the upper layer of the atmosphere absorbs the ultraviolet rays from the sun and temperature may exceed 0^{o}C (from –60^{o}C to 0^{o}C) . Higher temperature occurs in the stratosphere because of absorption of ultraviolet radiations by ozone. Stratopause is a isothermal boundary layer at top of the stratosphere which separates stratosphere from the mesosphere.

B) Upper atmosphere :

3. **Mesosphere** : This is the third layer of atmosphere. Above the warm stratopause , temperature decreases with increase in height to a minimum of about –90^{o}C at about 80 km height. This layer is also known as chemosphere. This layer extends upwards from the stratopause to about 80km. Pressure in this layer is very low and decreases from 1mb at about 50 km to about 0.01mb at 80 km nearly. The thin isothermal layer which separates mesosphere from thermosphere is called ‘mesopause’. Gaseous composition is homogenous up to mesopause. Above 80 km temperatures again rise with height and this inversion is referred to as mesopause.
4. **Thermosphere** : Outermost shell is known as thermosphere. It lies about 80 km height. In this layer, the atmospheric densities are extremely low. Atomic oxygen is important constituents of this sphere. In the thermosphere the temperature increases with height due to absorption of ultraviolet radiation from the sun by atomic oxygen. Probably temperature reaches to 950^0 C at 350 km and 1700^0 C at an undefined upper limit but these temperatures are essentially theoretical. Such temperatures are not felt by the hands exposed by astronaut or the artificial satellite because of rare filled air.

OTHER SPHERES

1. **Ozonosphere** : The lower part of the stratosphere between 15-35 km is concentrated with ozone (O_3) and is called ozonosphere. The highest density is at about 22km height. Ozone absorbs ultra violet radiation and protects the biological life from these harmful radiations injuries, skin cancer etc. Therefore, ozonosphere is called an umbrella of the earth.
2. **Ionosphere** : This layer consisting of electrons and ions and extending up to 100 to 300km is called as Kennelly Heaviside layer or ionosphere. The layer is extremely important for the transmission of radio-waves at longer distances.
3. **Exosphere** : This layer exists between 500km to 750km. Neutral atomic oxygen, ionized oxygen and hydrogen atoms are present but they do not obey gas laws.
4. **Magnetosphere** : The layer at about 2000km is magnetosphere and only electrons and protons are present in the layer. The distribution of these particles is governed by magnetic field of the earth and not by gravity.
5. **Van Allen belts** : At about 4000 km and 20,000 km the charged particles are concentrated and these zones are known as van- Allen radiation belts.
6. At 80,000km or so the earth's atmosphere probably merges into that of sun.

ATMOSPHERIC WEATHER VARIABLES

1) Temperature : The temperature is a measure of the internal energy that a substance contains. This is the most measured quantity in the atmosphere.Air temperature is a measure of how hot or cold the air is. It is the most commonly measured weather parameter. More specifically, temperature describes the kinetic energy, or energy of motion, of the gases that make up air. As gas molecules move more quickly, air temperature increases.

Air temperature affects the growth and reproduction of plants and animals, with warmer temperatures promoting biological growth. Air temperature also affects nearly all other weather parameters. For instance, air temperature affects:

- the rate of evaporation
- relative humidity
- wind speed and direction
- precipitation patterns and types, such as whether it will rain, snow, or sleet.

2) **Wind Speed :** The wind speed is a measure of the average speed of movement of the wind at a specific point. When measured, the value represents an average taken over a couple of minutes. Wind speed, or wind flow velocity, is a fundamental atmospheric quantity.

Wind speed is caused by air moving from high pressure to low pressure, usually due to changes in temperature. Wind speed affects aircraft and maritime operations, construction projects, growth and metabolism rate of many plant species, and countless other implications.

3) **Atmospheric pressure :** The pressure exerted by the earth's atmosphere at any given point. The atmosphere that blankets the Earth gently presses down on us, and the subtle variations in this *atmospheric pressure* greatly affect the weather. For example, forecasters often talk of low pressure bringing rain. In areas of low air pressure, the air is less dense and relatively warm, which causes it to rise. The expanding and rising air naturally cools and the water vapor in the air condenses, forming clouds and the drops that fall as rain. In high pressure regions, on the other hand, the air is dense and relatively cool, which causes it to sink. The water vapor in the sinking air does not condense, leaving the sky sunny and clear. So if you're trying to hit a home run, would you prefer a beautiful, sunny day or one in which it looks like rain? On the overcast day, the ball has less air to push aside on its way out of the ballpark, making it easier to hit a homer.

4) **Humidity :** Humidity is the amount of water vapor in the air. Water vapor is the gaseous state of water and is invisible.Humidity indicates the likelihood of precipitation, dew or fog. Higher humidity reduces the effectiveness of sweating in cooling the body by reducing the rate of evaporation of moisture from the skin. This effect is calculated in a heat index table or humidex. The amount of water vapor that is needed to achieve saturation increases as the temperature increases. As the temperature of a parcel of air becomes lower it will eventually reach the point of saturation without adding or losing water mass. The differences in the amount of water vapor in a parcel of air can be quite large, for example; A parcel of air that is near saturation may contain 28 grams of water per cubic meter of air at 30 °C, but only 8 grams of water per cubic meter of air at 8 °C.

   There are three main measurements of humidity: absolute, relative and specific. Absolute humidity is the water content of air expressed in gram per cubic meter. **Relative humidity:** This is the ratio of actual vapor pressure to the saturation vapor pressure at a specific temperature. expressed as a per cent, measures the current absolute humidity *relative* to the maximum (highest point) for that temperature. **Specific humidity:** This is the ratio of the weight of water vapor in a specified volume to weight of the air in that same volume or it is a ratio of the water vapor content of the mixture to the total air content on a mass basis.

5) **Radiation** : Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation. When the temperature of a body is greater than absolute zero, inter-atomic collisions cause the kinetic energy of the atoms or molecules to change. Intensity, quality, duration, direction, quantity, and periodicity are the important aspects of solar radiation which are biologically significant.

IMPORTANCE OF RADIATION IN CROP PRODUCTION

1. It provides the necessary energy for all the phenomena concerning biomass production.
2. Photosynthetically Active Radiations (PAR) are the real source of energy for photosynthesis process. Plants are efficient biological convertors of solar energy into biomass. Radiation defines the yield of a crop in particular region.
3. It also provides the energy for the physical processes taking place in plant soil and atmosphere.
4. It conditions (governs) the distribution of temperature and hence crop distribution on the earth surface.
5. Almost all growth, development and yield governing processes such as germination, elongation formative activity, reproduction, flowering, photo-periodism, leaf enlargement, pigmentation etc. are affected by radiation.

6) **Rainfall :** Rain is liquid water in the form of droplets that have condensed from atmospheric water vapor and then precipitated—that is, become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation.

7) **Evaporation :** Evaporation is a type of vaporization of a liquid that occurs from the surface of a liquid into a gaseous phase that is not saturated with the evaporating substance. Evaporation that occurs directly from the solid phase below the melting point, as commonly observed with ice at or below freezing or moth crystals (napthalene or paradichlorobenzene), is called sublimation.

Evaporation is an essential part of the water cycle. The sun (solar energy) drives evaporation of water from oceans, lakes, moisture in the soil, and other sources of water. In hydrology, evaporation and transpiration (which involves evaporation within plant stomata) are collectively termed evapotranspiration. Evaporation of water occurs when the surface of the liquid is exposed, allowing molecules to escape and form water vapor; this vapor can then rise up and form clouds. The tracking of evaporation from its source on the surface of the earth, through the atmosphere as vapor or clouds, and to its fate as precipitation closes the atmospheric water cycle, and embodies the concept of the precipitation shed.

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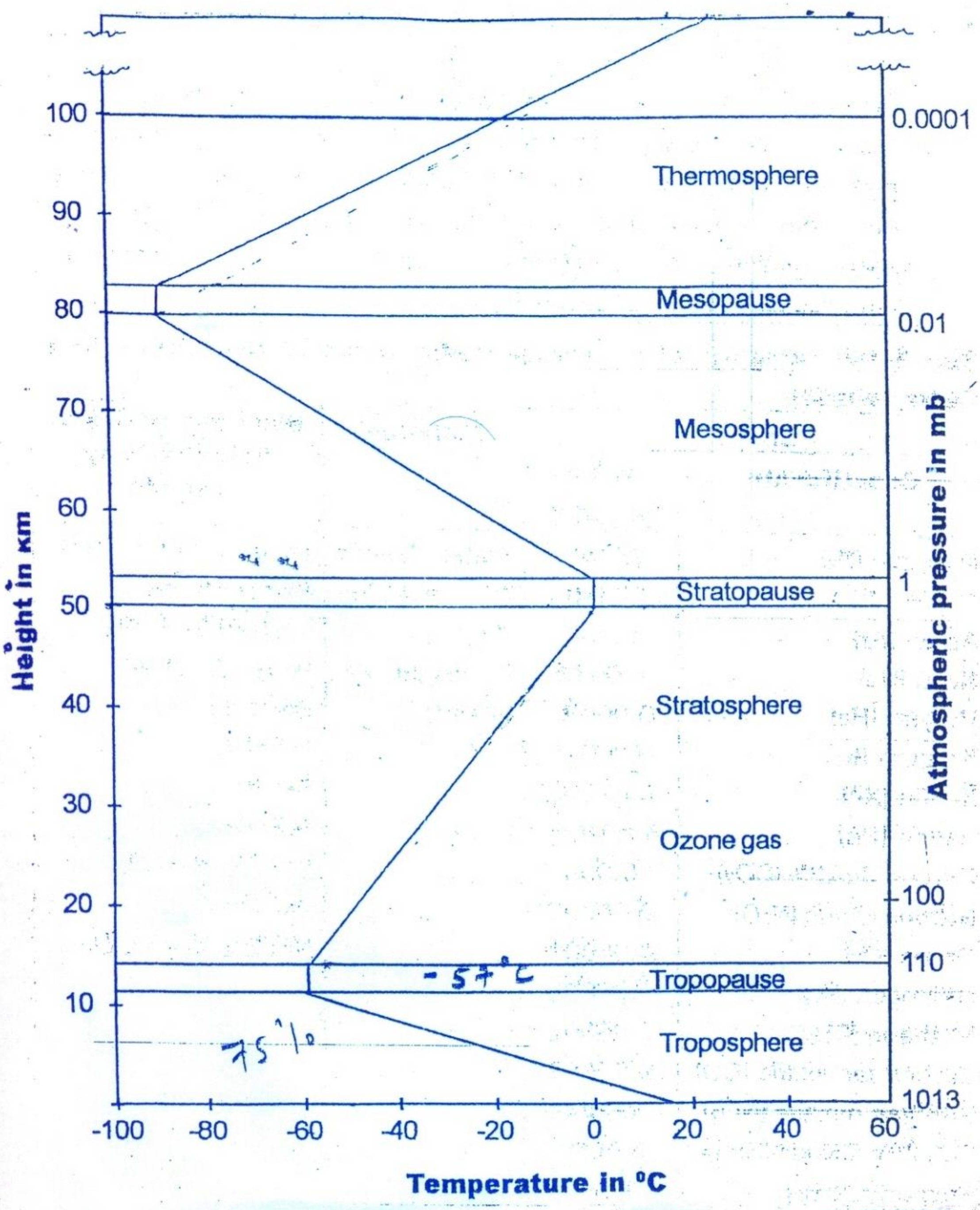


Fig. Vertical structure of the atmosphetre based on temperature variation

LECTURE 3

ATMOSPHERIC PRESSURE – ITS VARIATION WITH HEIGHT

Atmosphere is a dynamic medium and contains large amount of various gases, water vapour, etc. up to 400 km height. All these gases exert their weight on surface of the earth. Thus, atmospheric pressure can be defined as **the weight exerted by air column on unit surface of the earth. The presence of water vapour in air decreases the pressure.** The air that extends above the earth's surface in different layers is called the atmosphere. The pressure exerted by the atmosphere is called atmospheric pressure.

$$\text{Pressure (p)} = \frac{\text{Force}}{\text{Area}}$$

MEASUREMENT OF ATMOSPHERIC PRESSURE

Atmospheric pressure is measured by an instrument called as barometer. There are four types of barometers as follows :

1. Fortin's barometer.
2. Kew pattern barometer
3. Aneroid barometer
2. Barograph for automatic and continuous record of pressure.

UNITS OF PRESSURE

The atmospheric pressure has the dimensions $ML^{-1} T^{-2}$ and measured in following units.

1) Height of mercury column measured in inches, cm or in mm.
2) Bar is a force equal to 10^6 dynes /cm^2

   1 bar = 1000 mill bar (mb) = 10^6 dynes / cm^2

   1 mb = 10^{-3} bar = 10^3 dynes/cm^2
3) SI (Standard International) unit for pressure is Pascal.

   1 Pascal = force of 1 Newton /m^2 = 1 Nm^{-2} = 10 dynes / cm^2 = kg / m / s^2

The standard atmospheric pressure is given at mean sea level at 45°N (latitude) and at temperature of 15^0C.

1 Atmospheric pressure = 29.92 inches or 76 cm or 760 mm.
= 1013.250 millibar
= 101.325 kilo Pascal (Kpa)
= 14.7 lbs/$inch^2$
= 1.014×10^6 dynes/cm^2
= 1013.25 hpa
= 101325 Pa

ATMOSPHERIC VARIATION OF PRESSURE WITH HEIGHT OR VERTICAL VARIATION

The air pressure depends on the density or mass of the air. The density of air depends on its temperature, composition and force of gravity. It is observed that the density of air decreases with increase in height so the air pressure also decreases with increase in height.

We are actually living near the bottom of an ocean of air. At sea level, the weight of the air presses on us with a pressure of approximately 14.7 lbs/in^2. At higher altitudes, less air means less weight and less pressure. Pressure and density of air decreases with increasing elevation. Air exerts pressure as it has weight. Air pressure is the highest at the sea level.

Air pressure decreases at higher altitudes because the height of the air column decreases, which causes a linear decrease in air pressure. Air pressure decreases at higher altitudes also because the density of air decreases. Air pressure decreases by about 3% for every 1,000 feet of increase in height. For example, on the great Mount Everest, atmospheric pressure is only 30% of the atmospheric pressure at sea level.

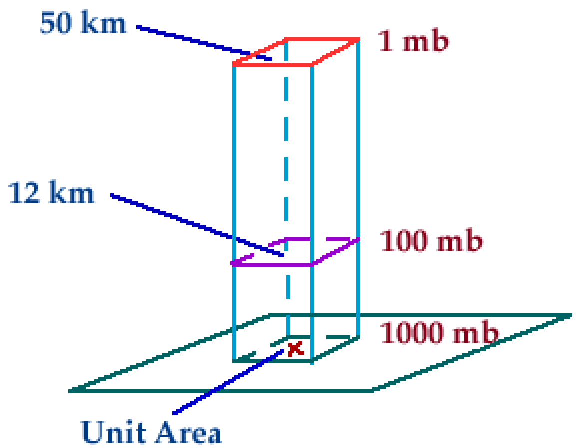
As air pressure decreases in hilly areas, we can feel our ears "pop," which happens in order to balance the pressure inside and outside our body. The decrease in air pressure may cause the nose to bleed, especially if the individual has high blood pressure. This is because the air pressure cannot completely counter-balance the blood pressure, causing the blood vessels in the nose to rupture. That is why doctors advise blood pressure patients to avoid going to hill stations. Our nose does not bleed if we fly in an aeroplane. Because aircraft has "pressurised cabins" that have sufficient air pressure to safeguard the passengers.

Atmospheric pressure decreases with altitude due to:

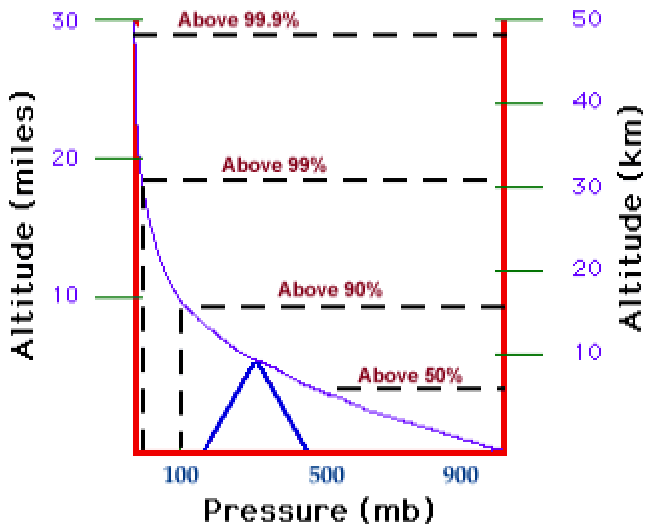
- Decrease in the height of the air column, which causes a linear decrease in atmospheric pressure
- Decrease in the density of air, which leads to a decrease in atmospheric pressure

The pressure at sea level is 1013.25 mb, at 11 km height it is 110mb, at 50km height it becomes 1mb and 80 km it is only 0.01mb. This indicates how rapidly the atmospheric gas becomes thinner to decrease density and so the pressure. The atmospheric pressure decreases on an average at the rate of about 34 millibars per every 300 m height.

The number of air molecules above a surface changes as the height of the surface above the ground changes. For example, there are fewer air molecules above the 50 kilometer (km) surface than are found above the 12 km surface. Since the number of air molecules above a surface decreases with height, pressure likewise decreases with height.



Most of the atmosphere's molecules are held close to the earth's surface by gravity. Because of this, air pressure decreases rapidly at first, then more slowly at higher levels.



Since more than half of the atmosphere's molecules are located below an altitude of 5.5 km, atmospheric pressure decreases roughly 50% (to around 500 mb) within the lowest 5.5 km. Above 5.5 km, the pressure continues to decrease, but at an increasingly slower rate (to about 1 mb at 50 km).

Isobar : It is defined as the line on weather map joining the places having same atmospheric pressure. Isobars are plotted on the map to show the distribution of pressure. The isobars are drawn at pressure intervals of 2,3,4 or 5 millibars. Close isobars show rapid change in pressure.

Such lines are drawn by reducing the pressures at sea level to eliminate the effect of altitude on pressure. Where isobars are closely spaced, a rapid or steep change in pressure in a right direction at right angles to the isobars is indicated. When isobars are widely spaced, a slow change in pressure is indicated. Two isobars never cross each other and must either form closed curve or terminate on the edge of the map. Isobars are plotted on the map to show the distribution of pressure. The isobars are drawn at a pressure intervals of 2, 3, 4 or 5 millibars. Close isobars show rapid change in pressure.

Diurnal variation in pressure: At a given station the pressure shows two highs and two lows. In normal hourly pressure record for a day , two maxima one major at 10 A.M. (morning) and another secondary minimum at 10 P.M.(afternoon) and two.

Pressure gradient or barometric slope: The change in atmospheric pressure per unit horizontal distance in a given direction is called pressure gradient or isobaric slope or barometric slope. The winds are the results of these pressure gradients.

Isobaric surface : It is the surface in which at every point (place) the atmospheric pressure is same (equal). If there were no temperature differences the atmospheric pressure have been same at all the places.

To represent vertical pressure distribution, the lines of equal pressures are drawn. At the surface shown by these lines the atmospheric pressure is equal and the surface is called ***isobaric surface***.Isobaric surfaces in the atmosphere represent various heights where the pressure is same and therefore two isobaric surfaces may not be parallel with each other.

VERTICAL VARIATION OF ATMOSPHERIC PRESSURE

The pressure depends on the density or mass of the air. The density of air depends on its temperature, its composition and force of gravity. It is observed that the density of air decreases with increase in height so the pressure also decreases with increase in height. It is found that in troposphere for 900 ft rise in height the pressure decreases by one inch from standard atmospheric pressure of 30 inch. The rate of decrease in pressure with increase in height can be given by the formula $dp/dh = -\delta g$

The pressure at sea level is 1013.26 mb, at 50 km height it becomes 1mb and 80 km it is only 0.01 mb. This indicates how rapidly the atmospheric gas becomes thinner to decrease density and so the pressure. The pressure decreases on an average at the rate of about 34 millibars per every 300 meters height.

Horizontal variation of atmospheric pressure : The pressure and temperature act as inverse of each other. Thus, when the temperature is high the pressure is low and when the temperature is low the pressure is high. The presence of water vapour in the air makes the air mass lighter in weight. Thus, the saturated air will have lower density than that of dry or unsaturated air. The non-uniform heating

Table 4 : Vertical variation of pressure

Altitude (km)	Pressure (mb)	Altitude (km)	Pressure (mb)
0	1013.25	30	11.52
2	795.00	40	2.78
4	616.00	50	00.93
6	472.00	60	00.35
8	356.00	70	00.12
1	264.00	80	00.03
15	120.00	90	00.008
20	55.21	100	00.003

of earth surface by the sun and consequently of air is main reason for pressure variation.

The horizontal distribution of pressure depends on temperature, extent of water vapour, latitude and land –water relationship. Along the equator lies a belt of low pressure known as the *equatorial low* or *doldrums* or *calm*. In the cold polar latitudes are the vaguely high pressure area known as *polar high*.

Centered about 60^{o} to 70^{o} north and south latitude are the sub polar low pressure belts and at 25^{o} to 35^{o} north and south latitude are the sub-tropic high. These pressure zones result from temperature differences. In addition to this, the wind also plays important role in the redistribution of air masses.

Fig.3 Vertical variation of pressure

Fig.4 Horizontal distribution of pressure

minimums one major at 4 P.M. are observed. Thus, there is double oscillation caused by alternate heating and cooling of atmosphere. The amplitude of variation is never more than 5 mm which is often overshadowed by other large pressure system approaching or receding to a station.

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LECTURE 4

WINDS - TYPES , DAILY AND SEASONAL VARIATION OF WIND SPEED, CYCLONES, ANTICYCLONES, LAND BREEZE AND SEA BREEZE

DEFINITIONS OF WIND

1. Air in horizontal motion is called as wind.
2. The horizontal flow of air is called as wind.
3. The air that moves parallel to any part of the earth's surface is called as wind.

This motion tends to equalize lateral differences in temperature, humidity and pressure in the atmosphere. Wind is the third important weather element. The main cause for wind is differences in temperature over the surface. Temperature, pressure and wind are related with each other. High temperature means low pressure and vice versa. At low temperature air density is high while at high temperature are density is low. Therefore , wind is always result of a difference in pressure between area of high pressure (low temp) to the area of low pressure (high temperature).

TYPES OF WIND

Local Winds:

Local winds are those that are created as a result of scenery such as mountains, vegetation, water bodies and so on. They usually change very often and the weather forecast people talk about this kind on the TV every day. They can move from mild to extreme winds in just hours. Good examples of local winds are sea breezes and land breezes, and mountain and valley breezes. Local winds cover very short distances.

Global Winds :

Global winds are really large air masses that are created mainly as a result of the earth's rotation, the shape of the earth and the sun's heating power.

Doldrums:

This is the very low pressure area along the equator where prevailing winds are calmest. This low-pressure area is caused by the constant heating of the sun. This belt extends to about 5° north and south of the equator.

- **Tropical Easterlies (Trade Winds):**

  This is the belt extending as far as 30° north and south latitude of the Inter- tropical Convergence Zone (ITCZ).

- **Horse Latitudes:**

  This is wind belt that forms at about 30° north and south latitude between the trade winds and the prevailing Westerlies.

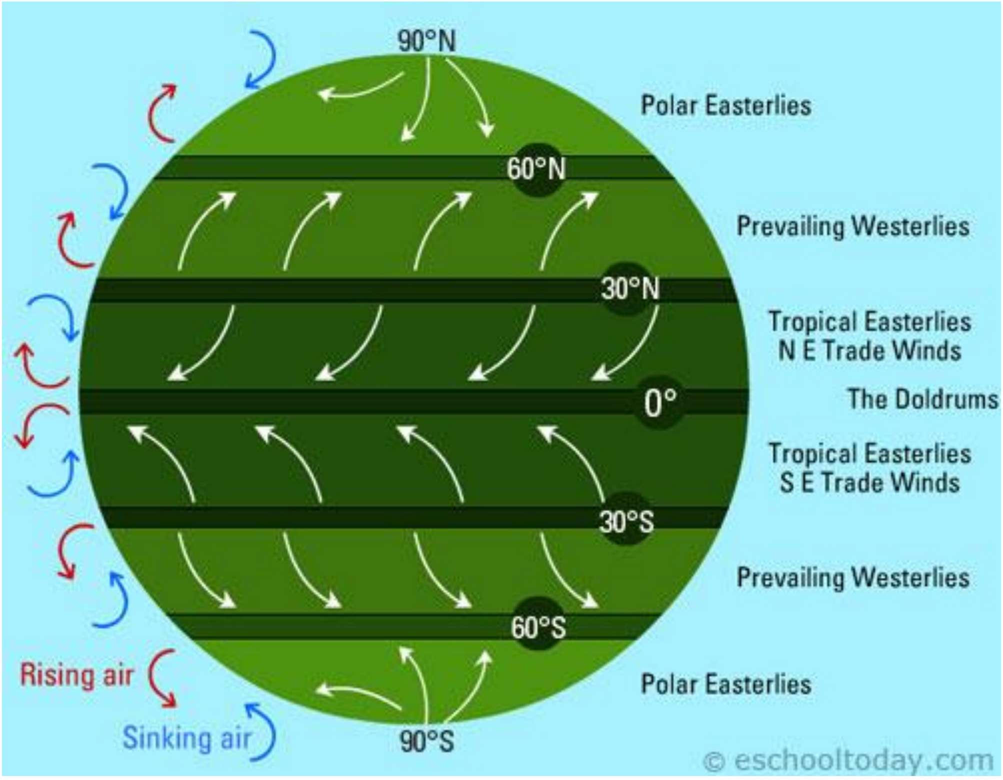


Fig.4 : Above are some standard wind belts with the white arrows showing the direction of winds, red arrow showing vertical rising air, and blue arrow showing cold sinking air.

- **Prevailing Westerlies:**

  This is the belt extending from 30° to 60° latitude from the ITCZ.

- **Polar Easterlies:**

  This belt covers from 60° latitudes to the north and south poles.

AIR CURRENT : Vertical or nearly vertical movement of air resulting from convection, turbulence or any other cause referred as air current.

Isotech : This is the line on the weather map joining places at equal wind speed.

CLASSIFICATION OF WIND

Wind

- **Vertical**
  - 1) Divergence
  - 2) Convergence
  - 3) Eddies
  - 4) Convection
- **Horizontal**
  - Periodic Monsoon winds
  - Regular planetary Earths Circulation System
  - Local
    - 1) Land/sea breeze
    - 2) Mountain/valley breeze
    - 3) Fohn/chinoot
    - 4) Tornadoes

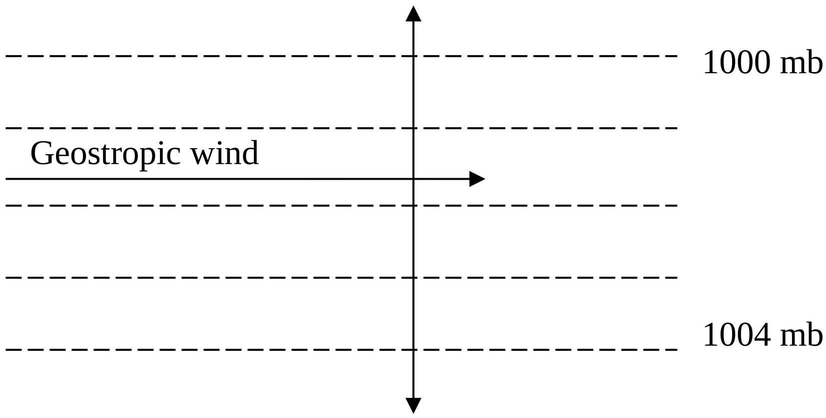
1) Geostropic wind:

When pressure gradient force gets exactly balanced with the coriolis force acting in the diametrically opposite direction, wind blowing in this idealized condition is termed as geostropic wind.

The pressure gradient force initiate the motion and coriolis force commences into equilibrium and there is balanced wind flow, parallel to isobars. Winds are essentially geostropic in nature above 500 to 1000 meter.

Low pressure

Pressure gradient force



Coriolis force

High pressure

Fig 5 : Geostropic wind

$$Vg = \frac{1}{2\,\omega \sin ø\, \delta} \cdot \frac{dp}{dh}$$

dp/dh = pressure gradient

$$\text{Velocity} \; \alpha \; \frac{1}{Ø}$$

2) Gradient Wind :

It arises, when balance is obtained between pressure gradient force on one hand and coriolis force and centrifugal force together on the other hand. These winds move parallel to isobars but in carved path, while geostropic wind move parallel to straight isobars.

Pressure gradient = Coriolis force + Centrifugal force

$$\frac{1}{\delta} \cdot \frac{dp}{dh} = 2\,V\,\omega \sin + \frac{v^2}{r}$$

Both gradient winds and geostropic winds are similar, only difference between them is, in gradient wind centripetal acceleration is taken into consideration. In both winds, frictional forces are ignored.

3) Thermal wind :

If the atmosphere is warm, the pressure changes slowly with height and if cold, pressure changes rapidly with height. These thermal differences produces difference in wind velocity at two levels. A wind shear occurs between the bottom and the top of layer of air. The vector difference between winds at the top and bottom of any layer is called as thermal wind of that layer. The vertical movement of air is called as current. Air current includes eddies, convenctional currents, convergent ascent and subsidence. Temperature is one of the reason for changing pressure .

IMPORTANCE / ROLE / EFFECTS OF WINDS IN AGRICULTURE

1. Wind increase the transpiration and intake of CO_2 .
2. The turbulence created by wind increase CO_2 supply and the increase in photosynthesis.
3. When wind is hot, desiccation of the plants takes place, because humid air in the inter cellular places is replaced by dry air.
4. The hot and dry wind makes the cells expanding and early maturity, it results in the dwarfing of plants.
5. Under the influence of strong wind the shoots are pressurized and get deformed.
6. Strong winds produces lodging of crops.
7. Strong winds affect the plants life both mechanically and physiologically.
8. The coastal area affected by strong wind brings salt and make the soil unsuitable for growing plant.

Diurnal variation of wind:

The wind has maximum speed in the early afternoon and minimum in the early morning before sunrise.

THE GLOBAL PATTERN OF SURFACE WINDS

a) **Trade winds** : The condition of greatest heating and expansion at the equator, causes rising of air and creating low pressure belt [5°N to 5°S latitude] is known as “doldrum” or “equatorial low” or “calm”. The rising air from equator causes increase in pressure at 35°N and 35° S latitude. Therefore, reduction in surface pressure on equator and increase in pressure at 35° N and 35° S which is known as subtropical high or Horse latitudes. Therefore, wind flow from the horse latitudes to the equatorial region. They are called as trade winds. While moving, these winds are deflected by coriolis force to the right in northern hemisphere and to left in the southern hemisphere. Thus, these winds flow from 35° N to the equator in the direction North East in Northern hemisphere while they move in South East direction in southern hemisphere, these winds are known as North East trade and South East trades respectively. The force is 10 – 20 mph.

b) **Westerlies or Antitrade winds :** The wind that flow from sub-tropical high (high pressure area i.e. horse latitude in both the hemisphere) to the low pressure area at about 60° to 70° latitude in both the hemisphere (sub polar low) are known as Westerlies or prevailing westerlies or antitrade winds. These winds instead of flowing in straight line are deflected due to coriolis force. In Northern hemisphere, their direction is North-West and in the Southern hemisphere, it is South-West. Winds are forceful and change their direction frequently. In the southern hemisphere at 40^0 to 65^0S,the winds are violent and have high frequency creating large noise. Therefore, the latitude is known as Roaring Forties.

c) **Polar winds or polar easterlies** : High pressure area exist on the poles which is intensified by the extreme cold. Therefore, wind flows from the polar high to sub polar low pressure area at about 60^o to 65^o latitude. The winds flow North East direction in Northern hemisphere and South East direction in Southern hemisphere. It is called as polar winds or polar easterlies. These winds consist of cold air.

2. Local winds : These winds are generated due to local conditions and have influence over very small area, therefore, such winds are called as local winds.

a) **Land and sea breeze** : An interchange of air between the sea and coastal land due to unequal heating and cooling of water and land surface is known as land and sea breeze. During day time the coastal land is heated very fast as compared to sea water, causing low pressure over the land. Therefore, the surface air blows from sea to land is known as sea breeze. In tropics, the breeze may set at any time between 8 am to 1 am. These winds are cold and bring humidity with it. Therefore, in summer winds are refreshing. During night time, the land cools faster than the sea, causing high pressure area over land as compared to sea. Therefore, air blows from land to sea and this is known as land breeze. See breeze is stronger than land breeze as temperature difference is more during daytime than night time.

Land breeze
(Night time)

Sea breeze
(Day time)

Fig.6 : Land and sea breeze

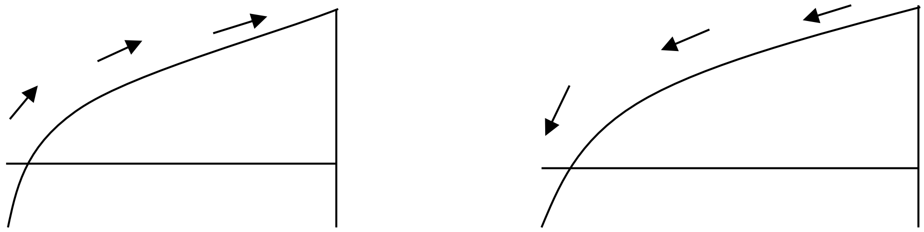
a) **Mountain (katabatic) and Valley (anabatic) breeze**:

They are present is hilly areas. An interchange of air between the mountain and valley due to unequal heating & cooling is known as mountain and valley breeze. During day time, slopes of mountains receive direct sunlight hence become hotter than other nearby places at the same height.

The warm air along the slope rises up to reach the neighboring area at about the same altitude, but less exposed to solar radiation. The ascending warm air is called as **valley winds** (anabatic). This warm air may form clouds round the peak resulting in the afternoon showers.

Reversely, at night time slope will loose energy much faster and becomes colder than surrounding. This chilled air descend downward . It is known as **mountain breeze** (katabatic) .

Monsoon winds : An interchange of air between the land and oceans due to



Valley breeze (Day time)   Mountain breeze (Night time)

Fig.7 : Valley and mountain breeze

unequal heating and cooling of continents and ocean is known as **Monsoon winds.** It has annual period of occurrence. During summer the land is heated as compared to an ocean which causes low pressure over the land and the winds blow from oceans to continents. During winter the lands cooled down faster than the oceans causing high pressure over continents and low pressure over oceans and therefore winds blow from continents to oceans. The Indian monsoon is the best example of this alternate circulation system.

c) Fohn and Chinook winds:

Like katabatic winds, they are down slope breezes but, instead of being dry and cold like katabatic, they are dry and warm. They develop on leeward side of the mountain range, when stable air is forced to flow over the barriers by the regional pressure gradient. Fohn winds are common in Alps in Europe, whereas, Chinook are common in rocky North America.

d) Tornadoes :

These are smallest, most violent and destructive of all storms. Funnel shaped having small diameter(10mt) and moving with very high velocity about 500 miles/ hr. are the characteristics of tornadoes . Where, the funnel clouds touch the ground, there is complete destruction at about 900 – 1200 ft wide. These are small eddies of intense turbulence generated by the mixing of dry polar air masses with moist, warm tropical air. This is the feature of American weather.

4. Cyclones and Anticyclones :

a) CYCLONES

A cyclone is a storm or system of winds that rotates around a center of low atmospheric pressure. It is the atmospheric disturbance in which the air pressure decreases at a particular location and there is movement of air towards center. A system of close isobars with the lowest pressure at the center is called cyclone.

It is a barometric depression wherein the pressure decreases from its outer rim to its center. The velocity of wind is more than 34 knots. In cyclones, air close to the ground is forced inward toward the center of the cyclone, where pressure is the 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.

The pressure gradient force and coriolis force cause air flow in cyclone to spiraling convergent system. In cyclone, the winds blow in a circular manner in clockwise direction in the southern hemisphere and in anticlockwise direction in the northern hemisphere. Cyclones are also known as '*lows*' or '*depressions*'. Cyclones (commonly known as lows) generally are indicators of rain, clouds, and other forms of bad weather.

CHARACTERISTICS OF CYCLONES

1. **Pressure distribution** : The lowest pressure is in the center and it increases towards the outer rim gradually.
2. **Temperature distribution**: The rear and left hand sides facing the direction of it are the coldest while the front and right hand sides are warmest.
3. **Distribution of moisture and clouds** : Relative humidity increases towards the center of the cyclone, being greatest in the eastern and south eastern side. Velocity of clouds lie at different heights in the cyclonic area. Cirrus clouds appear in the front.
4. **Distribution of rainfall** : Highest rainfall occurs at the front or warmer side but cooler sides have less frequent rains.
5. **Wind velocity and direction**: Wind velocity increases from outer rim to the center. Highest velocity is reached at some distance away from the center. Cyclones in general move in the direction of motion of the great mass of air carried by the primary atmosphere currents.
6. **Eye of the cyclone** : The center of the cyclone is the region with calm air, no cloudiness , little horizontal motion and no precipitation. This central region is known as ***'eye'*** of the cyclone.

b. ANTICYCLONES

An anticyclone is a system of winds that rotates around a center of high atmospheric pressure. When there is an area of high pressure at center, the flow of air starts from center to outer sides. A system of closed isobars with the highest pressure at the center is called '*anticyclone*'. The air flow has spiraling diverging system. The direction of rotation of anticyclones in the northern hemisphere is clockwise. These are also known as '*highs*'. Anticyclones (commonly known as highs) are predictors of fair weather.

Air at the center of an anticyclone is forced away from the high pressure towards low pressure. 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.

CHARACTERISTICS OF ANTICYCLONES

1. Air pressure : The high pressure center enclosed by isobars decreasing in pressure in oval or elliptical shape is known as ***anticyclones***. They are just opposite to cyclones. They bring fare weather and move in clockwise direction in northern hemisphere.Pressure decreases from center to periphery.Dimensions of anticyclones exceed those of cyclones.

2. Moisture in anticyclones : Anticyclones are associated with dry, cool air, little cloud, slight precipitation. Air descends at the center, therefore, temperature increases relative humidity decreases and clouds are dissipated.

3. Temperature in anticyclones : Temperatures near the ground in anticyclones are lower than the normal air temperatures. At higher altitudes temperatures are generally higher.

4. Direction and velocity of wind : At ground air spirally rushes outward from the center to periphery. Wind velocities are much lesser than in cyclones. Anticyclones move along with the general direction of the great air currents.

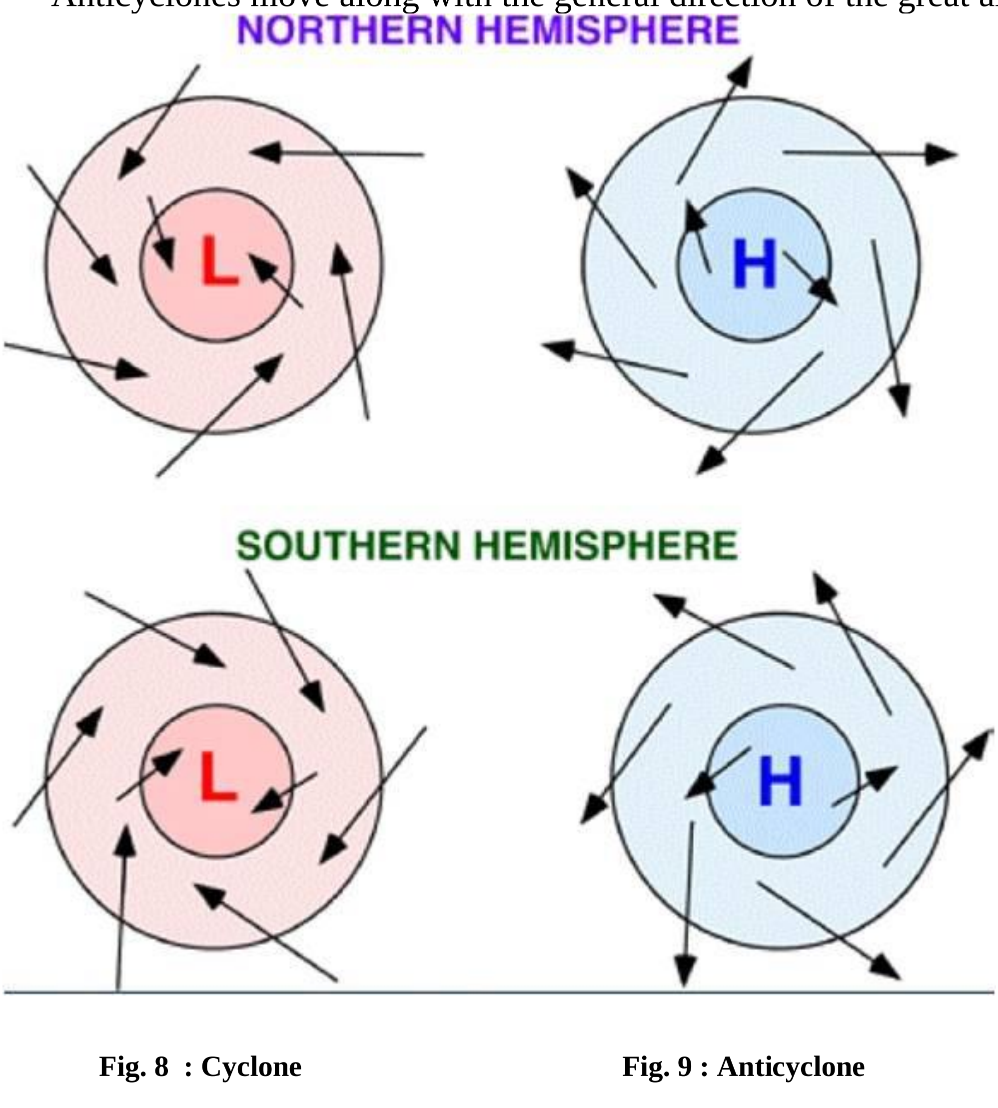


Fig. 8 : Cyclone **Fig. 9 : Anticyclone**

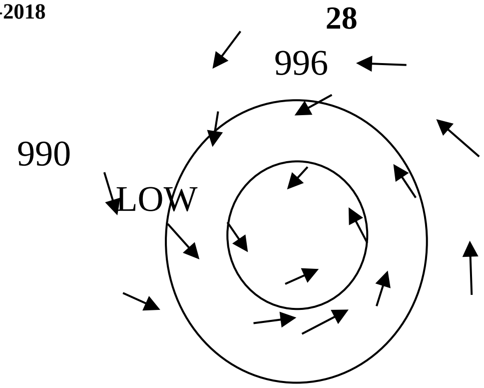


Fig.10: Cyclone

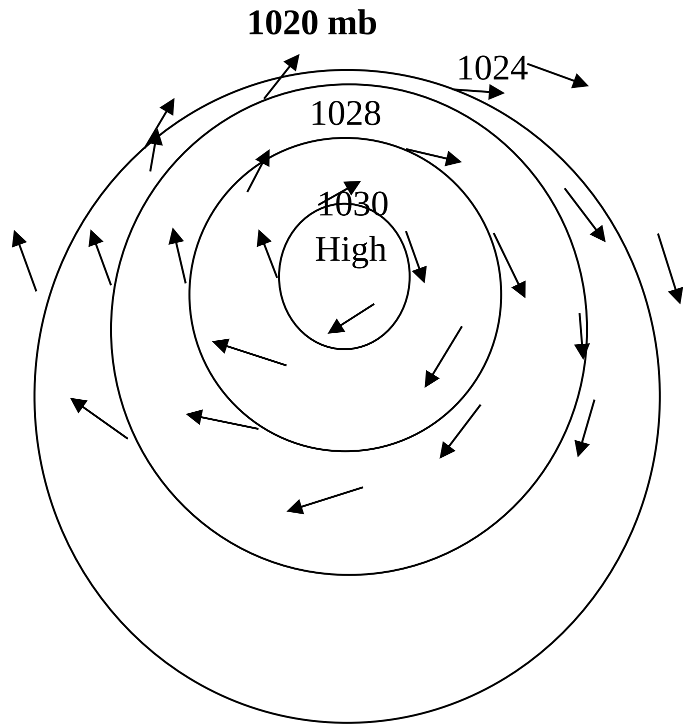


Fig. 11 : Anticyclone

EARTHS GENERAL CIRCULATION SYSTEM

A study of sea level equivalent of air pressure readings of various places reveals existence of pressure systems in the world with distinctive features which accounts for various phenomena of winds their movement along various latitudes. These have vital bearings on changes of season and determination of climate.

The major zonal systems are –

1) Equatorial Trough of low pressure and Inter tropical convergence zone:

In the equatorial latitudes low pressure belt is present, because falling of vertical sun rays raise the air temperature and lowers the air pressure. Pressure in this region is 1011 to 1008 mb. Along the equatorial trough, a belt of calm and variable wind occurs which is known as doldrums. High temperature, high humidity, heavy rainfall over a widespread area and light shifting winds characterizes the area. Within the equatorial trough, there is Inter Tropical convergence zone (ITCZ). This is the zone where the northeast and southeast trade winds meet and converge.

2) Subtropical belts of High pressure :

In subtropical zones, there are high pressure belts in both the hemispheres, where air pressure is more than 1020 mb. The rising air of equatorial low or ITCZ rise from the surface of tropopause and flows pole ward at around latitudes 30^0 N and S and produces high pressure belts. The surface winds over a broad area at systems center are very gentle or even clam over vast areas of North – Atlantic ocean. This is the result of weak horizontal air pressure which is characteristic of anticyclones. This zone is referred as horse latitude.

3) Sub polar low:

These regions are present at about 50^0 to 60^0 latitudes. Sub polar low pressure belt of southern hemisphere is continuous over the cold ocean surface, while in the northern hemisphere it is interrupted by large continental land masses

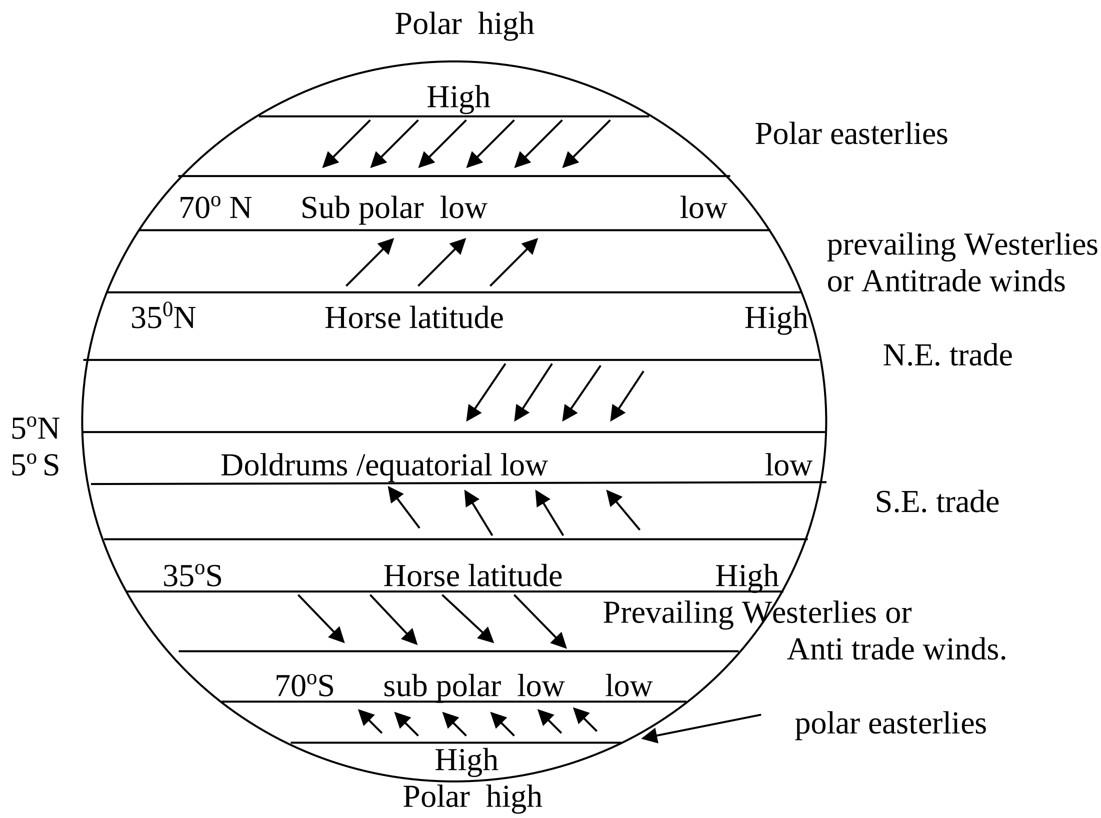


Fig.12 : Earth's general circulation system of wind

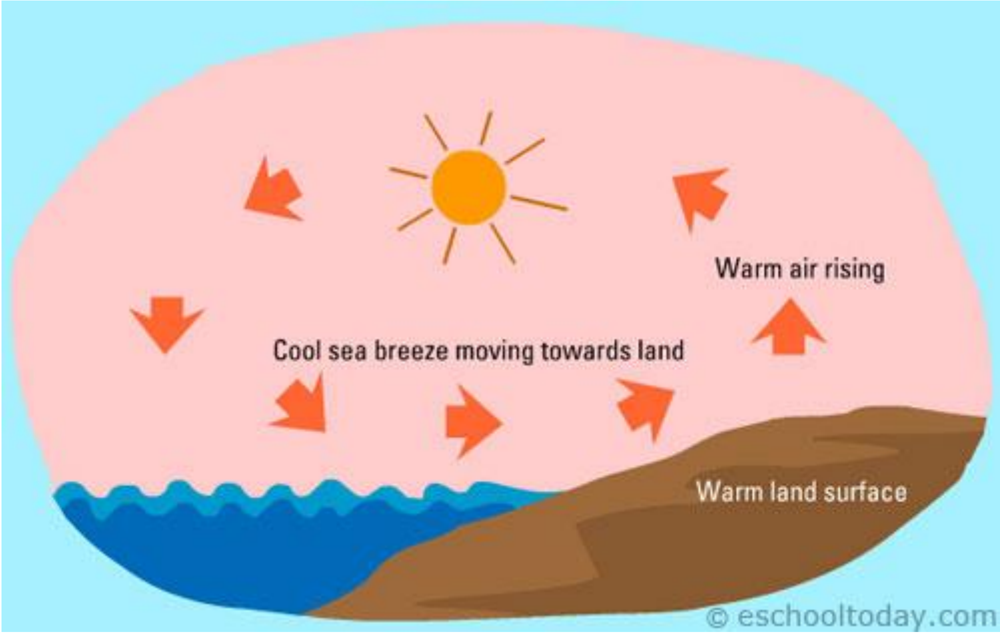
4) Polar High Pressure:

High pressure cells in the polar region are called polar high, which are typically anticyclonic in relation to movement of air, The Arctic high is present in Northern hemisphere when as Antarctic high is present in southern one.

Land and Sea Breezes

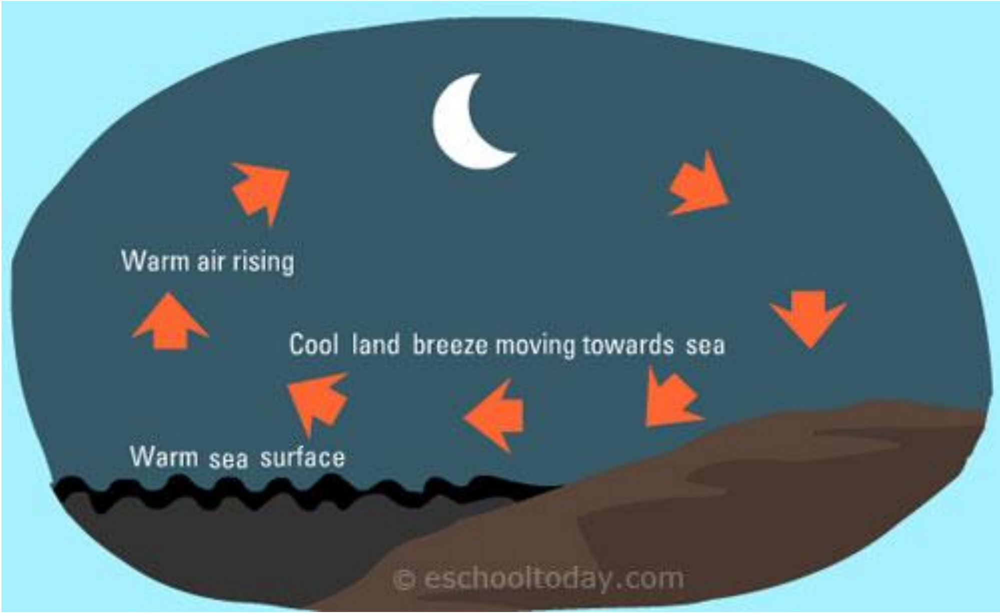
As the names suggest, the two breezes occur along coastal areas or areas with adjacent large water bodies. Water and land have different heating abilities. Water takes a bit more time to warm up and is able to retain the heat longer than land does.

Now let us see the two diagrams below:



In the day, when the sun is up, the land heats up very quickly and the air above it warms up a lot more than the air over the water. The warm air over the land is less dense and begins to rise. Low pressure is created.

The air pressure over the water is higher with cold dense air, which moves to occupy the space created over the land. The cool air that comes along is called a sea breeze.



In the night, the reverse happens. The land quickly loses its' heat whiles the water retains its' warmth. This means the air over the water is warmer, less dense and begins to rise. Low pressure is created over the water. Cold and dense air over the land begins to move to the water surface to replace the warmer rising air. The cool breeze from the land is called a land breeze.

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LECTURE 5

NATURE AND PROPERTIES OF SOLAR RADIATION, SOLAR CONSTANT, DEPLETION OF SOLAR TRADIATION, SHORT WAVE, LONG WAVE AND THERMAL RADIATION, NET TRADIATION, ALBEDO

The sun is the primary source of energy supplying 99.9 per cent energy for various physical, biological, biochemical, geological etc. processes which are taking place on the earth. The sun radiates its energy in the form of wave lengths from 0.15 to 4.0 µ and is generally called as short wave lengths. On contrary after absorption of solar energy, earth emits its energy between 4 to 100 µ and is categorized as long wave radiations. The temperature of the sun is 6000^{o}K and gives out energy about 5.6 x 10^{27} calories /minute.

Radiation : The transfer of thermal (heat) energy in the form of electromagnetic waves from one place to another through vacuum with speed of light (3 x 10^5 km/sec) is called radiation.

Insolation: Incoming solar radiation or energy received on the surface of the earth is known as ***insolation***.

Solar radiation : It is the form of energy that is received from sun in the form of insolation through short wave length.

There are three methods of transfer of heat or energy that means three different ways by which heat can flow from one point to another are :

1. Conduction 2. Convection and 3. Radiation

For conduction and convection of heat , material medium is necessary. But for radiation material medium is not necessary because radiation takes place in the form of electromagnetic waves.

The ultimate source of all the energy for physical and biological processes occurring on the earth is radiation received from the sun that is why it is commonly called solar radiation.

TYPES OF RADIATION (FORMS OF RADIATION)

Short wave radiation : The radiation that is received from the sun in the form of insolation is called as short wave radiation. The sun radiated its energy in the form of wave lengths from 0.15 to 0.76 µ and are generally called as short wave length.

Long wave radiation : The radiation reflected back to space by the different objects including earth is called as long wave radiation. Radiation wave length range 0.76 to 100 µ.

Global radiation or total radiation on the earth :

The total of direct beam solar radiation and the diffuse sky radiation received by a unit horizontal surface is called as global radiation.

Net radiation : The difference between the total incoming radiation and the total outgoing radiation is called net radiation.

Terrestrial radiation : The sunrays are first absorbed by earth surface, therefore, the temperature of the earth is increased. Then afterwards it is reflected back to atmosphere. Therefore, the atmosphere gets warmed by the long wave radiation. Afterwards atmosphere starts re-radiating the same to earth. Thus radiation both from earth and atmosphere together is terrestrial radiation.

Direct radiation : the direct beam solar radiation received by a unit horizontal surface is called direct radiation.

TERMINOLOGY USED IN RADIATION (PROPERTIES OF RADIATION)

1. **Transmissivity** : It is defined as the ratio of quantity of radiant energy transmitted through a body to the total quantity of energy incident upon in is called Transmissivity.
2. **Reflectivity** : The ratio of the quantity of radiant energy reflected by a body to the total quantity of energy incident upon it, is called reflectivity.
3. **Absorptivity** : It is defined as the ratio of the amount of radiant energy absorbed by body to the total quantity incident on it, is called Absorptivity.
4. **Emmissivity** : It is defined as the ratio of radiant energy emitted by a surface at a specified wave length and temperature to the radiant energy emitted by an ideal black body at the same wavelength and temperature.

   The emissivity of a given surface is the measure of its ability to emit radiation energy in comparison to a blackbody at the same temperature. The emissivity of a surface varies between zero and one. This is a property that measures how much a surface behaves as a blackbody. The emissivity of a real surface varies as a function of the surface temperature, the wavelength, and the direction of the emitted radiation. The fundamental emissivity of a surface at a given temperature is the spectral directional emissivity, which is defined as the ratio of the intensity of radiation emitted by the surface at a specified wavelength and direction to that emitted by a blackbody under the same conditions.

5. **Radiation flux density :** It is defined as the amount of energy received on a unit surface in a unit time. Unit of radiant flux density is langely min^{-1}.
6. **Black body** : A body will absorb completely all radiation incident up on it. The black body is a physical ideal, the perfect radiator and perfect absorber. Soils & liquids behave as black body. While gases do not behave as black body. The earth behave a black body.
7. **Solar constant** : The flux density (or intensity) of the solar beam at the top of the atmosphere and the earth's mean distance from the sun is known as solar constant. The solar constant, a measure of flux density, is the conventional name for the mean solar electromagnetic radiation (the solar irradiance) per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU) from the Sun (roughly the mean distance from the Sun to the Earth). The solar constant includes all types of solar radiation, not just the

visible light. It is measured by satellite as being 1.361 kilowatts per square meter (kW/m^2) at solar minimum and approximately 0.1% greater (roughly 1.362 kW/m^2) at solar maximum.

8. Albedo : The fraction or per cent of the reflected solar radiation from the surface to incoming solar radiation. Thus, it usually refers to the reflectivity of a particular band or portion of the spectrum Or Albedo is also defined as the ratio of reflected radiations to the total incident radiations. The albedo of crop surfaces is ranging between 23 to 30%.

Albedo is the "whiteness" of a surface. It is a reflection coefficient, and has a value of less than one. Albedo is derived from Latin word '*albedo*' "whiteness" (or reflected sunlight) in turn from *albus* "white", is the diffuse reflectivity or reflecting power of a surface.

It's dimensionless, expressed as a percentage and is measured on a scale from zero (no reflection) of a perfectly black surface to 1 for perfect reflection of a white surface. Because albedo is the ratio of all reflected radiation to incident radiation, it will include both the diffuse and specular radiation reflected from an object. Albedo depends on the frequency of the radiation.

The albedo is an important concept in climatology, astronomy, and calculating reflectivity of surfaces in Leadership in Energy and Environmental Design (LEED) sustainable-rating systems for buildings. The average overall albedo of Earth, its *planetary albedo*, is 30 to 35% because of cloud cover, but widely varies locally across the surface because of different geological and environmental features.

Absorptivity (α), reflectivity (ρ) and transmissivity (t)

If the amounts of radiation energy absorbed, reflected, and transmitted when radiation strikes a surface are measured in percentage of the total energy in the incident electromagnetic waves. The total energy would be divided into three groups, they are called absorptivity (α), reflectivity (ρ) and transmissivity (t).

$$\alpha + \rho + t = 1 \quad (1)$$

- Absorption is the fraction of irradiation absorbed by a surface.
- Reflectivity is the fraction reflected by the surface.
- Transmissivity is the fraction transmitted by the surface.

DEPLETION OF SOLAR RADIATION

If the Sun's radiation was not filtered or depleted in some manner, our planet would soon be too hot for life to exist. We must now consider how the Sun's heat energy is both dispersed and depleted. This is accomplished through dispersion, scattering, reflection, and absorption.

DISPERSION : Earlier it was learned that Earth's axis is inclined at an angle of 23 1/2°. This inclination causes the Sun's rays to be received on the surface of earth at varying angles of incidence, depending on the position of Earth. When the Sun's rays are not perpendicular to the surface of Earth, the energy becomes dispersed or spread out over a greater area.

If the available energy reaching the atmosphere is constant and is dispersed over a greater area, the amount of energy at any given point within the area decreases, and therefore the temperature is lower. Dispersion of insolation in the atmosphere is caused by the rotation of Earth. Dispersion of insolation also takes place with the seasons in all latitudes, but especially in the latitudes of the polar areas.

SCATTERING : About 25 per cent of the incoming solar radiation is scattered or diffused by the atmosphere. Scattering is a phenomenon that occurs when solar radiation passes through the air and some of the wavelengths are deflected in all directions by molecules of gases, suspended particles, and water vapor. These suspended particles then act like a prism and produce a variety of colors. Various wavelengths and particle sizes result in complex scattering affects that produce the blue sky. Scattering is also responsible for the red Sun at sunset, varying cloud colors at sunrise and sunset, and a variety of optical phenomena. Scattering always occurs in the atmosphere, but does not always produce dramatic settings. Under certain radiation wavelength and particle size conditions all that can be seen are white clouds and a whitish haze. This occurs when there is a high moisture content (large particle size) in the air and is called diffuse reflection. About two-thirds of the normally scattered radiation reaches earth as diffuse sky radiation.Diffuse sky radiation may account for almost 100 per cent of the radiation received by polar stations during winter.

REFLECTION: Reflection is the process whereby a surface turns a portion of the incident back into the medium through which the radiation came. A substance reflects some insolation. This means that the electromagnetic waves simply bounce back into space. Earth reflects an average of 36 per cent of the insolation. The percent of reflectivity of all wavelengths on a surface is known as its albedo. Earth's average albedo is from 36 to 43 per cent. That is, Earth reflects 36 to 43 per cent of insolation back into space. In calculating the albedo of Earth, the assumption is made that the average cloudiness over Earth is 52 per cent. All surfaces do not have the same degree ofreflectivity; consequently, they do not have the same albedo.

Some examples are as follows:

1. Upper surfaces of clouds reflect from 40 to 80 per cent, with an average of about 55 per cent.
2. Snow surfaces reflect over 80 per cent of incoming sunlight for cold, fresh snow and as low as 50 per cent for old, dirty snow.
3. Land surfaces reflect from 5 per cent of incoming sunlight for dark forests to 30 per cent for dry land.
4. Water surfaces (smooth)reflect from 2 per cent,when the sun is directly overhead, to 100 per cent when, the Sun is very low on the horizon. This increase is not linear. When the Sun is more than 25°above the horizon, the albedo is less than 10 per cent. In general, the albedo of water is quite low. When Earth as a whole is considered, clouds are most important in determining albedo.

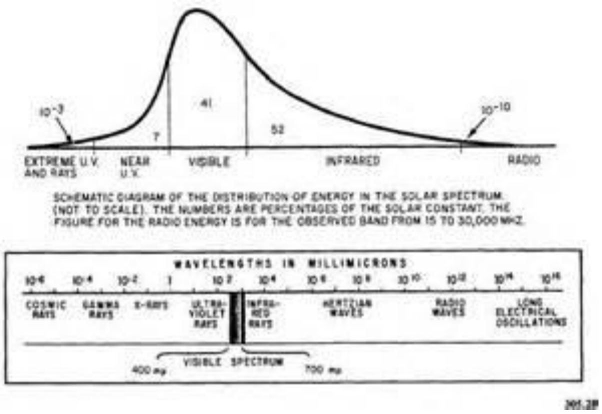

Fig. 15 Depletion of solar radiation

SHORT WAVE RADIATION

Shortwave radiation **(SW)** is radiant energy with wavelengths in the visible **(VIS),** near-ultraviolet (UV), and near-infrared (NIR) spectra.

There is no standard cut-off for the near-infrared range; therefore, the shortwave radiation range is also variously defined. It may be broadly defined to include all radiation with a wavelength between 0.1μm and 5.0μm or narrowly defined so as to include only radiation between 0.2μm and 3.0μm.

There is little radiation flux (in terms of W/m^2) to the Earth's surface below 0.2μm or above 3.0μm, although photon flux remains significant as far as 6.0μm, compared to shorter wavelength fluxes. UV-C radiation spans from 0.1μm to .28μm, UV-B from 0.28μm to 0.315μm, UV-A from 0.315μm to 0.4μm, the visible spectrum from 0.4μm to 0.7μm, and NIR arguably from 0.7μm to 5.0μm, beyond which the infrared is thermal.

Visible light and ultraviolet radiation are commonly called shortwave radiation, while infrared radiation is referred to as long wave radiation. The Sun radiates energy mainly in the form of visible light, with small amounts of ultraviolet and infrared radiation. For this reason, solar radiation is usually considered shortwave radiation.

LONG WAVE RADIATION

Outgoing Longwave Radiation (OLR) is the energy radiating from the Earth as infrared radiation at low energy to Space.

OLR is electromagnetic radiation emitted from Earth and its atmosphere out to space in the form of thermal radiation. The flux of energy transported by outgoing longwave radiation is measured in W/m^2.

Over 99% of outgoing longwave radiation has wavelengths between 4 µm and 100 µm in the thermal infrared part of the electromagnetic spectrum. Contributions with wavelengths larger than 40 µm are small, therefore often only wavelengths up to 50 µm are considered . In the wavelength range between 4 µm and 10 µm the spectrum of outgoing longwave radiation overlaps that of solar radiation, and for various applications different cut-off wavelengths between the two may be chosen.

Radiative cooling by outgoing longwave radiation is the primary way of the Earth System loses energy. The balance between this loss and the energy gained by radiative heating from incoming solar shortwave radiation determines global heating or cooling of the Earth system (Energy budget of Earth’s climate). Local differences between radiative heating and cooling provide the energy that drives atmospheric dynamics.

THERMAL RADIATION

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation. When the temperature of a body is greater than absolute zero, inter-atomic collisions cause the kinetic energy of the atoms or molecules to change. This results in charge-acceleration and/or dipole oscillation which produces electromagnetic radiation, and the wide spectrum of radiation reflects the wide spectrum of energies and accelerations that occur even at a single temperature.

Examples of thermal radiation include the visible light and infrared light emitted by an incandescent light bulb, the infrared radiation emitted by animals are detectable with an infrared camera, and the cosmic microwave background radiation. Thermal radiation is different from thermal convection and thermal conduction—a person near a raging bonfire feels radiant heating from the fire, even if the surrounding air is very cold.

Sunlight is part of thermal radiation generated by the hot plasma of the Sun. The Earth also emits thermal radiation, but at a much lower intensity and different spectral distribution (infrared rather than visible) because it is cooler. The Earth's absorption of solar radiation, followed by its outgoing thermal radiation are the two most important processes that determine the temperature and climate of the Earth.

If a radiation-emitting object meets the physical characteristics of a black body in thermodynamic equilibrium, the radiation is called blackbody radiation.Planck's law describes the spectrum of blackbody radiation, which depends only on the object's temperature. Wien's displacement law determines the most likely frequency of the emitted radiation, and the Stefan–Boltzmann law gives the radiant intensity.

NET RADIATION

Earth's net radiation, sometimes called net flux, is the balance between incoming and outgoing energy at the top of the atmosphere. It is the total energy that is available to influence the climate. Energy comes in to the system when sunlight penetrates the top of the atmosphere. Energy goes out in two ways: reflection by clouds, aerosols, or the Earth's surface; and thermal radiation—heat emitted by the surface and the atmosphere, including clouds. The global average net radiation must be close to zero over the span of a year or else the average temperature will rise or fall.

SIGNIFICANCE OF RADIATION IN AGRICULTURE

Intensity, quality, duration, direction, quantity and periodicity are the important aspects of solar radiation which are biologically significant.

The importance of the radiation in crop production is as follows :

1. It provides the necessary energy for all the phenomena concerning biomass production.
2. Photosynthetically Active Radiations (PAR) are the real source of energy for photosynthesis process. Plants are efficient biological convertors of solar energy into biomass. Radiation defines the yield of a crop in particular region.
3. It also provides the energy for the physical processes taking place in plant soil and atmosphere.
4. It conditions (governs) the distribution of temperature and hence crop distribution on the earth surface.
5. Almost all growth, development and yield governing processes such as germination, elongation formative activity, reproduction, flowering, photo-periodism, leaf enlargement, pigmentation etc. are affected by radiation.

Units of radiation :

1 cal cm^{-2} min^{-1} = 697 Wm^{-2}

1 cal cm^{-2} = 1 langley (LY)

1 watt = 1 Joule / sec

1 k. lux = 92.9 fc = 4 Wm^{-2}

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LECTURE 6

ATMOSPHERIC TEMPERATURE : TEMPERATURE INVERSION, LAPSE RATE, DAILY AND SEASONAL VARIATIONS OF TEMPERATURE, VERTICAL PROFILE OF TEMPERATURE,ENERGY BALANCE OF EARTH

Temperature : The degree of hotness or coldness is known as temperature.

When any object receives energy in the form of heat, its temperature increases. Air or atmosphere receives the heat energy from the sun and its temperature increases. Due to different amount of heat energy receipt at different places, the air temperatures at different places also vary. The variation in the air temperature basically results into air motion so as to equalize the energy content of the different region of the earth. Temperature is a fundamental element of climate from many points of view, the most important in controlling the distribution of life on the earth. Most of the weather elements are dependent on it, directly or indirectly. Thus, temperature of air can be regarded as the basic cause for weather changes.

TEMPERATURE INVERSION

When the temperature increases with increase in height, this condition is known as inversion.

Temperature inversion, a reversal of the normal behaviour of temperature in the troposphere (the region of the atmosphere nearest the Earth's surface), in which a layer of cool air at the surface is overlain by a layer of warmer air. (Under normal conditions air temperature usually decreases with height.)

Inversions play an important role in determining cloud forms, precipitation, and visibility. An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of air from below is limited to levels below the inversion. Diffusion of dust, smoke, and other air pollutants is likewise limited. In regions where a pronounced low-level inversion is present, convective clouds cannot grow high enough to produce showers and, at the same time, visibility may be greatly reduced below the inversion, even in the absence of clouds, by the accumulation of dust and smoke particles. Because air near the base of an inversion tends to be cool, fog is frequently present there.

Inversions also affect diurnal variations in air temperature. The principal heating of air during the day is produced by its contact with a land surface that has been heated by the Sun's radiation. Heat from the ground is communicated to the air by conduction and convection. Since an inversion will usually control the upper level to which heat is carried by convection, only a shallow layer of air will be heated if the inversion is low and large, and the rise in temperature will be great.

There are four kinds of inversions: ground, turbulence, subsidence, and frontal.

A ground inversion develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere; this occurs most often on clear nights, when the ground cools off rapidly by radiation. If the temperature of surface air drops below its dew point, fog may result. Topography greatly affects the magnitude of ground inversions. If the land is rolling or hilly, the cold air formed on the higher land surfaces tends to drain into the hollows, producing a larger and thicker inversion above low ground and little or none above higher elevations.

A turbulence inversion often forms when quiescent air overlies turbulent air. Within the turbulent layer, vertical mixing carries heat downward and cools the upper part of the layer. The unmixed air above is not cooled and eventually is warmer than the air below; an inversion then exists.

A subsidence inversion develops when a widespread layer of air descends. The layer is compressed and heated by the resulting increase in atmospheric pressure, and as a result the lapse rate of temperature is reduced. If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion. Subsidence inversions are common over the northern continents in winter and over the subtropical oceans; these regions generally have subsiding air because they are located under large high-pressure centres.

A frontal inversion occurs when a cold air mass undercuts a warm air mass and lifts it aloft; the front between the two air masses then has warm air above and cold air below. This kind of inversion has considerable slope, whereas other inversions are nearly horizontal. In addition, humidity may be high, and clouds may be present immediately above it.

Inversion happens due to the following seasons:

1) Earth surface looses heat more than it gains
2) Cold air from hill tops and slopes tend to flow downward and get replaced by warm air.
3) Cold air masses replaces warm air mass. When air mass with different temperature come together.

There are following types of inversion :

1. **Surface inversion** : This occurs due to radiational cooling of the ground. Air near the ground is cooler *viz.* in winter while above it, air is warmer.
2. **Advection inversion** : Advection means transport of energy or mass in horizontal plane in downward direction. Occurs from an actual warming layer over a cold one.

LAPSE RATE

The rate of temperature decrease with increase in height is called a lapse rate. It is an average 6.5 ^oC /km in the troposphere. The phenomena of increase in temperature with height is known as negative lapse rate of temperature or thermal inversion.

Lapse rate, rate of change in temperature observed while moving upward through the Earth's atmosphere. The lapse rate is considered positive when the temperature decreases with elevation, zero when the temperature is constant with elevation, and negative when the temperature increases with elevation (temperature inversion). The lapse rate of non rising air—commonly referred to as the normal, or environmental,lapse rate-is highly variable, being affected by radiation, convection, and condensation; it averages about 6.5 °C per km (18.8 °F per mile) in the lower atmosphere (troposphere). It differs from the adiabatic lapse rate, which involves temperature changes due to the rising or sinking of an air parcel.

Types of lapse rates

There are three types of lapse rates that are used to express the rate of temperature change with a change in altitude, namely the ***dry adiabatic lapse rate***, the ***wet adiabatic lapse rate*** and the ***environmental lapse rate***.

Dry adiabatic lapse rate

Since the atmospheric pressure decreases with altitude (see Earth's atmosphere), the volume of an air parcel expands as it rises. Conversely, if a parcel of air sinks from a higher altitude to a lower altitude, its volume is compressed by the higher pressure at the lower altitude. An *adiabatic lapse rate* is the rate at which the temperature of an air parcel changes in response to the expansion or compression process associated with a change in altitude, under the assumption that the process is adiabatic (meaning that no heat is added or lost during the process).

Earth's atmospheric air is rarely completely dry. It usually contains some water vapor and when it contains as much water vapor as it is capable of, it is referred to as saturated air (i.e., it has a relative humidity of 100%). The ***dry adiabatic lapse rate*** refers to the lapse rate of unsaturated air (i.e., air with a relative humidity of less than 100%). It is also often referred to as the *dry adiabat, DALR* or *unsaturated lapse rate*. It should be noted that the word *dry* in this context simply means that no liquid water (i.e., moisture) is present in the air ... water vapor may be and usually is present.

The dry adiabatic lapse rate can be mathematically expressed as:

$$\Gamma_d = \frac{g}{c_{pd}}$$

where:

Γ_d = the dry adiabatic lapse rate, 0.0098 K/m (equivalent to 9.8 K/kilometre or 5.4 °F/1000 feet)

g = Earth's gravitational acceleration, 9.8076 m/s^2

c_{pd} = the specific heat of dry air at constant pressure, 1004.64 J/(kg .K)

The troposphere is the lowest layer of the Earth's atmosphere. Since g and c_p vary little with altitude, the dry adiabatic lapse rate is approximately constant in the troposphere.

A process (change of state) that take place without any addition or with drawl of heat is called as adiabatic process. The rate of which temperature decrease in a rising expanding air parcel is called adiabatic lapse rate.

Air parcel of dry air (unsaturated air, which is no part of its energy becomes saturated) displaced upward its pressure diminishes to equal to that of new environment and its volume increases, will cause in fall of temperature of the air parcel. The rate of fall of temperature of unsaturated air parcel during adiabatic cooling is known as dry adiabatic lapse rate or DALR. The DALR is about 9.8 ^{o} C/ km.

Saturated adiabatic lapse rate : An unsaturated parcel of air will rise from earth's surface and cool at the dry adiabatic rate of -9.8 K/kilometre (5.4 °F/1000 ft) until it has cooled to the temperature, known as the *atmospheric dew point*, at which the water vapor it contains begins to condense (i.e., change phase from vapor to liquid) and release the latent heat of vaporization. At that dew point temperature, the air parcel is saturated and, because of the release of the heat of vaporization, the rate of cooling will decrease to what is known as the ***saturated adiabatic lapse rate***. This rate is also often referred to as the *wet adiabat*, *saturated lapse rate*, *SALR*, *moist adiabatic lapse rate* or *MALR.*

The saturated adiabatic lapse rate is not a constant since it depends upon how much water vapor the atmospheric air contained when it started to rise, which means the amount of heat of vaporization available for release is variable. In the troposphere, the rate can vary from about 4 K/kilometre (2.2 °F/1000 ft) in regions where the ambient temperature is about 25 °C (77 °F) to about 7 K/kilometre (3.8 °F/1000 ft) in regions where the ambient temperature is about – 10 °C (14 °F).

After the air parcel has reached its dew point and cooling has decreased to the wet adiabatic lapse rate, it will eventually rise to a point where all of its water vapor has condensed and its rate of cooling will then revert back to the dry adiabatic lapse rate.

The wet adiabatic lapse rate can be mathematically expressed as:

$$\Gamma_w = g\,\frac{1 + \dfrac{H_v\, r}{R_{sd}\, T}}{c_{pd} + \dfrac{H_v^2\, r\, \epsilon}{R_{sd}\, T^2}}$$

where:

Γ_w = Wet adiabatic lapse rate, K/m

g = Earth's gravitational acceleration = 9.8076 m/s^2

H_v = Heat of vaporization of water, J/kg

r = The ratio of the mass of water vapor to the mass of dry air, kg/kg

R = The universal gas constant = 8,314 J/(kmol .K)

M = The molecular weight of any specific gas, kg/kmol = 28.964 for dry air and 18.015 for water vapor

R/M = The specific gas constant of a gas, denoted as R_s

R_{sd} = Specific gas constant of dry air = 287 J/(kg .K)

R_{sw} = Specific gas constant of water vapor = 462 J/(kg .K)

ϵ =The dimensionless ratio of the specific gas constant of dry air to the specific gas constant for water vapor = 0.6220

T = Temperature of the saturated air, K

c_{pd} = The specific heat of dry air at constant pressure, J/(kg .K)

A saturated air parcel displaced upward. It is immediately cooled below its dew point and water vapour condenses out, with release of latent heat. The rate of fall of temperature of saturated air parcel during adiabatic cooling is known as saturated adiabatic lapse rate or SALR. The SALR is 4 ^oC / km or 2.2^{o}F/1000ft.

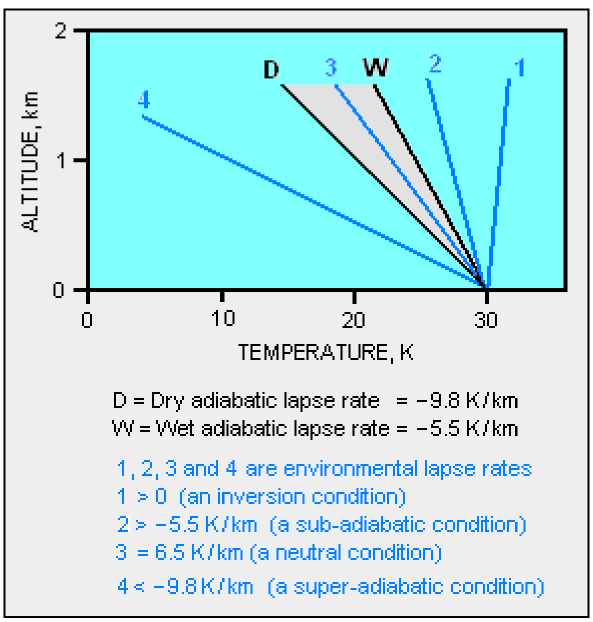

Fig.16 : Dry and saturated adiabatic lapse rate

TEMPERATURE VARIATION

Air temperature at any location changes during a day, week, month, year or for any period. On these basis, it is classified as –

B. Periodic temperature variation

1) Diurnal temperature variation or daily temperature cycle.

2) Annual temperature variation or Annual temperature cycle.

C. Horizontal variation

D. Vertical variation

A. **Periodic temperature variation** : The air temperature continuously changes during a day, week, month, year or any period and these change is called periodic temperature variation.

Periodic temperature variations are –

1) **Diurnal temperature variation or daily temperature cycle** : The daily pattern of air temperature is known as diurnal variation of temperature. The diurnal temperature variation gives rise to daily maximum and minimum temperatures. The diurnal temperature range is the greatest at low latitude and is least at high latitude.

From the sunrise, sun energy is continuously supplied and the temperature continuously rises, recording maximum between 2.00 to 3.00 p.m. though the maximum amount of solar radiation is received at 12.00 pm. This delay in time to reach maximum temperature is known as ***thermal lag or thermal inertia***.

Similarly, minimum air temperature occurs just before sunrise. This is due thermal lag in transfer of heat from the surface to the air/space.

Daily range of temperature affected by clouds. Daily range of temperature is small on the surface of oceans.

2) **Annual temperature variation or Annual temperature cycle**: The change in average daily temperature during the year is called as annual temperature cycle. The annual temperature variation gives rise to seasons i.e. summer and winter. The annual temperature range varies greatly from place to place. There is thermal lag of 30 to 40 days. In northern hemisphere winter minimum occurs in January and summer maximum in July and vice versa in southern hemisphere. Daily, monthly and annual temperature ranges are worked out for stations. When the loss by earth radiation of heat exceeds the receipts, the temperature falls and when the solar radiation exceeds the loss by earth radiation, the temperature increases in a cycle. The difference between the highest and lowest temperatures for a given period is known as range.

Annual temperature change is the result of the twin movement of earth, it's rotation on its axis and it's revolution around sun. Mid winter to mid summer increases solar radiation.

Solar radiation is maximum in July -August.Summer solstice occurs on 22nd June. Whereas, in Jan - Feb. solar radiation is minimum. On 21st December winter solstice occurs.

B. **Horizontal temperature variation**: The atmospheric temperature varies horizontal direction due to horizontal transport (advection) of heat energy. The rate of change of temperature with horizontal distance is known as temperature gradient. In general, as we go towards the poles, the temperature continuously decreases being lowest at the poles (i.e. As the latitude increases the solar energy received on the earth correspondingly decreases). The sun crosses the equator twice in a year, two maxima and two minima are observed in annual march (cycle) of temperatures.

Isotherm : A line on the weather map which joins the places of equal temperature is called isotherm.

C. **Vertical temperature variation**: When we move upward, temperature alternately decreases and increases. The vertical temperature profile forms the basis of the layering of the atmosphere. The vertical temperature variation does not show uniform behavior and the atmosphere can be divided into four spheres.

- **Troposphere**(0 to11km)**:** Wherein temperature decreases from 15°C to -60 °C.
- **Stratosphere**11 to 50km)**:** Wherein temperature increases from -60 °C to 0 °C.
- **Mesosphere**(50 to 80km)**:**Wherein temperature decreases from 0 °C to -90 °C.
- **Thermosphere** (above 80km)**:** Wherein temperature increases from –90 °C to 95°C at 350 km height and 170 °C at undefined upper limit. This is due to absorption of solar radiation by atomic oxygen.

RADIATION BUDGET OR ENERGY BALANCE

The difference between all incoming and outgoing radiation at the earth surface and top of the atmosphere is known as '***radiation balance of the earth surface***'. R_B= (incoming - outgoing) radiation.

The net radiation is the difference between total incoming and outgoing radiations and is a measure of the energy balance 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 a crop surface is as follows.

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

Where,R_n is net radiation, G is surface soil heat flux, H is sensible 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 R_n). 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. If water is not limiting, most of the R_n is used for evapotranspiration. Thus, air temperature increases when the water is limited as the energy that is supposed to evapotranspiring water is used to heat the air.

It can be seen at the top of the atmosphere. If the incoming solar radiation (insolation) is considered as 100 units at the outer atmosphere, 30 units are returned to space through reflection from the earth's surface (4 units), reflection from clouds (20 units) and back scattered by air (6 units) without heating the atmosphere. Out of

70 units remaining, 16 units are absorbed by water vapour, dust and ozone and 3 units are absorbed by clouds. The remaining 51 units are transmitted through the atmosphere and absorbed at the ocean and land surface. Out of the 51 units absorbed at the earth's surface, 23 units are used for latent heat flux and 7 units are used for sensible heat flux and the earth emits 21 units in the form of long wave radiation. Out of 21 units emitted by the earth, 15 units are absorbed by water vapour and carbon dioxide and 6 units are lost to space. The net emission to space in the form of long wave radiation by water vapour and carbon dioxide is 38 units and 26 units by clouds so as to balance the 100 units if incoming solar radiation received at the outer atmosphere (Fig.2). The positive sign is for incoming solar radiation while negative for outgoing radiation lost to the space and then balance. Total of all incoming and outgoing radiations over earth surface is zero.

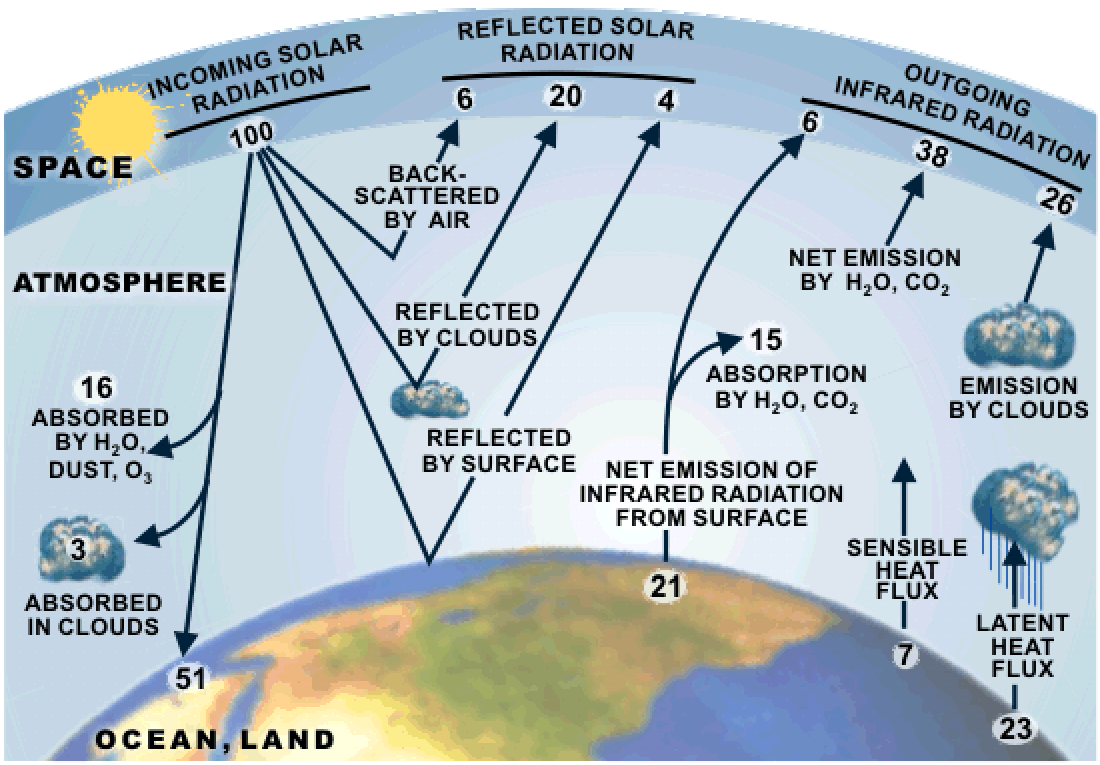

Fig. 17: The mean annual radiation and heat balance of the atmosphere relative to 100 units of incoming solar radiation, based on satellite measurements and conventional observations

Fig.17 : Radiation budget or heat balance

LECTURE 7

ATMOSHERIC HUMIDITY – CONCEPT OF SATURATION, VAPOUR PRESSURE, PROCESS OF CONDENSATION,FORMATION OF DEW, FOG, MIST, FROST,CLOUD

Water vapour from different water bodies like ocean, sea, river, lake , soil moisture is evaporated. Similarly it is transpired from the plants trees forest and vegetation. All these water vapours are present in the atmosphere. The water in gasepos form in the atmosphere is known as water vapour.

Humidity : Water vapour present in the atmosphere is known humidity. It is expressed in percentage. The percentage of water in the atmosphere is highly variable and changes according to season, land and sea presence etc. but in any case it never exceeds 4% by volume in atmosphere. Water vapour (humidity) decreases with increase in height and most of the water vapour content exist below 500 mb or 5574 meter height. Humidity depends mainly on the air temperature.

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

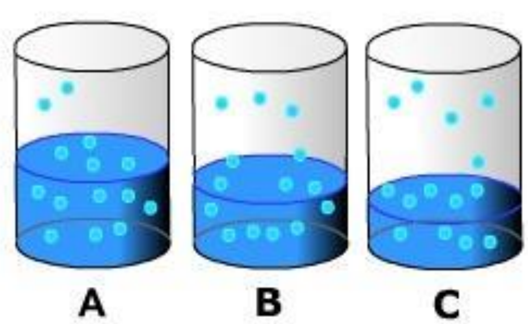

Fig. 18 Evaporation and condensation in an enclosed beaker of water

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.

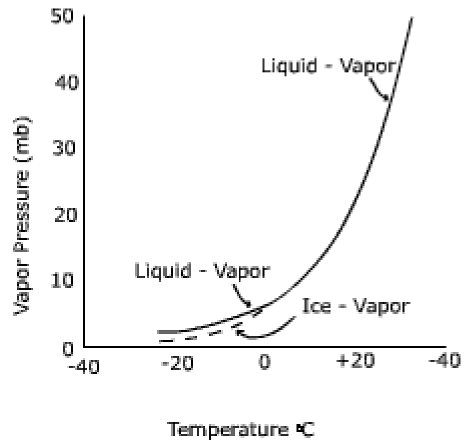

Fig.19 Relationship Between Air Temperature and Vapor Pressure

Note that below 0°C 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° 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 vapor pressure at -20° 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 vapor pressure).

Vapour pressure : Like other atmospheric gases, water vapour exerts a pressure on the earths surface which is called as **vapour pressure**. It is a part of atmospheric pressure due to the water vapour is known as partial pressure in the atmosphere. Vapour pressure is expressed in millibars (mb) or in kilo pascal (Kpa).

Actual vapour pressure : The pressure exerted by actual air (dry air) is known as

actual vapour pressure.

Saturated vapour pressure : There is an upper limit to the amount of water vapour, that the air can hold it is called saturation or saturated air and the vapour pressure exerted by this air is called saturated vapour pressure. When air is completely saturated, then there will be no evaporation and hence both the dry bulb and wet bulb thermometers will indicate the same temperature.

Absolute Humidity (A.H.) : Absolute humidity is defined as the actual mass of water vapour present in the given volume of air. It is measured in grams per cubic meter (gm/m^3) or pounds per cubic feet. It is also known as vapour density. It is dependent on temperature only.

A.H. = density of water vapour

$$A.H. = \frac{\text{Weight of water vapour}}{\text{volume of air}}$$

Specific humidity : The mass of water vapour in the given mass of air containing the moisture. It is expressed in grams per gram or grams per kilogram.

Relative humidity (R.H):Relative humidity represents the amount of water vapour vapour actually present in air compared with the maximum amount the air can hold at a given temperature. It tells simply relative content and indicate degree of saturation of air of a given temperature. Relative humidity of saturated air is 100%. The proportion of water vapour present relative to the maximum quantity is called relative humidity (R.H.). OR

It is the ratio of

$$RH = \frac{\text{Actual quantity of water vapour present in a given volume of air}}{\text{Maximum amount of water vapour in the same volume of air}} \times 100$$

Dew point : It is defined as the temperature at which the actual mass of water vapour present in a certain volume of air is just able to saturate it and the invisible water vapour begins to condense into visible form like water droplets.

PROCESS OF CONDENSATION AND ITS FORMS

CONDENSATION

It is the process in which water vapour is converted into liquid is called condensation OR condensation is the phenomena in which state of water changes from vapour to liquid. In this process heat energy is released (exothermic). Condensation is just inverse of evaporation. In evaporation heat energy of about 600 calories is required to evaporate 1gm of water producing cooling effect. In condensation same amount of 600 calories of heat is released for producing 1gm of water giving warming effect.

Sublimation : When the process of condensation occurs at temperature below freezing point, the water vapour in the atmosphere is directly converted into ice crystals (solid form) without intervening the liquid stage. This process of conversion of water vapour directly into solid state is called sublimation.OR It is the process in which water vapour is directly converted into solid form of water is called sublimation.

Conditions for condensation : To occurs condensation in the atmosphere, following three conditions must be fulfilled.

a) **Presence of sufficient water vapour** : An adequate amount of water vapour is necessary to bring out saturation of air. Air can easily be brought to saturation when sufficient moisture is present or by decrease in temperature.

b) **Presence of condensation nuclei** : Microscopic or sub microscopic particles (size 0.1 to 1.0 micron) like salt particles (injected in atmosphere by sea spray), some combustion products released from industries like sulfuric acid and nitric acid, dust etc. are present in the atmosphere and are hygroscopic in nature. These particles have water affinity and water vapour can only deposit and condense on them thus these microscopic and hygroscopic particles around which condensation begins are known as hygroscopic or condensation nuclei. In the absence of hygroscopic nuclei, condensation can not trigger even if the air is super saturated with relative humidity greater than 100% & temperature below freezing point.

c) **Cooling of air :** For saturation of atmospheric air with vapour, its cooling up to and below dew point is necessary and this cooling takes place by adiabatic and non adiabatic processes.

Forms of condensation :

Forms : Water vapour → cooling → condensation

1. Dew 2. Fog 3. Frost 4. Smog 5. Mist 6. Rime 7. Cloud 8. Rain 9. Snow 10. Sleet 11. Hail 12. Drizzle and 13. Shower

The important forms of condensation and their formation is described below-

1. **Dew** : The deposition of water vapour in the form of tiny droplets on the colder bodies by condensation is known as dew. The clear sky and the absence of wind is necessary for the formation of dew. It occurs in early morning hours. The temperature of air and earth surface decreases to such extent that condensation takes place. The objects on which dew forms must be good radiators and bad conductor are necessary condition for formation of dew.
2. **Frost** : When the temperature of air falls below $0^{o}c$ before the dew point is reached, the water vapour is directly converted into crystals of ice and deposit on surface is called frost. Frost is frequently called as form of sublimation. It is

injurious for vegetation.

3. **Fog** : The temperature of air decreases to such an extent that water droplets remain suspended in air but do not deposit over surface is called fog. It also occurs in early morning hours. It affects visibility. Extremely small water droplets suspending in the atmosphere and reducing the horizontal visibility is fog.

   Classification of Fog:

   A) Thick Fog : Restricts visibility up to 45 meters
   B) Moderate Fog : Restricts visibility up to 450 meters
   C) Thin Fog : Restricts visibility up to 900 meters.

4. **Mist** : Mist is less dense fog. It is similar to fog. It disappears with rising sun. The obscurity is known as mist. The suspended water droplets restrict visibility between 1000 to 2000 meters or 4 on the coded scale (IMD) The obscurity is known as mist. Relative humidity is at least 75% Mist disappears with rising sun.
5. **Smog** : The combined effect of smoke, dust and fog droplets reduce the visibility. This phenomena is called as smog.
6. **Rime** : It is formed when wet fog having super cooled droplets immediately freeze on striking objects like telegraph post having temperature below freezing point. While ice is formed on windward side.
7. **Cloud** : It is form of condensation. The temperature of the air is cooled sufficiently to cause condensation of the surplus moisture into cloud.
8. **Haze:** Some solid particles like dust, smoke from fire and industry restrict visibility is haze.

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LECTURE 8

PRECIPITATION – PROCESS OF PRECIPITATION, TYPES OF PRECIPITATION SUCH AS RAIN, SNOW, SLEET AND HAIL

Precipitation : It can be defined as earthward falling of water drops or ice particles that have formed by rapid condensation in the atmosphere and are too large to remain suspended in the atmosphere. Practically it is used to describe an appreciable deposit either in solid or liquid form from the atmosphere to the earth surface. Therefore, fog, frost, cloud, dew are not included in the precipitation.

MECHANISM OR PROCESSES OF RAIN FORMATION OR PRECIPITATION PROCESS

Raindrops have diameter extending from 0.5 to 4.0 mm . To form one raindrop, about one million cloud particles must unite together which cannot be explained on the basis of condensation. There are two mechanisms as follows by which raindrop can be formed.

1. **Bergeron mechanism (theory)** : When air ascends, clouds are formed. The cloud is having very low temperature, therefore, called cold cloud. In these cloud ice particles as well as water drops are formed due to very low temperature (-15^{0}C to -25^{0}C). These ice particles are growing readily by deposition of water vapour (sublimation) developing into hexagonal shaped ice crystals. These ice crystals on collision form snow pellets and melt into water droplets, when falling on ground through a warm atmosphere. This theory is suggested by Sweedish meteorologist Bergeron in 1933. Artificial rain making is based on this mechanism.
2. **Collision and coalescence mechanism (theory)**: The cloud is having slightly higher temperature, hence called hot cloud. In these clouds fine water droplets exist instead of ice particles. These fine water droplets colliode, coalescence (combine) and grow into the larger size and fall on earth as rain drop.

FORMS OF PRECIPITATION

A) Liquid form : Rain, drizzle and shower.
B) Solid form : Snow and hail.
C) Mixed form : Sleet and Hailstorm

A. Liquid form:

1. **Rain** : Rain is defined as precipitation of drops of liquid water. The cloud consists of minutes droplets of water of diameter 0.02mm nearly when these minute water droplets in clouds combine and form large drops, that become so large so that they cannot remain suspended in the air. They fall down as rain. The rain drop has a size as much as 5 mm.
2. **Drizzle** : It is more or less uniform precipitation of very small and numerous rain drops which are carried away even by light winds. The size of drizzle drop is 0.5 mm. Drizzle falls from low lying nimbostratus cloud.

3. **Shower** : Precipitation lasting for a short time with relatively clear intervals is called as shower. This occurs from the passing clouds.

B. Solid form :

1. **Snow**: Snow is defined as precipitation of water in the solid form of small or large ice crystals. It occurs only when the condensing medium has a temperature below freezing temperature 0^{o}C. Snow is generally in the form of individual crystals or in flakes that aggregates of many crystals. Snow flakes are found in high clouds. Snow is measured with snow gauge.
2. **Hail** : Hail is a precipitation of solid ice. On warm sunny day, a strong convective column may cause the formation of pellets having spherical shape and concentric layers of ice. Such formation is known as hail. Hail falls from cumulo - Nimbus clouds and is often associated with thunder and storm. Hail stones may achieve even large size as much as cricket ball. It damages the crop beyond recovery.

C. Mixed form:

1. **Sleet** : Simultaneous precipitation of the mixture of rain and snow is called as sleet. Some times half frozen drops also fall.
2. **Hailstorm** : Rainfall associated with hail stones is called hailstorms.

TYPES OF RAINS / PRECIPITATION TYPE

There are mainly three types of rains, they are as follows :

A. Convectional rains : Due to heating, the air near the ground becomes hot and light and starts upward movement. This is known as convection. As it moves upward, it cools at the dry adiabatic lapse rate (DALR 9.8^{o}c/km) and becomes saturated and relative humidity increases to 100% and dew point is reached level. Above condensation air cools at saturated adiabatic lapse rate (SALR = 4^{o}C/km). First cloud is formed and then the further condensation results into precipitation (rain). These rains are known as convectional rains and mostly occur in the tropics, where the condensation begins. This level or height is known as condensation.

B. **Orographic or relief rains** : When moist air coming from the sea or ocean encounters mountain or relief barrier, it cannot move horizontally and has to overcome mountain. When this air rises upward, cools down, cloud is formed and condensation starts giving precipitation. These rains are known orographic rains. Thus high rains are possible on the wind ward side of the mountain.

After crossing the mountain divide, when air decends downward, the pressure increases, air is compressed and air is warmed up at DALR. This decreases relative humidity and this dry air does not give any precipitation. This is known as rain shadow region e.g. such rains occurs in Himalayas and Sahyadri belts. Ratnagiri, Mahabaleshwar, Roha and Pen are windward side of Sahyadri ranges receives heavy rains while Pune, Nasik, Ahemdnagar, Solapur are leeward side, it is rain shadow region, receives less rains.

C. **Cyclonic, frontal and convergent rains** : Frontal precipitation is produced when two opposing air currents with different temperatures meet, vertical lifting takes place. This convection gives rise to condensation and precipitation. When the warm and moist air mixes with cold mass, the temperature of the warm air falls down saturation takes place and may give precipitation. This is known as frontal precipitation. Such mechanisms are responsible for cyclone formation between 55^0 to 60^0 latitudes in both the hemispheres. The rains received from the cyclones are called as cyclonic rains.

Thunder storms : It is the atmospheric disturbances which is always accompanied by thunder and lightening and sometimes by hail. Thunder storms are nothing but a series of electrical discharges between cloud and cloud or between cloud and earth. Thunder storms occur in every part of the world and their frequency decreases with increases in latitude. Its chief characteristics are an immense cumulo-nimbus cloud accompanied by copious precipitation, a marked drop in temperature and a more or less destructive outrushing squall wind which precedes the rainfall.

Hailstorms : Rainfall associated with hailstones is called hailstorms.

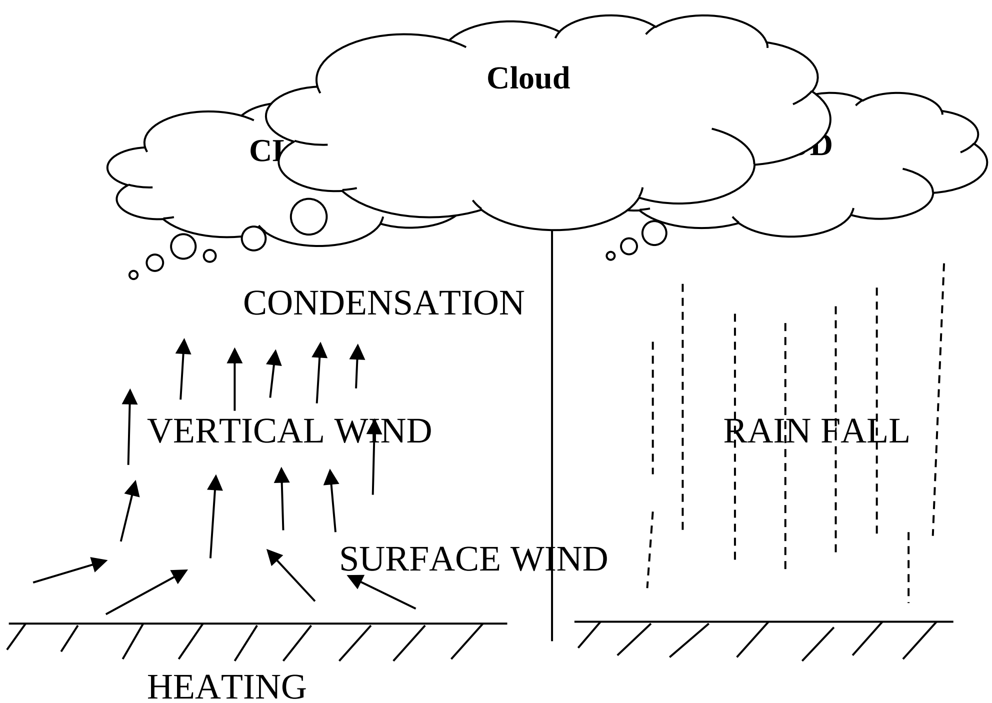

Fig.20 : Convectional precipitation

Vertical lifting

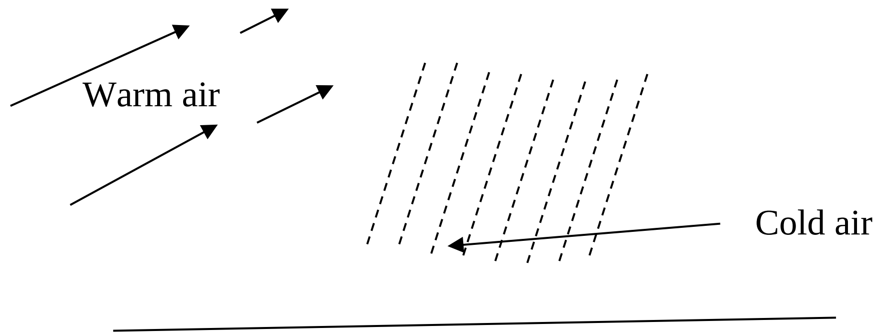

Fig.21 : Cyclonic or frontal precipitation

LECTURE 9

CLOUD – FORMATION and ITS CLASSIFICATION

Cloud is the precipitation making important weather element. It is a form of condensation. Presence of convectional currents in lower layers of troposphere causes formation of clouds. The moist air rises adiabatically and experiences decrease in temperature and at one time it get saturated. If it rises further, the water vapour in moist air gets condensed on dust particles. These condensed masses of particles from a cloud. Due to buoyancy effect of air, this mass remains floating in upper layers of air.

Cloud can be defined as a mass of tiny droplets or ice crystals or both condensed on hygroscopic nuclei and suspending in atmosphere.

Clouds and fogs are composed of water droplets or ice crystals or both of the order of size 20 to 60 microns (0.008 – 0.024 millimeter).

TYPE OF CLOUDS : There are four general basic types of clouds distinguishable partly by their form and partly by their height above the ground.

1) **Cirrus (Ci) :** Cirrus meaning “Curl” is recognized by its veil like Fibrous or feathery form. It is the highest type of cloud, ranging from approximately 20,000 to 35,000 feet (7-12 km) in altitude. Also known as high clouds.
2) **Cumulus (Cu) :** Cumulus meaning “heap” is the wooly, bunchy cloud with rounded top and flat base. It is most common in the summer season and in latitude where high temperature prevails and it always results from convection. Its height is variable and depends on relative humidity of the air.
3) **Stratus (St) :** It is a sheet type cloud without any form to distinguish it. It is always lower than cumulus.
4) **Nimbus (Nb) :** It is any dark and ragged cloud and from which precipitation occurs.

CLASSIFICATION OF CLOUD

Clouds have been classified according to their height and appearance by World Meteorological Organization (WMO) into 10 categories. The possible weather they indicate is also stated in Table 6. From the height, clouds are grouped into 4 categories as:

I. Family A : High clouds with height from 7 to 12 km.
II. Family B : Middle clouds with height from 3 to 7 km.
III. Family C : Low clouds with height from ground to 3 km
IV. Family D: Clouds with vertical development ranging from 0.5 to 16 km.

Following clouds can make precipitation

1. Nimbostratus (Nb-St) : Produce continuous precipitation.
2. Stratus (St) : Gives drizzle
3. Cumulo-Nimbus : Thunder head, chief precipitation maker.

Isoneph : It is a line on weather map joining the places of equal cloud cover is known as isoneph or line joining places of equal cloud cover on a weather map is known as isoneph.

CLASSIFICATION OF CLOUDS

Table 6 : International cloud classification and possible weather change indicated by the clouds

Cloud family and height	Name of the cloud and abbreviation	Compos-ition	Possible weather change	Description and appearance
1	2	3	4	5
Family A, High cloud 7 to 12km OR 20,000 to 35,000 ft.	1.Cirrus (Ci)	Ice crystals	May indicate storm, showery weather close by	Wispy and feathery, sun shines without shadow, does not produce precipa-tation.
	2.Cirrocumulus (Cc)	Ice crystals	Possible storm	Meckerel sky, often fore runners of cyclones, look like rippled sand.
	3.Cirrostratus (Cs)	Ice crystals	Storm may be approaching	Whitish veil, produce halo
Family B, middle clouds 3 to 7 km OR 6500 to 20,000ft.	4.Altocumulus (Ac)	Ice water	Steady rain or snow	Separate little wool pack, sheep back clouds.
	5. Altostratus (As)	Water and ice	Impending rain or snow	Fibrous veil or sheet, gray or bluish,produce corons, usually cast shadow
Family C, low clouds, Ground to 3 km OR ground to 6500ft.	6.Stratocumu-lus (Sc)	Water	Rain possible	Long paralle rolls, pushed together or broken masses which look soft and gray but with darker parts, air is smooth above but strong updrafts occur below.
	7. Stratus (St)	Water	May produce drizzle	A low uniform layer, resembling fog, but resting not on the ground, chief winter cloud.
	8.Nimbostratus (Ns)	Water or Ice crystals	Continuous rain or snow	Low stratus, chief preci-pitation maker, look dark gray, uniform layer.
Family D, Clouds with vertical development from 0.5 to 16km OR 1600 to 60,000ft.	9.Cumulus (Cu)	Water	Fair weather	Looks like wool pack,dark below due to shadow, may develop into cumulo-Nimbus flat base.
	10.Cumuloni-mbus (Cb)	Ice in upper levels and water in lower levels	Violent winds rain or all possible thunder storm, hail lightening possible.	Thunder head, towering anvil top, violent up and down drafts, aviators avoid the, develop from cumulus, **chief precipi-tation makers.**

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LECTURE 10

ARTIFICIAL RAINMAKING; MONSOON MECHANISM AND IMPORTANCE IN INDIAN AGRICULTURE

ARTIFICIAL RAIN MAKING

Rainfall from the convective or orographic clouds can be obtained by seeding such clouds externally or adding condensation or freezing nuclei through aircraft, rockets or ground base generators.

We are not that lucky enough to enjoy such eternal blessing whole year like rains. At the times Rain God disappoints us,how does one tackle drought? Well, one could try to make it rain. That seems to be the general idea behind the **cloud-seeding method**. It is a method for producing artificial rain.

(A) Cloud seeding : Clouds with temperature below freezing point are seeded with dry ice (Solid carbon dioxide below -80^{o}C) or by minute crystals of silver iodide at temperatures below -5 ^{o}C. In such clouds on introduction of these nuclei, ice crystals are formed on which super cooled water droplets are thus lost and ice crystals are grown in size at the cost of water droplets. These ice crystals grow further, become heavier, melt and fall as rain drops. Rain drop formation in cold clouds is based on Bergeron-Findeisen mechanism.

(B) Warm cloud seeding : Clouds with temperature above freezing point are seeded by introducing large hygroscopic particles such as sodium chloride on liquid water droplets. These initiate coalescence mechanism by which rain drops grow in size and fall down as small raindrops. The success of cloud seeding is much controversial and elusive.

Rainmaking also known as **artificial precipitation or artificial rainfall**, is the act of attempting to artificially induce or increase precipitation, usually to save off drought. According to the clouds' different physical properties, this can be done using airplanes or rockets to sow to the clouds with catalysts such as dry ice, silver iodide and salt powder, to make clouds rain or increase precipitation, to remove or mitigate farmland drought, to increase reservoir irrigation water or water supply capacity, or to increase water levels for power generation.

In the United States, rainmaking was attempted by traveling showmen. It was practiced in the old west, but may have reached a peak during the dust bowl drought of the American West and Midwest in the 1930s. The practice was depicted in the 1956 film *The Rainmaker*. Attempts to bring rain directly have waned with development of the science of meteorology, the advent of laws against fraud and increased communication technology, with some exceptions such as cloud seeding and forms of prayer including rain dances, which are still practiced today. Prayer for more rain is also a cross cultural practice in Christians and Muslims in areas where people keep "traditional" non-scriptural religions.

When the weather is hot, only a few would miss an opportunity to get drenched, and if it is a rain dance party in question, there would be nothing better for the party freak youths. Hope you got what I am talking about. It's the Glorious Rain!When it falls,the noise is like a song of nightingale.We tend to forget all our worries in its sound and sweet smell of earth. All love rain for one reason or other.

SEEDS OF HOPE

Often there are clouds, but no rain. This is because of a phenomenon called **super cooling**. The temperature of the cloud might be close to zero and there might even be crystals of ice in it.The water vapour in the cloud does not condense to liquid water. The super cooling gets disturbed by the method of cloud seeding.

Cloud-seeding is the attempt to change the precipitation that falls from clouds, by dispersing 'salt' or other chemicals into air. Usually used chemicals for the purpose of cloud seeding include dry ice, silver iodide, liquid propane and sodium chloride. Initially, clouds are identified that are apt for seeding with the help of radar. Then,aircraft disperse salts using flares or explosives in the lower portions of clouds. The salts grow in size as water joins with them and this leads to rain.

For clear understanding it can be explained in three stages:

Agitation

The first stage includes the usage if certain chemicals like calcium oxide, compound of urea and ammonium nitrate or chloride calcium carbide, in order to stimulate air mass of the target area to rise high and to form rain clouds. The chemicals mentioned above are capable of absorbing water vapor present in the air mass and thus helpful in stimulating the condensation process.

Building up stage

It is the second stage and in this stage the cloud mass is built up using various chemicals like urea, dry ice, ammonium nitrate, kitchen salt and sometimes even calcium chloride to increase nuclei which further increases the density of clouds.

Seeding

In the final stage, super cool chemicals such as dry ice and iodide are used which are helpful in building up vast beads of water (nuclei) and makes them to fall on the earth as rain drops.

The rockets that contain rain making chemicals can be directly fired into clouds either from the aircraft or from the ground. Those rain making chemicals are usually shot from a largely pressurized canister into the base of the clouds which normally hangs above the top of the mountain to cluster up and to rain on the mountain.

Large ionizers produce negatively charged particles or electrons. These particles naturally attract dust particles present in the ambient air in desert and dry arid regions.

Those particles then move up and away from the ionizers as a result of the hot ground air moving and forming convection currents as a result.

As the particles reach the height around which the clouds usually form, they stabilize and the negative charge of the particles begins to attract the vaporized water molecules around resulting in the formation of mini clouds. The particles act as nuclei around which all the moisture can come together, the process is very similar to how crystals are formed. Gradually, the size of those mini clouds grows as more particles move up and attract more of the humidity.

For this process to work , the ambient humidity should be at least 30%. These clouds being to rain, as the temperature starts to cool down, mostly during night times in the desert. The resulting rain will be combined with thunder and lightning, as the charged particles act as giant electrodes in the sky across which the lightning discharges

This process of artificial rainfall creation is more interesting and relevant for dry regions or deserts. For regions with more cloud formation, but little rain, the artificial rainfall approach to cause rains is to seed the clouds with chemicals (sprayed with small planes flying through the clouds) that will act as nuclei for the water drops to congeal around until they become heavy enough to start falling down in a beautiful and all artificial rainfall.

MONSOON MECHANISM

Today the Mechanism of Monsoon is a widely-studied subject globally.
The following facts are important to understand the mechanism of Indian monsoon:

Differential Heating and Cooling of Land and Water

a. Due to this lower pressure is found on the landmass.

b. High pressure is found on the water bodies/seas and oceans around India.

Shift in the position of Inter Tropical Convergence Zone (ITCZ)

a. Inter Tropical Convergence Zone is the equatorial trough (lower pressure area). It is normally positioned at 5° north of equator.

b. During summer it shifts its position to the Ganga plain, and is also known as monsoon trough, during the monsoon season.

Presence of High Pressure Area, East of Madagascar

a. High pressure area is found east of Madagascar approximately at 20° S over the Indian Ocean.

b. The intensity and position of this high pressure area affects the Indian monsoon.

Intensely Heated Tibetan Plateau

a. Tibetan plateau gets intensely heated during summer.

b. It results in the strong vertical currents.

c. At 9 km over the plateau from mean sea level, high pressure is formed.

Westerly Jet Stream and Tropical Easterly Jet Stream

a. Westerly Jet stream moves to the north of the Himalayas.

b. At this time (during summer) tropical easterly jet stream is present over the Indian Peninsula.

Southern Oscillation

a. Changes in the pressure conditions over the southern oceans also affect monsoons. Normally when the tropical Eastern south Pacific Ocean experiences high pressure, the tropical Eastern south Indian Ocean experiences low pressure.

b. But in certain years, the usually prevailing pressure conditions are reversed. It results in the low pressure on the Eastern Pacific Ocean, in comparison to the eastern Indian Ocean. Winds oscillate between Eastern south Pacific Ocean and Eastern Indian Ocean.

c. This periodic change in pressure conditions and wind is known as the Southern Oscillation or 'SO'.

EL Nino

A feature connected with the SO is the EI Nino.

a. It is a warm ocean current that flows past the Peruvian coast, in place of the cold Peruvian current every 2 to 5 years.

b. The changes in pressure conditions are connected to the EI Nino. Hence, the phenomenon is referred to as ENSO (EI Nino Southern Oscillations).

Warm waters along the Pacific coast in the South Pacific Ocean cause heavy rainfall on the Peruvian coast. Rainfall may fail in south East Asia due to the shift of warm water from eastern south Indian Ocean. This is called Elnino effect.

The climate of India is strongly influenced by the monsoon winds. It refers to a season in which the wind system reverses completely. The monsoons are experienced in the tropical area roughly between 20° N and 20° S.

Various atmospheric conditions influence the monsoon winds. The first condition is the differential heating and cooling of land and water. This creates low pressure on the landmass, while high pressure is created over the seas around during day time, but is reversed during the night time.

The second condition is the shift in the position of Inter-Tropical Convergence Zone (ITCZ). In summer, the equatorial trough normally positioned about 5°N of the equator moves over the Ganga plain creating a monsoon trough during the monsoon season.

The third condition is the presence of the high-pressure area that develops east of Madagascar. It is approximately at 20°S over the Indian Ocean. The intensity and position of this high-pressure area affects the Indian Monsoon.

The fourth condition develops during the summer. The Tibetan Plateau gets intensely heated resulting in strong vertical air currents and high pressure over the plateau about 9 km above sea level. The fifth condition develops during the summer due to the movement of the westerly jet streams to the north of the Himalayas and the presence of the tropical easterly jet stream over the Indian Peninsula.

Changes in pressure over the southern oceans also affect the monsoons. In certain years, there is a reversal in the pressure conditions. This periodic change in pressure conditions is known as the Southern Oscillation, or SO. OR

The Southern Oscillation is connected to El Nino, which is a warm ocean current that flows past the Peruvian Coast. It flows every two to five years in place of the cold Peruvian current. The phenomenon is, referred to as ENSO (El Nino Southern Oscillations). In India, the monsoon lasts for 100 to 120 days from early June and to mid-September. The monsoon winds encounter various atmospheric conditions on their way and hence are pulsating in nature, and not steady.The monsoon arrives with a sudden downpour of rainfall that continues for several days. This is known as the 'burst' of the monsoon.

The monsoon arrives at the southern tip of the Indian Peninsula generally by the first week of June. By early September, the monsoon starts to withdraw or retreat and is a more gradual process. By mid-October, it withdraws completely from the northern half of the peninsula. The withdrawal takes place progressively from north to south from the first week of December to the first week of January. This is the start of the winter season.

The retreating monsoon winds move over the Arabian Sea and the Bay of Bengal, and collect moisture on the way. These monsoon winds reach the southern states of India by October, and are responsible for a second round of rainfall. These are called the winter monsoons. The winter monsoon is experienced in the states of Tamil Nadu, Kerala and Andhra Pradesh in the first week of January.

IMPORTANCE OF RAINFALL IN AGRICULTURE

Among the various individual climatic parameters which influence the growth characteristics of crops in southern Africa the most important is considered to be water. Limitations in water availability are frequently a restrictive factor in plant development, and water is essential for the maintenance of physiological and chemical processes within the plant, acting as an energy exchanger and carrier of nutrient food supply in solution. In any regional study of agricultural production rainfall is therefore of fundamental importance. Focus is invariably on the patterns of rainfall in time and over an area, by asking initially

- how much it rains where it rains (its spatial distribution)
- when it rains (its seasonal distribution)
- how frequently it rains and
- what the duration and intensity of rainfall events are.

In their analyses of rainfall, however, the concerns of farmers go further, since they need to consider also how variable the rainfall is from year to year or for a given month and how frequently droughts of a certain level of severity are likely to recur. The reservoir of water from which crops draw their moisture supply through the soil is derived mainly in the form of rainfall, with relatively minor contributions in southern Africa from dew, fog and snow. Not all rainfall is, however, freely available to the crop through the soil, as some is intercepted by the plant before reaching the soil, part runs into streams as stormflow after rainfall events (without being utilised by plants), some percolates into the deeper soil layers beyond the root zones and a portion is evaporated directly from the soil surface without being transpired through the plant.

Importance of Monsoon in Indian Agriculture

In India, Monsoon refers to the rainy season. The humid south-west monsoon winds causes plenty of rainfall during the period between early June and October.

A large portion of Indian farmers still depends upon rain-fall to carry out the agricultural activities. Since, agriculture is one of the most important constituent on Indian economy (contributing around 16 percent of its total GDP), monsoon season has an indirect impact on its economy as well.

India has a tropical monsoon type climate. So here the temperature in the summer months is high and the rainfall is heavy. High temperature and heavy rainfall in the summer months are important for the growth of different types of *kharif* crops in different parts of India.

Unlike other countries in high latitudes, India enjoys long hours of sunshine even during the winter months. So with winter precipitation (supplemented by irrigation) a second *rabi* crop can be easily grown.

The amount of rainfall is the most important determinant of the type of crop raised. Wet crops are raised in wet zone and dry crops in the dry zone.

- Crops like rice, jute, sugarcane, etc. require high temperature and heavy rainfall for their cultivation. So these crops are cultivated in summer.
- Crops like wheat, barley etc. require moderate temperature and rainfall. So these are cultivated in winter.
- Rubber trees require uniformly high temperature and regular rainfall all the year round.
- In the southern parts of the Deccan, the temperature is fairly high all the year round and the rainfall is well-distributed over 6 to 8 months. So rubber is grown in the southern parts of the Deccan.

A large number of farmers depend upon monsoon-rains to meet the food requirement of their family. They engage in agricultural activities not to sell the crops, but for their own needs.

Normal rainfall is essential for adequate agricultural output. In a large country like India, it is essential to maintain the food prices. Food inflation may destabilize the entire nation. The food prices depend upon the agricultural output.

Rainfall is said to be normal when it is between 96% and 104% of the average rainfall for the past 50 years. The average of recorded rainfall for the past 50 years is 80 cm.

In spite of the introduction of improved irrigation methods, around 40% of our cropped area still entirely depends upon rain-water. Further, a number of dams, reservoirs, rivers, and canals are rain-feed and depends upon the monsoon rains.

How does Monsoon happen? As a consequence of high temperature over the Tropic of cancer, the region develops low pressure. The winds from high pressure water-belts such as Bay of Bengal, Arabian sea and Indian ocean, starts moving towards the low-pressure belts. They shift their direction while crossing the equator and start blowing from the south-west direction. The wind gets moistened while passing along these seas. This moisture-laden wind causes heavy rainfall across the various places in India.

Conclusion: The monsoon rainfall is very uncertain. It may arrive early and linger on for a long time or it may arrive too late. It may cause too heavy rainfall in some parts and too little in others. It may course floods and droughts. So the Indian present lives are at the mercy of the monsoon.

TYPES OF MONSOON

There are two types of monsoon -1) South west monsoon & 2) North-east monsoon

1) SOUTH WEST MONSOON

In summer the continents are hotter and the sea-water colder, hence the winds will blow from sea to land. India is positionally situated in north east trade winds and should have north east winds throughout the year but, a low pressure trough lies along the Gangas and upper India, due to which south west winds predominate. During April to September, a low pressure centre is formed over north west India. The south east trade winds of the Indian ocean below to th**e** equator and then turning to the right under the influence of coriolis force move on as a south west winds, round the low pressure centre over India. This monsoon blows from the African coast. This moisture laden air, while rising the mountains of Asia, cools, condenses and precipitates. As a result the pressure is lowered to increase pressure gradient. There are two branches of the monsoon.

The south west monsoon is active over the country during June to September of the year. The country receives 80-90% of its total rainfall covering major portion of the country. South west monsoon enters in Kerala normally on 1st June. It enters in southern part of Maharashtra on 6th June and extends over the whole state by 11 or 12th June. By 15th July south west monsoon reaches the extreme parts of the country.

When south west monsoon is established, a trough of low pressure forms over north India. When the axis of this trough is in the normal position, a good and well distributed rainfall is received over the country. If this axis shifts north, close to Himalaya, heavy rains and floods occur over north east India *viz.*, Assam with abeyance of monsoon activity over rest of the country. If this situation persists for long time, a drought is resulted.

2) NORTH EAST MONSOON

Complete reversal of the south west monsoon wind takes place as the high pressure center is located in eastern Asia (1035 mb) and low in about 10^{o}S (about 1010 mb). During this time, from north to south, the cold season is established. This monsoon is active during Oct. to Nov. The winds are generally dry but gives rains to Andhra Pradesh, Tamil Nadu state and southern districts which are not covered by south monsoon. Monsoon winds also exist over West Africa, Brazil, Eastern USA, Australia, Philippines etc.

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LECTURE 11

WEATHER HAZARDS-DROUGHT,FLOODS,FROST,TROPICAL CYCLONES, AND EXTREME WEATHER CONDITIONS SUCH AS HEAT WAVE AND COLD WAVE

WEATHER HAZARDS

Any risky weather either too excessive or too deficient being unfavourable for the normal crop growth, animal husbandry,social and industrial activity etc. or causing damages to them can be defined as a *meteorological hazards*. *A weather hazard* can be defined as any type of extreme weather condition that can damage crops and animals leading to abnormal decrease in production and income. The extent to which these hazards create risk depends on the time of occurrence, intensity and duration of the hazard besides the age, stage of development and inherent resistance of the crop or livestock involved. Severe weather or meteorological disaster is a sudden, excessive change in weather causing devastation and distress. The space (area affected), time (or range of time) and intensity of the phenomenon are important parameters of a hazard in deciding damages caused.

Major abnormalities affecting the crop production are :

Excessive rains (floods); scanty rains(drought); untimely rains; storms, cyclones and depressions; thunderstorms, hailstorms and dust storms; cold waves accompanied by frost; heat waves ; excessive or defective insolation and high winds.

Excessive rains (floods) : When heavy rains occur particularly over catchment area of rivers, the magnitude of floods may well be imagined. For such large scale phenomena, the remedies depend on large scale planning by the government for multipurpose or hydroelectric schemes. Planned afforestation of the denuded area is one of the remedies which should receive every support from the government.

Watershed development programme, under implementation during the VIIIth five year plan , appears to be promising in the direction of soil erosion and runoff control leading to water flows into the rivers. For floods, individual farmer can only keep the drainage channels of his fields open and go for flood resistant cultivars, especially in case of rice.

Scanty rains (Drought) : Frequent crop failure in dryland agriculture is due to droughts or prolonged dry spell during the crop period. Several management practices have been recommended to mitigate the adverse effect of drought.

- Increasing the water holding capacity of soils through the application of bulky organic manures,
- Soil and moisture conservation practices to minimize runoff,
- Collection of runoff water during periods of heavy rains for use during drought period,
- Minimising evaporation and transpiration losses through mulches, shelterbelts and chemicals,

- Introduction of drought resistant and drought escaping crops and cultivars,
- Intercropping to avoid total crop failure,
- Farm forestry for sustainable production in dryland farming, and
- Identification of remunerative cropping systems for dryland agriculture

Untimely rains : Onset and withdrawal of monsoon largely determine the success of dryland agriculture. Late onset of monsoon delays sowing of crops leading to poor yields. Early withdrawal of rains affect the yield due to soil moisture stress especially when the *kharif* crops are at critical stages of grain development. Continuous, cyclonic rains from August lead to problem in harvesting the crops, especially groundnut in South India.

Land should be prepared for *kharif* crops, taking advantage of premonsoon showers, such that sowing could be completed, taking advantage of earliest monsoon rain. Alternately, short duration pulse crops are recommended for abnormal delay in monsoon. As it is not possible to predict withdrawl of monsoon, it is always better to go for intercropping long and short duration crops to avoid total crop failure, especially in areas of frequent crop failures.

Storms, cyclones and depressions : One of the features of colossal meteorological phenomena like cyclonic storms and depressions can be predicted and forecasted. On receipt of warnings, precautionary measures can be taken for minimizing the risk. Warning of heavy rain, especially during sowing and harvest times will be practically useful as sowings can be postponed and harvesting hastened, wherever such disturbances are expected. Weather warning on such aspects leads to efficient use of agrochemicals used for plant protection and weed control.

Thunderstorms, hailstorms and dust storms : These are comparatively local in character. They usually occur before the onset and after the withdrawal of monsoon. Though short in duration, the precipitation and associated squalls are often very violent. Hailstorms are very destructive to standing crops and even to livestock and human life. Protection against them is difficult, particularly under rural conditions. However, farmers warned before hand can harvest their crops if they are already ripe. Shelterbelts and windbreaks can offer considerable protection to horticultural crops.

Cold waves accompanied by frost : Cold waves and frost are common during winter in northeast frontiers of India. There is considerable damage to grain and horticultural crops due to frost and freezing temperature. Many tropical and sub tropical plants are killed even at temperatures higher than about 0^{o}C. Information on frequency and intensity of frosts can indicate frost free growing season, which would help in selecting suitable crop species and varieties for areas subjected to frost.

- For better frost protection, the soil must be moist, compact and weed free. Frost damage is more common in sandy soils than in heavy soil under similar temperature conditions,

- Straw mats, screens of dry grass netting, wax papers, plastic covers known as hot caps should be placed over small plants during late afternoon and removed early in the morning for frost protection,
- Smoking and fogging by burning wood,straw,straw dust,sump oil,tar,naphthalene etc.,
- Creation of frost smoking in which artificial fog or chemical mist with particles sufficiently large to prevent long wave radiation,
- Use of high speed fans for temperature inversion near ground,
- Flooding the field for increasing the thermal capacity and conductivity for releasing latent heat when water freezes, and
- Replacing the heat lost through radiation by heat emitted from suitable heaters or small fires. Common materials for heating the wood, coal, charcoal, diesel oil. Heaters are the best for frost protection.

Heat waves : Just as cold waves are injurious to crops in winter, heat waves are injurious in summer. Deccan and central parts of the country experience hot waves during March, April and May. During this period, temperatures go beyond 43^{o}C. Blowing of hot winds leads to pollen and premature fruit drop. Most of the water bodies dry up in a short time leading to water shortage.

Heat evasion by shading of plants appears to be effective to minimize the adverse effect of heat wave. A number of shade structures from wood or fire are used, especially to protect vegetable crops grown on sandy soils during summer. Windbreaks also can reduce the heat wave effect by decreasing the velocity of hot winds.

Excessive or defective insolation : During clear day in summer, soil temperatures reach as high as 70^{o}C over black soils. High soil temperature affect seed germination and functional activity of roots. Irrigation can depress the soil temperature, but the effect lasts only as long as there is enough moisture on the surface layers. A layer of chalk or surface mulch of straw or any other organic waste helps not only to keep the soil layers cool, but also to conserve soil moisture. When the insolation is weak, soil temperature decrease to the extent of affecting plant growth. A black cover (charcoal powder) is useful for absorbing insulation and heating up the soil.

High winds : Wind affects the crops directly by increasing the evapotranspiration and causing several types of mechanical damage including lodging. When the wind is hot, it decreases the plant desiccation. Use of shelterbelts is the only remedy for protecting the crops from high winds. Shelterbelts are primarily meant for altering wind speed and its direction. They also aid in soil conservation and efficient use of soil moisture by reducing evapotranspiration rate of crops.

In practice, there are three main types of shelterbelts.

1) Dense shelterbelts with little permeability,

2) Shelter belts with medium and even permeability from soil surface to top of the belt, and
3) Alley type shelterbelts which may be rows of tall trees without shrubs as an under storey and which are open in the lower parts.

Dense shelterbelts are permeable to air flow and hence exhibit to air flow and hence exhibit sharp peaks of stream lines at distances of about 1 to 2 times the height of the belt. The stream lines, however, descend steeply and become horizontal at about 15 to 25 times the height of the belt. Thus, as compared to permeable belt, larger wind reduction is achieved immediately behind the dense belt. However, the original wind velocity is restored at much shorter distance in case of dense belt than permeable belt. Thus, the wind reduction zone is much greater in the permeable belt.

In alley type belts, as there are gaps between the trees, many steamlines pass through lower part of the belt. The wind reduction in immediate neighbourhood , in the beside will be lower than in other types. However, the zone of wind reduction would be wide in this case also.

For the best wind speed reduction and greatest downward influence, the shelter should be more porous on lower heights. In fact, the density can increase with height in proportion to the logarithmic nature of the wind profile. The optimal degree of permeability of a shelterbelt is about 30-35 per cent, if large cultivated fields are to be protected. This would mean that there should be many small gaps in the belt such that their total area works out to be 30-50 per cent of the total area of the belt.

Drought

A prolonged drought can have a serious impact on agricultural communities, affecting crops, livestock and families dependent on these commodities. The greatest impact from drought is of course the decrease in water supplies. This can result in crop loss and reduce crop and forage growth and availability.

The impact on livestock is equally devastating, and can result in animal deaths from limited water supplies or feed availability. Plants can also concentrate toxins under drought conditions, making them more lethal to livestock. Drought conditions can also increase the level of disease and insect infestations for plants and livestock.

The dry conditions can also lead to wind erosion of top soil, or increase the risk for fire hazards, and given decreased water sources, can result in devastating losses. Families and businesses can also be impacted by limited or restricted water sources during drought situations.

The following resources will help you prepare and protect your family, farm, livestock and crops during drought situations.

Floods

Floods are one of the leading causes of death from natural disasters in the United States. Over 200 flood-related fatalities are reported each year with over half being vehicle-related when people try to drive through floodwaters. Floods can damage and devastate homes and farms, displace families as well as pets and livestock, damage crops, and disrupt agriculture processing and business.

Flood situations are variable and can occur as a result of spring snowmelt, severe thunderstorms, prolonged rains, inadequate drainage or failure of levees and dams. The impact can be local affecting a neighborhood or community, or very large, affecting entire river basins and multiple states. Some develop slowly – allowing time to prepare and evacuate – while others (e.g., flash floods) can develop quickly, even within minutes.

While flood situations cannot be entirely prevented, steps can be taken to prevent or minimize injury and loss and speed the recovery process. The following resources will help you prepare your family, home and farm, animals and business for flood situations.

Bad Weather conditions can cause heavy damages to the environment and agitate everyday life. An imbalance in the phenomenon of nature can bring about great change on the weather maps.

Severe Thunderstorms are a common sight in an area experiencing bad weather conditions. Thunderstorms could result in lightning, heavy rains, tornadoes or hailstones causing bad weather with lot of destruction to human life and assets. When the water vapour inside a cloud condenses to become ice a large amount of heat energy is given out during this transition and the process produces hailstones. Strong rising air currents are produced as a result of this. In contrast to this cool descending air currents give rise to downdraughts that break up the cloud when the rising air currents fade away. These Thunderstorms could normally last for 1 hour or more. The collision of ice inside a cloud creates electrical charges. These electrical charges come together to form the effect of lightning. Thunderstorms and lightning are connected to each other. Thunder is a rumbling sound coming from various parts of a storm. We see lightning instantaneously while we hear thunder a little later. This is because the speed of light is greater than the speed of sound.

Tornadoes can be defined as a bad weather condition in which strong air currents take the shape of a funnel and create massive destruction wherever they spread. The damage caused by the tornadoes is an effect of major wind violation. These tornadoes have the capacity to attract almost anything that comes under its spell like cattle, dogs, cats and at times even humans! Their intensity is unfathomable and once a tornado arises nothing can be done until it cools down.

The ice formed inside a storm cloud could cause yet another bad weather condition called as hailstones. Hailstones are made of ice and their size could be as big as a tennis ball. Hailstones are initially small in size but due to more and more water freezing over them they gradually grow in size and fall on earth with a speed of

50 meters per second causing huge damages. Crops can be ruined almost instantaneously with a single spell of hailstones.

Hurricanes are one of the powerful bad weather conditions causing great deal of damage such as floods in low lying coastlines. Heat energy released due to condensing water vapours makes these hurricanes extremely powerful in nature. Hurricanes are destructive in nature causing torrential rains which in effect flood the land around it. Floods carry massive potential to wipe away any trace of life form that comes its way. Hurricanes instigating heavy rains or melting snow are two main causes of floods. The areas adjoining major rivers are mainly susceptible to the outpour of floods.

In today's fast moving world, knowledge about weather can be of prime importance for any decision relating to life. Whether you are planning a new trip for your vacation or deciding the location of your next business enterprise, knowledge of weather of the city you reside in has become a basic necessity.

'Weather' describes seasonal changes in climate, temperature, rainfall, winds and storms. Extreme weather, such as heavy rainfall and high winds can threaten people, property and our environment. Heat, cold, rainfall, wind and storm events in a particular area vary, depending on:

- where it is in the world (for example, distance from the equator)
- whether it is inland or coastal
- the type of landscape around it (for example, hills, mountains, valleys and plains).

Weather patterns are also influenced by other factors including:

- Climate Change
- global warming
- changes in the sun's activity (such as sunspots).

Climate change

Climate change is expected to bring warmer weather and more floods and storms to New Zealand. Sea level rise could swamp low lying coastal areas. Salt from seawater coming inland may get into freshwater lakes, rivers and streams. It may also soak into the ground, affecting ground water supplies and leading to potential water shortages.

Find out more about how Climate Change affects our region's natural hazards.

El Niño and La Niña

El Niño and La Niña are natural weather events - extremes of the 'El Niño Southern Oscillation' (ENSO) phenomenon. ENSO is the movement of air masses and ocean circulations, which cause small scale climate change lasting a maximum of two years.

During an El Niño period, trade winds weaken and nutrient rich currents off South America reduce. Fisheries become less productive. For New Zealand, El Niño means stronger and more frequent westerly winds in the summer. This may cause drought on the east coast and more rain in the west. In winter the winds will be more from the south, lowering temperatures.

During La Niña trade winds strengthen and blow westward across the Pacific Ocean, resulting in warm water in the Western Pacific around Indonesia. Meanwhile the cool nutrient rich currents rise up in the Eastern Pacific. For New Zealand this means more north-easterly winds, rain to the north-east of the North Island and lower rainfall in the south and south-west of the country. Central Otago and South Canterbury areas can get droughts in either situation.

HEAT WAVE

A **heat wave** is a prolonged period of excessively hot weather, which may be accompanied by high humidity, especially in oceanic climate countries. While definitions vary,[1] a heat wave is measured relative to the usual weather in the area and relative to normal temperatures for the season. Temperatures that people from a hotter climate consider normal can be termed a heat wave in a cooler area if they are outside the normal climate pattern for that area.

The term is applied both to routine weather variations and to extraordinary spells of heat which may occur only once a century. Severe heat waves have caused catastrophic crop failures, thousands of deaths from hyperthermia, and widespread power outages due to increased use of air conditioning. A heat wave is considered extreme weather, and a danger because heat and sunlight may overheat the human body.

COLD WAVE

A **cold wave** (known in some regions as a **cold snap**) is a weather phenomenon that is distinguished by a cooling of the air. Specifically, as used by the U.S. National Weather Service, a cold wave is a rapid fall in temperature within a 24-hour period requiring substantially increased protection to agriculture, industry, commerce, and social activities. The precise criterion for a cold wave is determined by the rate at which the temperature falls, and the minimum to which it falls. This minimum temperature is dependent on the geographical region and time of year.[1]

In the United States, a *cold spell* is defined as the national average high temperature dropping below 18 °F (−8 °C).

Effects

A cold wave can cause death and injury to livestock and wildlife. Exposure to cold mandates greater caloric intake for all animals, including humans, and if a cold wave is accompanied by heavy and persistent snow, grazing animals may be unable to reach needed food and die of hypothermia or starvation. They often necessitate the purchase of foodstuffs to feed livestock at considerable cost to farmers.

Cold spells are associated with increased mortality rates in populations around the world.[3] Both cold waves and heat waves cause deaths, though different groups of people may be susceptible to different weather events.[4] In developed countries, more

deaths occur during a heat wave than in a cold snap, though the mortality rate is higher in undeveloped regions of the world. Globally, more people die of cold weather than hot weather, due to the rise in diseases like cold, flu, and pneumonia.
Extreme winter cold often causes poorly insulated water pipelines and mains to freeze. Even some poorly protected indoor plumbing ruptures as water expands within them, causing much damage to property and costly insurance claims. Demand for electrical power and fuels rises dramatically during such times, even though the generation of electrical power may fail due to the freezing of water necessary for the generation of hydroelectricity. Some metals may become brittle at low temperatures. Motor vehicles may fail when antifreeze fails or motor oil gels, producing a failure of the transportation system. To be sure, such is more likely in places like Siberia and much of Canada that customarily get very cold weather.

Fires become even more of a hazard during extreme cold. Water mains may break and water supplies may become unreliable, making firefighting more difficult. The air during a cold wave is typically denser and thus contains more oxygen, so when air that a fire draws in becomes unusually cold it is likely to cause a more intense fire.

Winter cold waves that aren't considered cold in some areas, but cause temperatures significantly below average for an area, are also destructive. Areas with subtropical climates may recognize unusual cold, perhaps barely freezing, temperatures, as a cold wave. In such places, plant and animal life is less tolerant of such cold as may appear rarely. The same winter temperatures that one associates with the norm for Kentucky, northern Utah, or Bavaria are catastrophic to winter crops in Florida or California that might be grown for wintertime consumption farther north, or to such all-year tropical or subtropical crops as citrus fruits. Likewise, abnormal cold waves that penetrate into tropical countries in which people do not customarily insulate houses or have either suitable clothing or reliable heating may cause hypothermia and even frostbite.

Cold waves that bring unexpected freezes and frosts during the growing season in mid-latitude zones can kill plants during the early and most vulnerable stages of growth, resulting in crop failure as plants are killed before they can be harvested economically. Such cold waves have caused famines. At times as deadly to plants as drought, cold waves can leave a land in danger of later brush and forest fires that consume dead biomass. One extreme was the so-called Year Without a Summer of 1816, one of several years during the 1810s in which numerous crops failed during freakish summer cold snaps after volcanic eruptions that reduced incoming sunlight.

A cold wave is a weather phenomenon that is distinguished by marked cooling of the air, or attention due to the hazards of tissue damage and organ failure. They can cause death and injury to livestock and wildlife. Exposure to cold mandates greater caloric intake for all animals, including humans, and if a cold wave is accompanied by heavy and persistent snow, grazing animals may be unable to reach needed food and die of hypothermia or starvation. They often necessitate the purchase of foodstuffs at considerable cost to farmers to feed livestock.

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COLD WAVES bring unexpected freezes and frosts during the growing season in mid-latitude zones can kill plants during the early and most vulnerable stages of growth, resulting in crop failure as plants are killed before they can be harvested economically. Such cold waves have caused famines. At times as deadly to plants as drought, cold waves can leave a land in danger of later brush and forest fires that consume dead biomass. One extreme was the so-called Year Without a Summer of 1816, one of several years during the 1810s in which numerous crops failed during freakish summer cold snaps after volcanic eruptions that reduced incoming sunlight.

LECTURE 12
AGRICULTURE AND WEATHER RELATIONS

Despite technological advances, such as improved varieties, genetically modified organisms, and irrigation systems, weather is still a key factor in agricultural productivity, as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The earth's average surface temperature has increased by 1°F in just over the last century.

On the other hand, agricultural trade has grown in recent years, and now provides significant amounts of food, on a national level to major importing countries, as well as comfortable income to exporting ones. The international aspect of trade and security in terms of food implies the need to also consider the effects of climate change on a global scale.

A study published in Science suggest that, due to climate change, "southern Africa could lose more than 30% of its main crop, maize, by 2030. In South Asia losses of many regional staples, such as rice, millet and maize could top 10%".

The 2001 IPCC Third Assessment Report concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence. In Africa and Latin America many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall sharply for even small climate changes; falls in agricultural productivity of up to 30% over the 21st century are projected. Marine life and the fishing industry will also be severely affected in some places.

Climate change induced by increasing greenhouse gases is likely to affect crops differently from region to region. For example, average crop yield is expected to drop down to 50% in Pakistan according to the UKMO scenario whereas corn production in Europe is expected to grow up to 25% in optimum hydrologic conditions.

More favourable effects on yield tend to depend to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth and increase of efficiency in water use. Decrease in potential yields is likely to be caused by shortening of the growing period, decrease in water availability and poor vernalization.

In the long run, the climatic change could affect agriculture in several ways : productivity, in terms of quantity and quality of crops agricultural practices, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers environmental effects, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity rural space, through the loss and gain of cultivated lands, land speculation, land renunciation, and hydraulic amenities. adaptation, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

They are large uncertainties to uncover, particularly because there is lack of information on many specific local regions, and include the uncertainties on magnitude of climate change, the effects of technological changes on productivity, global food demands, and the numerous possibilities of adaptation.

Most agronomists believe that agricultural production will be mostly affected by the severity and pace of climate change, not so much by gradual trends in climate. If change is gradual, there may be enough time for biota adjustment. Rapid climate change, however, could harm agriculture in many countries, especially those that are already suffering from rather poor soil and climate conditions, because there is less time for optimum natural selection and adaption.

Weather and climate are the most pervasive factors of crop environment . We will discuss it's effect on crop development and environment.

(1) Knowledge of agrometeorology is useful in several aspects of practical agriculture as indicated below:

(2) It has practical utility in timing of agriculture operations so as to make the best use of favorable weather conditions and make adjustments for adverse weather.

(3) The dangers of crop production due to the pest and disease incidence , occurrence of prolonged drought , soil erosion, frost and weather hazards can be minimized.

(4) Weather support also provides guidelines for long range or seasonal planning of crops and cultivars most suited to anticipated climatic conditions.

(5) Agrometeorological information can be used in land planning, risk analysis of climatic hazards, production and harvest forecasts and linking similar crop environments for crop adaptability and productivity.

Weather elements

Weather is a phrase of climate representing atmospheric condition at a given place and at a fiven instant of time as against climate, representing atmospheric condition for longer period of time over a large area. Components of weather and climate or simply weather elements include:

- Temperature
- Solar radiation
- Humidity
- Cloud
- Pressure
- Wind
- Precipitation

The influence of weather and climate on crop growth and development and final yield is complicated by complexity of interactions with crops and the environment during the crop season. The influence of weather and climate on crop productivity can be summarized as indicated below:

Weather parameters with favorable influence

(1) Weather and climate are important factors to determining the success or failure of agriculture.

(2) All the agriculture operations from sowing to harvest of crops depend on the mercy of weather.

(3) Climate determines suitability of a crop to a particular region while weather plays a major role in the productivity of a crop in the region.

(4) The excess or shortage of elements of weather and climate exerts a negative influence on crop growth, development and final yield.

(5) The effect of weather and climate is complex as elements of climate operate simultaneously in nature.

(6) Due to complexity of environment in which a crop is grown, it is difficult to assign an optimum value of climatic element for maximum crop productivity.

Weather parameters with negative influence

- Excessively and untimely rains.
- Scanty rains with prolonged dry spells.
- Heat and cold waves.
- Dust-storms, thunderstorms and hailstorms.
- High winds.
- Floods.

Weather variables having both positive and negative effects on crop productivity.

- Solar radiation..
- Temperature.
- Humidity.
- Wind.
- Precipitation.

LECTURE 13
MODIFICATIONS OF CROP MICROCLIMATE
MICROCLIMATE

Microclimate: Any climatic condition in a relatively small area, within a few metres or less above and below the Earth's surface and within canopies of vegetation. The term usually applies to the surfaces of terrestrial and glaciated environments, but it could also pertain to the surfaces of oceans and other bodies of water.

The strongest gradients of temperature and humidity occur just above and below the terrestrial surface. Complexities of microclimate are necessary for the existence of a variety of life forms because, although any single species may tolerate only a limited range of climate, strongly contrasting microclimates in close proximity provide a total environment in which many species of flora and fauna can coexist and interact.

Microclimatic conditions depend on such factors as temperature, humidity, wind and turbulence, dew, frost, heat balance, and evaporation. The effect of soil type on microclimates is considerable. Sandy soils and other coarse, loose, and dry soils, for example, are subject to high maximum and low minimum surface temperatures. The surface reflection characteristics of soils are also important; soils of lighter colour reflect more and respond less to daily heating. Another feature of the microclimate is the ability of the soil to absorb and retain moisture, which depends on the composition of the soil and its use. Vegetation is also integral as it controls the flux of water vapour into the air through transpiration. In addition, vegetation can insulate the soil below and reduce temperature variability. Sites of exposed soil then exhibit the greatest temperature variability.

Topography can affect the vertical path of air in a locale and, therefore, the relative humidity and air circulation. For example, air ascending a mountain undergoes a decrease in pressure and often releases moisture in the form of rain or snow. As the air proceeds down the leeward side of the mountain, it is compressed and heated, thus promoting drier, hotter conditions there. An undulating landscape can also produce microclimatic variety through the air motions produced by differences in density.

The microclimates of a region are defined by the moisture, temperature, and winds of the atmosphere near the ground, the vegetation, soil, and the latitude, elevation, and season. Weather is also influenced by microclimatic conditions. Wet ground, for example, promotes evaporation and increases atmospheric humidity. The drying of bare soil, on the other hand, creates a surface crust that inhibits ground moisture from diffusing upward, which promotes the persistence of the dry atmosphere. Microclimates control evaporation and transpiration from surfaces and influence precipitation, and so are important to the hydrologic cycle- i.e.the processes involved in the circulation of the Earth's waters.

The initial fragmentation of rocks in the process of rock weathering and the subsequent soil formation are also part of the prevailing microclimate. The fracturing of rocks is accomplished by the frequent freezing of water trapped in their porous parts. The final weathering of rocks into the clay and mineral constituents of soils is a chemical process, where such microclimatic conditions as relative warmth and moisture influence the rate and degree of weathering.

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LECTURE 14
Climatic normals of different crops

Rice:

(a) Rice needs hot and humid climate.
(b) Minimum temperature for germination, flowering and grain formation is 10, 23 and 20-21°C, respectively.
(c) Optimum temperature for growth, flowering and grain formation is 21-36, 25-29 and 20-25, respectively.
(d) Maximum temperature for which rice crop tolerate is 40°C.
(e) Requirement of rainfall throughout growth period is 100-150 cm.
(f) Rice is a short day plant.

Wheat:

(a) Wheat needs cold and dry climate.
(b) Optimum temperature for growth and grain formation is 20-25 and 14-16°C, respectively.
(c) Water required for proper growth is 60-90 cm.
(d) Wheat is a long day plant.

Maize:

(a) Maize grows from sea level to 3000 meter altitude.
(b) Minimum temperature for germination is 6-7°C.
(c) Most suitable temperature for germination and growth is 21-23 and 30-32°C, respectively.
(d) Maize crop requires 50-80 cm rainfall for proper growth.
(e) Maize is a day neutral plant.

Sorghum:

(a) Sorghum is a short day plant.
(b) Minimum temperature for germination is 7-8°C.
(c) Suitable temperature for optimum crop growth is 27-32°C.
(d) Requirement of rainfall throughout growth period is 40-60 cm.
(e) It can tolerate drought conditions as well as water logging condition.

Pearl Millet/Bajra:

(a) Bajra is a warm weather crop.
(b) Best suited temperature for crop growth is between 27-30°C.
(c) Requirement of rainfall throughout growth period is 25-35 cm.
(d) It can tolerate hot temperature.
(e) Bajra is a short day plant.

Barley:

(a) Barley needs cold weather during early crop growth period and warm and dry weather at maturity.
(b) Water requirement for good crop growth is 35-50 cm.

(c) Barley is a long day plant.

Gram:

(a) Gram is a winter season crop.
(b) It is a long day plant.
(c) Minimum temperature for germination is 6-8°C.
(d) Suitable temperature for optimum crop growth is 20-25°C.
(e) Requirement of water throughout growth period is 35-45 cm.
(f) Severe cold and frost at the time of flowering causes detrimental effect to gram seed development.

Field Pea:

(a) Field pea requires cool growing season.
(b) Minimum temperature for germination is 4-6°C.
(c) Optimum temperature for its growth is 13-18°C.
(d) Water requirement for proper growth is 40-60 cm.
(e) Field pea is a short day plant.
(f) Frost can damage the plant during flowering period.
(g) High humidity is harmful to pea crop due to incidence of disease.

Pigeonpea:

(a) Pigeon pea grows well under warm tropical and subtropical climate.
(b) During vegetative growth, crop prefers a fairly moist and warm climate.
(c) During flowering and ripening stage, it requires bright suimy weather for proper fruit setting.
(d) It is highly susceptible to frost at the time of flowering.

Green gram:

(a) Green gram requires hot climate.
(b) It requires an average annual rainfall of 60-80 cm.
(c) Best suited temperature for crop growth is between 25-32°C.
(d) It can tolerate drought to a great extent.
(e) It is a day neutral plant.
(f) It is considered to be the hardiest pulse among all pulse crops.

Black gram:

(a) Black gram requires a hot and humid growing season.
(b) Black gram can be grown successfully from sea level up to an elevation of 2000 meter altitude.
(c) Water requirement for proper growth is 40-60 cm.
(d) Heavy rains during flowering stage are harmful to yield of pea crop.

Soybean:

(a) Soybean grows well in warm and moist climate.
(b) Optimum temperature for growth of most of the varieties is 26-32°C.
(c) Water requirement for proper growth is 60-75 cm.

(d) Soybean is a short day plant.

Groundnut:

(a) Groundnut is wide spectrum adoptable crop which grown in all 3 seasons.
(b) It requires tropical climate.
(c) It requires an average annual rainfall of 50-100 cm.
(d) Best suited temperature for crop growth is between 25-35°C.
(e) Flowering and seed setting affected by cloudy weather.
(f) It is a day neutral plant.
(g) It resists drought and tolerate flooding for one week once it establish.

Rap-seed and Mustard:

(a) Cool temperature, clear dry weather with bright sunshine accompanied with adequate soil moisture increases the oil percentage of crop.
(b) Water requirement for proper growth is 35-45 cm.
(c) The crop cannot tolerate drought as well as water logging condition

Sunflower:

(a) Sunflower is also a wide spectrum adoptable crop, grown in all 3 seasons.
(b) It requires subtropical climate.
(c) The requirement of annual rainfall varies from 30-150 cm.
(d) Best suited temperature for crop growth is between 20-25°C.
(e) During vegetative phase, crop requires cold temperature.
(f) Higher temperature (> 38°C) during reproductive stage reduces the oil content.
(g) It is a day neutral plant.

Cotton:

(a) Cotton is a warm season crop.
(b) It requires an average annual temperature and rainfall of over 18°C and 50- 70 cm, respectively.
(c) A daily mean temperature of 16°C for seed germination, 21-27°C for proper vegetative growth and 27-32°C for fruiting phase.
(d) Abundant sunshine during boll maturation and harvesting is essential to obtain a good quality crop produce.
(e) Heavy showers of rain or heavy irrigation during fruiting period causes shedding of flowers and young bolls.

Sugarcane:

(a) Sugarcane is a tropical plant.
(b) It requires an average annual rainfall of 250-300 cm.
(c) Optimum temperature for crop growth is between 32-35°C.
(d) Besides temperature and rainfall, light (day length) plays a very important role in proper growth and development i.e. tillering of cane.
(e) Short day length decreases number of tillers plant^{-1}
(f) Under long day length conditions, plant produces more dry matter.

Potato:

(a) Potato is a temperate and cool climate crop.

(b) Optimum temperature for germination and vegetative growth is 25 and 17°C, respectively.

(c) For tuberization, it requires 17-20°C temperature.

(d) Tuberization stopped, when temperature exceeds 30°C.

(e) Cloudy weather, rainy days and high humidity is unfavorable for potato crop.

Rice :

It is a semi aquatic plant and hence its water requirement is very high. Rice can be grown in pre-*kharif*, *kharif* as well as in *rabi* seasons proving its wider adaptability to varied climatic conditions. It requires 20-36^{o}C average day temperature with night temperature of 20-23 ^{o}C. The crop can tolerate 19 ^{o}C-40 ^{o}C. The optimum temperature required for germination is at least 10 ^{o}C, for flowering is 22-23 ^{o}C and for grain formation is 20-21 ^{o}C. A mean air temperature of around 22 ^{o}C is required for the entire growth. Very high temperature along with high wind speed cause sun burning and scald diseases. Low temperature reduces formation of spikelets, germination, seedling development,tillering and shoot height. Soil temperature above 16 ^{o}C after transplanting is very essential. Light intensity up to 200% of normal gives more tillers, panicles and well developed grains. Higher relative humidity(%) within the crop canopy is usually conducive. For obtaining the maximum yield the accumulated sunshine hours during the crop span if rice is 1000 with 220-240 hrs in the last 30 days. Rice has very high water requirement. Optimum well distributed rainfall during its almost 4 months growing period is 1120 to 1500 mm. Standing water from end of tillering to grain ripening is useful. The crop is highly sensitive to water deficiency at flowering and heading stages.Total water requirement of the crop varies from 80 to 180 cm depending upon crop variety, local climate, growing season and soil type. In *kharif* season,when humidity is high and evaporative demands are low ,maintenance of continuous submergence is not essential but during *rabi* season it is required. Great economy in water use by rice crop can be achieved if suitable measures are adopted to reduce the deep percolation losses by suitable irrigation techniques.

Wheat :

The best adaptation of wheat is in areas with moderate temperature and sub-humid to semi-arid conditions. Wheat is basically a temperate climate crop, grown in the summer season in temperate region and winter or *rabi* season in the sub-tropics. A mean daily air temperature of around 15 to 20 ^{o}C is required for its growth and development.Higher temperatures of about 30-35 ^{o}C have in general detrimental effect to the crop performance. The crop can withstand intense cold condition. The optimal range of temperature for the germination of winter wheat and for its vegetative growth is 15to20 ^{o}C.Minimum, optimum and maximum cardinal temperatures for germination of wheat crop are 3 to 4.5, around 25 and 30-32 ^{o}C, respectively. High temperature during rapid growth and tillering periods results in poor tillering , low number of effective tillers, poor growth rate, short shoot height, low LAI, short ears with lower number of spikelets, lower fertilization, lower grain weight and lower quality. High soil moisture content is useful for high germination, good start of seedlings, good seed setting and development. The crop shows resistance to drought though it is highly sensitive to moisture stress during the period from shooting to advance heading stages. Bright sunny days with dryness and cooler nights during ripening period give better sized quality grains. Optimum rainfall requirement is 50-87.5 cm during the growing season and the total water requirement is 45-55 cm . Daily CU varies from 0.17 to 0.87 cm from emergence to grain filling. The high range being 0.62 for the period from boot to dough stages. A delay in sowing to avail the maximum advantage of cool weather leads to poor crop stands on account of decreasing soil moisture.

Maize :

It is essentially a warm and humid region crop and grows well in areas of moderate climate throughout the year. Maize grows well in areas where the mean temperature is around 24 ^oC and night temperature is above 15 ^oC. No maize cultivation is possible in areas where mean summer temperature is below 19 ^oC or where average night temperature during the three summer months falls below 21 ^oC. High night temperatures also result in less yield. If the maximum temperature during the flowering period is around 35 ^oC or more, the fertilization will be hampered and as result yield will be poor. Maize is adapted to humid climate and has moderate to high water requirement depending upon type of soil, season. It requires 50-75 cm of rainfall. The crop requires high amount of water during its inflorescence. Maize is very sensitive to excess water and hence it is desirable to plant on ridges. It can escape early season drought.

Sorghum :

It grows well in dry lands under erratic rainfall condition. It can tolerate hot, dry and sunny climate. A temperature range of 15-41 ^oC with the optimum being 25-32 ^oC is conducive for the crop growth. The crop can tolerate well above 50 ^oC for a long period. The minimum temperature for its germination is 7-10 ^oC, while optimum being 18-21 ^oC. Day temperature higher than 21 ^oC in the first month and 27 ^oC thereafter hastens maturity. Its roots are much more sensitive than shoots to high temperature. It is sensitive to low temperature during germination, early growth and grain formation stages. The minimum emergence temperature is 8 ^oC. The crop is ‘camel’ in crop world because of its tolerance to fairly high temperature with low soil moisture requirement. A well distributed rainfall of 50-75 cm up to the heading stage is conducive. Erratic, heavy rains creating water logging for a longer period is undesirable though the crop can tolerate flooded condition, partially. Total water requirement is around 40-65 cm. High soil moisture at sowing gives poor emergence. Deep loamy soils are very suitable for the crop. Long nights reduces tillering and hastens floral initiation.

Cotton :

This crop is heat loving and is sensitive to temperature and soil water conditions. Cool nights and low day time temperature encourage much vegetative growth. The crop requires abundant sunshine with adequate moisture, fairly high temperature and around 200 days frost free period. Temperature below 18 ^{o}C retards germination. A mean annual temperature well over 16 ^{o}C is essential for high yields and temperature above 39 ^{o}C is detrimental to the crop growth. Night temperature of 18-21 ^{o}C leads to good branch development. Temperature below 21 ^{o}C are not conducive for proper flower bud initiation. After emergence the soil moisture should not fall. Bright sunny days after emergence are undesirable in early stages. Cloudiness prolongs the vegetative growth. During later boll development period low night temperatures results in shorter fibres and bad boll opening. The overall development rate is maximized at a temperature range of 25 to 30 ^{o}C. The minimum rainfall limit for cotton is 50-65 cm. Heavy rainfall during sowing and at early stages are undesirable. Excessive rainfall at later stages may cause the shedding of leaves, blooms and bolls.

The crop has a deep and extensive root system. Naturally, its water need is very high. Total water requirement of the crop varies from 70-110 cm. Peak daily water use rate is 0.35 inch.

Jute :

It is a crop of the humid monsoon climate. Growth of jute is favoured by humid and warm to hot weather. In jute growing belt, the maximum temperature is not more than 43 ^{o}C, the minimum temperature is above15 ^{o}C with relative humidity never below 65%. Around 100-120 cm well distributed rainfall with bright sunshine is conducive for its growth. A temperature range of 27-35 ^{o}C with relative humidity more than 80 % is good for the crop growth. The crop at seedling stage can not withstand water logging. The crop is a short day plant. Under high temperature (around 32 ^{o}C) the crop height as well as basal diameter increases.

Sugarcane :

It is a tropical crop and requires warm humid climate for its growth. As it grows the year round, it passes through all types of weather and seasonal conditions. The setts require the mean daily temperature of around 22 ^{o}C for good sprouting. The optimum range is from 27-38 ^{o}C; temperature beyond 38 ^{o}C is not conducive. Soil temperature 27-28 ^{o}C is optimum for the plant growth. The maximum temperature above 37 ^{o}C inhibits growth. The maximum temperature above37 ^{o}C inhibits growth. Adequate warmth and plenty of moderate light near the base of young shoots are essential to induce early tillering. Night time temperature has a crucial role in cane growth. Weak light reduces its growth. Moist humid climate (relative humidity above 70 %) with 20-32 ^{o}C temperature range, long days, short nights and ample water supplies are highly conducive to good vegetative growth. Low minimum temperatures retard flowering and very low temperature reduces quality of juice. The crop yield is reduced to one-half if the sunshine is cut down to half the normal. The crop requires 125 to 165 cm of rainfall in a year. The crop has an extensive fibrous root system. The optimum yields of sugarcane are obtained by maintaining a very high moisture level throughout the root zone during the entire growing season. The total water requirement of the crop varies between 70-85 acre inches annually.

CLIMATIC NORMALS FOR ANIMAL PRODUCTION

Like crop plants and fruit trees, livestock production is greatly influenced by meteorological conditions. Food production from animals can, therefore, be greatly increased and improved in quality if proper environmental conditions are provided to them in animal houses.

*CATTLE

Cattle belongs to the warm-blooded group of animals having a physiological system called ‘thermoregulation’, since the body temperature of these animals in cold weather is maintained by an internal combustion system; and in hot weather, they bring the body temperature down by various cooling mechanisms. These mechanisms consists of an increased vascularity of the subcutaneous area, and the evaporation of certain amounts of water either from the surface of the body (perspiration), or from inside the body, more particularly in the respiratory organs. In both the cases the energy, required to transform the water from liquid to the gaseous state, is removed from the body to be released into the environment. If the ambient temperature is higher than the ideal body temperature and the atmospheric humidity is relatively high, these cooling mechanisms cannot function satisfactorily, and the body of the animal becomes warmer and ultimate death may follow. Different breeds of cattle have, however, varying adaptations to different environment. European cattle have a comfort zone between -1^{o} and 15 ^{o}C while Indian cattle are comfortable between 10^{o} and 27^{o}C (Mather, 1974).

All domestic animals have adapted to variations in heat and cold. The range of tolerance and comfort for adult animals is quite wide, when compared to new born animals that have more narrowly defined ranges of comfort, and are generally at levels considerably higher than those for their parents. Scientific breeding must, therefore, provide the animals with temperature and humidity levels corresponding to their range of comfort.

In the case of calves for slaughter, weight is inversely proportional to environmental temperatures. When cattle are gaining weight, the ideal temperature for them falls further. For example, a 500kg animal will feel most comfortable at a temperature of 10^{o}C.

The desired environment also varies with different breeds of beef cattle. Short horn cattle gain much more weight at 10^{o} than at 27^{o}C. Moderate winds are desirable as compared to calm for gaining more weight. This also improves the feed utilization by the animals.

Type of Livestock	Temperature range (^{o}C)	Humidity range (%)

Calves for breeding	5-20	50-80
Calves while fattening	18-20	50-60
Young breeding cattle	5-20	50-80
Young cattle while fattening	10-20	50-80
Milk cows	0-15	15-80
Suckling pigs	33-22	50-80
Pigs for slaughter	22-15	50-80
Sows	5-15	50-80
Sheep	5-15	50-80
Chicks	34-21	50-70
Egg laying hens	15-22	50-80

*MILK CATTLE

Low temperature is favourable for higher milk production of good quality. The optimum temperature range of milk production is 0 to15 ^{o}C, irrespective of the weight of the cattle. Beyond 15^{o}C the fat content of cow's milk begins to decline. However variation in ideal temperatures is recorded from breed to breed. In case of Holstein cows there is no adverse effect on the milk yield of animals even at a temperature of -12^{o}C; while the milk yield of Jersey cows begins to decline when the temperature drops to -1C. A 20 per cent reduction in milk yield of jersey cows, has been recorded at a temperature of -12^{o}C. On the warmer side, milk yield of the Jersey cows is unaffected at a temperature of 27^{o}C while production drops rapidly when the temperature exceeds 24^{o}C. In case of Brahman cow's milk production does not fall until 35^{o}C temperature is reached. When the temperatures are within the ideal range, changes in relative humidity produce no significant change in milk production; but at temperature beyond 24^{o}C, high relative humidity amplifies the effect of high temperature towards reduced production.

The adverse effects of high temperatures (exceeding 33^{o}C) are minimized to some extent by winds blowing between 8 and 16 kmph. However, at lower temperatures, no positive results of wind are recorded.

*GOAT AND SHEEP

These animals live in diverse climates. It is, therefore, not surprising to find breeds of goat well adapted to extremes of temperature. Thus it is very difficult to set ideal temperature limits for breeding goat. Sheep are also one of the most tolerant of domestic animals to increased temperature. The environmental requirements of goat are, therefore, applicable to sheep as well. Like goat, sheep originated in different areas, therefore the zone of thermal indifference varies enormously from breed to breed. The most critical period in a sheep's life is the day it is born. It has been estimated that in United States 20 to 25 per cent of the lambs die within 5 days of their birth. Thus the proper environment for lambs from birth to weaning and weaning to slaughter are very critical (Glimp and David, 1974). Sheep of European origin have a zone of thermal indifference between 16^oC and 12^oC for lambs, and between 15^oC and 5^oC for sheep used in the production of meat or wool. In the case of sheep for milk a lower temperature results in higher fat content. Sheep kept at a temperature of 32^oC and relative humidity between 60 and 65 per cent showed an increase in body temperature, respiration rate and pulse rate as compared to those kept within the range of 3 to 13^oC.

***PIGS**

Independent of the weight, the optimum temperature for sows is between 8 to 15^oC. This temperature range is to be maintained after giving birth and the entire duration of lactation. In cool and humid climates, it has been recorded (Smith and Allen, 1976) that death rates of pigs during transportation and after, increases rapidly above 18^oC. Strong sunshine appears to add to the death rate. However, the young animals require quite different environmental conditions to develop properly. It is therefore essential to have separate stalls for suckling pigs and their mothers. The two groups will only meet at the temperature boundary for suckling pigs and their mothers.

***SUCKLING PIGS**

At birth, pigs require a temperature around 33^oC. As the suckling pig gains weight, they begin to tolerate lower temperatures. For example, when a pig attains 20kg weight, the ideal temperature for the animal is 22^oC. For pigs intended for fattening or breeding, the range of ideal temperatures become lower and lower as they gain weight. Whereas a 20kg pig is most comfortable at 22^oC, a 60 kg pig will prefer a temperature closer to 15 ^oC. Fattening is very sensitive to the humidity levels in the environment. They do well within a narrow humidity range of 50 to 70 per cent. Keeping pigs quite dry under hot and dry weather can lead to their death through hypothermia. In hot climates where temperature exceeds 30^oC in addition to shade, sprays of water and wet mud are provided to compensate for their limited ability to evaporate water from respiratory tracts.

LECTURE 15
WEATHER FORECASTING, BASICS, TYPES AND ITS IMPORTANCE IN AGRICULTURE AND FORECASTING NET WORK IN INDIA

WEATHER FORECASTING

Any advance information about the probable weather in future obtained by evaluating the present and past meteorological conditions of the atmosphere is called weather forecasting. OR The prediction of weather in advance is called weather forecast. Weather forecasting is the predication of weather.

Weather forecasting in Agriculture : Forecasting of weather elements *viz.*, sunshine hours, occurrence of dew, relative humidity, rainfall, temperature, winds etc. which are important in agriculture and for farming operations is known as agricultural forecast.

CLASSIFICATION OF WEATHER FORECASTING / TYPES OF WEATHER FORECASTING

Weather forecasting on the basis of their validity period or time scale are classified as follows :

1) **Now casting :** Denotes very short range, say few hours to 24 hours. Forecast at the time of cricket match during the day. It denotes very short range i.e. few hours to 24 hours.
2) **Short range forecast (SRF) :** Valid for 3 days or 72 hours and are issued twice a day. It is an outlook for the subsequent two days. The short range forecast includes cloud spread, rainfall distribution, heavy rainfall warnings, maximum and minimum temperatures, heavy rainfall warnings, heat and cold waves, low pressure areas, cyclone warning, hail / thunderstorm, dust storm. Snow, frost and likelihood of maximum wind speed. The short range forecast is issued twice a day based on synoptic conditions. Though the short range forecasting is useful in weather based agricultural operations, the reaction time to the farmer is too short for preventive measures against adverse weather.
3) **Medium range forecast (MRF) :** This forecast of warning of weather elements hazardous to agriculture is valid for 3 to 10 days period. In this forecast, irregularities (anomalies) of the weather elements such as temperature, rainfall from normal values are predicted. Agricultural operations like sowing, planting, spraying, dusting, irrigation scheduling, storing, fertilizer application, transportation of Agricultural and live stock goods protection from frost, hails, etc. can be forecasted. The forecast includes cloud amount, rainfall, maximum and minimum temperatures, average wind speed and wind direction. The medium range weather forecast is an objective and challenging one to weather scientists as it involves enormous numerical computations with expertise in weather science. A National Centre for Medium Range Weather Forecasting (NCMRWF) was established in 1988 in New Delhi to develop atmospheric models for medium range weather forecasting.
4) **Long range forecast (LRF) :** Valid for a period more than 10 days, say a month or a season. Long range forecast (LRF) : This forecast is valid for more than 10 days, say a month or a season. The IMD received issuing LRF since the year 1988 onwards on total monsoon rainfall of the country by 25th May. These forecasts can be used for predicting likely trends in food grains production of India before beginning of the *kharif* season. The cultivable cropped area depends upon monsoon rains and its distribution. These forecasts can hold the food grain prices in check through buffer stock operations. Crop-weather watch group in the Agriculture Ministry, Govt. of

India closely follow the forecast & its impact on food grains production during the *kharif* season. The all India drought during 2002 was well managed by the Govt. of India with effective planning system of distributing food grains across the drought affected states.

For monsoon IMD publishes forecasting in two phases. For June-September monsoon, forecasting is done in April and for whole year forecasting is published in June.

For April forecasting following data is required.

1) Temperature between December-January of north Atlantic ocean.
2) Temperature of February-March of equators in Indian ocean.
3) Atmospheric pressure over sea of February-March from east Asia.
4) Temperature of January month from south –east Europe
5) Density of warm water masses in equatorial region of Pacific ocean.

IMPORTANCE OR SIGNIFICANCE OF WEATHER FORECAST IN AGRICULTURE

1. The forecast of the weather events helps for suitable planning of farm.
2. It helps in to undertake or with held the sowing operation.
3. It helps is following farm operations.

a) To irrigate crop or not
b) Whether to apply fertilizer or not
c) Whether to start harvesting or with held it.

4. It helps in transportation and storage of food grains.
5. Helps for management of cultural operations like ploughing, harrowing, hoeing etc.
6. It helps in measures to protect live stock.

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LECTURE 16

CLIMATE CHANGE,CLIMAIC VARIABILITY,GLOBAL WARMING, CAUSES OF CLIMATE CHANGE AND ITS IMPACT ON REGIONAL AND NATIONAL AGRICULTURE

Climate change can be defined as a trend in one or more climatic variables characterized by a fairly smooth continuous increase or decrease of the average value during the period of record. Any long term conspicuous deviation from usual prevalent climate bringing variations in normal temperature , rainfall , atmospheric circulation with abnormal expression in extreme climate such as floods, droughts, extreme temperatures etc. can be termed as *climatic a change*. It is to be noted climate has large inertia and not so flexible to change readily. Any change for a month or a year or so can not be considered a climate change as it can be normalized in long term data in averaging. Rather it is a weather change. Climate requires large period or change ranging from a smaller cycle of sunspot activity of 11 years and 20,36,76,100,1000,23000,40000 and lastly to 100,000 years associated with orbital changes[e.g. eccentrically of the earth] oscillating between ice ages and interglacial.

Causes of climate change

Causes for climate change can be categorized into two classes.

1) Natural causes which includes orbital changes in the earth revolution, variation, oceanic circulation, changes in position of continents and size, volcanic activity, changes in atmospheric constituents by natural events, variations in solar activity.

2) Human causes which involved abnormal human activities such as deforestation, fossil duel, combustion changes in atmospheric constituents and lastly nuclear war causing nuclear winter.

Mechanisms of climate change

Energy received from the sun is absorbed by the earth – atmosphere system and is used for heating land, water and air and for running atmospheric engine is derived from sun and is a part of this energy balance equation.

Atmospheric circulation is determined by this energy balance at the earth surface.

It is imperative that the change in energy balance brings about a change in atmospheric surface temperatures and circulation mainly and is basically responsible for any change in climate. Thus, the reason for climate change id to be sought and interpreted through the energy balance of the earth-atmosphere system. Climatic changes occurred so for on different time scales have been attributed to the various factors responsible basically for energy balance and consequently changing surface temperature and circulation.

The factors are :

i) Change in intensity of the radiation at the top of the atmosphere
ii) Change in the reflectivity (albedo) of the atmosphere and earth’s surface

iii) Change in intensity or absorption and emission of long waves radiations which depends upon the constituents of the atmosphere such as carbon dioxide, water vapour, dust etc.

Astronomical parameters are responsible for change in radiation intensity. For second factor, human and natural activities are concerned.

Pollution factors responsible for heat balance and climate change

i) Increase in the carbon dioxide in the atmosphere
ii) Increase in the amount of aerosols or particular matter in the atmosphere
iii) Improper agricultural practices changing soil dust into atmosphere
iv) Thermal pollution increasing atmospheric heat produced by burning fossil,nuclear fuels
v) Increase in albedo of the earth's surface by urbanization, deforestation and by defoliation by chemical warfare
vi) Change in the rate of transfer of thermal energy and momentum between the ocean and the atmosphere due to the oil films on sea as oil pollution. All these factors together affect the radiation balance of the earth's surface.

Climate change would strongly affect agriculture, but scientists still don't know exactly how**.** Most agricultural impacts studies are based on the results of general circulation models .These climate models indicate that rising levels of greenhouse gases are likely to increase the global average surface temperature by 1.5-4.5 C over the next 100 years, raise sea-levels (thus inundating farmland and making coastal groundwater saltier), amplify extreme weather events such as storms and hot spells, shift climate zones poleward, and reduce soil moisture. Impacts studies consider how these general trends would affect agricultural production in specific regions. To date, most studies have assumed that agricultural technology and management will not improve and adapt. New studies are becoming increasingly sophisticated, however, and adjustments experiments now incorporate assumptions about the human response to climate change.

Climate variability

Climate variability refers to the climatic parameter of a region varying from its long-term mean. Every year in a specific time period, the climate of a location is different. Climate varies over seasons and years instead of day-to-day like weather. Some summers are colder than others. Some years have more overall precipitation. Even though people are fairly perceptive of climate variability, it is not as noticeable as weather variability because it happens over seasons and years. Evidence includes statements like: "the last few winters have seemed so short," or "there seem to be more heavy downpours in recent years."

Scientists think of **climate variability** as the way climate fluctuates yearly above or below a long-term average value. You can think of it as a story with two parts: **average** and **range**. These parts complement each other; understanding the range gives context to the average and vice versa.

Global Warming

Global warming is the term used to describe a gradual increase in the average temperature of the Earth's atmosphere and its oceans, a change that is believed to be permanently changing the Earth's climate. There is great debate among many people, and sometimes in the news, on whether global warming is real (some call it a hoax). But climate scientists looking at the data and facts agree the planet is warming. While many view the effects of global warming to be more substantial and more rapidly occurring than others do, the scientific consensus on climatic changes related to global warming is that the average temperature of the Earth has risen between 0.4 and 0.8 °C over the past 100 years. The increased volumes of carbon dioxide and other greenhouse gases released by the burning of fossil fuels, land clearing, agriculture, and other human activities, are believed to be the primary sources of the global warming that has occurred over the past 50 years. Scientists from the Intergovernmental Panel on Climate carrying out global warming research have recently predicted that average global temperatures could increase between 1.4 and 5.8 °C by the year 2100. Changes resulting from global warming may include rising sea levels due to the melting of the polar ice caps, as well as an increase in occurrence and severity of storms and other severe weather events.

Global warming is a slow steady rise in Earth's surface temperature.[1] Temperatures today are 0.74 °C (1.33 °F) higher than 150 years ago.[2] Many scientists say that in the next 100–200 years, temperatures might be up to 6 degrees Celsius higher than they were before the effects of global warming were discovered.

The basic cause seems to be a rise in atmospheric carbon dioxide, as predicted by Svante Arrhenius a hundred years ago. When people use fossil fuels like coal and oil, this adds carbon dioxide to the air. When people cut down many trees (deforestation), this means less carbon dioxide is taken out of the atmosphere by plants.

If the Earth's temperature becomes hotter the sea level will also become higher. This is partly because water expands when it gets warmer. It is also partly because warm temperatures make glaciers melt. The sea level rise may cause coastal areas to flood. Weather patterns, including where and how much rain or snow there is, will change. Deserts will probably increase in size. Colder areas will warm up faster than warm areas. Strong storms may become more likely and farming may not make as much food. These effects will not be the same everywhere. The changes from one area to another are not well known.

People in government and Intergovernmental Panel on Climate Change (IPCC) have talked about global warming. They do not agree on what to do about it. Some things that could reduce warming are to burn less fossil fuels, adapt to any temperature changes, or try to change the Earth to reduce warming. The Kyoto

Protocol tries to reduce pollution from the burning of fossil fuels. Most governments have agreed to it. Some people in government think nothing should change.

Global warming and **climate change** are terms for the observed century-scale rise in the average temperature of the Earth's climate system and its related effects. Multiple lines of scientific evidence show that the climate system is warming. Although the increase of near-surface atmospheric temperature is the measure of global warming often reported in the popular press, most of the additional energy stored in the climate system since 1970 has gone into the oceans. The rest has melted ice and warmed the continents and atmosphere. Many of the observed changes since the 1950s are unprecedented over tens to thousands of years.

Scientific understanding of global warming is increasing. The Intergovernmental Panel on Climate Change (IPCC) reported in 2014 that scientists were more than 95% certain that global warming is mostly being caused by human (anthropogenic) activities, mainly increasing concentrations of greenhouse gases such as carbon dioxide (CO_2). Human-made carbon dioxide continues to increase above levels not seen in hundreds of thousands of years. Currently, about half of the carbon dioxide released from the burning of fossil fuels remains in the atmosphere. The rest is absorbed by vegetation and the oceans. Climate model projections summarized in the report indicated that during the 21st century the global surface temperature is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) for their lowest emissions scenario and 2.6 to 4.8 °C (4.7 to 8.6 °F) for the highest emissions scenario. These findings have been recognized by the national science academies of the major industrialized nations and are not disputed by any scientific body of national or international standing.

Future climate change and associated impacts will differ from region to region around the globe. Anticipated effects include warming global temperature, rising sea levels, changing precipitation, and expansion of deserts in the subtropics. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers, permafrost and sea ice. Other likely changes include more frequent extreme weather events including heat waves, droughts, heavy rainfall with floods and heavy snowfall; ocean acidification; and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment of populated areas due to rising sea levels. Because the climate system has a large "inertia" and CO_2 will stay in the atmosphere for a long time, many of these effects will not only exist for decades or centuries, but will persist for tens of thousands of years.

Possible societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, building systems resilient to its effects, and possible future climate engineering. Most countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC), whose ultimate objective is

to prevent dangerous anthropogenic climate change. Parties to the UNFCCC have agreed that deep cuts in emissions are required and that global warming should be limited to well below 2.0 °C (3.6 °F) relative to pre-industrial levels, with efforts made to limit warming to 1.5 °C (2.7 °F).
Public reactions to global warming and concern about its effects are also increasing. A global 2015 Pew Research Center report showed a median of 54% consider it "a very serious problem". There are significant regional differences, with Americans and Chinese (whose economies are responsible for the greatest annual CO_2 emissions) among the least concerned.

Causes of Climate Change

Climate change is a long-term shift in weather conditions identified by changes in temperature, precipitation, winds, and other indicators. Climate change can involve both changes in average conditions and changes in variability, including, for example, extreme events.

The earth's climate is naturally variable on all time scales. However, its long-term state and average temperature are regulated by the balance between incoming and outgoing energy, which determines the Earth's energy balance. (Learn more about the Earth's climate system here). Any factor that causes a sustained change to the amount of incoming energy or the amount of outgoing energy can lead to climate change. As these factors are external to the climate system, they are referred to as 'climate forcers', invoking the idea that they force or push the climate towards a new long-term state – either warmer or cooler depending on the cause of change. Different factors operate on different time scales, and not all of those factors that have been responsible for changes in earth's climate in the distant past are relevant to contemporary climate change. Factors that cause climate change can be divided into two categories - those related to natural processes and those related to human activity. In addition to natural causes of climate change, changes internal to the climate system, such as variations in ocean currents or atmospheric circulation, can also influence the climate for short periods of time. This natural internal climate variability is superimposed on the long-term forced climate change.

- **Natural Causes**
- **Human Causes**
- **Short lived and long lived climate forcers**

Natural Causes

The Earth's climate can be affected by natural factors that are external to the climate system, such as changes in volcanic activity, solar output, and the Earth's orbit around the Sun. Of these, the two factors relevant on timescales of contemporary climate change are changes in volcanic activity and changes in solar radiation. In terms of the Earth's energy balance, these factors primarily influence the amount of incoming energy. Volcanic eruptions are episodic and have relatively short-term effects on climate. Changes in solar irradiance have contributed to climate trends over the past century but since the Industrial Revolution, the effect of additions of greenhouse gases to the atmosphere has been over 50 times that of changes in the Sun's output.

Human Causes

Climate change can also be caused by human activities, such as the burning of fossil fuels and the conversion of land for forestry and agriculture. Since the beginning of the Industrial Revolution, these human influences on the climate system have increased substantially. In addition to other environmental impacts, these activities change the land surface and emit various substances to the atmosphere. These in turn can influence both the amount of incoming energy and the amount of outgoing energy and can have both warming and cooling effects on the climate. The dominant product of fossil fuel combustion is carbon dioxide, a greenhouse gas. The overall effect of human activities since the Industrial Revolution has been a warming effect, driven primarily by emissions of carbon dioxide and enhanced by emissions of other greenhouse gases.

The build-up of greenhouse gases in the atmosphere has led to an enhancement of the natural greenhouse effect. It is this human-induced enhancement of the greenhouse effect that is of concern because ongoing emissions of greenhouse gases have the potential to warm the planet to levels that have never been experienced in the history of human civilization. Such climate change could have far-reaching and/or unpredictable environmental, social, and economic consequences.

Short-lived and long-lived climate forcers

Carbon dioxide is the main cause of human-induced climate change. It has been emitted in vast quantities from the burning of fossil fuels and it is a very long-lived gas, which means it continues to affect the climate system during its long residence time in the atmosphere. However, fossil fuel combustion, industrial processes, agriculture, and forestry-related activities emit other substances that also act as climate forcers. Some, such as nitrous oxide, are long-lived greenhouse gases like carbon dioxide, and so contribute to long-term climate change. Other substances have shorter atmospheric lifetimes because they are removed fairly quickly from the atmosphere. Therefore, their effect on the climate system is similarly short-lived. Together, these short-lived climate forcers are responsible for a significant amount of current climate forcing from anthropogenic substances. Some short-lived climate forcers have a climate warming effect (‘positive climate forcers') while others have a cooling effect (‘negative climate forcers').

If atmospheric levels of short-lived climate forcers are continually replenished by ongoing emissions, these continue to exert a climate forcing. However, reducing emissions will quite quickly lead to reduced atmospheric levels of such substances. A number of short-lived climate forcers have climate warming effects and together are the most important contributors to the human enhancement of the greenhouse effect after carbon dioxide. This includes methane and tropospheric ozone – both greenhouse gases – and black carbon, a small solid particle formed from the incomplete combustion of carbon-based fuels (coal, oil and wood for example).

Other short-lived climate forcers have climate cooling effects, most notably sulphate aerosols. Fossil fuel combustion emits sulphur dioxide into the atmosphere (in addition to carbon dioxide) which then combines with water vapour to form tiny droplets (aerosols) which reflect sunlight. Sulphate aerosols remain in the atmosphere for only a few days (washing out in what is referred to as acid rain), and so do not have the same long-term effect as greenhouse gases. The cooling from sulphate aerosols in the atmosphere has, however, offset some of the warming from other substances. That is, the warming we have experienced to date would have been even larger had it not been for elevated levels of sulphate aerosols in the atmosphere.

Green house effect

Except ozone most of the gases in the atmosphere are transparent to the incoming short wave radiation from the sun. The carbon dioxide and water vapour though present in smaller proportions block the outgoing long wave radiation emitted by the earth. Had the atmosphere not behaved thus, the earth's surface temperature would have been much lower(-18^{o}C), much below the freezing temperature. The surface temperature, in fact is around 15^{o}C representing the warning of 33^{o}C. This phenomenon of increasing temperature is called **"*green house effect* ".**

Pollution of green house gases : The gases responsible for green house effect are carbon dioxide(CO_2), methane(CH_4),nitrous oxides(N_2O), chlorofluro carbons (CFC) and water vapour(H_2O).Their role increase in concentration due to pollution, contribution in GH effect, id to be discussed in brief here.

A. Carbon dioxide (CO_2) **:** This gas though in small proportion it is responsible for half of the total green house effect . It absorbs short wavelengths of 2,3 and 4µ from the sun . It also absorbs 14-16 µ and 15µ IR long wave length emitted by the earth and emits still larger wave length producing warning on the earth. The increase in proportion of CO_2, will result in warming effect changing global climate. Its present proportion in atmosphere is 0.034% by volume or 340 ppm in 1860, its proportion was 290 ppm, in 1960 it was 310 ppm. It is now increasing at the rate of 1.5 ppm per year, and at this it should double by 2030 AD or so. WMO has predicted 450 ppm of CO_2 in 2050. The major sources of CO_2 release are burning of fossil fuels, deforestation followed by release by volcanoes, oceans, decaying plants and by out breathing. For each 10% rise in concentrations, the temperature increases by 3^{o}C. Present day models predict an increase from 2 to 4 ^{o}C, if the concentration of gas doubles.

B. Methane (CH_4) **:** The proportion of methane in air is about 1.3 to 1.6 ppm. Its concentration is rapidly increasing in this century. It is generated by the activities of microorganisms at swamps, paddy fields, marshs. Paddy fields and ruminants are the main sources of this gas. This gas absorbs in the infra-red region. This is mainly *biogenic pollution*.

C. Nitrous oxide (N_2O) **:** Its proportion in air is 0.25 to 0.35 ppm. It is released through industry. It interacts with ozone decreasing its content ozone is destroyed. It has no important absorption peak.

D. Chlorofluro carbons (CFC)**:** These chemicals (F_{12},F_{11},CCl_3,F,CH_3Cl) are largely used in cooling systems and in the walls of domestic and commercial refrigerators. CFC's are used in foam insulation, packing, aerosols, clearing, solvents and medical sterilizers. CFC's are released through industry, their content in atmosphere being less than 1 ppm. CFCs are mainly responsible for ozone (O_3) in the atmosphere.

Effects of Climate Change on Agriculture

Agriculture is considered to be one of the most vulnerable sectors. The Declaration of the World Summit on Food from November 2009 stated: "Climate change poses additional severe risks to food security and the agriculture sector. Its expected impact is particularly fraught with danger for smallholder farmers in developing countries, notably the Least Developed Countries (LDCs), and for already vulnerable populations." In a newly published report the WTO and UNEP state that in low-latitude regions, even a small temperature increase of 1°C would lead to reductions of 5-10 per cent in the yields of major cereal crops. By 2020, crop yields in African countries could fall by up to 50 per cent.

Climate change has started to significantly affect agriculture and rural landscapes: In recent years both droughts and floods attributed to changing climatic conditions have been getting more pronounced. Rising temperatures are expected to bring crop-shrinking heat waves, melting glaciers and ice sheets, and rising sea levels, with major consequences for global food security.

Over the next 100 years, accelerated warming and expansion of water in the oceans, and increased melting rates of low-lying glaciers and ice caps are expected to increase sea levels by a metre or more. This will have major consequences for low-lying farmland across the world. For instance, a one metre sea level rise would affect half the rice land of Bangladesh. A two metre rise would inundate much of the Mekong Delta which produces half the rice in Vietnam, the world's second most important rice exporter, etc.

The melting of mountain glaciers is another global threat. Already the snow caps on Mount Kenya and Kilimanjaro in east Africa have largely disappeared. The shrinking of glaciers in the Himalayas is particularly alarming since they feed the Indus, Ganges, Yangtze, Yellow and Mekong Rivers on which the irrigation systems of hundreds of millions of Asian farmers depend. As a result, Asia's rivers are likely to become ever more erratic or even cease to flow during the dry season.

Climate change will also affect the environmental services provided by major ecosystems, such as rainforest, impairing their crucial role in distributing rainfall over vast areas, whilst removing huge amounts of carbon from the atmosphere at the same time.

As greenhouse gas concentrations increase and temperatures rise, the frequency and intensity of extreme weather events such as cyclones, floods, droughts and heat waves may also change. Rising ocean temperatures, in particular, are expected to affect storm and cyclone development.

Across the world in the last few years, flooding and other extreme weather, attributed to climate change, is reaching new heights. For example:

- In 1995, half of Bhola Island, Bangladesh, became permanently flooded, leaving 500,000 people, mainly farmers, as the world's first climate refugees.
- Since 2001, much of the Murray-Darling Basin, Australia's breadbasket, is experiencing the worst droughts for over 100 years. Storage levels will take many years of above average rainfall to recover.
- Threats to Uganda's coffee crop are threatening the country's main export income.
- The UN is having to feed millions of people in Africa, and particularly Ethiopia and Kenya.
- Millions of people have been affected by major floods in South Asia.
- Increasingly erratic monsoons are causing major problems for farmers in India.

Agriculture feeds and clothes the world. Although the long-term effects of climate change are still largely unknown, scientists can observe short-term effects of climate change on crops and animals. In addition, scientists can prognosticate about the changes that are likely to occur in agriculture if global climate change causes changes in temperatures and rainfall.

Effect on Crops

Data have shown that levels of atmospheric CO_2 are increasing. Research is being conducted to determine what types of plant responses can be expected from these changes (see section on CO_2 increase below). Others worry that climate change is going to permanently alter weather patterns, temperatures, and rainfall. NOAA data show that for much of the Southeast, annual average rainfall has been relatively constant or slowly increasing; air temperatures are slightly lower than 100 years ago. However, the frequency of rainfall events greater than 2 inches is increasing, leading to longer dry periods between rain events. Crop yields are likely affected by these changes to some extent already, but it is not clear if future changes will be catastrophic or not. Plants are surprisingly resilient, and can withstand a variety of conditions while still being productive. In addition, other factors such as location, soil fertility, crop varieties, and management practices will all affect future yields. Below we list some of the effects we could expect for agriculture due to various aspects of climate change.

Increased concentrations of CO_2 may boost crop productivity. In principle, higher levels of CO_2 should stimulate photosynthesis in certain plants; a doubling of CO_2 may increase photosynthesis rates by as much as30-100%. Laboratory experiments confirm that when plants absorb more carbon they grow bigger and more quickly. This is particularly true for C_3 plants (so called because the product of their first biochemical reactions during photosynthesis has three carbon atoms). Increased carbon dioxide tends to suppress photo-respiration in these plants, making them more water-efficient. C_3 plants include such major mid-latitude food staples as wheat, rice, and soybean. The response of C_4 plants, on the other hand, would not be as dramatic (although at current CO_2 levels these plants photosynthesize more efficiently than do C_3 plants). C_4 plants include such low-latitude crops as maize, sorghum, sugar-cane, and millet, plus many pasture and forage grasses.

Despite technological improvements that increase corn yields, extreme weather events have caused significant yield reductions in some years. Crops grown in the United States are critical for the food supply here and around the world. U.S. exports supply more than 30% of all wheat, corn, and rice on the global market. Changes in temperature, amount of carbon dioxide (CO_2), and the frequency and intensity of extreme weather could have significant impacts on crop yields.

- Higher CO_2 levels can increase yields. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of CO_2 concentrations. The yields for other crops, such as corn, exhibit a much smaller response (less than 10% increase). However, some factors may counteract these potential increases in yield. For example, if temperature exceeds a crop's optimal level or if sufficient water and nutrients are not available, yield increases may be reduced or reversed.
- More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. For example, in 2008, the Mississippi River flooded just before the harvest period for many crops, causing an estimated loss of $8 billion for farmers.
- Dealing with drought could become a challenge in areas where summer temperatures are projected to increase and precipitation is projected to decrease. As water supplies are reduced, it may be more difficult to meet water demands.
- Many weeds, pests and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. Currently, farmers spend more than $11 billion per year to fight weeds in the United States.The ranges of weeds and pests are likely to expand northward. This would cause new problems for farmers' crops previously unexposed to these species. Moreover, increased use of pesticides and fungicides may negatively affect human health.

Impacts on Livestock

It is expected that increased air temperatures will cause more stress on livestock. Both humans and livestock are warm-blooded animals, so both are affected by increased heat and humidity. During stifling heat, livestock reproduction declines as well as their appetite. Decreased appetite will lengthen the time needed for the livestock to reach their target weight (most animals only eat about half of normal quantities when they are heat-stressed). Stress can also increase the incidence of sickness, decrease rates of reproduction, and increase fighting among animals in confinement. In some areas, night-time temperatures are even more above average than daytime temperatures during heat-waves, which has resulted in increased mortality rates. Despite the warmer winter temperatures, global warming could have a negative overall impact upon livestock.

Americans consume more than 37 million tons of meat annually. The U.S. livestock industry produced $100 billion worth of goods in 2002. Changes in climate could affect animals both directly and indirectly.

- Heat waves, which are projected to increase under climate change, could directly threaten livestock. A number of states have each reported losses of more than 5,000 animals from just one heat wave. Heat stress affects animals both directly and indirectly. Over time, heat stress can increase vulnerability to disease, reduce fertility, and reduce milk production.
- Drought may threaten pasture and feed supplies. Drought reduces the amount of quality forage available to grazing livestock. Some areas could experience longer, more intense droughts, resulting from higher summer temperatures and reduced precipitation. For animals that rely on grain, changes in crop production due to drought could also become a problem.
- Climate change may increase the prevalence of parasites and diseases that affect livestock.The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive.
- Increase in carbon dioxide (CO_2) may increase the productivity of pastures, but may also decrease their quality. Increase in atmospheric CO_2 can increase the productivity of plants on which livestock feed. However, studies indicate that the quality of some of the forage found in pasturelands decreases with higher CO_2. As a result, cattle would need to eat more to get the same nutritional benefits.

Impacts on Fisheries

American fisheries catch or harvest five million metric tons of fish and shellfish each year. These fisheries contribute more than $1.4 billion to the economy annually (as of 2007). Many fisheries already face multiple stresses, including overfishing and water pollution. Climate change may worsen these stresses. In particular, temperature changes could lead to significant impacts.

The ranges of marine species have shifted northward as waters have warmed. The ranges of many fish and shellfish species may change. Many marine species have certain temperature ranges at which they can survive. For example, cod in the

North Atlantic require water temperatures below 54°F. Even sea-bottom temperatures above 47°F can reduce their ability to reproduce and for young cod to survive. In this century, temperatures in the region will likely exceed both thresholds.

- Many aquatic species can find colder areas of streams and lakes or move northward along the coast or in the ocean. However, moving into new areas may put these species into competition with other species over food and other resources.
- Some diseases that affect aquatic life may become more prevalent in warm water. For example, in southern New England, lobster catches have declined dramatically. A temperature-sensitive bacterial shell disease likely caused the large die-off events that led to the decline.
- Changes in temperature and seasons could affect the timing of reproduction and migration. Many steps within an aquatic animal's lifecycle are controlled by temperature and the changing of the seasons. For example, in the Northwest warmer water temperatures may affect the lifecycle of salmon and increase the likelihood of disease. Combined with other climate impacts, these effects are projected to lead to large declines in salmon populations.

  In addition to warming, the world's oceans are gradually becoming more acidic due to increases in atmospheric carbon dioxide (CO_2). Increasing acidity could harm shellfish by weakening their shells, which are created from calcium and are vulnerable to increasing acidity. Acidification may also threaten the structures of sensitive ecosystems upon which some fish and shellfish rely.

Temperature Increase

While some species would benefit from higher temperatures, others might not. A warmer climate might, for example, interfere with germination or with other key stages in their life cycle. It might also reduce soil moisture; evaporation rates increase in mid-latitudes by about 5% for each 1C rise in average annual temperature. Another potentially limiting factor is that soil types in a new climate zone may be unable to support intensive agriculture as practiced today in the main producer countries. For example, even if sub-Arctic Canada experiences climatic conditions similar to those now existing in the country's southern grain-producing regions, its poor soil may be unable to sustain crop growth.

Warmer temperatures may make many crops grow more quickly, but warmer temperatures could also reduce yields. Crops tend to grow faster in warmer conditions. However, for some crops (such as grains), faster growth reduces the amount of time that seeds have to grow and mature. This can reduce yields (i.e., the amount of crop produced from a given amount of land).

For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline.

Many scientists project that the average temperatures throughout the US will rise in the next few decades. Much of this warming could occur at night, but the models are not clear on this. If temperatures increase, cooler areas of the country might be more habitable for some of the main food crops grown in the US – thus, expanding the areas in which certain crops could be grown or moving their ranges north. For example, less frequent freezes could allow citrus to move north from its current range in Florida to other areas of the Southeast. In areas where crops are being grown in their warmest productive temperature ranges already, heat stress or increased disease could reduce yields. However, research on new crop varieties and technological advances could improve yields in spite of reductions due to temperature increases. A report from the IPCC (Intergovernmental Panel on Climate Change) is optimistic that general crop yields for the next century could increase in a range from 5-20% during the first few decades of the 21st century, and they expect the crop yield to remain somewhat steady (but positive) through the rest of the century. If climate change reduces the global amount of arable land, however, total yields could still decrease.

Extreme Weather Events

Some scientists believe that climate change will lead to more extreme weather events. Extreme weather events include heat waves, droughts, strong winds, and heavy rains. Climate models do not do a good job of predicting how extreme weather events might change under global warming. For example, models do not agree on whether the number of hurricanes in a warmer world would be more or less than current values, but scientists generally feel that the strength of the largest hurricanes will increase. The length of the hurricane season could also increase. Observational changes in the number of tornadoes per year we see now may be due to increases in the number of people watching the skies and the growth of urban areas rather than any strict climate changes. It is not clear if observed changes in extreme weather events we see now are part of long natural cycles or if they are in response to climate change. Nonetheless, all of these events can be detrimental to crop growth.

Droughts are damaging because of the long-term lack of water available to the plants. Droughts have been responsible for some of the more serious famines in the world, although sociological factors are also important. Heat waves can cause extreme heat stress in crops, which can limit yields if they occur during certain times of the plants' life-cycle (pollination, pod or fruit set). Also, heat waves can result in wilted plants (due to elevated transpiration rates) which can cause yield loss if not counteracted by irrigation. Strong winds can cause leaf and limb damage, as well as "sandblasting" of the soil against the foliage. Heavy rains that often result in flooding can also be detrimental to crops and to soil structure. Most plants cannot survive in prolonged waterlogged conditions because the roots need to breathe. In addition, flooding can erode topsoil from prime growing areas, resulting in irreversible habitat damage. Heavy winds combined with rain (from events such as hurricanes and tornadoes) can down large trees, and damage houses, barns and other structures involved in production agriculture.

Carbon Dioxide Increase

Scientists are in agreement that the levels of atmospheric CO_2 (carbon dioxide) have increased in recent years. Prior to the Industrial Revolution, they were measured at 280 parts per million by volume (ppmv); currently the levels are around 380 ppmv. These levels have been steadily increasing by 1.9 ppm yearly since the year 2000, largely as a result of fossil fuel burning. Carbon dioxide is critical to photosynthesis (and thus plant growth). Scientists agree that even small increases in carbon dioxide result in more plant growth. It is likely that higher levels of carbon dioxide will result in higher harvestable crop yields. However, this depends critically on the availability of sufficient water and nutrients necessary for plant growth. Some scientists believe that one drawback to this increased productivity will be crops with lower nutrient and protein levels. If true, this could have a significant, widespread impact on long-term human health if additional fertilizers were not incorporated into crop production.

Weeds, Pests and Disease

While crops are expected to respond to increased CO_2 with strong vegetative growth, other plants are also thought to respond in a similar fashion. Weeds have become more prolific and are expected to invade new habitats as global warming increases. For example, researchers at Duke University found that poison ivy is actually becoming more toxic as levels of atmospheric carbon dioxide increase. Studies have also shown that herbicides become less effective in a higher carbon dioxide environment, meaning that higher rates of herbicides will be necessary to achieve the same levels of control. Insect pests, some of which carry plant diseases, could become more prolific and widespread as temperatures increase. If pests live longer and reproduce more each year, it is possible that they could spread crop diseases into new production areas. It is also possible that increases in temperature, moisture and carbon dioxide could result in higher populations of destructive pests.

Irrigation and Rainfall

Changes in climate may also impact the water availability and water needs for agriculture. If temperature increases and more sporadic rainfall events result from global warming, it is possible that irrigation needs could increase in the future. For example, rainfall in parts of the southeastern US states has increased about 10% over the past century. However, part of this increase may be due to changes in the frequency of tropical storms. Tropical storms usually result in rainfall events greater than 2 inches in a day which occur at irregular intervals; these are less useful in an agricultural sense than are rainfall events that occur more frequently, even with lower accumulations. Plants growing in a high carbon dioxide environment may have lower water needs. In addition, widespread increased humidity will slow transpiration, further reducing the need for water. However, these benefits will probably be overshadowed by the lack of available water due to increased droughts and heat waves. The crops will transpire more heavily than when under “normal” growing conditions, and would likely need more water to adjust to these climactic changes. In anticipation of these changes, plant breeders are currently working to develop new varieties of crops that are considered to be drought tolerant, and more adaptable to varying levels of temperature and moisture.

Feed Quality

As indicated above, increased carbon dioxide may result in feed and forage that is less nutritious even if there is more of it. It is likely that growers would be forced to use feed additives in order to see the expected growth gains in livestock, and to avoid illnesses. This increased cost to the grower would result in increased food costs to the consumer. Availability could also decrease if there is not enough water and nutrients in stressed soils to keep up with plant growth.

Disease

Insect parasites and diseases could also become more prolific as global warming progresses. New diseases may also emerge in the Southeast that were once considered to inhabit only tropical areas. It is expected that in cases of increased heat stress and humidity, most livestock will not be able to fight these diseases without the use of costly medicines.

Agriculture and Food Supply

- Moderate warming and more carbon dioxide in the atmosphere may help plants to grow faster. However, more severe warming, floods, and drought may reduce
- yields.
- Livestock may be at risk, both directly from heat stress and indirectly from reduced quality of their food supply.
- Fisheries will be affected by changes in water temperature that shift species ranges, make waters more hospitable to invasive species, and change lifecycle timing.

Agriculture and fisheries are highly dependent on specific climate conditions. Trying to understand the overall effect of climate change on our food supply can be difficult. Increases in temperature and carbon dioxide (CO_2) can be beneficial for some crops in some places. But to realize these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met. Changes in the frequency and severity of droughts and floods could pose challenges for farmers and ranchers. Meanwhile, warmer water temperatures are likely to cause the habitat ranges of many fish and shellfish species to shift, which could disrupt ecosystems. Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology.

International Impacts

Internationally, the effects of climate change on agriculture and food supply are likely to be similar to those seen in the United States. However, other stressors such as population growth may magnify their effects. For example, in developing countries, adaptation options like changes in crop-management or ranching practices or improvements to irrigation are more limited than in the United States and other industrialized nations. Impacts to the global food supply concern the United States because they can affect food prices here at home. In addition, food shortages abroad can pose humanitarian crises and national security concerns.

The impact on net global agricultural productivity is also difficult to assess. Higher yields in some areas may compensate for decreases in others -- but again they may not, particularly if today's major food exporters suffer serious losses. In addition, it is difficult to forecast to what extent farmers and governments will be able to adopt new techniques and management approaches to compensate for the negative impacts of climate change. It is also hard to predict how relationships between crops and pests will evolve.

Climate and agricultural zones would tend to shift towards the poles. Because average temperatures are expected to increase more near the poles than near the equator, the shift in climate zones will be more pronounced in the higher latitudes. In the mid-latitude regions (45 to 60 latitude), the shift is expected to be about 200-300 kilometres for every degree Celsius of warming. Since todays latitudinal climate belts are each optimal for particular crops, such shifts could have a powerful impact on agricultural and livestock production. Crops for which temperature is the limiting factor may experience longer growing seasons. For example, in the Canadian prairies the growing season might lengthen by 10 days for every 1C increase in average annual temperature.

Mid-latitude yields may be reduced by 10-30% due to increased summer dryness. Climate models suggest that today's leading grain-producing areas -- in particular the Great Plains of the US -- may experience more frequent droughts and heat waves by the year 2030. Extended periods of extreme weather conditions would destroy certain crops, negating completely the potential for greater productivity through CO_2 fertilization. During the extended drought of 1988 in the US corn belt region, for example, corn yields dropped by 40% and, for the first time since 1930, US grain consumption exceeded production. The poleward edges of the mid-latitude agricultural zones -- northern Canada, Scandinavia, Russia, and Japan in the northern hemisphere, and southern Chile and Argentina in the southern one -- may benefit from the combined effects of higher temperatures and CO2 fertilization. But the problems of rugged terrain and poor soil suggest that this would not be enough to compensate for reduced yields in the more productive areas.

The impact on yields of low-latitude crops is more difficult to predict. While scientists are relatively confident that climate change will lead to higher temperatures, they are less sure of how it will affect precipitation -- the key constraint on low-latitude and tropical agriculture. Climate models do suggest, however, that the inter tropical convergence zones may migrate poleward, bringing the monsoon rains with them. The greatest risks for low-latitude countries, then, are that reduced rain fall and soil moisture will damage crops in semi-arid regions, and that additional heat stress will damage crops and especially livestock in humid tropical regions.

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Books recommended :

1. Atmosphere, weather and climate By- Roger G.Barry and Richard J.Chorley
2. Climatic Classification : ICARSAT
3. Contemporary Climatology By -Hendarson, Sellers and Robinson
4. Introduction to Agrometeorology By -H.S.Mavi
5. Meteorology By -S.R.Ghadekar
6. Agricultural Climatology By -J.R. Kakde