CLASSROOM STUDY MATERIAL

GEOGRAPHY

Part - 2

DELHI JAIPUR HYDERABAD PUNE AHMEDABAD LUCKNOW CHANDIGARH GUWAHATI

FOR DETAILED ENQUIRY,
PLEASE CALL: +91 8468022022,
+91 9019066066

ENQUIRY@VISIONIAS.IN /C/VISIIONIASDELHI /VISION_IAS VISION_IAS WWW.VISIONIAS.IN /VISIONIAS_UPSC

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www.visionias.in

GEOGRAPHY PART 2

sihagn27@gmail.com

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COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

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sihagn27@gmail.com

Student Notes:

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1. Composition of the Atmosphere

Student Notes:

In general, atmosphere is a layer of gases and dust surrounding a planet that is held in place by the gravity of the planet body. An atmosphere is more likely to be retained if the gravity is high and the atmosphere's temperature is low. In fact, earth's atmosphere makes earth unique in the solar system. Planet Earth's atmosphere is best suitable for life and thus, it is important to understand the composition as well as structure of it. In this context, man has started studying the atmosphere thousands of years before. The Rig Vedic verses have mention of Monsoon, seasons etc.

Earth's atmosphere is composed of gases, water vapours and dust particles. Although other important properties of the atmosphere such as temperature and pressure, can vary considerably in both time and space, its composition in terms of the relative proportions of the gases present in any unit volume, tends to remain remarkably constant. Thus, the atmosphere generally tends to act very much as a single gas, which we commonly known as 'air'. The horizontal variation in the per cent share of these components of atmosphere has less variation as compare to vertical variation.

1.1. Gases

The main component gases of dry air are listed in Table 1. It should be noticed that nitrogen and oxygen together make up about 99 per cent of the volume, and that the other one per cent is chiefly Argon. Other gases such as Methane, Ozone are found in traces.

Constituent gas	Percentage volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.036
Neon	0.002
Helium	0.0005
Krypton	0.001
Xenon	0.00009
Hydrogen	0.00005

Table 1 – Average composition of dry air

Nitrogen does not easily enter into chemical union with other substances, but it is an important constituent of many organic compounds. Atmospheric nitrogen acts as a reservoir pool for nitrogen cycle. Nitrogen fixing organisms such as Rhizobium use free nitrogen of the atmosphere to convert it to usable form such as nitrates.

Oxygen is an important part of the atmosphere and is necessary to sustain terrestrial life as it is used in respiration. It is also used in combustion. It is believed that first oceans got saturated with oxygen and after that it started flowing into the atmosphere. Source of oxygen is plants with photosynthesis. Mountain climbers sometime require oxygen cylinders due to low concentration of oxygen at greater heights.

Argon is an inert gas. Argon extracted from the atmosphere is used for industrial purposes such as bulb manufacturing, welding equipments etc.

Carbon dioxide is released from the earth's interior, respiration, soil processes, deforestation, and combustion. Carbon dioxide is meteorologically a very important gas as it is transparent to the incoming solar radiation but opaque to outgoing terrestrial radiations. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the greenhouse effect.

Ozone is another important constituent of atmosphere. Ozone is made up of three atoms of oxygen when three molecules of oxygen gas convert into two molecules of Ozone using sun's high energy radiations. It is found in very small quantity (0.00005 per cent by volume) in the upper atmosphere, 15-50km above the earth's surface. Maximum concentration is found at the height of 15-35km. It protects the life on earth by absorbing ultra-violet rays radiating from the sun and prevents them from reaching the surface of the earth. In the absence of the ozone layer, high energy ultra-violet rays would have made earth unfit for habitation.

Student Notes:

1.2. Water Vapour

Table 1 refers to the average constituents of dry air. The lower parts of the atmosphere, up to 10-15 km, contain in addition water vapour, which is largely derived by evaporation from water bodies on the earth and by transpiration from plants. It is one of the 'most variable' components of the atmosphere. It decreases with altitude and not found at great heights because mixing and turbulence is not sufficiently strong to carry it up very far. In the warm and wet tropics, it may account for 4% of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than 1% of the air. Water vapour also decreases from the equator towards the poles.

Water vapour, too, is capable of absorbing heat and acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour is fundamental to many essential meteorological processes, such as rain-making. It is source of all clouds and precipitation. In the condensation process, vast amount of energy is released in form latent heat of condensation, ultimate driving force for most of the storms.

The actual amount of the water vapour present in the atmosphere is known as the **absolute humidity**. It is the weight of water vapour per unit volume of air. The absolute humidity differs from place to place on the surface of the earth. The percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature is known as the **relative humidity**. It is greater over the oceans and least over the continents. The air containing moisture to its full capacity at a given temperature is said to be **saturated**. Moisture holding capacity of the air is directly proportional to its temperature.

1.3. Dust Particles

The atmosphere also carries in suspension variable amounts of solid material in the lower layers of atmosphere. Convectional air currents may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in comparison to equatorial and polar regions. The term 'dust particles' includes all the solid particles present in the air except the gases and water vapour. It includes sea salts, fine soil, smoke-soot, ash, pollen, dust and disintegrated particles of meteors and originates from different sources.

smaag2@gmail.com

Dust particles provide the necessary nuclei on which water vapour can condense to form **clouds** and eventually precipitation. Condensation on these fine particles near the surface causes formation of **fog**. Large amount of dust tend to make the atmosphere hazy, and in extreme cases, where pollution is involved, dust particles can be positively harmful to health. By the process of **scattering**, dust particles contribute to the varied colours of red and orange at sunrise and sunset. The blue colour of the sky is also due to selective scattering by dust particles. The duration of twilight is also affected by the presence of these dust particles in the air.

1.4. Changes in the Atmosphere

Since industrial revolution, human activities have caused various changes into earth's atmosphere. We look at four very different atmospheric changes here.

Student Notes:

1.4.1. Air Pollution

Air pollution is the introduction of chemicals, particulates, biological materials or other harmful materials into the earth's atmosphere. These pollutants can be solid particles, liquid, and gases. Major pollutants are carbon oxides (CO_x), Nitrous Oxides (NO_x), Volatile organic compounds, particulates, sulphur dioxide, Toxic metals such as lead and mercury etc. Many of these are new compounds in the atmosphere which have changed the composition to negligible level but their presence throws challenges for humans. It causes damage, disease and death of humans and other living organisms or infrastructure. Air pollution causes respiratory infections, heart disease, and lung cancer etc. Major sources of these pollutants involves vehicular emission, power plants, industries, waste incinerators, agricultural practices, fumes, waste deposition etc.

Acid rain is the result of increased pollutants in the atmosphere. Rain water is naturally acidic due to atmospheric carbon dioxide which makes weak acid with rain water. Acid rain is caused by other gases released when fossil fuels are burnt. Two gases are the main culprits: **Sulphur dioxide** (forms sulphuric acid) and **Nitrogen oxides** (forms nitric acid). These increase the acidity of rainwater. The dilute acid falls to ground as acid rain which causes the following problems:

- Lakes become acidic and plants and fishes die as a result
- Tree growth is damaged, whole forests can die as a result
- Acid rain attacks metal structures and also buildings made of limestone

1.4.2. Global Warming

In very cold regions, glass houses are constructed for growing vegetables. These are known as **Greenhouses**. In these houses, glass covering allows short wavelength sunrays to enter but does not allow it to be radiated back to atmosphere. At atmospheric level, the greenhouse gases do not allow thermal radiation from a planetary surface (long waves) to pass and re-radiate them in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average surface temperature above what it would be in the absence of the gases. Major **greenhouse gases** are: carbon dioxide, methane, nitrous oxide, water vapour and Ozone.

With increase in the percentage of greenhouse gases, it is believed that temperature of earth is increasing dramatically. This is termed as global warming. Main contributor for this rise in temperature is **carbon dioxide (**CO_2**)**. The scientists have observed that CO_2 is largely contributed from burning of fossil fuels. The burning of fossil fuels and extensive clearing of native forests has contributed to a 40% increase in the atmospheric concentration of carbon dioxide, from 280 to 392 parts per million (ppm) in 2012.

Other gases such as Methane, water vapour, Nitrous oxide, Hydroflurocarbons (HFCs), Perflurocarbons (PFCs), Sulphur hexafluoride (SF_6) are playing considerable role in global warming. SF_6, PFCs etc. are present only in traces but their life span and greenhouse potency is very high. For instance, SF_6 is the most potent greenhouse gas in existence. With a global warming potential 23,900 times greater than carbon dioxide, one pound of SF_6 has the same global warming impact of 11 tons of carbon dioxide. It is also very persistent in the atmosphere with a lifetime of 3,200 years. SF_6 is widely used in circuit breakers, gas-insulated substations, and other switchgear to manage the high voltages.

Global warming would adversely affect the ecosystem on the Earth and the weather patterns around the world in the following ways:

- Melting of ice at polar regions and glaciers on high mountains. It would increase the sea level.
- Many climatic and weather events are expected to change drastically. Recent examples of extreme temperature, precipitation are associated with the global warming.

Student Notes:

- Global warming would change the habitats of organism. Those unable to adjust to these rapid changes may not be able to survive.

1.4.3. Ozone Depletion

The release of chemical compounds such as Chlorofluorocarbons (CFCs) from earth into the atmosphere poses a serious threat to ozone layer. CFCs are synthetic industrial chemical compounds containing chlorine, fluorine, and carbon atoms. CFCs are widely used as cooling fluids in the refrigerating systems. CFCs when released in air are transported by the vertical atmospheric circulation and reach the ozone layer in the stratosphere. The CFCs absorb the ultra-violet radiation and decompose to chlorine oxide molecules and can convert the ozone into ordinary oxygen molecules. A study of the ozone layer based on data provided by the satellites, showed a substantial decline in the total ozone gas. The scientists have discovered a hole in the ozone layer over the continent of Antarctica. CFCs are transported to Antarctica region by atmospheric wind systems. Here, CFCs get trapped in the Antarctica cold air by polar vortex[1] and deplete ozone layer.

1.4.4. Ozone Pollution

Ozone occurs at ground-level naturally in low concentrations. The two major sources of natural ground-level ozone are hydrocarbons, which are released by plants and soil, and small amounts of stratospheric ozone, which occasionally migrate down to the earth's surface. Neither of these sources contributes enough ozone to be considered a threat to the health of humans or the environment. But the ozone that is a byproduct of certain human activities does become a problem at ground level. With more automobiles, and more industry, there's more ozone in the lower atmosphere. Tropospheric ozone is formed by the interaction of sunlight, particularly ultraviolet light, with hydrocarbons and nitrogen oxides, which are emitted by automobiles, gasoline vapors, fossil fuel power plants, refineries, and certain other industries.

High ozone levels usually occur during the warm, sunny summer months (from May through September). Typically, ozone levels reach their peak in mid to late afternoon. A hot, sunny, still day is the perfect environment for ozone pollution production.

Near the earth's surface, ozone molecules damages forests and crops; destroys nylon, rubber, and other materials; and injures or destroys living tissue. It is a particular threat to people who already have respiratory problems.

sinagn27@gmail.com

2. Structure of the Atmosphere

It is the lower part of the atmosphere which has interested man from times immemorial. But from the beginning of the 20th century, when aeroplanes and radio waves were invented, the knowledge of the upper part of the atmosphere became rather essential. The earth's atmosphere consists of zones or layers arranged like spherical shells according to altitude above earth's surface. Each zone has a unique set of characteristics. For the most part the layers are not at all sharply defined, and their boundaries are arbitrarily established. The density, temperature and composition of the atmosphere varies with altitude. Density is highest near the surface of the earth and decreases with increasing altitude. The temperature changes differently in different layers. Heavy gases such as Oxygen exist near the surface. At greater heights, the lightest gases do in fact separate out, forming several concentric gas envelopes around the Earth.

The atmosphere is divided into the five different layers depending upon the **temperature condition**. They are: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

[1] The stratospheric polar vortex is a large-scale region of air that is contained by a strong west-to-east jet stream that circles the polar region.

Student Notes:

2.1. Troposphere

Troposphere is the lowermost layer of the atmosphere. Its average height is 13 km and extends roughly to a height of 8 km near the poles and about 18 km at the equator. It is thickest at the equator because strong convection currents transport heat to such great heights. It contains 75 per cent of the total gaseous mass of the atmosphere. This layer contains dust particles and water vapour also. The temperature in this layer decreases at the rate of 1°C for every 165m of height (or at a mean rate of 6.5 degree C /km).The decrease occurs because air is compressible and its density decreases with height allowing rising air to expand and thereby cool. It is interesting to note that the lowest temperature in the entire troposphere is found over the equator and not at the poles. The air temperature at the top of troposphere is about minus 80^0C over the equator and about minus 45^0C over the poles.

Word 'troposphere' is derived from the Greek word 'tropos' meaning 'mixing'. Troposphere is marked by turbulence and eddies. It is also called the convective region, for all the convective cease at the upper limit of the troposphere. All changes in climate and weather take place in this layer. Clouds formation, thunderstorms etc. occur in this layer. Wind velocity increase with height and attain the maximum at the top.

At the top of the troposphere there is a shallow layer separating it from the next thermal layer of the atmosphere. This shallow layer is known as the **tropopause**. Tropopause has its greatest height near the equator. In the middle and high latitudes, the height of the tropopause varies according to seasons. For example, at latitudes 45N&S the average height of the tropopause in January is about 12.5 km while in July it becomes 15 km.

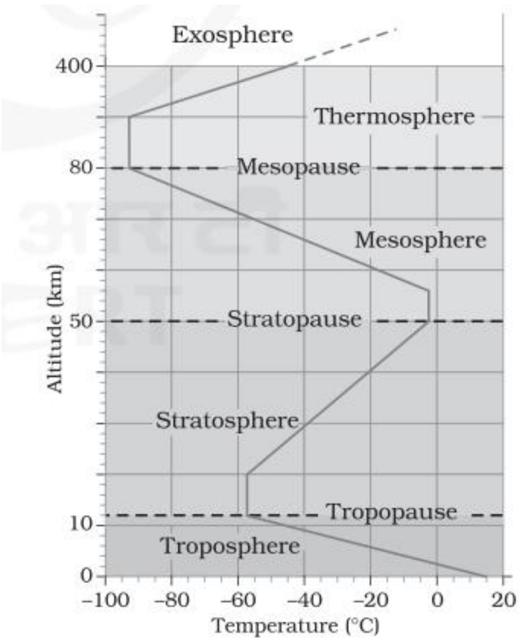

Figure 1 – Structure of atmosphere on the basis of temperature

2.2. Stratosphere

The stratosphere is found above the tropopause and extends up to a height of 50 km. The lower stratosphere is isothermal in character. This temperature region is found to be present up to about 20 km and after this temperature rises. In summers, the increase in the stratospheric temperature with latitudes continues upto the poles. But during the winter season the stratosphere is warmest between latitudes 50^0 – 60^0. Onwards, temperature decreases again. The thickness of the stratosphere is highest at the poles.

This layer is free of any clouds of weather changes. It is an ideal place for flying of big planes. At about 50 km, temperature begins to fall. This is end of stratosphere, and is called the **stratopause**.

Student Notes:

The portion of the stratosphere having maximum concentration of ozone is called **ozonosphere**. The rise in temperature with height in stratosphere is because of the absorption of ultra-violet by the ozone gas. Details of ozone gas are already discussed above.

2.3. Mesosphere

The mesosphere lies above the stratopause, and extends up to a height of 80 km from 50km. In this layer, once again, temperature starts decreasing with the increase in altitude and reaches up to minus 100° C at the height of 80 km. It is the coldest layer in the atmosphere. The exact upper and lower boundaries of the mesosphere vary with latitude and with season, but the lower boundary of the mesosphere is usually located at heights of about 50 km above the Earth's surface and the mesopause is usually at heights near 100 km. In summers, the height of mesosphere descends down to 85km at middle and high latitudes. The upper limit of mesosphere is known as the **mesopause**.

2.4. Thermosphere

The thermosphere is located between 80 and 400 km above the mesopause. In this layer the temperature increases rapidly with increase in height. It is estimated that the temperature reaches 1500 degree C. The air is so thin that a small increase in energy can cause a large increase in temperature. Because of the thin air in the thermosphere, scientists can't measure the temperature directly. They measure the density of the air by how much drag it puts on satellites and then use the density to find the temperature.

The Earth's thermosphere also includes the region called the **ionosphere.** It contains electrically charged particles known as ions, and hence, it is known as ionosphere. Ionization of molecules and atoms occurs mainly as a result of ultra-violet, x-rays and gamma radiations. The high temperatures in the thermosphere also cause molecules to ionize. This is why an ionosphere and thermosphere can overlap.

Radio waves transmitted from the earth are reflected back to the earth by this layer. This layer also protects the earth from meteorites and remains of abandoned satellites. They are burned and reduced to ashes due to high temperature as they enter this layer.

Ionosphere also includes some parts of mesosphere and exosphere. Ionosphere is further divided into different layers, namely D-layer (upto 99km), E-layer (90-130km), Sporadic E-Layer, F1 & F2 layer (150-380km) and G-layer (>400km). Layers such as D-layer, E-layer, exist only during day time and vanishes as soon as sun sets.

sihagn27@gmail.com

2.5. Exosphere

The uppermost layer of the atmosphere above the thermosphere is known as the exosphere. This is the highest layer but very little is known about it. It lies beyond 400km to 1000s of kms where it merges with outer space. At such great height the density of atoms is extremely low. It is largely home to Helium and Hydrogen. Temperature increases with height and may cross 5000^0C.

Stratification of atmosphere can also be done on the basis of **chemical composition**. According to International Space Symposium 1962, atmosphere can be divided into two broad layers, namely **Homosphere** and **Heterosphere**. Former is the lower layer and extends up to 88km from the earth’s surface. The proportions of the component gases are uniform at different levels. The three main-sub divisions of Homosphere are troposphere, stratosphere and mesosphere. Heterosphere extends beyond 88 km to more than 3500 km. Here, atmosphere is not uniform in its composition. It is also referred to as thermosphere as temperature rises with height. In this sphere, gases are arranged in roughly spherical shells. The innermost of these is a Nitrogen layer, found at heights between 100 and 200km; this is succeeded in turn by layers of Oxygen (200-1100km) and Helium (1100-3500km); and finally beyond 3500km only Hydrogen exists.

Student Notes:

3. Previous Years' UPSC Prelims Questions

1. Consider the following which can be found in the ambient atmospheres: (2010)
1. Soot
2. Sulphur hexafluoride
3. Water vapour

Which of the above contribute to the warming up of the atmosphere?
(a) 1 and 2 only
(b) 3 only
(c) 2 and 3 only
(d) 1, 2 and 3

Answer: D

2. The jet aircrafts fly very easily and smoothly in the lower stratosphere. What could be the appropriate explanation? (2011)
1. There are no clouds or water vapour in the lower stratosphere.
2. There are no vertical winds in the lower stratosphere.

Which of the statements given above is/are correct in this context?
(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

Answer: D

4. Previous Years UPSC Mains Questions

1. ***How does the cryosphere affect global climate? (150 words) (2017)***
2. ***Previous Years' Vision IAS Test Series Questions***
3. ***'Ozone depletion and the formation of Polar Ozone Holes doesn't lead to a further warming of the troposphere, but to a slight cooling.' Explain. (2014)***
4. ***It has been observed that the ozone hole develops over Antarctica, and not over manufacturing centers where chlorofluorocarbons are released prodigiously. How can you explain this phenomenon? Examine the possible health and environmental impacts of ozone depletion. (2015)***
5. ***What do you mean by bad ozone and what are the causes for its formation? Explain the reasons for the depletion of ozone, with special reference to formation of Ozone hole over Antarctica. (2017)***

sihag21@gmail.com

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INSOLATION, EARTH'S HEAT BALANCE, DIFFERENT ATMOSPHERIC CIRCULATIONS – GLOBAL WINDS, CYCLONES

Student Notes:

Contents

sihagn27@gmail.com

Student Notes:

sihagn27@gmail.com

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1. Insolation

Student Notes:

The earth's atmosphere is very much a **<u>dynamic</u>** entity. Large volumes of air are continually being moved both up and down and across the face of the Earth. As a proof, we feel air when it is in motion. There must be some energy involved here. It needs to be understood that the atmosphere is not a closed system. It is in contact with both the earth and with space, and receives energy from both directions. However, Earth itself directly contributes only a negligible amount of energy to the atmosphere, and its main role is to reflect energy from elsewhere. The ultimate sole source of atmospheric energy is in fact **<u>heat and light received through space from the Sun</u>**. This energy is known as **solar insolation.**

The Earth receives only a tiny fraction of the total amount of Sun's radiations. Only **two billionths** or two units of energy out of 1,00,00,00,000 units of energy radiated by the sun reaches the earth's surface due to its small size and great distance from the Sun. The unit of measurements of this energy is **Langley** (Ly). On an average the earth receives 1.94 calories per sq. cm per minute (2 Langley) at the top of its atmosphere.

1.1. Factors Influencing Insolation

The insolation received on earth is not same everywhere. The amount and the intensity of insolation vary from place to place, during a day, in a season and in a year. The factors that cause these variations in insolation are:

1. **Revolution of earth around sun:** earth revolves in an elliptical orbit around the sun. Thus, distance between the Sun and the earth vary. The earth is farthest from the sun on 4th July. This position of the earth is called **aphelion**. On 3rd January, the earth is the nearest to the sun. This position is called **perihelion**. Therefore, the <u>annual insolation received by the earth at perihelion is slightly more than the amount received at aphelion</u>. However, the effect of this variation in the solar output is masked by other factors like the distribution of land and sea and the atmospheric circulation. Hence, this variation in the insolation does not have great effect on daily weather changes on the surface of the earth.
2. **The rotation of earth on its axis:** earth rotates around its axis and makes an **angle of 66½** with the plane of its orbit round the sun. This particular characteristic of earth **has great amount of influence** on the amount of insolation received at different latitudes. The seasons in each hemisphere are dictated not by the closeness to the sun but by the axial tilt of the earth.
3. **The angle of inclination of the sun's rays:** Since the earth is round, the sun's rays strike the surface at different angles at different places. The angle formed by the sun's ray with the tangent of the earth's circle at a point is called **angle of incidence**. It influences the insolation in two ways as follows:
    - When the sun is almost overhead, the rays of the sun are vertical. The **angle of incidence** is large. Hence, they are concentrated in a smaller area, giving more amount of insolation at that place. If the sun's rays are oblique, angle of incidence is small and sun's rays have to heat up a greater area, resulting in less amount of insolation received there.

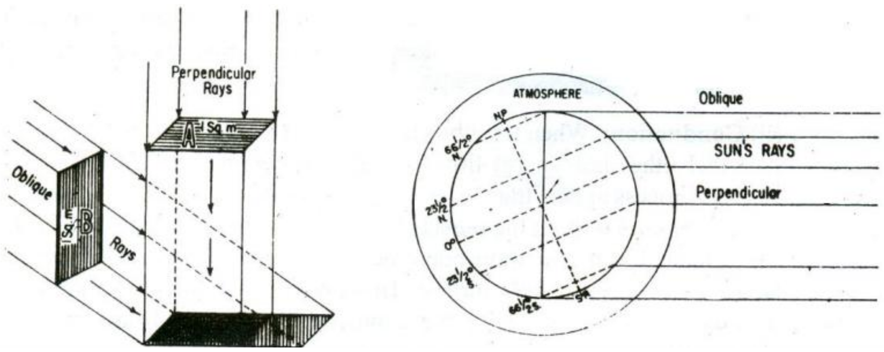

Figure 1 – effect of angle of inclination on Insolation

Student Notes:

- The sun’s rays with small angle **traverse more of the atmosphere** than rays striking at a large angle. Longer the path of sun’s rays, greater is the amount of reflection and absorption of heat by atmosphere. As a result the intensity of insolation at a place is less (figure 1). Angle of inclination of solar radiation depends on latitude of a place. The higher the latitude the less is the angle they make with the surface of the earth resulting in slant sun rays. Figure 1 show the winter Solstices in the Northern Hemisphere where angle of inclination is zero at 66 ½ N latitude.

Latitude	0°	20°	40°	60°	90°
December 22 (winter solstice)	12h 00m	10h 48m	9h 8m	5h 33m	0 m
June 21(summer Solstice)	12h	13h 12m	14h 52m	18h 27m	6 months

Table 1 – Length of Day on winter and summer Solstices in the Northern Hemisphere

4. **The length of the day:** the duration of day is controlled partly by latitude and partly by the season of the year. The amount of insolation has close relationship with the length of the day. It is because insolation is received only during the day. Other conditions remaining the same, the longer the days the greater is the amount of insolation. In summers, the days being longer the amount of insolation received is also more. As against this in winter the days are shorter the insolation received is also less. On account of the inclination of the earth on its axis at an angle of 23 ½^{0}, rotation and revolution, the duration of the day is not same everywhere on the earth. At the equator there is 12 hours day and night each throughout the year. As one moves towards poles duration of the days keeps on increasing or decreasing. It is why the maximum insolation is received in equatorial areas. Table 1 show the duration of day (in hours & minutes) on winter and summer solstices in the Northern hemisphere.
5. **The transparency of the atmosphere:** The earth’s atmosphere is more or less transparent to short wave solar radiation which has to pass through the atmosphere before striking the earth’s surface. The transparency depends upon cloud cover, its thickness, water vapour and solid particles, as they reflect, absorb or transmit insolation. High energy ultra-violet rays are absorbed by the **Ozone layer**. **Thick clouds** hinder the insolation to reach the earth while clear sky helps it to reach the surface. **Water vapour** absorbs insolation, resulting in less amount of insolation reaching the surface. Very **small-suspended particles** in the troposphere scatter visible spectrum both to the space and towards the earth surface.
6. **Solar variation:** It is the change in the amount of radiation emitted by the Sun. These variations have periodic components, the main one being the approximately 11-year sunspot cycle. **Sunspots** are temporary phenomena on the photosphere of the Sun that appear visibly as dark spots compared to surrounding regions. When there is an increase in sun spots it leads to increase[1] in the amount of solar radiation. But this change is almost negligible.

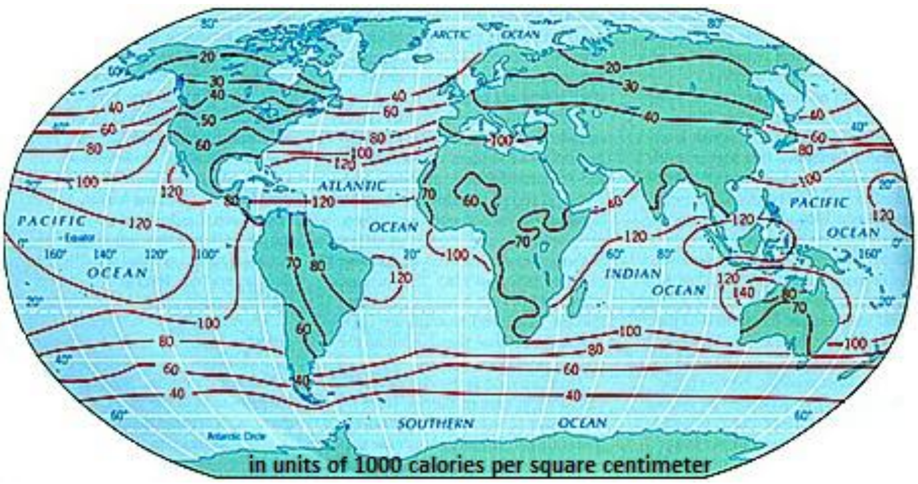

Figure 2 – average annual insolation on the surface of the earth

Student Notes:

7. **Topographical variations:** Earth does not have a featureless surface. The topographical variations are the major factors modifying the distribution of insolation. Variability in elevation, surface orientation (slope and aspect), and obstruction by surrounding topographic features creates strong local gradients of insolation. Similarly, in the northern hemisphere a south-facing slope (more open to sunlight and warm winds) will therefore generally be warmer and dryer due to higher levels of evapotranspiration than a north-facing slope.[1] This can be seen in the Swiss Alps, where farming is much more extensive on south-facing than on north-facing slopes. In the Himalayas, this effect can be seen to an extreme degree, with south-facing slopes being warm, wet and forested, and north-facing slopes cold, dry but much more heavily glaciated. Vegetation, human activities are more visible on the slopes where insolation is more relatively.

Under combined effect of the above discussed factors, the amount of total annual insolation received by different regions is different. The insolation received at the surface varies from about 320 Watt/m^2 in the tropics to about 70 Watt/m^2 in the poles. Maximum insolation is received over the subtropical deserts. **Equator receives comparatively less insolation than the tropics** due to presence of clouds. Generally, at the same latitude the insolation is more over the continent than over the oceans because more clouds over the oceans reflect sun rays back into space. **Isohels** are lines connecting points on the earth surface that receive equal amounts of sunshine. Isohels are more or less parallel to latitudes, especially in southern hemisphere (figure 2).

1.2. Heating and Cooling of the Atmosphere

Sun is the ultimate source of the atmospheric heat and energy, but its effect is not direct. For example, as we climb a mountain or ascend in the atmosphere, temperature become steadily lower, rather than higher, as we might expect. This is because the mechanism of heating the atmosphere in not simple. Four common types of energy transport are involved in heating of the atmosphere (figure 3). They are:

1. **Radiation:** it is the process where transference of heat is directly from space to atmosphere through electromagnetic radiations[2]. Photon[3] particles in the radiations collide with the air molecules in the atmosphere and transfer energy in this process. All objects whether hot or cold emit radiation continuously. The wavelength at which a body radiates depends on its surface temperature. The shorter the wavelength, higher the energy carried by the radiations The sun, having an extremely hot surface temperature, radiates fairly short wavelengths, part of which is felt as warmth, part of which are visible as light. The Earth, on the other hand, having a cool surface, re-radiates heat at much longer wavelengths. The re-radiate heat from the earth is called **Terrestrial radiation**. Atmosphere is transparent to short waves and opaque to long waves. The long wave radiation is absorbed by the atmospheric gases particularly by carbon dioxide and the other green house gases. Hence energy leaving the earth's surface heats up the atmosphere more than the incoming solar radiation.
2. **Conduction:** When two objects of unequal temperature come in contact with each other, heat energy flow from the warmer object to the cooler object and this process of heat transfer is known as conduction. The flow continues till temperature of both the objects becomes equal or the contact is broken. The conduction in the atmosphere occurs at zone of contact between the atmosphere and the earth's surface by terrestrial radiations. However, this is **a minor method** of heat transfer in terms of warming the atmosphere since it only affects the air close to the earth's surface. This is because of the fact that the air is poor conductor of heat[4].
3. **Convection:** In this process, energy is transferred through motion of molecules itself. The air in contact with the earth rises vertically on heating in the form of currents and further transmits the heat of the atmosphere. The heating of the air leads to its expansion. Its density decreases and it moves upwards. Continuous ascent of heated air creates vacuum

in the lower layers of the atmosphere. As a consequence, cooler air comes down to fill the vacuum. This process of vertical heating of the atmosphere is known as convection. The convective transfer of energy is confined only to the troposphere.

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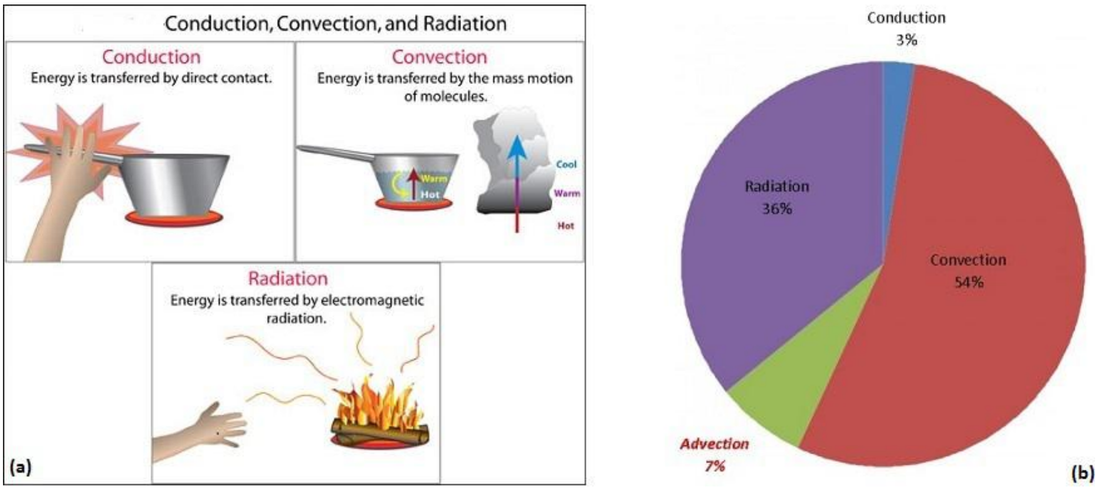

Figure 3 – (a) processes of heating and cooling of atmosphere and (b) per cent share of processes in heating up of atmosphere

4. **Advection:** The transfer of heat through horizontal movement of air is called advection. These winds take the characteristics of their source of origin with them. The temperature of a place will rise if it lies on the path of winds coming from warmer regions. The temperature will fall if the place lies on the path of the winds blowing from cold regions. Horizontal movement of the air is relatively more important than the vertical movement. In summer seasons, 'Loo' of north India is a hot wind and 'Sirocco' is also a hot wind carries heat of Sahara desert to Mediterranean regions. In middle latitudes, most of diurnal (day and night) variation in daily weather is caused by advection alone.

2. Heat Budget

The average temperature of the earth overall does not change in spite of continuous supply of sun rays. This is possible only when an equal amount of energy is sent back to space by the earth's system. In the way there is balance between incoming solar radiation and outgoing terrestrial radiations. This balance is known as the **heat budget of the earth**. Figure 4 depicts the heat budget of the planet earth. Consider that the insolation received at the top of the atmosphere is 100 per cent. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed. Only the remaining part reaches the earth surface.

Roughly **35 units** are **reflected** back to space even before reaching the earth's surface. The details of this reflected radiation are as under:

• Reflected from the top of clouds	-	27 units
• Reflected by ice-fields on earth	-	02 units
• Reflected by the atmosphere	-	06 units
Total	-	35 units

The reflected amount of radiation is called the **albedo of the earth**. The above given radiation does neither heat the atmosphere nor the earth's surface.

The remaining **65 units** are **absorbed** as:

• Absorbed by the atmosphere	-	14 units
• Absorbed by the earth	-	51 units (Scattered + direct radiation)
Total	-	65 units

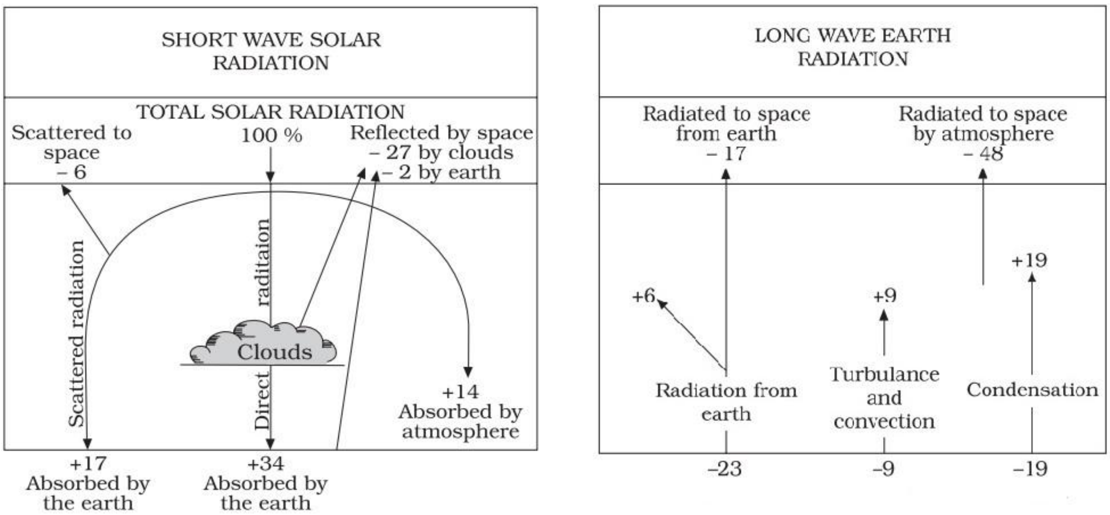

Figure 4 – Heat Budget of the Earth

Scattering takes place by gas molecules and dust particles. This takes place in all directions, some of it earthwards and some towards space. In overall, earth receives 51 units of radiation which in turn radiates back in the form of terrestrial radiation. The details of this reflected radiation are as under:

- Radiated to space directly - 17 units
- Radiated to atmosphere - 34 units

The details of 34 units radiation absorbed by atmosphere from terrestrial radiations are as under

- Absorbed directly - 06 units
- Absorbed through convection and turbulence - 09 units
- Absorbed through Latent heat of condensation[5] - 19 units

Total - 34 units

Total units absorbed by the atmosphere are 48 (14 units insolation + 34 units Terrestrial radiation). These are radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is:

- Radiated back by earth - 17 units
- Radiated back by atmosphere - 48 units

Total - 65 units

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These returning 65 units balance the total of 65 units received from the sun. This account of incoming and outgoing radiation always maintains the balance of heat on the surface of the earth. This is termed the heat budget or **heat balance** of the earth.

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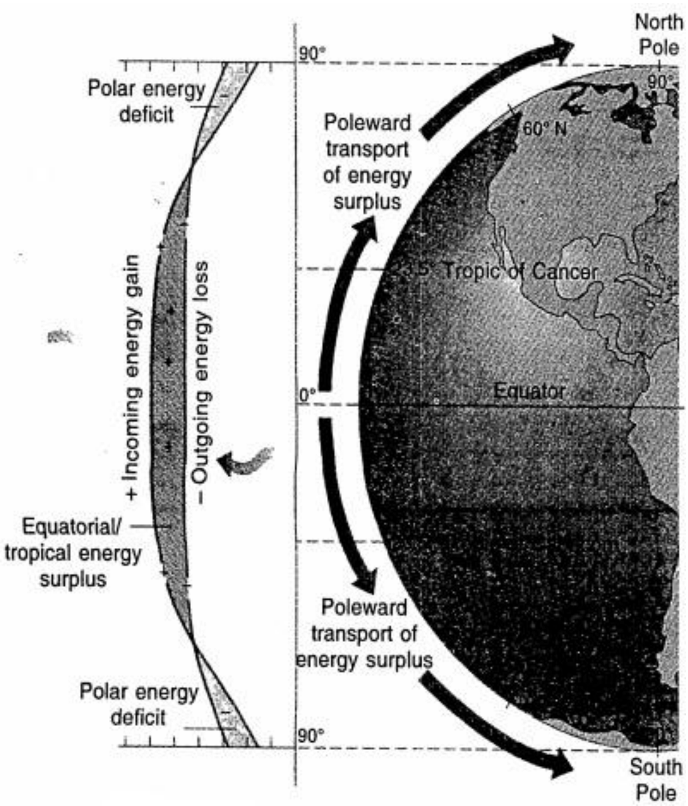

Figure 5 – heat energy budget by latitudes

2.1. Latitudinal Heat Balance

Although the earth as a whole maintains balance between incoming solar radiation and outgoing terrestrial radiation. But this is not true when we observe at different latitudes. Heat budget at latitudinal level is non-zero. As previously discussed, the amount of insolation received is directly related to latitudes. Some part of the earth has surplus radiation balance while the other part has deficit.

Figure 5 depicts the latitudinal variation in the net radiation balance of the earth — the atmosphere system. The figure shows that there is a surplus of net radiation balance between 40^0 N & S degrees and the regions near the poles have a deficit. This in theory should mean that tropical areas should get steadily warmers, and the Arctic and Antarctic even colder. But such is not the case. The surplus heat energy from the tropics is redistributed pole wards and as a result the tropics do not get progressively heated up due to the accumulation of excess heat or the high latitudes get permanently frozen due to excess deficit. This transfer of surplus heat from tropics to polar region is being performed by atmospheric and oceanic circulations such as winds and ocean currents. According to one estimate, about 75 per cent of heat transfer is carried out by atmospheric circulation and the remaining 25 per cent by the ocean currents. In fact, winds and ocean currents are produced due to imbalance of heat.

3. Temperature

The temperature is the measurement in degrees of how **hot (or cold) a thing (or a place) is**. The temperature of the atmosphere is not same across the Earth. It varies in spatial and temporal dimensions. The temperature of a place depends largely on the insolation received by that place. The interaction of insolation with the atmosphere and the earth's surface creates heat which is measured in terms of temperature. It is important to know about the temperature distribution over the surface of the earth to understand the weather, climate, vegetation zones, animal and human life etc. following factors determine the temperature of air at any place.

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1. **The latitude of the place:** Intensity of insolation depends on the latitude. The amount of insolation depends on the inclination of sun rays, which is further depends upon the latitude of the place. At the equator sun's rays fall directly overhead throughout the year. Away from the equator towards poles, the inclination of the Sun's rays increases. In conclusion, if other things remain the same, the temperature of air goes on decreasing from the equator towards poles.
2. **The altitude of the place:** the atmosphere is largely heated indirectly by re-radiated terrestrial radiation from the earth's surface. Therefore, the **lower layers of the atmosphere are comparatively warmer than the upper layers, even in the same latitudes**. For example, Ambala (30 21' N) and Shimla (31 6') are almost at the same latitude. But the average temperature of Shimla is much lower than the Ambala. It is because Ambala is located in plain at an altitude of 272 m above sea level whereas Shimla is located at an altitude of 2202 m above sea level. In other words, the temperature generally decreases with increasing height (figure 6(a)). The rate of decrease of temperature with height is termed as the **normal lapse rate**. It is 6.5°C per 1,000 m. That's why, the mountains, even in the equatorial region, have snow covered peaks, like Mt. Kilimanjaro, Africa.
3. **Distance from the Sea:** the land surface is heated at a faster rate than the water surface. Thus the temperature of the air over land and water surfaces is not the same at a given time. In summers, the sea water is cooler than the land and in winters, land is much colder than the sea water. The coastal areas experience the sea breezes during the daytime and the land breezes during the night time. This has a moderating influence on the temperature of the coastal areas. Against this the places in the interior, far away from the sea, have extreme climate. The daily range of temperature is less near the coastal area and it increases with increase in distance from the sea coast (figure 6(b)). The low daily range of temperature is the characteristic of marine climate. That's why, the people of Mumbai have hardly any idea of extremes of temperature.

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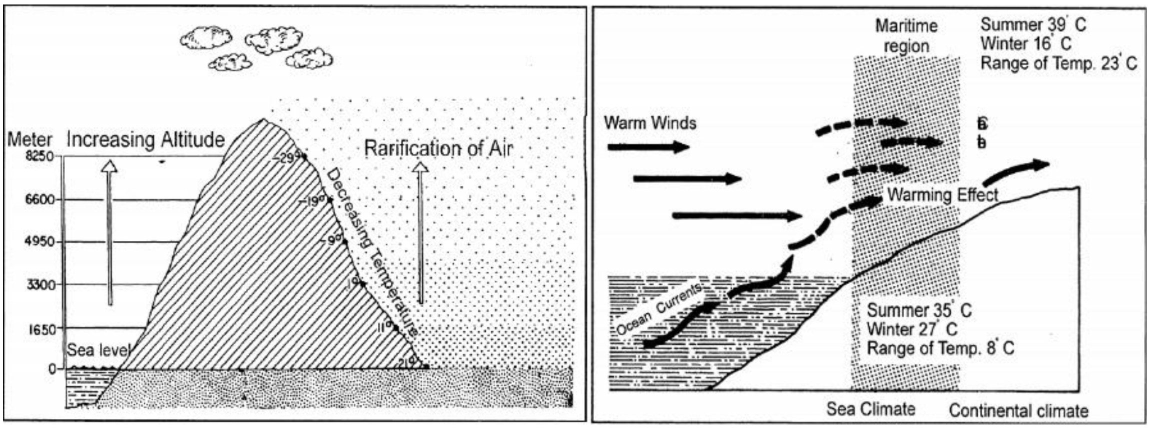

(a) – effect of altitude **(b) – maritime influence**

Figure 6 – effect of altitude & distance from sea on temperature

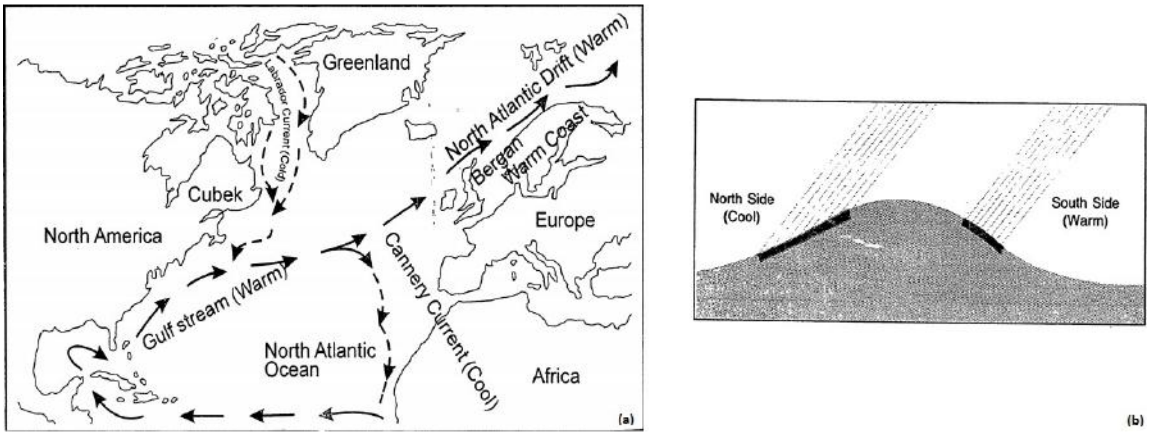

Figure 7 – (a) effect of ocean currents & (b) effect of slope on temperature

4. **Ocean Currents:** the effect of warm ocean currents and the cold ocean currents is limited to the adjoining coastal areas. The warm ocean currents flow along the eastern coast of tropical and sub-tropical regions and western coast of higher latitudes. On the other hand, cold ocean currents flow along the eastern coast of higher latitude and along the western coast of tropical and sub-tropical areas. The North Atlantic drift, an extension of Gulf Stream, warm the coastal districts of Western Europe (such as Norway) and British Isles keeping their ports ice-free (figure 7(a)).
5. **Air-mass circulation:** air masses in form of winds helps in the redistribution of temperature. The places, which come under the influence of warm air-masses experience higher temperature and the places that come under the influence of cold air masses experience low temperature. The effect of these winds is, however, limited to the period during which they blow. Local winds like cold Mistral of France considerably lower the temperature and Sirocco, a hot wind that blows from Sahara desert raises the temperature of Italy, Malta etc.

   The temperature rises at the time of arrival of temperate cyclones, while it falls sharply after their passage. Sometimes, local winds can cause sudden change in temperature. In northern India, 'Loo', a local hot wind, raise the temperature to such an extent that heat waves prolong for several days in continuation and many people die of sunstroke.

6. **Slope, Shelter and aspect:** slopes of a mountain facing the Sun experiences high temperature than the slopes on the leeward side due to more insolation (figure 7(b)). A steep slope experiences a more rapid change in temperature than a gentle one. Mountain ranges that have an east-west alignment like the Alps show a higher temperature on the south-facing 'sunny slope' than the north facing 'sheltered slope'. Consequently, there are more settlements in southern side and it is better utilized for agricultural and other purposes.

   The mountain ranges at certain places stop the cold winds and prevent the temperature from going down. This is found in areas where mountains lie in the direction facing the winds as in the case of Himalayas. **In the absence of Himalayas, winters of India would have been very different.**

7. **Nature of ground surface:** the nature of surface in terms of colour, vegetation, soil, land use, snow cover etc. affects the temperature of a place. In the tropical and subtropical deserts, the sandy surface record high temperature because they absorb most of the solar radiations. Snow has very high **albedo**[6] and thus, reflects much of the insolation without absorption. Thick vegetation (such as Amazon forest) cuts off much of the in-coming insolation and in many places sunlight never reaches the ground. It is cool in the jungle and its shade temperature is a few degrees lower than that of open spaces in corresponding latitudes. **Light soils reflect more heat than darker soils**. Dry soils like sands are very sensitive to temperature changes, whereas wet soils, like clay retain much moisture and

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warm up more slowly. Urban areas have relatively higher temperature than the surrounding.

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3.1. Distribution of Temperature

The global distribution of temperature can well be understood by studying the **isotherms**. The Isotherms are lines joining places having equal temperature. As already discussed, latitudes have pronounced effect on the temperature, the isotherms are generally parallel to the latitude. The deviation from this general trend is more pronounced in January than in July, especially in the northern hemisphere. Figure 8 and 9 show the distribution of surface air temperature in the month of January and July. In the northern hemisphere the land surface area is much larger than in the southern hemisphere. Hence, the effects of land mass and the ocean currents are well pronounced. Following are the chief features of isotherms:

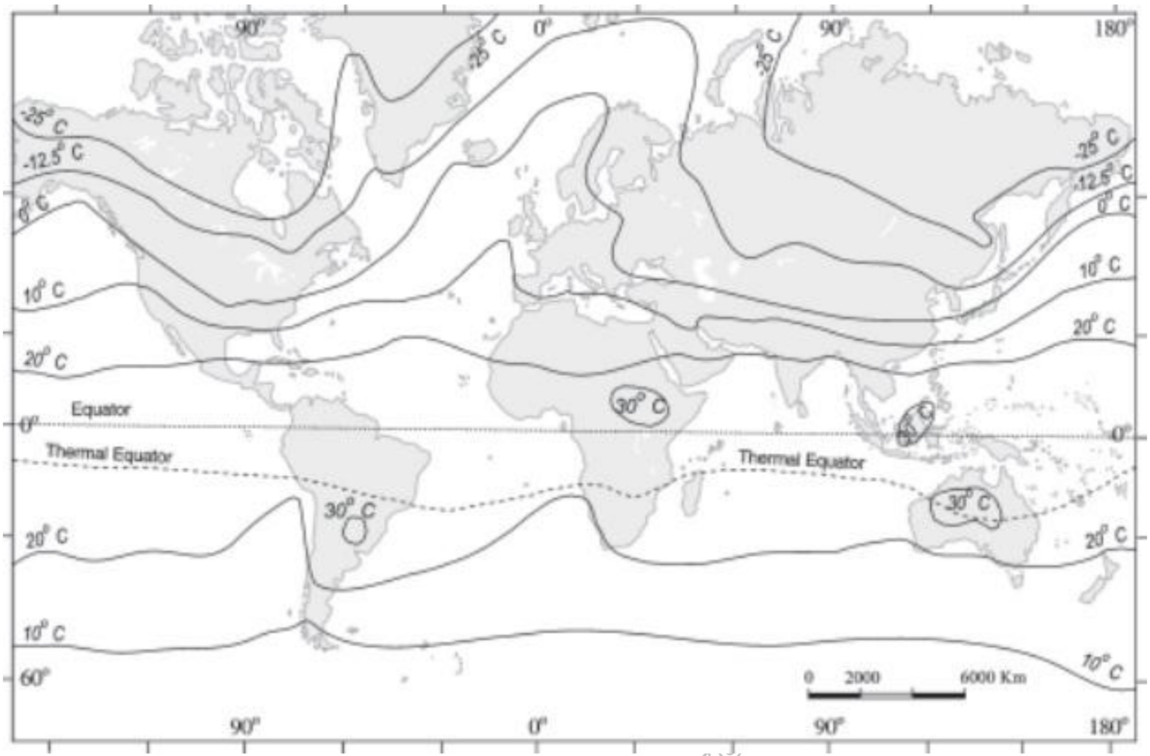

Figure 8 – isotherms in the month of January

- The isotherms are generally parallel to equator. They show successive temperature decrease towards the poles.
- The rate of change of temperature is indicated by the spacing between isotherms. Closely drawn isotherms indicate rapid change in temperature and vice-versa.
- The isotherms deviate to the north over the ocean and to the south over the continent in January. It is for two reasons – warm and cold ocean currents and difference between the temperature of land and water. For example, the presence of warm ocean currents, Gulf Stream and North Atlantic drift, make the Northern Atlantic Ocean warmer and the isotherms bend towards the north. Over the land the temperature decreases sharply and the isotherms bend towards south in Europe. The mean January temperature along 60° E longitude is minus 20° C both at 80° N and 50° N latitudes.
- In the southern hemisphere, the isotherms are more or less parallel to the latitudes due to less landmass and the variation in temperature is more gradual than in the northern hemisphere. The isotherm of 20° C, 10° C, and 0° C runs parallel to 35° S, 45° S and 60° S latitudes respectively.
- In July the isotherms generally run parallel to the latitude.

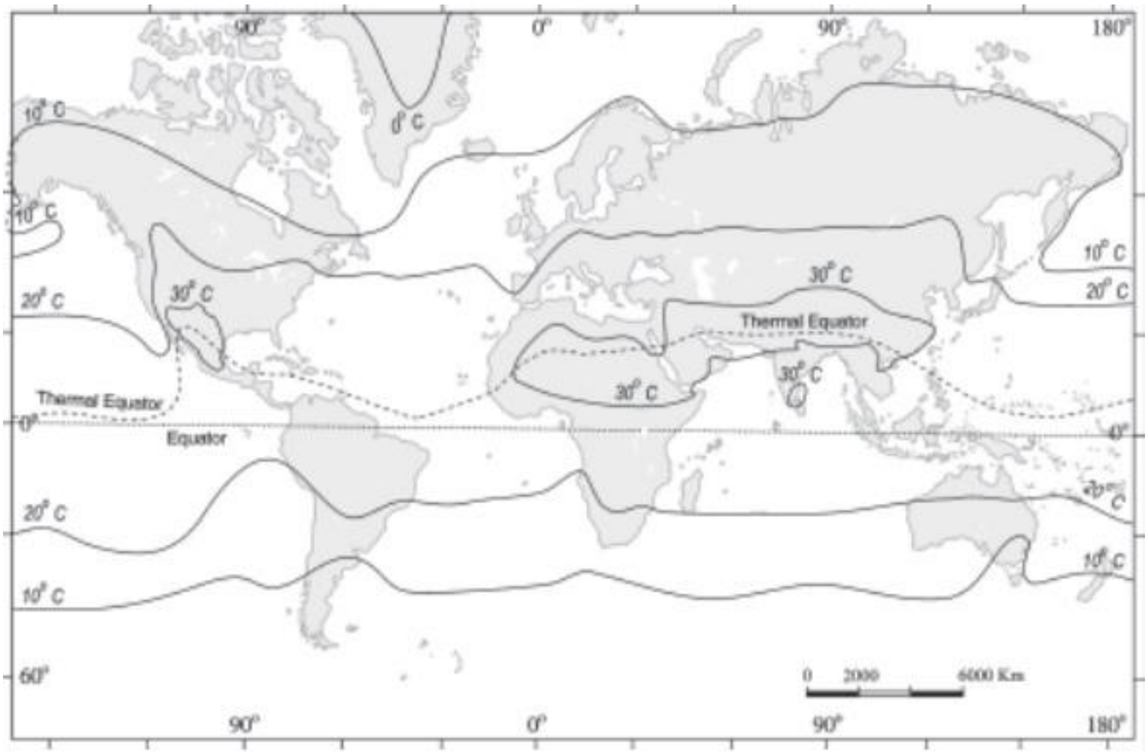

Figure 9 – isotherms in the month of July

3.2. Temperature Anomaly

The difference between the mean temperature of any place and the mean temperature of its parallels is known as temperature anomaly. On the map the lines joining the places of equal temperature anomaly are known as Isothermal anomaly lines.

Temperature anomaly could be positive or negative. Due to uneven distribution of land and water the maximum temperature anomalies are found in the Northern Hemisphere and minimum in the Southern Hemisphere.

3.3. Temperature Inversion

As already discussed, temperature decreases with increase in altitude. In normal conditions, as we go up, temperature decreases with normal lapse rate. It is 6.5°C per 1,000 m. Against this normal rule sometimes, instead of decreasing, temperature may rise with the height gained. The cooler air is nearer the earth and the warmer air is aloft. This rise of temperature with height is known as **Temperature inversion**. Temperature inversion takes place under certain specific conditions. These are discussed below:

- **Long winter nights:** if in winters the sky is clear during long nights, the terrestrial radiation is accelerated. The reason is that the land surface gets cooled fairly quickly. The bottom layer of atmosphere in contact with the ground is also cooled and the upper layer remains relatively warm.
- **Cloudless clear sky:** The clouds obstruct the terrestrial radiation. But this radiation does not face any obstacles for being reflected into space when the sky is clear. Therefore the ground is cooled quickly and so is the air in contact with it cooled.

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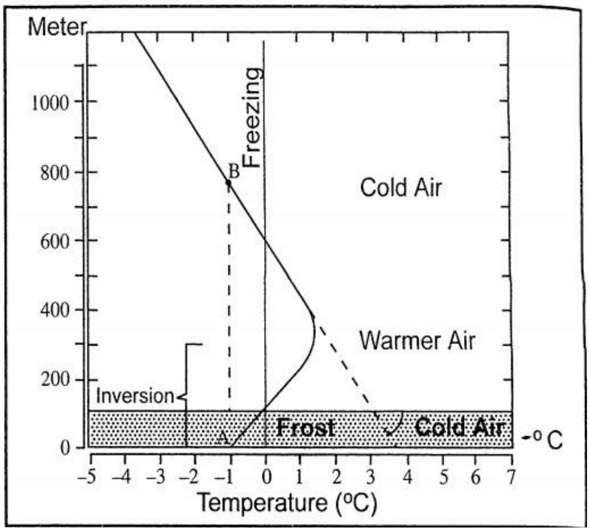

Figure 10 – temperature inversion

- **Dry air:** humid air absorbs the terrestrial radiation but dry air is no obstruction to terrestrial radiation and allows the radiation to escape into space.
- **Calm atmosphere:** the blowing of winds bring warm and cold air into contact. Under conditions of calm atmosphere the cold air stays put near the ground.
- **Ice covered surface:** in ice covered areas due to high albedo less insolation is received. During night due to terrestrial radiation most of the heat is lost to atmosphere and the surface is cooled. The air in contact with it is also cooled but the upper layer remains warm.

The stability of the night time **temperature inversion is usually destroyed soon after sunrise** as the sun's energy warms the ground, which warms the air in the inversion layer. The warmer, less dense air then rises, destroying the stability that characterizes the nightly inversion. **The phenomenon of inversion of temperature is especially observed in valleys**. During winters the mountain slopes cool very rapidly due to the quick radiation of heat. The air resting above them also becomes cold and its density increases. Hence, it moves down the slopes and settles down in the valleys. This air pushes the comparatively warmer air of valleys upwards and leads to the phenomenon of inversion of temperature. That is why, apple orchids in Himalayan region, tea garden of Darjeeling are found in upper slopes of the valleys.

sihagn27@gmail.com

Effect on Humans

- In cities, impurities present in the atmosphere such as smoke, dust particles and other pollutants do not go up in the air due to temperature inversion. They form dense fog near the earth's surface, especially in winters. It causes problems in breathing. Frost formed may be harmful for crops in fields.
- At some places, people lit fire or use big blowers to mix hot and cold air in order to drain off the area of the adverse conditions created by temperature inversion.
- In valleys people make terraced fields in the upper slopes and also settle down there.

3.4. Temperature Ranges

Temperature of a place varies within a day and also differs in different seasons. Range of temperature is the difference between maximum and minimum temperatures. There are two terms which are used to consider temperature ranges.

1. **Diurnal range of temperature:** the daily pattern of temperature change that we normally experience illustrates energy changes on a small time scale. On a calm day with little cloud, air temperatures usually reach their **minimum just before sunrise**, because the ground has been giving off long-wave radiation all through the night, gradually becoming colder and cooling the air above by conduction. With sunrise, temperature of the ground begins to

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rise. Maximum insolation receives at midday. But the **peak of air temperature is usually about 2:00 PM**. After sun-set, the air initially remains fairly warm as it is still being heated by long-wave radiation from the ground, but this gradually expires. Desert areas typically have the greatest diurnal temperature variations while Low lying, humid areas typically have the least range.

2. **Annual average range of temperature:** it is the monthly range of temperature or the **difference between the average temperature of hottest month and average temperature of the coldest month** of the year. The annual range is lower in low latitudes and higher in high latitudes. In the same latitudes, it is higher over the continents and lower over the oceans and coastal regions. The highest annual range of temperature is more than 60° C over the north-eastern part of Eurasian continent. This is due to continentality. The least range of temperature, 3°C, is found between 20° S and 15° N.

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4. Atmospheric Circulation

Varying amount of insolation received by the earth causes differential heating of the earth and its atmosphere. Temperature difference thus produced account for the density differences in the air. Air expands when heated and gets compressed when cooled. This results in variations in the atmospheric pressure. The result is that it causes the movement of air from high pressure to low pressure, setting the air in three-dimensional motion on global scale. Air in horizontal motion is wind. Atmospheric pressure also determines when the air will rise or sink. The wind redistributes the heat and moisture across the planet, thereby, maintaining a constant temperature for the planet as a whole. The vertical rising of moist air cools it down to form the clouds and bring precipitation. There is, in fact, an intimate relationship between winds and pressure, and knowledge of pressure variations is a prerequisite to understanding air motion.

4.1. Atmospheric Pressure

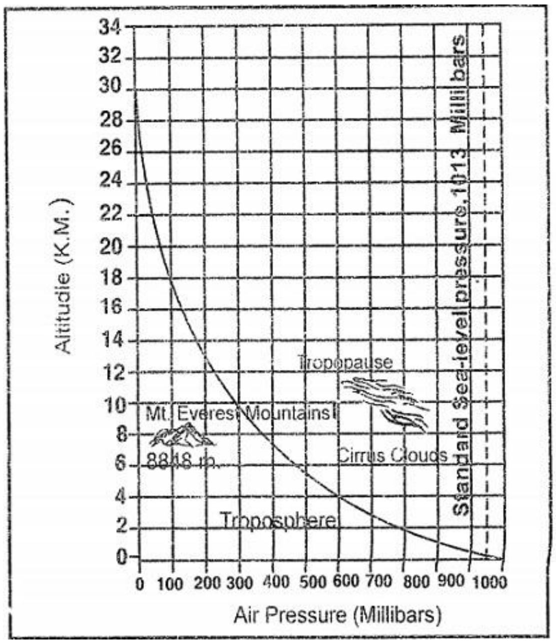
The atmosphere is held on the earth by the gravitational pull of the earth. A column of air exerts weight in terms of pressure on the surface of the earth. The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the **atmospheric pressure**. Pressure is normally measured in millibars or pascals and spatial variations of pressure are depicted on maps by means of **isobars**, which are lines connecting places having the same barometric pressure. The actual pressure at a given place and at a given time fluctuates and it generally ranges between 950 and 1050 millibars. Air pressure is measured with the help of a mercury **barometer** or the aneroid barometer.

siragnz7@gmail.com

The gradual change of pressure between different areas is known as the barometric slope or pressure gradient. The closer the isobars are together, the greater the pressure gradient; for example, widely spaced isobars indicate a weak pressure gradient.

4.2. Pressure Variations

In the lower atmosphere the pressure decreases rapidly with height with decrease in density of air. It does not always decrease at the same rate. But to make calculations simple, a decrease of about 1 mb for each 10 m increase in elevation is taken into consideration (figure 11). In spite of high vertical pressure gradient, we do not experience strong vertical air currents. This is possible because of equal and opposite gravitation force acting upon air.



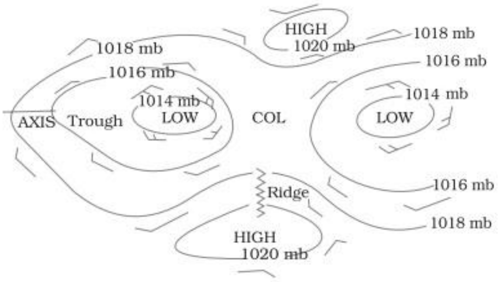


Figure 11 - vertical pressure variation **Figure 12 - Isobars, High pressure and Low pressure system**

The effects of low pressure are more clearly experienced by the people living in the hilly areas as compared to those who live in plains. In high mountainous areas rice takes more time to cook because low pressure reduces the boiling point of water. Breathing problem such as faintness and nose bleedings are also faced by many trekkers from outside in such areas because of low pressure conditions in which the air is thin and it has low amount of oxygen content.

Unlike vertical high pressure gradient, small horizontal pressure gradients are highly significant in terms of the wind direction and velocity. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison. Figure 12 shows the patterns of isobars corresponding to pressure systems. Low pressure system is enclosed by one or more isobars with the lowest pressure in the centre. High-pressure system is also enclosed by one or more isobars with the highest pressure in the centre. The terms '**high pressure**' and '**low pressure**' do not usually signify any particular absolute values, but are used relatively.

Sea-level pressure conditions over the globe for both January (figure 13) and July (figure 14) show some marked differences between the two hemispheres. The northern hemisphere tends to have the greater seasonal contrasts in its pressure distributions and the southern hemisphere exhibits much simpler average pressure patterns overall. These differences are largely related to the unequal distribution of land and sea between the two hemispheres. Ocean areas, which dominate the southern hemisphere, tend to be much more equable than continents in both temperature and pressure variations.

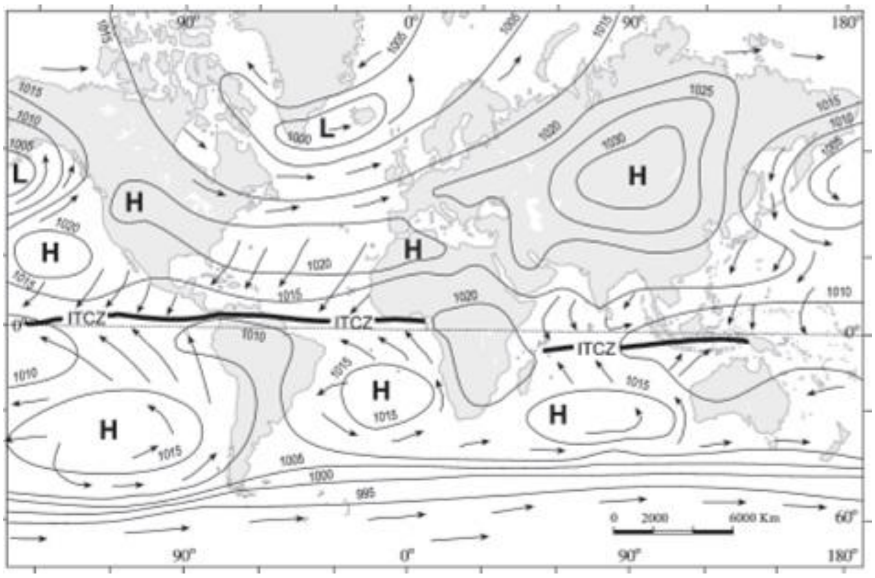


Figure 13 – Distribution of pressure (in mb) for January month

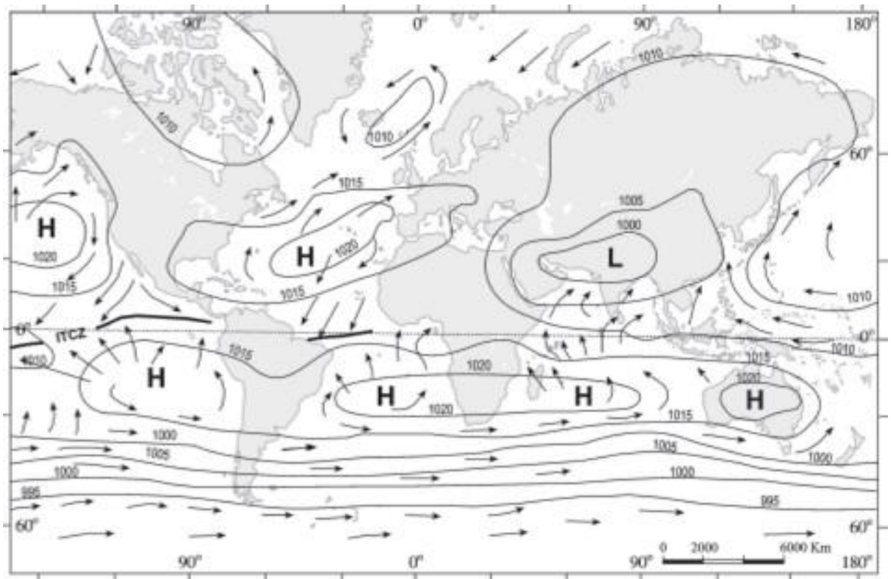


Figure 14 – Distribution of pressure (in mb) for July month

4.3. Forces Governing Air Movement

We know that the air pressure is unevenly distributed in the atmosphere and air attempts to balance this unevenness. Hence, it moves from high pressure areas to low pressure areas. Horizontal movement of air in response to difference in pressure is termed as **wind** while vertical or nearly vertical moving air is called **air current**. Both winds and air currents form the system of circulation in the atmosphere.

4.3.1. Pressure Gradient

The existence of pressure differentials in the atmosphere is the immediate primary force causing air movement. The rate of change of pressure with respect to distance is the **pressure gradient**. The pressure gradient force always acts down the pressure gradient, attempting to cause the general movement of air away from high-pressure towards low pressure areas. The force exerted is proportional to the steepness of the gradient (figure 15(a)). The gentler the pressure gradient slower is the speed of the wind and vice-versa.

If alone this force is exerted to the air, wind would have direction perpendicular to the isobars. However, there are other forces also which, in fact, make wind to flow more nearly parallel to the isobars.

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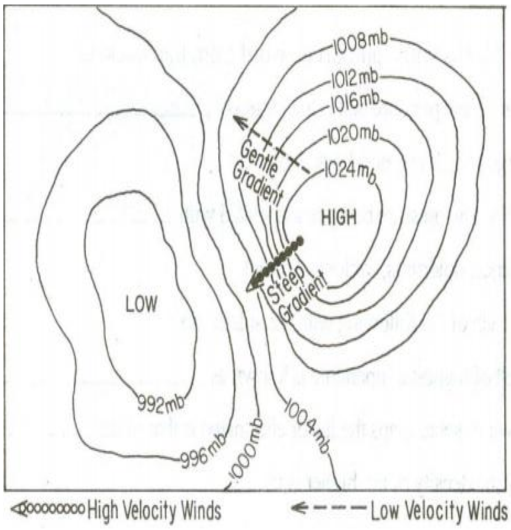
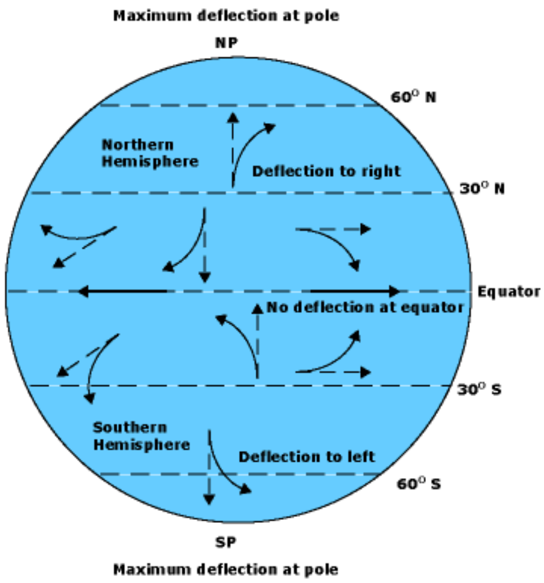
4.3.2. Coriolis Force

Winds do not cross the isobars at right angles as the pressure gradient directs them. They get deflected from their original paths. One of the most potent influences on wind direction is the deflection caused by the earth's rotation on its axis. This deflection is always to the right of the direction of motion in the northern hemisphere and to the left in the southern hemisphere (figure 15(b)). This influence is known as **Coriolis force**.





(a) Relationship between pressure **(b) Coriolis force under action gradient and speed of winds**

Figure 15 – forces governing air movement

The degree of the deflecting force varies with the speed of the moving air and with latitude. The faster the wind, the greater the effect of rotation can be. Similarly, the rate of deflection increases with the increasing distance from the Equator because the Coriolis force is zero at the Equator and maximum at Poles. It must be noted that it is an apparent or relative deflection. If viewed from outer space, objects moving across the face of the earth would not in fact appear to be deflected. In relation to star positions, they would travel in a straight line, while the earth rotates beneath them. The phenomenon affects all freely moving objects – air, ocean currents, rockets and projectiles etc. Thus, it is not actually any force. But it is simplest to accept that deflection is caused by a force.

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4.3.3. Centripetal Force

This force applies when the isobars are curved, as within cyclones. The fact that air is following a curved path means that in addition to the pressure gradient and the Coriolis force, a third force is acting centripetally, pulling air inwards. Wind which is in balance with these three forces is known as the **gradient wind**.

4.3.4. Frictional Force

It lessens the speed of the wind. It is greatest at the surface and its influence generally extends upto an elevation of 1 - 3 km. Over the sea surface the friction is minimal. By reducing speed of wind, it weakens the Coriolis force. This allows the pressure gradient to assert its greater strength by causing the air to flow more towards low pressure. Thus, the usual situation is that surface winds flow at a slight angle to the isobars (figure 16(b)).

4.4. Geostrophic Wind

The velocity and direction of the wind are the net result of the wind generating forces. The winds in the upper atmosphere, 2 - 3 km above the surface, are free from frictional effect of the surface and are controlled by the pressure gradient and the Coriolis force. At such height in the free atmosphere, winds generally blow at right angles to the pressure gradient: this indicate that the pressure gradient force is exactly balanced by the Coriolis force acting in a diametrically opposite direction. This sort of air motion is known as the **geostrophic wind** (figure 16(a)).

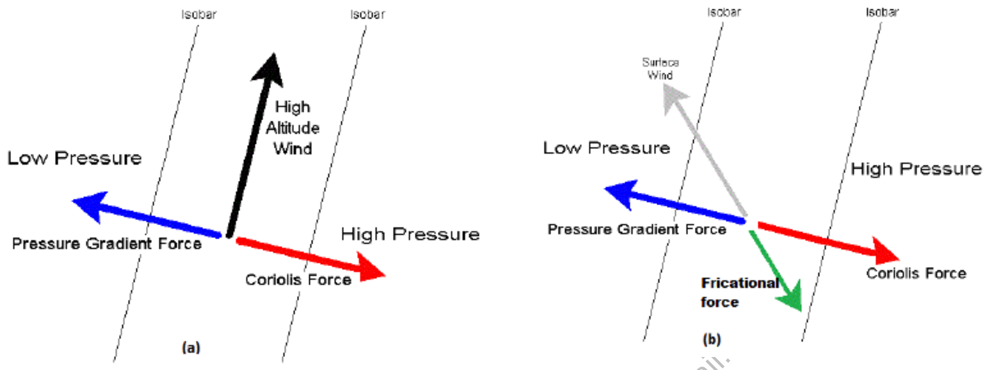

Figure 16 – forces governing air movement: (a) geostrophic balance between pressure gradient and Coriolis force; (b) the additional effect of frictional force on surface wind

Not all winds are exactly geostrophic. As pressure pattern change, the balance is upset, but the wind always strives to readjust itself until it obtains the new geostrophic speed.

4.5. Distribution of Pressure Belts

The horizontal distribution of air pressure across the latitudes is characterized by high or low pressure belts (figure 17(a)). These pressure belts are:

- **Equatorial low pressure belt:** This belt extends from equator to 10^0N and 10^0S latitudes. This belt is **thermally produced** due to heating by Sun.. Due to excessive heating horizontal movement of air is absent here and only vertical currents are experienced in this belt. Therefore, this belt is called **doldrums** (the zone of calm). . This belt is also known as-**Inter Tropical Convergence Zone (ITCZ)** because the trade winds flowing from sub tropical high pressure belts converge here.
- **Sub-tropical high pressure belt:** these extend roughly between 25^0 and 35^0 latitudes in both the Hemispheres. The existence of these pressure belts is due to the fact that the up rising air of the equatorial region is deflected towards poles due to the earth's rotation. After becoming cold and heavy, it descends in these regions and get piled up. This results in high pressure. Calm conditions with feeble and variable winds are found here.. In southern

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hemisphere, this belt is broken by small low-pressure areas in summer over Australia and South Africa. In northern hemisphere, the belt is more discontinuous by the presence of land masses, and high pressure occurs only over the ocean areas as discrete cells; these are termed the **Azores** and **Hawaiian cells** in the Atlantic and Pacific areas respectively.

These belts are also called **Horse latitudes**. In older days, vessels with cargo of horses passing through these belts found difficult in sailing under these calm conditions. They used to throw the horses in the sea in order to make the vessels lighter. In the upper atmosphere over this belt the upper level westerlies and anti-trade winds converge and set up descending currents in the atmosphere.

- **Sub-polar low pressure belt:** it extends along 60^0 latitudes (55^0-65^0) in both the hemisphere. These belts are not thermally induced instead the winds coming from the sub-tropics and the polar regions converge in this belt and rise upward. The great temperature contrast between the subtropical and the polar regions, gives rise to cyclonic storms in this belt. In Southern hemisphere, this low pressure belt is more pronounced due to vast presence of ocean and also referred as the **sub-antarctic low**. But in the northern hemisphere, there are large land masses along 60^0 latitudes which are very cold. Therefore, the pressures over these landmasses are increased. Thus, the continuity of the belt is broken.
- **Polar high pressure belt:** Because of low temperature, air compresses and its density increases. Hence, high pressure is found here throughout the year. This is more marked over the land area of the Antarctic continent than over the ocean of the North Pole. In northern hemisphere, high pressure is not centered at the pole, but it extends from Greenland to Islands situated in the northern part of Canada.

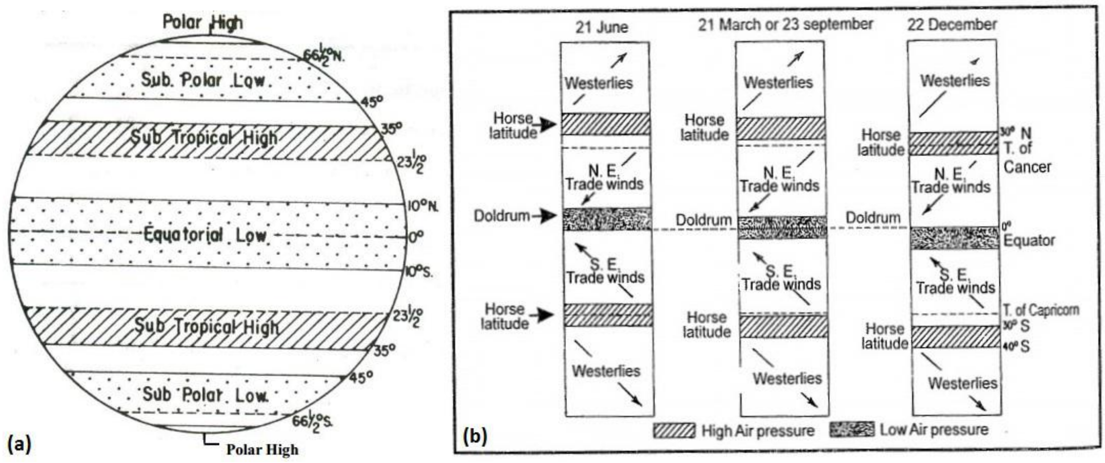

Figure 17 – (a) global pressure belts and (b) shifting of pressure belts

4.6. Shifting of Belts

Pressure belts are not fixed. The main cause of their formation is the uneven distribution of temperature on the surface of earth. Consequently, the pressure belts swing either to the north (in July) or the south (in December) of the equator by following the apparent annual migration of the sun (figure 17(b)). Sun's movement is recorded between tropic of Cancer and tropic of Capricorn. During the month of July, low pressure equatorial belt extends upto the tropic of Cancer in Asian region. While in January, it extends to latitudes 10^0-15^0 S. Most profound effect of shifting of belts is seen in the temperate region. Winds blowing from the Horse latitudes in the form of westerlies create unique climatic conditions in the temperate parts of the world, especially in the Mediterranean region.

4.7. General Circulation of the Atmosphere

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As discussed earlier that wind is the result of pressure gradient which is largely caused by differential heating of the earth. Winds in the atmosphere are neither unidirectional nor have a same pattern as we go up in the atmosphere. In fact, winds may change their direction and intensity multiple times within same day. Largely, wind movement in the atmosphere may be classified into three broad categories:

- **Primary circulation:** it includes planetary wind systems which are related to the general arrangement of pressure belts on the earth's surface. The pattern of the movement of the planetary winds is called the **general circulation of the atmosphere**. In fact, it is the primary circulation patterns which prepare the broad framework for the other circulation patterns.
- **Secondary circulation:** it consists of cyclones and anti-cyclones, monsoon
- **Tertiary circulation:** it includes all the local winds which are produced by local causes such as topographical features, sea influences etc. Their impact is visible only in a particular area.

4.7.1. Planetary Winds

Primary or planetary winds blow from high pressure belts to low pressure belts in the same direction throughout the year. They blow over vast area of continents and oceans. Trade winds, Westerlies and polar easterlies together form the planetary wind circulation (figure 18). These are described below:

- The air at the **Inter Tropical Convergence Zone (ITCZ)** rises because of convection caused by high insolation and a low pressure is created. The winds from the tropics converge at this low pressure zone. The converged air rises along up. It reaches the top of the troposphere up to an altitude of 14 km. and moves towards the poles. This causes accumulation of air at about 30^0 N and S. Part of the accumulated air sinks to the ground and forms a subtropical high. Another reason for sinking is the cooling of air when it reaches 30^0 N and S latitudes. Down below near the land surface the air flows towards the equator as the **easterlies[1] or tropical easterlies or trade winds**. Because of Coriolis force, their direction becomes north-east and south-east in northern and southern hemisphere respectively. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Thus, winds originated at ITCZ come back in a circular fashion. Such a cell in the tropics is called **Hadley Cell**.
- In the middle latitudes (30^0-60^0) the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high pressure belt. These winds are deflected due to coriolis force and become **westerly** in both the hemisphere. Deflected wind is called **westerlies**. These winds meet along the sub-polar low pressure belt to raise high in the troposphere. From here, air moves away in both directions – towards pole and equator. These winds start descending down above the sup-tropical high pressure belt and polar high pressure belt to form cells. These cells are called **Ferrel cell** and **Polar cell** respectively.

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[1] Wind direction is reported by the direction from which it originates. For example, a easterly wind blows from the east to the west.

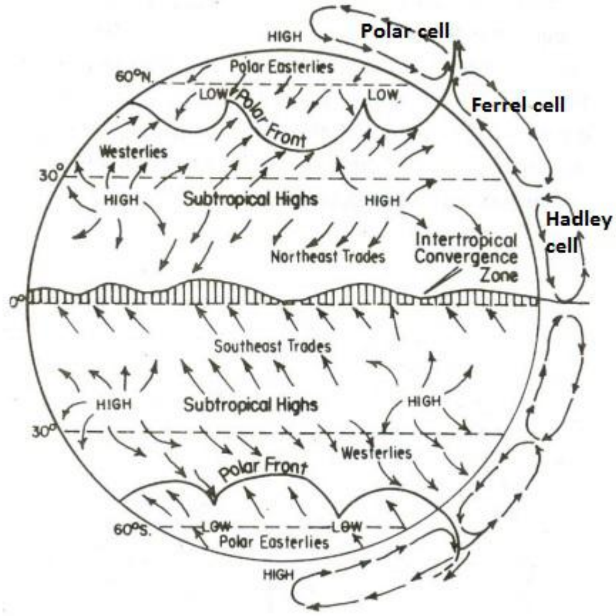

Figure 18 – Planetary winds

- The prevailing westerlies are relatively more variable than the trade winds both in direction and intensity. There are more frequent invasions of polar air masses along with the travelling cyclones and anti-cyclones. These moving cells of low and high pressures largely affect the movement of westerlies. The westerlies are stronger in the cold. In the southern hemisphere, westerlies are so powerful and persistent due to absence of land between 40^0-60^0 S that these are called '**roaring forties'**, '**furious fifties'** and '**screaming sixties'** along 40^0 S, 50^0 S and 60^0 S latitudes.
- Winds move away from polar high pressure to sub-polar low pressure along the surface of the earth in Polar cell. Their direction becomes easterlies due to coriolis force. These are called **polar easterlies**.
- Winds coming from the sub-tropical and the polar high belts converge to produce cyclonic storms or low pressure conditions. This zone of convergence is also known as **polar front (see fronts and cyclones)**.

4.8. Local Winds

Besides major wind systems of the earth's surface, there are certain types of winds which are produced by purely local factors and therefore, are called **local winds**. These local winds play a significant role in the weather and climate of a particular locality. Following is a brief account of some of the well-known local winds which are found in different parts of the world.

4.8.1. The Land and Sea Breezes

These winds are defined as the complete cycle of diurnal local winds occurring on sea coasts due to differences in the surface temperature of sea and adjacent land (figure 19). There is complete reversal of wind direction of these coastal winds. The land and sea breeze system is very shallow with average depth of 1-2km. Over lakes, the height of circulation is much less. Warm tropical areas, where intense solar heating persists throughout the year, experience stronger and regular breezes compare to higher latitudes. Details of land and sea breezes are given in table 2.

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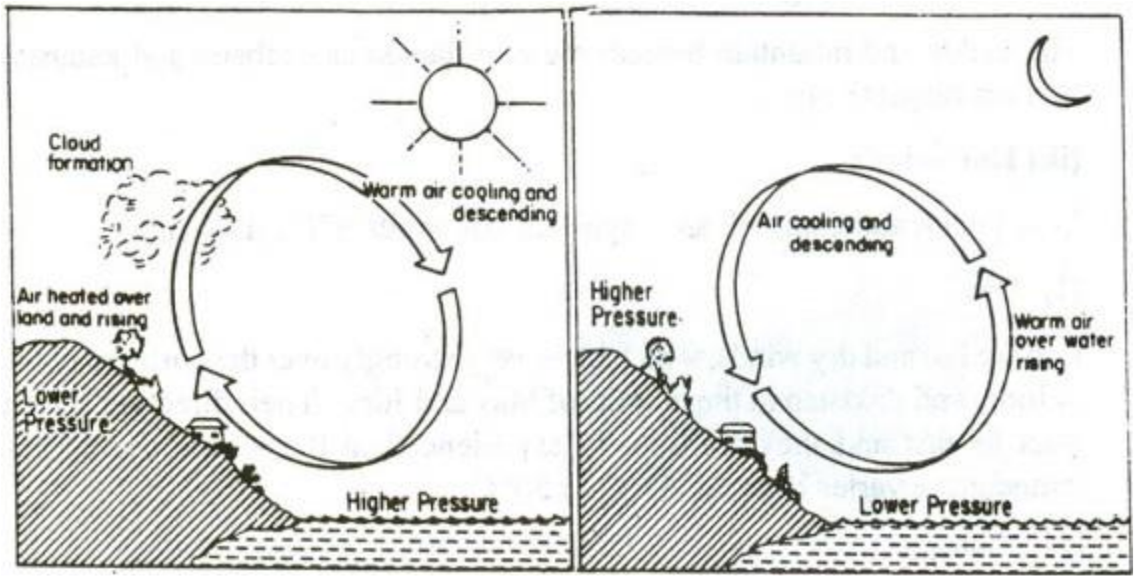

Figure 19 – Sea and Land Breezes

Sea Breeze	Land Breeze
During the day the land heats up faster and becomes warmer than the sea. The heated air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high.	In the night, the land cools up faster than the surrounding sea. This creates relatively high pressure on land.
Pressure gradient is created from sea to land.	Pressure gradient is created from land to sea.
the wind blows from the sea to the land as the sea breeze	the wind blows from the land to the sea as the land breeze
Reaches at maximum intensity in mid-afternoon	Reaches at peak shortly before the sunrise
Helpful for fishermen in returning from sea after a good catch.	In morning, fishermen enter into sea with the help of land breeze and stays there till mid-afternoon.

Table 2 – land and sea breezes

shagn27@gmail.com

4.8.2. The Mountain and Valley Breezes

Another combination of local winds that undergoes a daily reversal consists of the mountain and valley breezes (figure 20). During the day the slopes get heated up more than the valleys. Hence, the pressure is low over the slopes while it is comparatively high in the valleys below. Air moves up from slope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the **valley breeze or anabatic wind**. The valley breeze is sometimes accompanied by the formation of cumulus cloud near mountain peaks to cause orographic rainfall.

During the night the slopes get cooled and the dense air descends into the valley as the mountain wind. The cool air, of the high plateaus and ice fields draining into the valley is called **mountain breeze or katabatic wind**.

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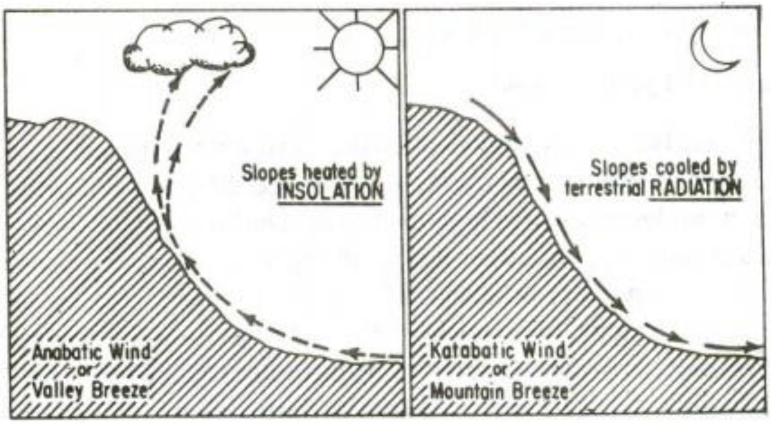


Figure 20 – mountain and valley breezes

4.8.3. Hot Local Winds

Local winds that are hot are caused by the advection of hot air from a warm source region. They may also be produced by dynamic heating of air as it descends from an elevated area to lowland. Few famous hot winds are:

- '**Loo'** is a hot and dry wind, which blows very strongly over the **northern plains of India and Pakistan** in the months of May and June. Their direction is from west to east and they are usually experienced in the afternoons. Their temperature varies between 45°C to 50°C.
- '**Foehn'** is strong, dusty, dry and warm local wind which develops on the leeward side of the **Alps mountain ranges**. Regional pressure gradient forces the air to ascend and cross the barrier. Ascending air sometimes causes precipitation on the windward side of the mountains. After crossing the mountain crest, the Foehn winds starts descending on the leeward side or northern slopes of the mountain as warm and dry wind. The temperature of the winds varies from 15°C to 20°C which help in melting snow. Thus making pasture land ready for animal grazing and help the grapes to ripe early.
- '**Chinook'** is the name of hot and dry local wind, which moves down the eastern slopes of the **Rockies in U.S.A. and Canada**. The literal meaning of chinook is 'snow eater' as they help in melting the snow earlier. They keep the grasslands clear of snow. Hence, they are very helpful to ranchers.
- '**Sirocco'** is a hot, dry dusty wind, which originates in the Sahara desert. It is most frequent in spring and normally lasts for only a few days. After crossing the Mediterranean sea, the Sirocco is slightly cooled by the moisture from the sea. Still it is harmful for vegetation, crops in that region. Its other local names are **Leveche** in Spain, **Khamsin** in Egypt, **Gharbi** in Aegean Sea area.
- **Harmattan** is a strong dry wind that blows over northwest Africa from the northeast. Blowing directly from the Sahara desert, it is a hot, dry and dusty wind. It provides a welcome relief from the moist heat and is beneficial to health of people hence also known as 'the doctor'. It is full of fine desert dust which makes the atmosphere hazy and causes problems to the caravan traders. It may cause severe damage to the crops.

4.8.4. Cold Local Winds

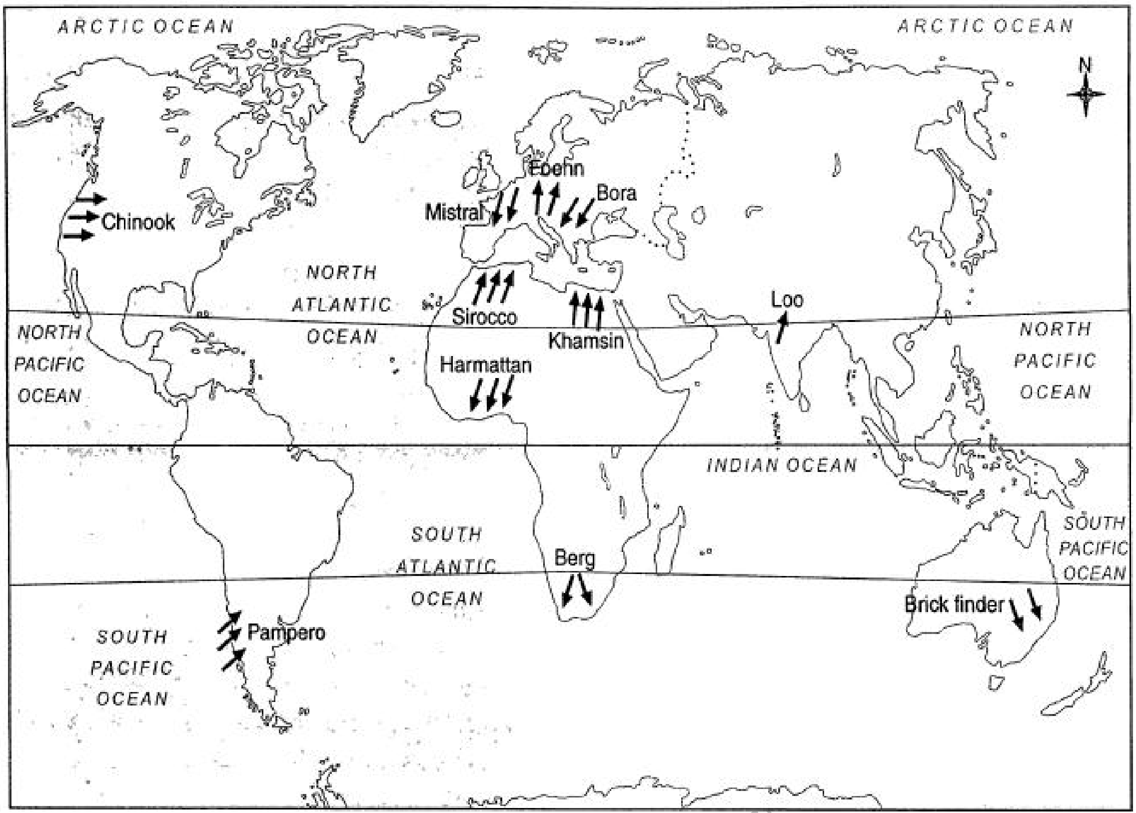
There are certain local winds which originate in the snow-capped mountains during winter and move down the slopes towards the valleys. Few of important these are:

- **'Mistral'** originates on the Alps and move over France towards the Mediterranean Sea through the Rhone valley. They are very cold, dry and high velocity winds. They bring down temperature below freezing point in areas of their influence. As a protective measure,

Student Notes:

many of the houses and orchards of the Rhone valley have thick rows of trees and hedges planted to shield them from the Minstral.

- '**Bora'** is a cold, dry north-easterly wind blowing down from the mountains in the Adriatic Sea region. It is also caused by pressure difference between continental Europe and the Mediterranean Sea. This is usually occurs in winter. It sometimes attain speeds of over 150 kmph.
- **'Blizzard**' is a violent and extremely cold wind laden with dry snow. Such blizzards are of common occurrence in the Antarctic. Wind velocity sometimes reaches 160 kmph and temperature is as low as -7^{0}C.



4.9. Upper Air Circulation

It is now realized that the causes of weather on the ground are intricately bound up with what happens at higher levels in the atmosphere. This applies especially to the development of anti-cyclones and depressions and to the general circulation of winds around the globe. Such phenomena can only be appreciated by understanding air circulation in the upper layers. Broadly speaking, wind speed tend to increase with altitude because of lower air density, lower frictional force etc. Direction of wind also is not same. For instance, during the month of July, surface wind(monsoonal) blow from south-west direction in India while at the height of 10km there are swift winds blowing from east to west.

On a global scale, pressure patterns higher up tend to be much simpler than those at the surface level, largely because of the diminished thermal and mechanical effects of land masses. There is a falling pressure gradient from the sub-tropical areas towards the poles. The gradient is strongest in winter, when the temperature contrasts between the respective polar areas and the equator are most marked.

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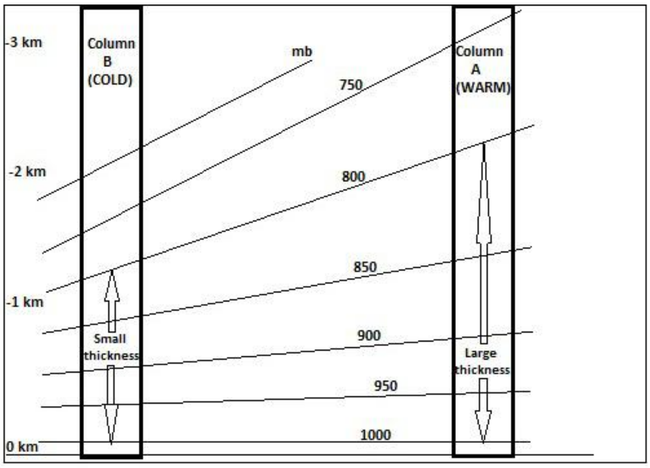

Figure 21 – different vertical temperature gradients in the two columns create an increasing pressure gradient.

4.9.1. Jet Streams

Changes in pressure distribution with height are largely related to changes of temperatures. We can see how this can be so with references to two adjacent columns of air in the troposphere depicted in figure 21. At ground level the pressure exerted by the two is the same, but important changes ensue if we assume that column A is warmer, and therefore less dense throughout than column B. This means that for any level higher up in the two columns, for instance at 2km, there is a greater pressure of air still above this level of column A than in column B. Therefore, a pressure gradient from A to B gradually develops and intensifies with height, where none existed at the surface. Now, it can be visualized that a gradual change of velocity of the wind with height, the wind at the top of the air layers being very much stronger than that lower down.

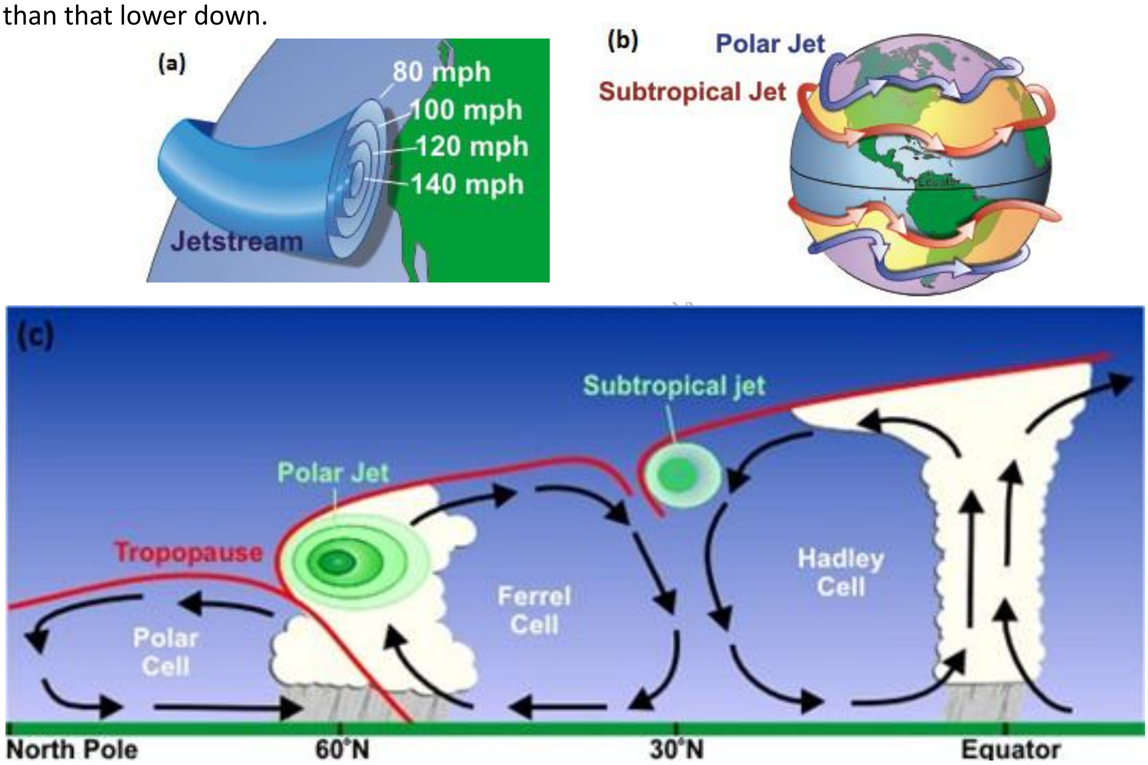

Figure 22 – jet streams: (a) maximum speed at centre; (b) Polar and subtropical jetstreams in both hemispheres; (c) cross-sectional view of jet streams

Applying this on a global scale by associating poles with cold air column and equator with warm air column, the gradual poleward decrease of temperature in the atmosphere from the equator should result in a large westerly component in the upper winds. It was found in 1940s during Second World War that high-flying aircraft encountered upper winds of very great velocity. These are known to be concentrated bands of rapid air movement, which are termed **jet streams**. Few of the features of jet streams are:

- These are narrow belts at the high altitude near the top of the troposphere.
- Their speed varies from about 110 km per hour (kmph) in the summer season to more than 180 kmph in the winter season.
- Their shape is circular. Speed in the jet streams decreases radially outwards (figure 22(a)). One way of visualizing this is to consider a river. The river's current is generally the strongest in the center with decreasing strength as one approaches the river's bank. It can be said that jet streams are "rivers of air".
- They are several hundred kilometers wide and about 2 km to 5km deep.
- The flow of jet streams is not in form of straight line. Their circulation path is wavy and meandering. These meandering winds are called **Rossby waves**
- They dip and rise in altitude/latitude, splitting at times and forming eddies, and even disappearing altogether to appear somewhere else.
- Jet streams also "follow the sun" in that as the sun's elevation increases each day in the spring, the average latitude of the jet stream shifts poleward. (By Summer in the Northern Hemisphere, it is typically found near the U.S. Canadian border.) As autumn approaches and the sun's elevation decreases, the jet stream's average latitude moves toward the equator.
- On occasions the jet stream breaks through the tropopause and enters into the lower stratosphere. Certain amount of water vapour manages to reach in lower stratosphere with jet streams and this layer exhibits occasional cirus clouds. At times, the jet stream effect extends down to an altitude of about 3 km from the earth's surface.
- There is a well marked longitudinal variation in the strength of the jet stream. In winter, the highest wind velocities of the jet stream are found near the east coast of Asia and weakest over the eastern Atlantic and Pacific Oceans. In summer, strongest jet is positioned along the Canadian border and Mediterranean region.

Two permanent jet stream zones occur in each hemisphere. One is sub-tropical jet stream and another is polar front jet stream. There is another jet stream which moves seasonally near equator. Description of these three streams is give below:

shagn27@gmail.com

<u>The polar front jet stream</u>

- It is originated because of temperature difference.
- It is associated with the polar front zone[7] in each hemisphere (figure 23).
- It runs at a more meandering path than the Sub Tropical Jet Stream
- It extends between 40 and 60 latitudes in both Hemispheres.
- It is found at a height between 6km and 9km in the atmosphere.
- It swings towards poles in summers and towards equator in winter. When swinging to south it takes very cold air with it to subtropical region.

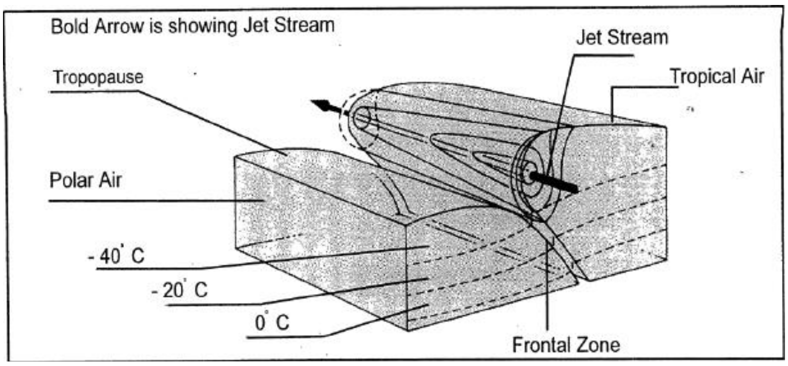

Figure 23 – origin of the Polar front Jet stream at polar front zone

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Sub-tropical jet stream

- It runs between 25^0 and 30^0 latitudes in both the hemispheres.
- It blows constantly
- Its speed is comparatively lower than polar jet streams
- The air currents arising near about the equator descend at 30^0 N and S latitudes. A part of these air currents takes the form of Sub Tropical Jet streams.
- It swings to the north of Himalayas in summer in North India.

Eastern Tropical Jet Stream

- It is a seasonal Jet Stream.
- It blows between equator and 20^0N latitude at the time of South-West Monsoon in summer over south-east Asia, India and Africa.
- Its direction is opposite to that of other two jet streams. It runs in eastern direction.
- It is located comparatively at higher height between 14km and 16km
- Its speed is around 180 km per hour.

Consequence of Jet Stream

- They affect weather conditions
- They substantially contribute to originating cyclones, anticyclones, storms and depressions and influence their behaviour.
- The bursting of monsoon in India is said to be closely related to Eastern Tropical Jet streams.
- If the weather is not disturbed the aeroplanes running in their parallel directions gain great speed and considerably save fuel.
- Sometimes aeroplanes cannot be flown in opposite direction.
- These jet streams are still being investigated with respect to their effect on weather conditions.

5. Air Mass

When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. Such homogenous areas have uniform characteristics in terms of temperature, pressure and moisture. The air with distinctive characteristics in terms of temperature and humidity is called an **air mass**. It is defined as a large body of air having little horizontal variation in temperature and moisture. The homogenous surfaces, over which air masses form, are called the **source regions**. There are five major source regions. These are:

1. Warm tropical and subtropical oceans
2. The subtropical hot deserts
3. The relatively cold high latitude oceans
4. The very cold snow covered continents in high latitudes
5. Permanently ice covered continents in the Arctic and Antarctica

The air masses are classified according to the source regions. Air masses originated from tropical region are warm while those originated from polar region are cold. Air masses originated from these regions are called **primary air masses**. Accordingly, following types of airmasses are recognised:

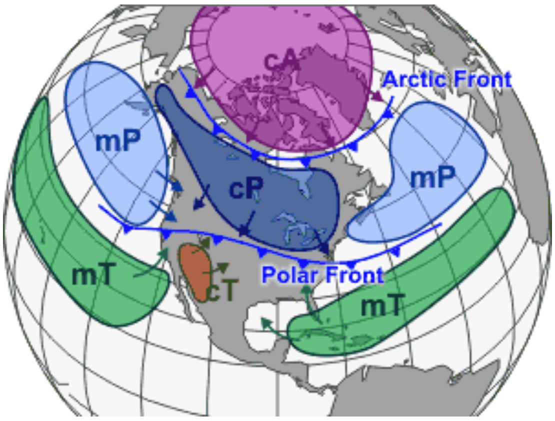

Figure 25 – Airmasses

1. Maritime tropical (mT)
2. Continental tropical (cT)
3. Maritime polar (mP)
4. Continental polar (cP)
5. Continental arctic (cA).

Where 'm' stands for Maritime; 'c' stands for continental; 'T' stands for tropical; 'P' stands for polar and 'A' stands for arctic region.

As these air masses move around the earth they can begin to acquire additional attributes. For example, in winter an arctic air mass (very cold and dry air) can move over the ocean, picking up some warmth and moisture from the warmer ocean and becoming a maritime polar air mass (mP) - one that is still fairly cold but contains moisture. If that same polar air mass moves south from Canada into the southern U.S. it will pick up some of the warmth of the ground, but due to lack of moisture it remains very dry. Another way of changes is internal modification in the airmasses. The resultant air mass by these processes is termed as secondary air mass. Air masses can control the weather for a relatively long time period: from a period of days, to months. Most weather occurs along the periphery of these air masses at boundaries called fronts.

6. Fronts

When two different air masses with distinct properties (temperature, moisture, density, pressure etc.) meet, the boundary zone between them is called a **front**. These air masses are brought together by converging movements in the general atmospheric circulation. The process of formation of the fronts is known as **frontogenesis** while **Frontolysis** is the end stage of a front (table 3). The fronts do not mix readily. In fact, they come in contact with one another along sloping boundaries. These sloping boundaries are actually a transition zone across which a sharp contrast in weather condition occurs. The air masses are of vast size covering tens of thousands of square kilometers. Therefore, frontal zones of discontinuity about 15 to 200 kms wide are relatively narrow. So on the weather map they are represented by only a thick line. A front can be recognized with following observations:

- Sharp temperature changes over a relatively short distance. Sometimes change of 10^0 to 20^0 C may be observed.
- Change in moisture content
- Rapid shifts in wind direction
- Pressure changes
- Clouds and precipitation patterns

Student Notes:

Frontogenesis	Frontolysis
creation of altogether new fronts	destruction or dying of a front
Only after the process of frontogenesis have been in operation for quite some time, front do come into existence	Process of frontolysis must continue for some time in order to destroy an existing front.
is likely to occur when the wind blow in such a way that the isotherms become packed along the leading edge of the intruding air mass	likely to occur when fronts move into regions of divergent air flow on crossing the sub-tropical high pressure regions, the fronts generally disappear
Convergence of the wind toward a point or contraction towards a line augments the process of Frontogenesis.	divergence of the wind from a point is helpful to the process of frontolysis
Cyclonic wind shear witnesses the creation of fronts. Contrarily, the areas of anti-cyclonic wind shear do not allow the formation of fronts. Even the pre-existing fronts degenerate in such areas.	

Table 3 – difference between frontogenesis and frontolysis

As a result of the observations of atmospheric conditions at the surface and aloft, the following types of fronts are identified:

6.1. Warm Front

When a warmer and lighter air mass moves against an existing cold and dense airmass, it rises over the coldet and denser air mass. This type of front is known as warm front. (figure 26a). As the warm air gradually ascends the gently sloping surface of the wedge of cold air lying ahead, it cools. This cooling leads to the cloudy condensation and precipitation. Unlike the cold front, the changes in temperature and wind direction are gradual.

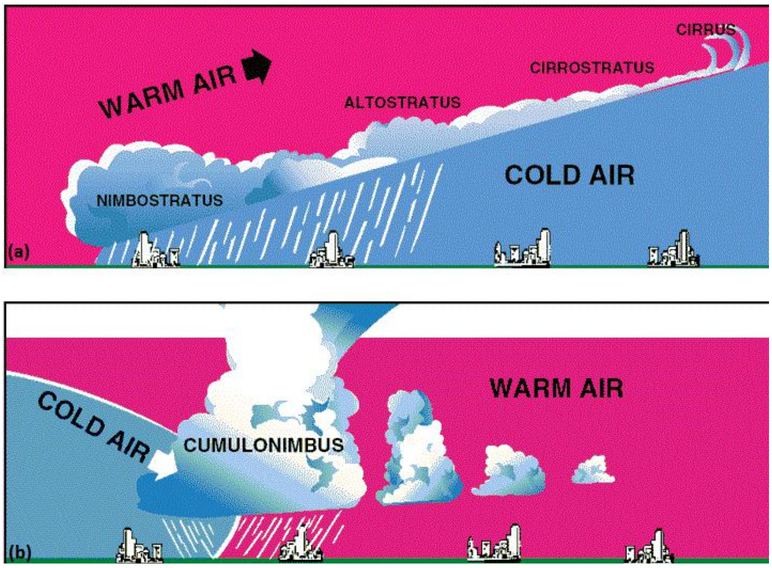

Figure 26 – Fronts: (a) Warm front; (b) Cold front

6.2. Cold Front

When a cold and dense airmass forces its way under warm and lighter airmass it makes the warm and lighter airmass to ride over it. This type of front is called cold front. The effect of friction retards the air motion near the ground, while the free air aloft has a higher velocity. This causes the cold front to become much steeper than the warm front.

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6.3. Stationary Front

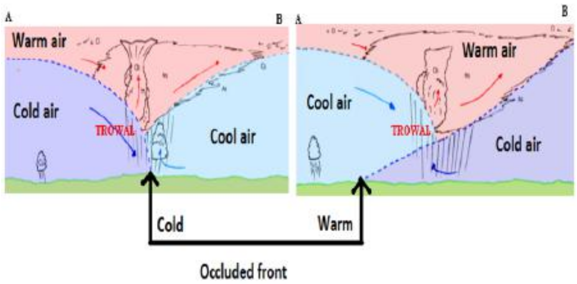
A stationary front forms when a cold front or warm front stops moving. This happens when two masses of air are pushing against each other but neither is powerful enough to move the other. Winds blowing parallel to the front instead of perpendicular can help it stay in place.

6.4. Occluded Front

Sometimes a cold front follows right behind a warm front. A warm air mass pushes into a colder air mass (the warm front) and then another cold air mass pushes into the warm air mass (the cold front). Because cold fronts move faster, the cold front is likely to overtake the warm front. This is known as an occluded front.

At an occluded front, the cold air mass from the cold front meets the cool air that was ahead of the warm front. The warm air rises as these air masses come together. Occluded fronts usually form around areas of low atmospheric pressure. The fronts occur in middle latitudes and are characterised by steep gradient in temperature and pressure. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation

There are two types of occlusion namely, cold front occlusion and war front occlusion (figure 27). The differences are given below in table 6.



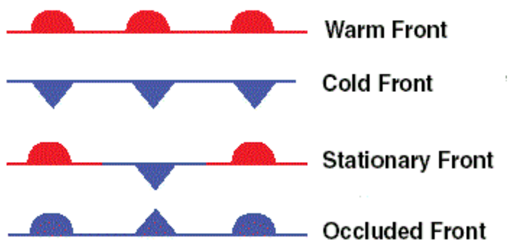


Figure 27- cold front occlusion and warm front occlusion **Figure 28 – symbols used for Fronts**

Cold front occlusion	Warm front occlusion
Occurs when the cold air which overtakes the warm air is colder than the retreating cold air	Occurs when the retreating cold air mass is colder than the advancing cold air mass
In the initial stage, weather system of the warm front persists. At the later stages the weather conditions resemble those of the cold front.	
Overtaking cold airmass plows under both air masses	Advancing cold air being relatively less dense overrides the retreating cold air mass

Table 6 – Occluded fronts – difference between cold front occlusion and warm front occlusion

7. Cyclones

The atmospheric disturbances which involve a closed circulation about a low pressure centre, anticlockwise in the northern atmosphere and clockwise in the southern hemisphere are called cyclones. They fall into the following two broad categories: (a) Extra-tropical and (b) tropical cyclones.

7.1. Extra-Tropical Cyclones

Extra-tropical cyclones are the weather disturbances in the mid and high latitude, beyond the tropics. These latitudes are an area of convergence where contrasting air masses generally meet to form polar fronts. The stages of development of extra-tropical cyclone are described below with diagram.

- Initially, the front is stationary (figure 29-1).
- In the northern hemisphere, warm air blows from the south and cold air from the north of the front. When the pressure drops along the front, the warm air moves northwards and the cold air move towards, south setting in motion an anticlockwise cyclonic circulation(figure 29-2).
- The cyclonic circulation leads to a well developed extra tropical cyclone, with a warm front and a cold front (figure 29-3).
- The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation (figure 29-4).
- The cold front approaches the warm air from behind and pushes the warm air up (figure 29-5). As a result, cumulus clouds develop along the cold front.
- The cold front moves faster than the warm front ultimately overtaking the warm front. The warm air is completely lifted up and the front is occluded and the cyclone dissipates (figure 29-6).

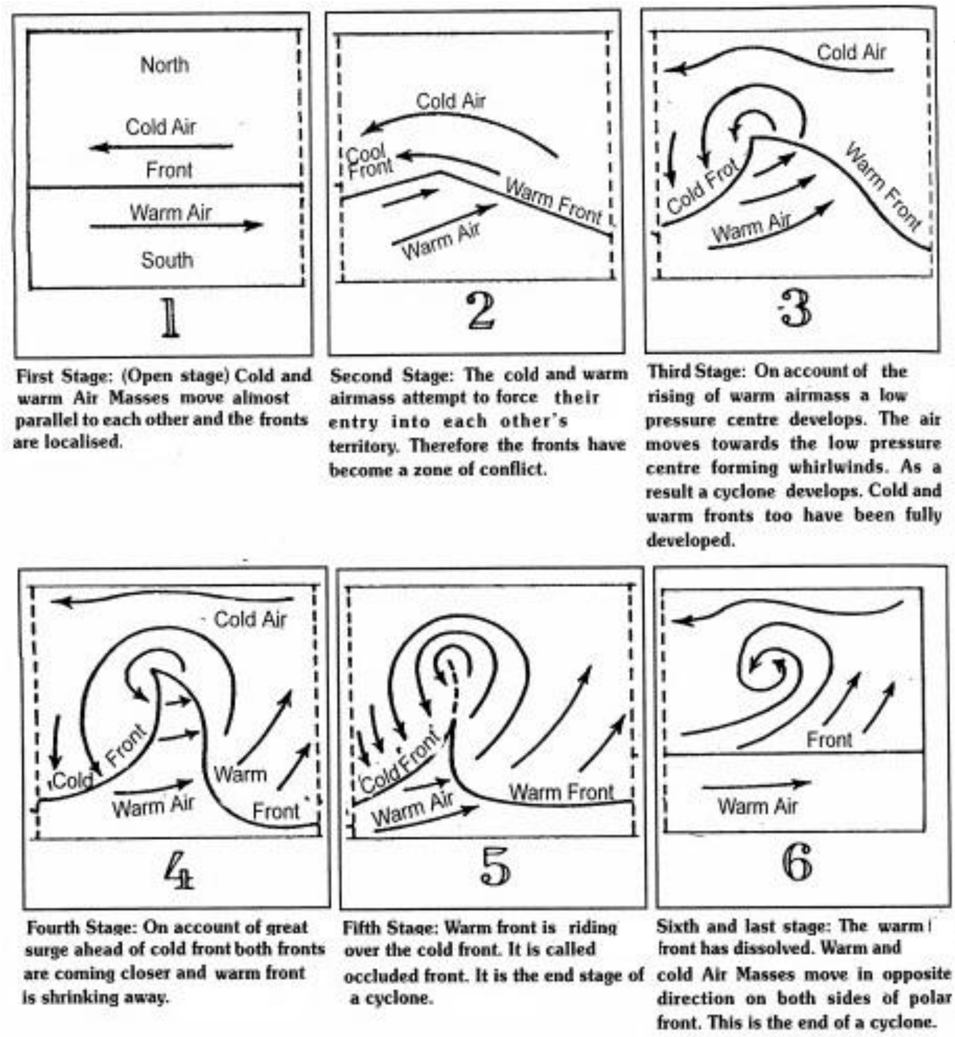


Figure 29 – life cycle of a extra-tropical cyclone

There is great degree of variation in **shape and size** of extra-tropical cyclones. Generally, the isobars are almost circular or elliptical. However, in certain depressions, the isobars take the shape of the letter 'V'. Such storms are called V-shaped depression. At times, the cyclones become so broad and shallow that they are referred to as troughs of low pressure.

Student Notes:

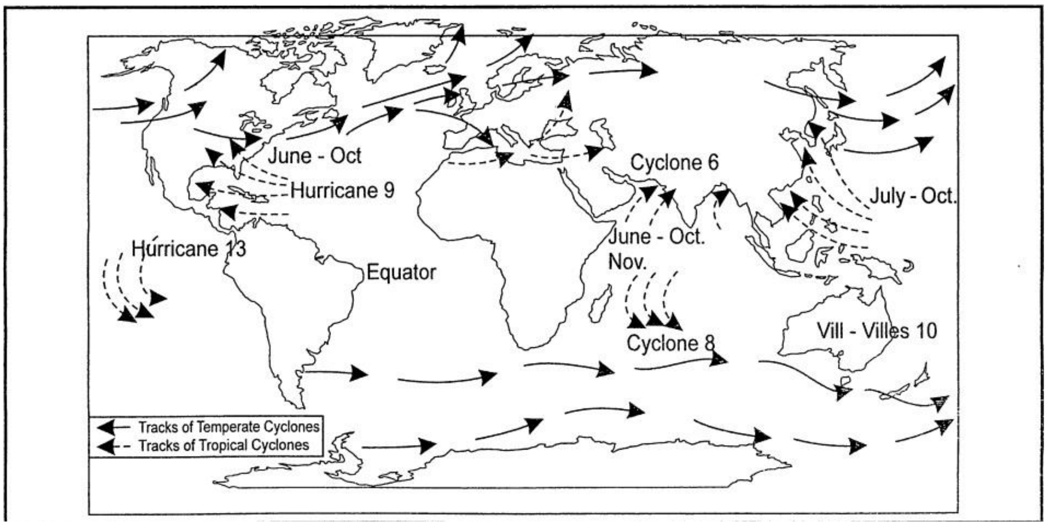


Figure 30 – world: pathways of cyclones (Numbers indicate average frequency of cyclones)

Student Notes:

Paths and movement of extra-tropical cyclone – the general direction of movement of temperate cyclones is from west to east with frequent trends towards the southeast to northeast (figure 30). They are subject to the general westerly flow of atmosphere in temperate zone. The heavy concentration of storms tracks in the vicinity of the Aleutian(Islands west to the Alaska Peninsula) and Icelandic lows is the most important feature of the distribution of extra-tropical cyclones. During winter months, the opposing air masses have greater contrasts in their properties. So the winter cyclones are greater in number and are more intense. On an average cyclone may cover a distance of about 1000 km per day. Cyclones invariably move towards higher latitudes.

Secondary cyclones – under the normal conditions, in the later stages of occlusion the cyclone weakens and ultimately dissipates. But sometimes, during the late maturing stage of a cyclone, a new low develops on the equatorward margin of the original cyclone. Thus, a secondary cyclone is formed which passes through different stages of its life cycle and matures very rapidly. It may follow the tract of primary cyclone or may move along new path.

Cyclone families – It is found that an extra-tropical cyclone never appears alone. It is usually followed by three or four cyclones forming a series. The primary or the leading cyclone gets occluded, while the new ones originate on the trailing front and are in an incipient stage. In the rear of the last member of the cyclone family there is an outbreak of polar air which builds up an anti-cyclone. Original cyclone would be in high latitudes and each secondary cyclone would follow progressively a more southerly path. Cyclone families frequent the oceans in a larger number.

Extra-tropical cyclone and Jet stream – there is a close relationship between the flow aloft and the cyclonic storm at the surface. Rossby waves produced at the top of troposphere helps in transporting large bodies of polar air to the lower latitudes and tropical air masses are carried to the higher latitudes. This results in the intensity of surface cyclonic activity. There are instances when extra-tropical cyclones form without the prior existence of a polar front. These depressions are actually initiated by a trough in the upper-air westerlies. Once such storms originate in the lower atmosphere they attract different air masses together which leads to the generation of fronts.

7.2. Tropical Cyclones

The tropical cyclone develops from the 'warm core' of extremely low pressure area in the tropical oceanic areas. They are energized from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. The arrangement of isobars is almost circular. With continuous supply of moisture from the sea, the storm is further

Student Notes:

strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the **landfall of the cyclone**. The **conditions favourable for the formation** and intensification of tropical storms are:

- Large sea surface with temperature higher than 27° C
- Presence of the Coriolis force
- Small variations in the vertical wind speed
- A pre-existing weak low-pressure area or low-level-cyclonic circulation -
- Upper divergence above the sea level system.

Large and continuous supply of warm and moist air from the ocean provides necessary energy in the form of latent heat of condensation. Coriolis force causes cyclonic circulation. At the equator, the Coriolis force is zero and the wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified. That is the reason why tropical cyclones are not formed near the equator.

Because of small variations in the vertical wind speed or wind shear, cyclone formation processes are limited to latitudes equatorword of the sub-tropical jet stream. It is the pre-existing low pressure area which intensifies and develops as cyclone. It must be pointed out that only a few of these disturbances develop into true tropical cyclones. Upper divergence helps in ascending air currents to be pumped out to maintain the low pressure at the centre of the cyclone.

Tropical cyclone shown in figure 31 has following features:

- **Eye** – it is the centre of cyclone around which strong spirally winds circulate in a mature tropical cyclone. It is a region of calm with subsiding air.
- **Eye Wall** – there is a strong spiraling ascent of air to greater height reaching the tropopause. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rain occurs here. From the eye wall rain bands may radiate and trains of **cumulus** and **cumulonimbus** clouds may drift into the outer region.
- The diameter of the circulating system can vary between 150 and 250 km.
- The diameter of the storm over the Bay of Bengal, Arabian Sea and Indian Ocean is between 600 - 1200 km. The system moves slowly about 300 - 500 km per day.

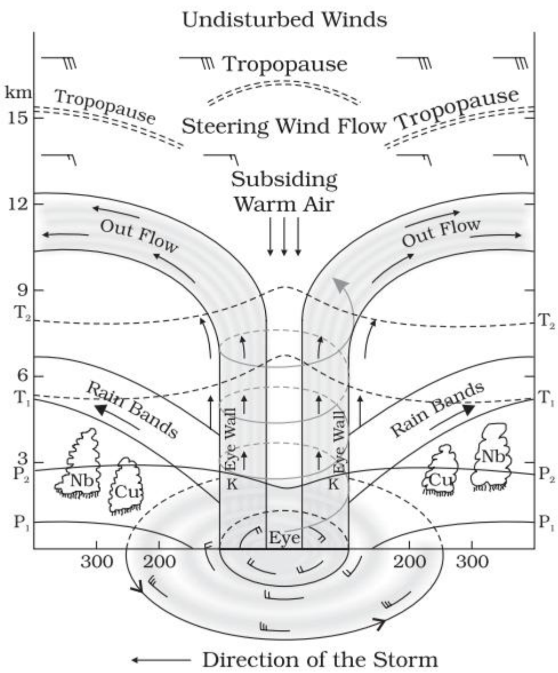


Figure 31 – tropical cyclone

Region	Local name
Indian Ocean	Cyclone or chakrvaat
Atlantic	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	Willy-willies

Figure 32 – different names of tropical cyclone

Student Notes:

Impact on humans

- This is one of the most devastating natural calamities. They move over to the coastal areas bringing about large scale destruction caused by violent winds, very heavy rainfall and storm surges.
- The cyclones, which cross 20ºN latitude generally, re-curve and they are more destructive.
- Trees are uprooted and broken and the loose objects swept away.
- A particular location on the land surface encounters opposite winds twice from the circular fashion of the cyclone. These winds create more damage to objects.
- Torrential rains that occur in the towering cumulonimbus clouds inundate the low-lying areas, cause floods and landslides resulting in great loss of life and property damage.
- Strom waves of great heights are great hazard to shipping. These are called storm surge whose height may go up to 20 meters. If cyclone wave combines with the spring tide, the result is disastrous.

Naming of tropical cyclones - In the beginning, storms(tropical cyclone) were named arbitrarily. Then the mid -1900's saw the start of the practice of using feminine names for storms. In the pursuit of a more organized and efficient naming system, meteorologists later decided to identify storms using names from a list arranged alphabetically.

There is a strict procedure to determine a list of tropical cyclone names in an ocean basin(s) by the Tropical Cyclone Regional Body responsible for that basin(s) at its annual/biennial meeting. There are five tropical cyclones regional bodies. The **Regional Specialized Meteorological Centre (RSMC)** – Tropical cyclones is responsible for monitoring and prediction of tropical cyclones over their respective regions. They are also **responsible to name the cyclones**.

In general, tropical cyclones are named according to the rules at a regional level. The **WMO/ESCAP Panel on Tropical Cyclones** at its twenty-seventh Session held in 2000 in Muscat, Sultanate of Oman agreed in principal to assign names to the **tropical cyclones in the Bay of Bengal and Arabian Sea**. After long deliberations among the member countries, the naming of the tropical cyclones over north Indian Ocean commenced from September 2004. The list of names India has added to the database includes Agni, Akash, Bijli, Jal (cyclones which have all occurred since 2004). The Indian names in the queue are Leher, Megh, Sagar and Vayu, while those suggested by Pakistan include Nilofar, Titli and Bulbul.

If public wants to suggest the name of a cyclone to be included in the list , the proposed name must meet some fundamental criteria. The name should be short and readily understood when broadcast. Further the names must not be culturally sensitive and not convey some unintended and potentially inflammatory meaning. A storm causes so much death and destruction that its name is considered for retirement and hence is not used repeatedly. Names are usually assigned to tropical cyclones with one-, three-, or ten-minute sustained wind speeds of more than 65 km/h depending on which area it originates.

Importance for naming tropical cyclones:

- It would help identify each individual tropical cyclone.
- It helps the public to become fully aware of its development.
- Local and international media become focused to the tropical cyclone.
- It does not confuse the public when there is more than one tropical cyclone in the same area.
- The name of the tropical cyclone is well remembered by million of people as it is unforgettable event whose name will long be remembered.
- Warnings reach a much wider audience very rapidly.
- It heightens interest in warnings and increases community preparedness.

sihan27@gmail.com

Difference between extra-tropical cyclone and tropical cyclone is given in table 7 below:

Extra-tropical cyclone	Tropical cyclone
have a clear frontal system and get energy from the horizontal temperature contrasts that exist in the atmosphere	Fronts are not present and get energy from warm and moist air of ocean
Large size (1500-3000km)	Relatively small in size
can originate over the land and sea	originate only over the seas
Travel both on oceans and land	on reaching the land they dissipate.
Affects a much larger area as compared to the tropical cyclone.	
	Wind velocity in a tropical cyclone is much higher and it is more destructive.
move from west to east	move from east to west

Table 7 – comparison between tropical and extra-tropical cyclone

7.3. Thunderstorms and Tornadoes

Unlike Tropical Cyclones, thunderstorms and tornadoes are highly localized weather phenomenon. They are of short duration, occurring over a small area but are violent. They are so small and short lived as to make their prediction very difficult.

A storm accompanied by thunder and lightning is called thunderstorm. It is associated with the cumulonimbus clouds.. Thunderstorms are caused by intense convection on moist hot days. When the clouds extend to heights where sub-zero temperature prevails, hails are formed and they come down as **hailstorm**. If there is insufficient moisture, a thunderstorm can generate **dust storms**. Stages in the development of thunderstorm are described below and shown in figure 33.

1. **Cumulus stage:** Warm, moist air rises in a buoyant plume or in a series of convective updrafts. As this occurs the air begins to condense into a cumulus cloud. As the warm air within the cloud continues to rise, it eventually cools and condenses. The condensation releases heat into the cloud, warming the air. This, in turn, causes it to rise adiabatically. The convective cloud continues to grow upward, eventually growing above the freezing level where super-cooled water droplets and ice crystals coexist Precipitation begins once the air rises above the freezing level.
2. **Mature stage:** it is characterized by the presence of both updrafts and downdrafts within the cloud. The downdrafts are initiated by the downward drag of falling precipitation. Cold descending air in the downdraft will often reach the ground before the precipitation. As the mature-stage thunderstorm develops, the cumulus cloud continues to increase in size, height and width. Cloud to ground lightning usually begins when the precipitation first falls from the cloud base. During this phase of the life cycle, the top of the resulting cumulonimbus cloud will start to flatten out, forming an anvil shape often at the top of the troposphere.

Student Notes:

Student Notes:

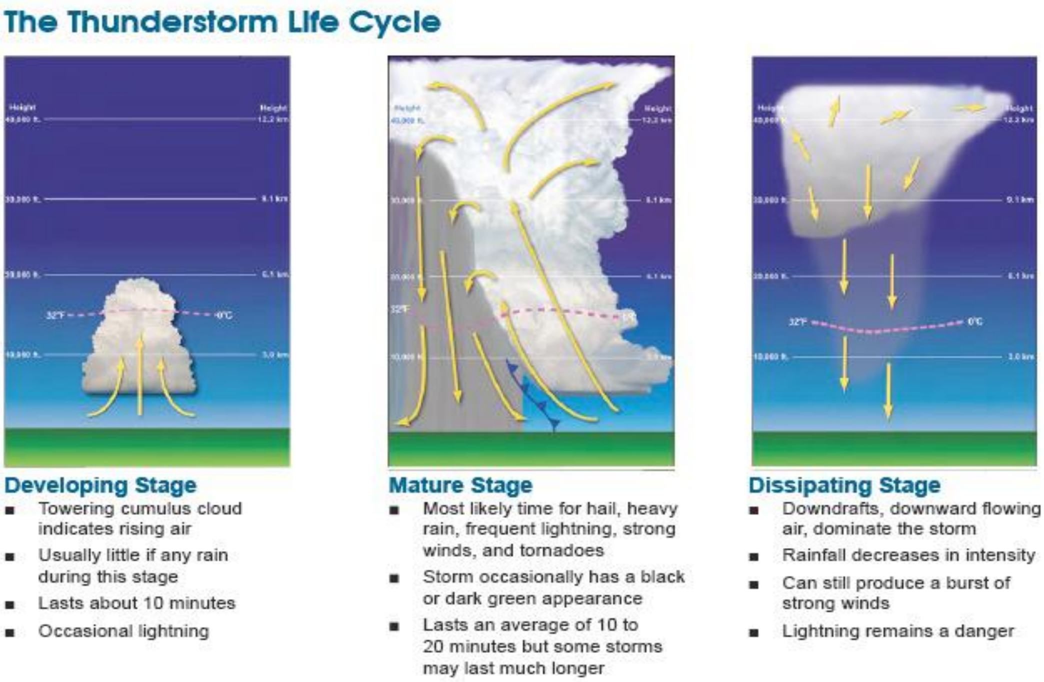


Figure 33 – three stages in the development of a thunderstorm: (a) cumulus stage; (b) Mature stage; (c) Dissipating stage

3. **Dissipating stage:** It is characterized by downdrafts throughout the entire cloud. Decay often begins when the super-cooled cloud droplets freeze and the cloud becomes glaciated, which means that it contains ice crystals. The cloud begins to collapse because no additional latent heat is released after the cloud droplets freeze, and because the shadow of the cloud and rain cooled downdrafts reduce the temperature below the cloud.

7.3.1. What Causes Lightning and Thunder

The rising air in a thunderstorm cloud causes various types of frozen precipitation to form within the cloud. Included in these precipitation types are very small ice crystals and much larger pellets of snow and ice. The smaller ice crystals are carried upward toward the top of the clouds by the rising air while the heavier and denser pellets are either suspended by the rising air or start falling toward the ground. Collisions occur between the ice crystals and the pellets, and these collisions serve as the charging mechanism of the thunderstorm. The small ice crystals become positively charged while the pellets become negatively charged. As a result, the top of the cloud becomes positively charged and the middle to lower part of the storm becomes negatively charged. When the strength of the charge overpowers the insulating properties of the atmosphere, lightning happens.

At the same time, the ground underneath the cloud becomes charged oppositely of the charges directly overhead. When the charge difference between the ground and the cloud becomes too large, a conductive channel of air develops between the cloud and the ground, and a small amount of charge (step leader) starts moving toward the ground. When it nears the ground, an upward leader of opposite charge connects with the step leader. At the instant this connection is made, a powerful discharge occurs between the cloud.

The channel of air through which lightning passes can be heated to 50,000°F—hotter than the surface of the sun! The rapid heating and cooling of the air near the lightning channel causes a shock wave that results in the sound we know as "thunder."

Student Notes:

7.3.2. Why Thunders are Cause of Concern

Each year, many people are killed or seriously injured by severe thunderstorms despite the advance warning. While severe thunderstorms are most common in the spring and summer, they can occur at just about any time of the year. Cloud-to-ground lightning, Hail, Tornadoes and waterspouts, Flash flood and Downburst are some of the hazards associated with thunderstorm.

There is no safe place outside during a thunderstorm but building constructed according to current guidance could provide safe seltor and avoid injury or death.

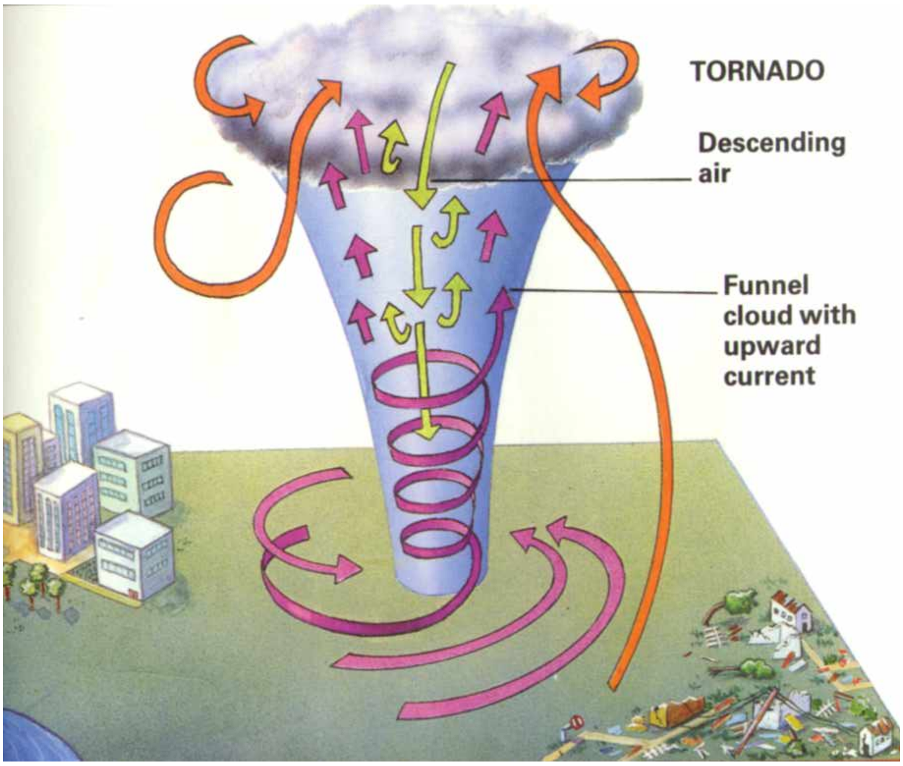
Tornado – From severe thunderstorms sometimes spiraling wind descends like a trunk of an elephant with great force, with very low pressure at the centre causing massive destruction on its way. Such a phenomenon is called a **tornado**. Excessive instability and steep lapse rate in the atmosphere are necessary pre-requisite for the development of a tornado. Tornadoes generally occur in middle latitudes. The tornado over the sea is called **water sprouts**. Chief features of tornadoes are:

- Tornado's funnel can have size of 90-460m in diameter.
- Tornadoes generally occur in middle latitudes.
- Tornadoes are the most violent of all the storms.
- They are very small in size and of short duration which makes weather prediction difficult.
- The velocity of winds revolving tightly around the core reaches more than 300 km per hour.
- It causes massive destruction on its way.
- When looked at from the ground, the funnel appears dark because of the presence of condensed moisture and the dust and debris picked up from the ground by the whirling tornado.
- Tornadoes may be found to be moving singly or in families of several individual tornadoes.
- These generally move in straight paths.

These violent storms are the manifestation of the atmosphere's adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms and the restless atmosphere again returns to its stable state.

sihag027@gmail.com

Student Notes:



References:

1. Since sunspots are darker than the surrounding photosphere it might be expected that more sunspots would lead to less solar radiation and a decreased solar constant. However, the surrounding margins of sunspots are brighter than the average, and so are hotter; overall, more sunspots increase the Sun's solar constant or brightness.
2. **Electromagnetic radiation** is a term used to describe all the different kinds of energies released into space by stars such as the Sun.
3. A **photon** is an elementary particle, the quantum of light and all other forms of electromagnetic radiation
4. **Conductor of heat** - Ability to transfer heat to adjacent molecules.
5. The **latent heat of condensation** for water is defined as the heat released when one mole of the substance condenses to form liquid droplets from water vapour. The temperature does not change during this process, so heat released goes directly into changing the state of the substance. The heat of condensation of water is equal to 40.8 kJ/mol. The heat of condensation is numerically exactly equal to the heat vaporization, but has the opposite sign.
6. **Albedo**: it is reflectivity or reflecting power of a surface. It is defined as the ratio of reflected radiation from the surface to incident radiation upon it. Albedos of typical materials in visible light range from up to 0.9 for fresh snow to about 0.04 for charcoal, one of the darkest substances.
7. The **polar front** is the boundary between the polar cell and the Ferrel cell in each hemisphere. At this boundary a sharp gradient in temperature occurs between these two air masses, each at very different temperatures.
8. An **adiabatic process** is a process that occurs without the transfer of heat or matter between a system and its surroundings.

8. UPSC Previous Years Prelims Questions

Student Notes:

1. Consider the following statements:

1. The albedo of an object determines its visual brightness when viewed with reflected light.
2. The albedo of Mercury is much greater than the albedo of the Earth.

Which of the statements given above is/are correct? (2008)

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

2. What causes wind to deflect toward left in the Southern hemisphere? (2010)

(a) Temperature
(b) Magnetic field
(c) Rotation of the earth
(d) Pressure

3. A new type of El Nino called El Nino Modoki appeared in the news. In this context, consider the following statements:

1. Normal El Nino forms in the Central Pacific ocean whereas El Nino Modoki forms in Eastern Pacific ocean.
2. Normal El Nino results in diminished hurricanes in the Atlantic ocean but El Nino Modoki results in a greater number of hurricanes with greater frequency.

Which of the statements given above is/are correct? (2010)

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

4. Westerlies in southern hemisphere are stronger and persistent than in northern hemisphere. Why?

1. Southern hemisphere has less landmass as compared to northern hemisphere.
2. Coriolis force is higher in southern hemisphere as compared to northern hemisphere

Which of the statements given above is/are correct? (2011)

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

5. The 2004 Tsunami made people realize that mangroves can serve as a reliable safety hedge against coastal calamities. How do mangroves function as a safety hedge? (2011)

(a) The mangrove swamps separate the human settlements from the sea by a wide zone in which people neither live not venture out
(b) The mangroves provide both food and medicines which people are in need of after any natural disaster.
(c) The mangrove trees are tall with dense canopies and serve as an excellent shelter during a cyclone or tsunami
(d) The mangrove trees do not get uprooted by storms and tides because of their extensive roots

6. La Nina is suspected to have caused recent floods in Australia. How is La Nina different from El Nino?

1. La Nina is characterised by unusually cold ocean temperature in equatorial Indian Ocean whereas El Nino is characterised by unusually warm ocean temperature in the equatorial Pacific Ocean.
2. El Nino has adverse effect on south-west monsoon of India, but La Nina has no effect on monsoon climate.

Which of the statements given above is/are correct? (2011)

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

Student Notes:

7. In the South Atlantic and South-Eastern Pacific regions in tropical latitudes, cyclone does not originate. What is the reason? (2015)
   (a) Sea surface temperatures are low
   (b) Inter-tropical Convergence Zone seldom occurs
   (c) Coriolis force is too weak
   (d) Absence of land in those regions

8. Consider the following statements:
   1. Jet streams occur in the Northern Hemisphere only.
   2. Only some cyclones develop an eye.
   3. The temperature inside the eye of a cyclone is nearly 10°C lesser than that of the surroundings.

   Which of the statements given above is/are correct? (2020)
   (a) 1 only (b) 2 and 3 only
   (c) 2 only (d) 1 and 3 only

9. UPSC Previous Years Mains Questions

1. Discuss the concept of air mass and explain its role in macro-climatic changes. (2015)
2. Tropical cyclones are largely confined to South China Sea, Bay of Bengal and Gulf of Mexico. Why? (2014)
3. Most of the unusual climatic happenings are explained as an outcome of the El-Nino effect. Do you agree? (2014)
4. The recent cyclone on east coast of India was called 'Phailin'. How are the tropical cyclones named across the world? Elaborate. (100 words)(UPSC 2013/5 marks)
5. What do you understand by the phenomenon of 'temperature inversion' in meteorology? How does it affect weather and the habitants of the place? (100 words) (UPSC 2013/5 marks)

10. Previous Years Vision IAS Test Series Questions

1. ***Describe the conditions for the formation of tropical cyclone and major areas in the world, which are affected by it.***

Answer:

sihagnz7@gmail.com

Tropical cyclone is a rotating wind system with centre of low pressure, surrounded by closed isobars having increasing pressure outward; and closed air circulation from outside towards the central low pressure in such a way that air blows inward in anticlockwise direction in the northern hemisphere.

The important conditions for the formation of tropical cyclone are as follows:

- **Water temperature:** of atleast26 degrees Celsiusis needed down to a depth of atleast 50 m.
- **Rapid cooling:** with the rising height which causes the formation of towering cumulonimbus clouds which is responsible for heavy downpour. This releases heat called latent heat of condensation after cooling that act as a heat engine for cyclone movement.
- **High humidity:** supplied by the warm moist air with temperature above 26 degree.
- **Low amount of wind shear** is required as the high wind shear is disruptive to the circulatory motion of the winds.
- **Coriolis force** should not be zero. For the circulatory motion of the wind coriolis force is must. That’s why the tropical cyclones do not originate at the equator; they originate 5 degree to 20 degree north and south of the equator.

Student Notes:

- Lastly it required the **pre-existing system of disturbed weather**, although without a circulation no development will take place.

There are six major regions of tropical cyclones in the world. They are:

- West Indies, Gulf of Mexico and Caribbean sea,
- Western North Pacific Ocean including Philippines islands, China Sea, and Japanese islands
- Arabian Sea and Bay of Bengal,
- Eastern Pacific Coastal Region off Mexico and Central America
- South Indian Ocean off Madagascar,
- Western South Pacific Ocean nearby Samoa, Fiji and east and north coast of Australia.

They are known by different names in different parts of the world such as hurricane in USA, typhoons in china, willy-willy in Australia, cyclones in Indian Ocean, Baguio in Philippines, Taif-u in Japan etc.

2. What do you understand by thermo-haline circulation? Also, explain its shutdown.

Approach:

Straight forward question, Explain the concepts of thermo-haline circulation and its shutdown.

Answer:

The thermohaline circulation is that part of the ocean circulation which is driven by density differences. Sea water density depends on temperature and salinity, hence the name thermo-haline. The salinity and temperature differences arise from heating/cooling at the sea surface and from the surface freshwater fluxes. Heat sources at the ocean bottom play a minor role.

In contrast to the wind-driven currents, the THC is not confined to surface waters but can be regarded as a big overturning of the world ocean, from top to bottom. The thermo-haline circulation consists of:

- Deep water formation: the sinking of water masses, closely associated with (but not to be confused with) convection, which is a vertical mixing process. Deep water formation takes place in a few localised areas: the Greenland-Norwegian Sea, the Labrador Sea, the Mediterranean Sea, the Weddell Sea, the Ross Sea.
- Spreading of deep waters e.g. North Atlantic Deep Water (NADW) and Antarctic Bottom Water (ABW), mainly as deep western boundary currents.
- Upwelling of deep waters: this is not as localised and difficult to observe. It is thought to take place mainly in the Antarctic Circumpolar Current region, possibly aided by the wind.
- Near-surface currents: these are required to close the flow. In the Atlantic, the surface currents compensating the outflow of NADW range from the Venezuela Current off South Africa via Gulf Stream and North Atlantic Current into the Nordic Seas off Scandinavia. The Gulf Stream is primarily a wind-driven current, as part of the subtropical gyre circulation. The thermohaline circulation contributes only roughly 20% to the Gulf Stream flow.

The thermohaline circulation plays an important role in supplying heat to the polar regions, and thus in regulating the amount of sea ice in these regions, although poleward heat transport outside the tropics is considerably larger in the atmosphere than in the ocean.

Student Notes:

Changes in the thermohaline circulation are also thought to have significant impacts on the Earth's radiation budget.

A shutdown or slowdown of the thermohaline circulation is a postulated effect of global warming. There is an assumption that global warming could, via a shutdown or slowdown of the thermohaline circulation, trigger localised cooling in the North Atlantic and lead to cooling, or lesser warming, in that region. This would particularly affect areas such as the British Isles and the Nordic countries, which are warmed by the North Atlantic drift.

3. Explain the process and mechanism responsible for the formation of temperate cyclones.

Approach:

Need to discuss what is temperate cyclone? What is the process responsible for its formation and its life stages and associated weather to different stages ?

Answer:

(Refer diagram from the goh cheng leong)

Location and where it formed

These are extra-tropical cyclones or synoptic weather system that are formed outside the tropics in the mid-latitudes of the earth. They are formed around the Arctic and Antarctic circles where the warm westerly meets with the cold easterlies. These are regions of low pressure where air masses of two different characteristics meet each other and generate a mutually contrasting weather conditions along the fronts and sectors. Fronts are basically the boundary between the two contrasting air masses. Temperate cyclone formation is associated with the front formation, horizontal gradient of the temperature and dew point. They are also known as baroclinic zones.

They are formed along the linear bands of temperature gradient having large wind shear, initially a low pressure centre occurs along the frontal zones near a favourable quadrant of a maximum in the upper level jet stream. When the two contrasting air masses try to encroach each other region they start generating the separated fronts in various parts of the temperate cyclone. Upper level jetstream known as a jet streak, usually being the right rear and left front quadrants, where divergence ensues. This causes air to rush out from the top of the air column which in turn forces convergence in the low-level wind field and increased upward motion within the column. The increased upward motion causes surface pressures to lower as the upward air motion counteracts gravity, lessening the weight of the atmosphere in that location, and thus strengthening the cyclone. As the cyclone strengthens, the cold front sweeps towards the equator and moves around the back of the cyclone. Meanwhile, it's associated warm front progresses more slowly, as the cooler air ahead of the system is denser, and therefore more difficult to dislodge. Later, the cyclones occlude as the poleward portion of the cold front overtakes a section of the warm front, forcing a tongue, or trowal, of warm air aloft. Eventually, the cyclone will become barotropically cold and begin to weaken.

Stages of the passage of temperate cyclone and the various weather phenomenon associated with the stages of temperate cyclone.

In the frontal eastern part we have **warm front** and the weather associated with the warm front is as low pressure, high temperature, high relative humidity, wind direction is from south east, rainfall is slow but continuous for longer period of time. This is due to the moderate slope of the warn front. The slope of warn front is gentle due to which the warm air becomes aggressive and move above the cold air and make the slope of warn front gentle that's why we have rainfall slow along the warm front.

Student Notes:

Following the warm front is the **warm sector** that involves a rise in temperature, low pressure with rainfall in subsequent spells. Wind direction changes from south-east to south side.

Following the warm sector is **the cold front** which has low temperature, high pressure and rainfall torrential due to the formation of cumulonimbus clouds.

Following the cold front is the **cold sector** that makes the weather clear and the sky is cloud free and clear. With the passage of the temperate cyclone from a place bring change in the associated weather condition the pre cyclone weather condition sets-in. This cyclone dissipation called as occlusion of cyclone.

4. Differentiate between temperate and tropical cyclones. Describe the process of formation of temperate cyclones? How do temperate cyclones affect the climate of India?

Approach:

- You need to discuss the difference between these in terms of their location, condition for formation, processes responsible, structural difference and their path of movement.
- Focus should be on the differences and not general discussion on temperate or tropical cyclones.
- Mention in brief how fronts form.
- Draw the diagrams of fronts, direction of movement from west to east.
- Write about Western disturbances in the northern India during winter season.

Answer:

Cyclone is a low pressure system in which the movement of wind is in a circulatory fashion around the low pressure centre. The difference between tropical and temperate cyclones can be analyzed on the basis of their location, condition for their formation, processes responsible, difference in structure and the path of their movement as below:

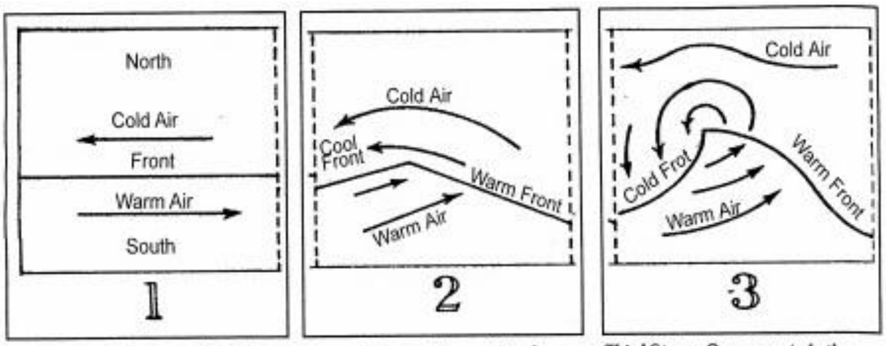
sjhaqn27@gmail.com

- Tropical cyclones develop over the ocean in warm and moist tropical air masses at latitudes between 20 and 25 degree north or south of the equator. Temperate cyclones develop in the mid and high latitude, beyond the tropics.
- Tropical cyclones gain their energy from the latent heat of evaporation of water from the ocean. Mid-latitude cyclones are powered by large temperature differences in the atmosphere. They develop when air masses of different temperatures meet.
- Tropical cyclones are small in size, just 100 to 1500 km in diameter. Mid-latitude cyclones are much larger than tropical cyclones. They have diameters of between 1000 and 4000 km.
- There is a very strong pressure gradient across the tropical cyclone and this can lead to very strong hurricane strength winds. Temperate cyclones have lower wind speeds.

Temperate cyclones are weather disturbances in the mid and high latitudes. These latitudes are areas of convergence where contrasting air masses, with different properties such as temperature, moisture content, and pressure, meet to form fronts. Cyclones are formed at the boundaries of these fronts.

In the initial stage of cyclone, warm and cold air masses blow parallel to the isobars and form stationary front. Subsequently, both the air masses try to push into each other's domain. This results in the readjustment of the isobars that become curved. Cold front and warm fronts are formed at two edges as shown in diagram. The warm air glides over the cold air. At this stage, cyclone is fully developed.

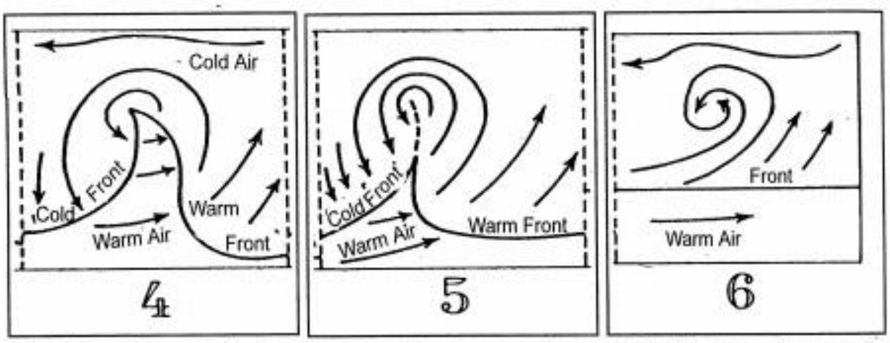
The cold front starts approaching the warm air from behind and pushes it up. This fast moving cold front overtakes the warm front and warm air is completely lifts up. This is the formation of occluded front. Occlusion starts first at point where warm front is closest to the cold front. Slowly, warm air is pinched off and cold air masses mix up. This eliminates the occluded front and cyclone. The life span of a cyclone is about 5 to 7 days.



First Stage: (Open stage) Cold and warm Air Masses move almost parallel to each other and the fronts are localised.

Second Stage: The cold and warm airmass attempt to force their entry into each other's territory. Therefore the fronts have become a zone of conflict.

Third Stage: On account of the rising of warm airmass a low pressure centre develops. The air moves towards the low pressure centre forming whirlwinds. As a result a cyclone develops. Cold and warm fronts too have been fully developed.



Fourth Stage: On account of great surge ahead of cold front both fronts are coming closer and warm front is shrinking away.

Fifth Stage: Warm front is riding over the cold front. It is called occluded front. It is the end stage of a cyclone.

Sixth and last stage: The warm front has dissolved. Warm and cold Air Masses move in opposite direction on both sides of polar front. This is the end of a cyclone.

In winters, northern India receives precipitation from temperate cyclones. Upper air westerlies, that flow from west to east, drive the low pressure depressions in the sub-continent. These depressions are formed in the Mediterranean region and Atlantic Ocean. These are called western disturbances in the Indian subcontinent. These disturbances decline with the passing away of winters.

An increase in the prevailing night temperature indicates the arrival of these depressions. Western disturbances carry moisture that gets dumped as snow over the higher reaches of the India as it passes over and as rain over the northern plains. Such rainfall is beneficial for the Rabi crop. Western disturbances also trigger cold waves in north India.

Student Notes:

Student Notes:

5. Recently, North America was badly affected by a cold wave – a fallout of the Polar Vortex. What do you understand by Polar Vortex? How does it affect ozone depletion?

Approach:

- Discuss vortex with its characteristic and place of formation
- Describe Vortex role in providing favourable conditions in depletion of ozone

Answer:

The polar vortex is a circulation of strong, upper-level winds that normally surround the poles in a cyclonic fashion with a low pressure system. It tends to keep the bitter cold air locked in the Arctic and Antarctic regions and prevent warm ozone rich air from outside these regions into it from penetrating. These are located in the upper troposphere and lower stratosphere. These gets strengthen in the winter and weaken in the summer due to their reliance upon the temperature differential between the equator and the poles. It is not a single storm. Extra-tropical cyclones that occlude and migrate into higher latitudes create lows within the polar vortex.

When the polar cyclone is weak, the general air flow pattern across mid-latitudes buckles and significant cold outbreaks occur. The upper-level winds that make up the polar vortex change in intensity from time to time. When those winds decrease significantly, it can allow the vortex to become distorted, and the result is a jet stream that plunges deep into latitudes towards equator, bringing the cold, dense air spilling down with it. A cold air outbreak caused by the polar vortex is much more widespread and lasts longer than a single storm as recently was seen in the North America.

Ozone depletion over Antarctica occurs within the polar vortex, which reaches to maximum in the spring of Southern Hemisphere. Ozone depletion is caused by active chlorine which catalyzes the destruction of ozone by reaction with it. The **polar stratospheric clouds** present in the polar stratosphere supports chemical reactions that produce this active Chlorine. These clouds can only form at temperatures below about −80 °C. Polar vortex is strong generally in the southern hemisphere. It helps in keeping the extremely cold air within the Antarctic region and do not let it mix with surrounding warm air. Ozone hole replenish itself, when the polar vortex breaks down allowing air outside the Antarctic to penetrate into the Antarctic.

bhagn2@gmail.com

Whereas Antarctic ozone hole appears every year, a smaller **Arctic ozone dent** appears in summers of northern hemisphere. Temperature of polar vortex over arctic is not very low because there is greater air exchange between the Arctic and the mid-latitudes. The cold air outbreak from arctic polar vortex is a frequent phenomenon. Such outbreaks affect weather of high-latitude areas of Europe and North America.

6. Describe the salient features which characterize tropical cyclones. Why, with only about 6 % of world tropical cyclones, the Indian sub-continent is one of the worst cyclone affected areas of the world?

Approach:

- The first part of the answer must address as to what a tropical cyclone is. Salient features in brief are to be put forward.
- Second part would have to mainly elaborate upon conditions prevailing in form of: local topography, population density etc.

Answer:

Cyclones developing in the regions lying between Tropic of Cancer and Capricorn are called tropical cyclones which are not regular like extra tropical or temperate cyclones. There salient features are:

Student Notes:

- **Varying size:** Average diameter range between 80- 300 km.
- **Varying velocities:** Average speed varies from 32 kmph in case of weak cyclone to more than 200 kmph in case of hurricanes.
- More vigorous and move with higher speed over oceans and ultimately die out after reaching interior portions of continents (result – affects only coastal areas)
- Isobars are fewer in number and circular in nature as a result of which winds rush up towards centre and attain higher velocities.
- No temperature inversion in various parts because they are not the result of warm and cold fronts.
- Tracks vary considerably as they are controlled by multitude of factors like trade winds, coriolis force and occasional interaction with westerlies.
- Confined to largely summer season only as they need continuous warm water supply to maintain the energy for the cyclone to develop.

The reasons behind Indian sub-continent being one of the worst effected regions are:

The primary reason is high risk and increased vulnerability which results in a natural hazard turning into a disaster. Other reasons are:

- Most of the countries of the region are developing or under-developed countries. As a result they suffer from poor infrastructure which abets their vulnerability.
- Higher population density and a large population living close to the coast. e.g. Cyclone Aila in Bangladesh and India
- Poor Disaster Management Framework. This gets manifested in the form of:
    - Lack of appropriate and fool proof Early Warning systems
    - Poor emergency response owing to understaffed Disaster Management agency and lack of coherent implementation of plan
    - Rehabilitation and recovery lack long-term approach.

7. What do you understand by heat balance or heat budget in meteorology? Also explain its importance in deciphering the climate change phenomenon.

Approach:

singh.m7@gmail.com

- Question seeks explanation on earth heat balance not on latitudinal heat balance. Answer should be supplemented with sufficient facts as question is very basic.
- Describe effect of Green House Gasses on heat balance and how it impacts climate on earth.

Answer: **[Student Note:** Answer discusses the issue in detail.]

There has been a perfect balance between incoming heat absorbed by earth and outgoing heat escaping from it in the form of radiation. If the balance is disturbed, then earth would get progressively warmer or cooler with each passing year. This balance between incoming and outgoing heat is known as Earth's heat budget.

Mechanism of heat balance

Insolation is primary source of energy for earth atmospheric system. Consider that the insolation received at the top of the atmosphere is 100 units. But while passing through the atmosphere some amount of this solar energy is reflected, scattered and absorbed by clouds, dust particles and ice. Only the remaining part reaches the earth's surface.

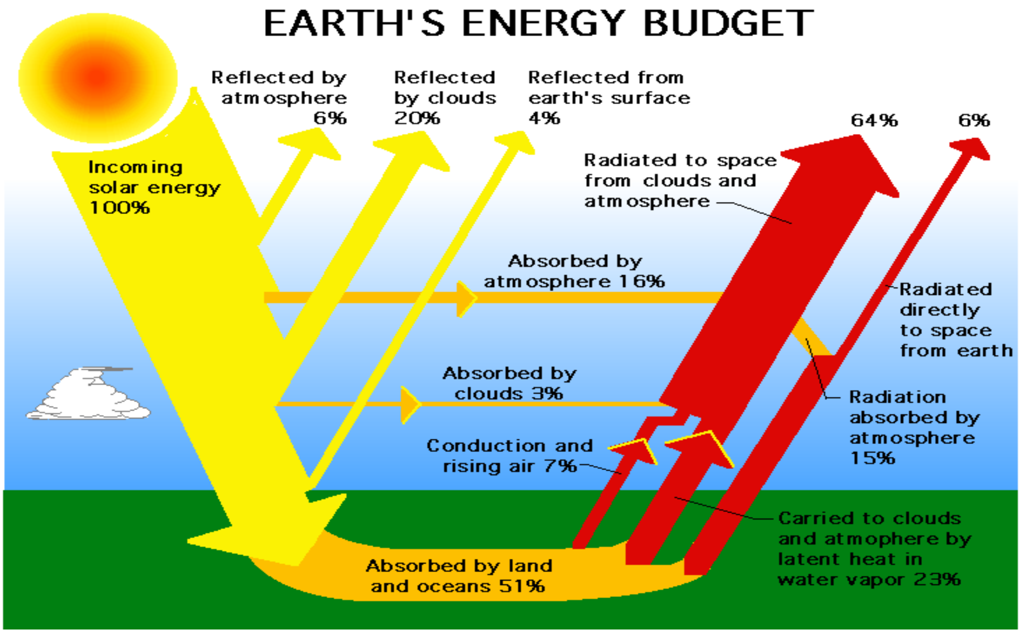
Amounts lost through scattering and reflections are:

a) Through Clouds- 27 units
b) By dust particles – 6 units
c) By Ice Caps and Glaciers- 2 units

Total 35 units are reflected back into space which is known as albedo of earth.

Now, the units received by earth and its atmosphere = 100- 35 = 65 units

These remaining 65 units are absorbed, 14 units within the atmosphere and 51 units by the earth's surface.



Student Notes:

The earth radiates back 51 units in the form of terrestrial radiation. Of these, 17 units are radiated to space directly and the remaining 34 units are absorbed by the atmosphere (6 units absorbed directly by the atmosphere, 9 units through convection and turbulence and 19 units through latent heat of condensation). 48 units absorbed by the atmosphere (14 units from insolation +34 units from terrestrial radiation) are also radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is 17+48=65 units which balance the total of 65 units received from the sun. This is termed the heat budget or heat balance of the earth. This explains why the earth neither warms up nor cools down despite the huge transfer of heat that takes place.

bhagn27@gmail.com

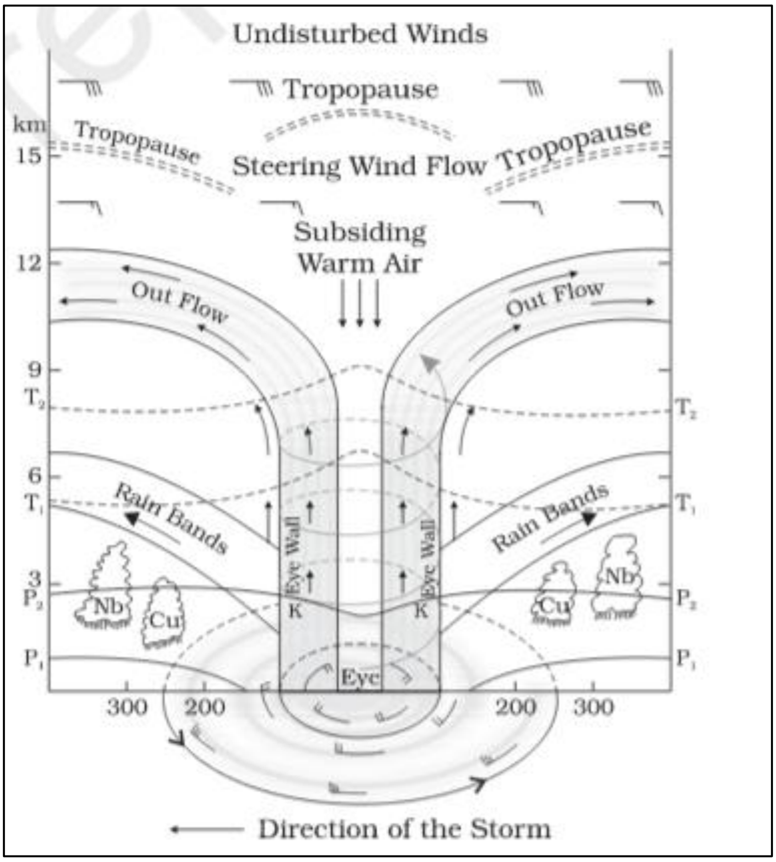
Significance of the concept of heat budget

It is important to keep track of the Earth's radiation budget because the production of greenhouse gases seems to be affecting the natural balance. The atmosphere is highly selective in its absorptive properties i.e. all gases cannot absorb all ranges of radiation. The major atmospheric gases (oxygen and nitrogen) are transparent to incoming sunlight, and are also transparent to outgoing thermal infrared. However, water vapour, carbon dioxide, methane, and other trace gases (referred as Greenhouse gases) are opaque to many wavelengths of thermal infrared energy. They absorb thermal infrared energy radiated by the surface. This has a very important insight into how atmospheric heating can change if the component of these greenhouse gases increases. Any abnormal rise in proportion of these gases can create serious problem of global warming.

Thus heat budget is not only an insight into how balance is maintained but also throws light into how the balance can be disturbed. In heat budget perspective we understand the role of different components and processes and how they operate in unison. Researchers with an interest in climate science use the heat budget in their calculations and projections to learn more about current weather patterns and to predict what may emerge in the future.

8. ***Why do tropical cyclones originate over the seas?***

Answer:



Tropical cyclones originate and intensify over *warm tropical oceans.* The conditions favourable for the formation and intensification of tropical storms are:

- *Large sea surface temperature* with temperature higher than 27^0 C that can release enormous latent heat.
- Presence of *Coriolis force* that can prevent filling of low pressure at the centre (absence of Coriolis force near the equator prohibits the formation of tropical cyclone between 0° -5° latitude).
- Small variations in the vertical winds, which disturbs the vertical transport of latent heat
- Pre-existing weak low pressure area.
- Upper divergence above sea level system.
- Unstable condition through the troposphere that creates local disturbances around which a cyclone develops.

The energy that intensifies the storm, comes from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. With continuous supply of moisture from the sea, storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates.

9. ***How does the latitude and tilt in the axis of rotation of earth affect the amount of radiation received at the earth's surface?***

Approach:

Focus should be on the explanation of seasonality

Student Notes:

Student Notes:

Answer:

The axial tilt angle of Earth affects climate largely by determining which parts of the earth get more sunlight during different stages of the year. This is the primary cause for the different seasons.

The earth moves around the sun in an elliptical fashion. When the Northern Hemisphere is tilted towards the sun, the Southern Hemisphere is tilted away from the sun. This leads to summer in the Northern Hemisphere and winter in the Southern Hemisphere as the Northern Hemisphere experiences the most direct sunlight and solar heating.

During winter in the Northern Hemisphere, the Southern Hemisphere is tilted towards the sun, which now experiences summer. It takes in more of the sun's rays than the Northern Hemisphere, and the days last longer in the Southern Hemisphere. Meanwhile, in the Northern Hemisphere, the days become shorter and the temperatures become cooler. The sunlight is weaker and less direct, so there is less energy being absorbed by the earth and atmosphere.

Thus if there were no axial tilt then there would be no change in the seasons from year to year. On the other hand, if Earth's axial tilt angle was great (45+ degrees), the seasonality of each hemisphere, individually, would be highly exaggerated.

10. What do you understand by shifting of wind belts? Illustrate their impact on climate of a region.

Approach:

Reasons for shifting of wind belts should be explained in brief. Then taking examples, show the climate changes that occur in due to this shifting.

Answer:

With the shifting of the position of sun, the insolation belts make a corresponding shift. This results in the north-south displacement of temperature belts. Since pressure and wind belts are largely controlled by the position of the sun, they are also displaced north and south with the apparent movement of the sun. During the summer months in the Northern Hemisphere, maximum insolation is received north of the equator. This condition causes the pressure belts to move north as well, and the wind belts of both hemispheres shift accordingly. Six months later, when maximum heating is taking place south of the equator, the various wind systems have migrated south in response to the migration of the pressure systems.

Regions occupying an intermediate position between different wind belts are affected by the seasonal migration of prevailing winds more than any other region. Such regions are brought under the influence of different air masses in different seasons of the year.

The region lying between latitudes 5° to 15° experiences two types of climatic conditions during a year. In summer, this region lies in the equatorial trough of low pressure and the inter-tropical convergence zone with abundant precipitation. But during the winter season, when all the wind belts move a few degrees towards the equator, the region comes under the influence of dry subtropical high and the trade winds. Thus, in this region the wet season alternates with dry season.

The second region in both the hemispheres lies between latitudes 30° to 40° where there is an alternation of moist and stormy winters and dry summers. During the high sun period, the above region comes under the influence of the calm and steady high-pressure system. Then the weather is fair and warm, and the skies are almost cloudless.

Student Notes:

But with the equator-ward migration of pressure - and wind-belts in winter, the region experiences the middle-latitude stormy westerlies with travelling cyclones and fronts which produce fairly large amount of winter precipitation. But such a type of alternation of dry summers and moist winters is restricted to the western sides of the continents only. The Mediterranean regions offer the best example of regions located within a zone of transition between two opposite wind systems.

The third region is located in a transition zone lies between latitudes 60° to 70". This region occupies the sub-polar low-pressure belt lying between the westerlies and the polar easterlies. It is because of the seasonal migration of wind belts that in winter this region experiences the outbursts of cold polar air, while during the summer months it comes under the influence of mill latitude stormy westerlies which bring in the warm tropical air.

11. Illustrate the socio-economic significance of local winds across the world with special emphasis on India.

Approach:

The Answer should introduce the concept of local wind briefly followed by examples of prominent local winds and their socioeconomic impact. Local winds in India should receive relatively detailed attention.

Answer:

Local Winds also known as named winds circulate in narrow areas, as compared to planetary winds, and develop due to local variations in temperature, pressure and humidity. Local terrain has a very strong influence on local winds. Their formation can also be attributed to formation of air currents, crossing mountain ranges, valleys and physical barriers. These can be regular or periodic and influence human health as well as socioeconomic activities.

Chinnook: are foehn winds in the interior West of North America. It can dry out soil and sublimate snow very quickly that's why also called the "snow-eater".They sometimes cause a sharp increase in the number of migraine headaches suffered by the locals, and are often called "chinook headaches".Chinooks can often override cold air in the city, trapping the pollutants in the cold air and causing inversion smog

chiragn21@gmail.com

Santa Ana: The Santa Ana winds are strong, extremely dry down-slope winds that originate inland and affect coastal Southern California and northern Baja California. The winds are known especially for the hot dry weather that they bring in the fall, and are infamous for fanning regional wildfires and hence also called the devil winds.

Khamsin: is a dry, hot, sandy local wind, blowing from the south, in North Africa and the Arabian Peninsula. Similar winds in the area are sirocco and simoom. These dry, sand-filled windstorms often blow sporadically over fifty days, hence the name.Carrying great quantities of sand and dust from the deserts it impacts health and day to day activities.

The Mistral: is a strong, cold and northwesterly wind that blows from southern France into the Gulf of Lion in the northern Mediterranean. It is usually accompanied by clear, fresh weather, and it plays an important role in creating the climate of Provence in France.The mistral has the reputation of bringing good health, since the dry air dries stagnant water and the mud, giving the mistral the local name mange-fange ("mud-eater"). It also blows away pollution from the skies over the large cities and industrial areas.

Student Notes:

KalBaisakhior calamity of the month of Baisakh is a dry local wind of west Bengal, Assam, Bangladesh and parts of Orissa and Bihar during summer season. It is responsible for heavy rain and hailstones in West Bengal, Assam and Orissa. These winds also known as 'Northwesters', cause destruction to life and property due to sudden rise in wind speed, lighting, thunder and hail. However, rain associated with the storm although small in amount, is extremely helpful for the pre-kharif crops like jute, paddy and large number of vegetables and fruits. It is good for the tea crop in Assam and the jute and rice in West Bengal

Aandhi: During the pre-monsoon season, northwest and adjoining central India is usually affected by dust storms. These winds add todiscomfort and can disrupt the lives of the people by uprooting houses, trees, telephone and electricity poles. These are harmful for mango crops.

Loo: is a hot, dry wind, that blows in Northern plains. It is very common in Bihar, Western Uttar Pradesh, Punjab and Haryana. It makes life miserable for the people. The heat wave takes its toll and many people die because of it.

Mango showers: occurs along the coast of Kerala. The showers prevent the mangoes from dropping prematurely from trees and are crucial for the mango cultivation in South India.

Cherry Blossom or Coffee showers: is a local wind that blows over the interior Karnataka during the hot weather season and is extremely helpful for coffee cultivation.

12. Explain the phenomenon of Anticyclones. Why are they called weatherless phenomena?

Approach:

- Explain what anticyclones are.
- How and where they are formed.
- Weather associated thus explaining that they are weather less phenomena.

Answer:

ghaan27@gmail.com

Anticyclones are wind systems which have highest pressure at centre and lowest at outer margins.

- Winds blow from centre to outer side in clockwise direction in northern hemisphere and anticlockwise direction in southern hemisphere.
- They are common in subtropical high pressure belts and are practically absent in tropics.
- They are much larger than temperate cyclones.
- They do not have fronts.

They cause stability because air descends from upper altitudes towards centre of anticyclone. It results in rainless weather because precipitation occures when there is rising of air in atmosphere causing unstability. This is why they are called weatherless phenomenon.

13. What are air masses? How are they classified? Discuss their role in frontogenesis.

Approach:

- Briefly define air masses.
- Describe how they are classified.
- Describe the process of frontogenesis and explain in some detail the role of air masses in it.

Answer:

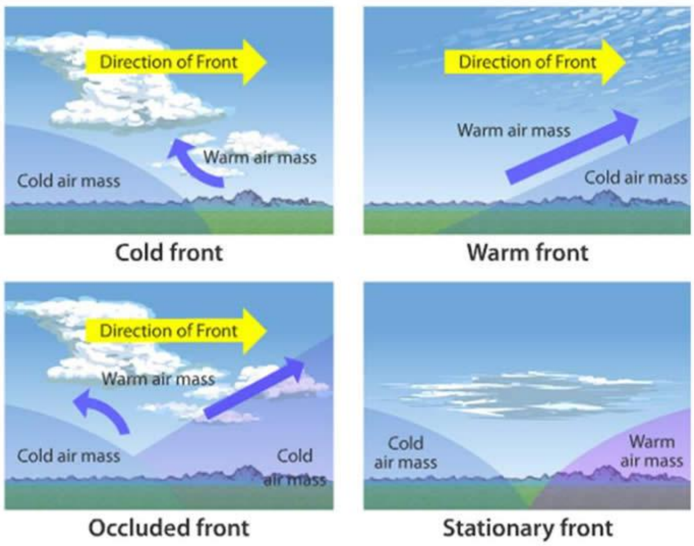
- When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area.
- This air with distinctive characteristics in terms of temperature and humidity is called an air mass.
- It is defined as a large body of air having little horizontal variation in temperature and moisture.

Classification of airmasses

- The air masses are classified according to their source regions.
- There are five major source regions.
    - Warm tropical and subtropical oceans;
    - The subtropical hot deserts;
    - The relatively cold high latitude oceans;
    - The very cold snow covered continents in high latitudes;
    - Permanently ice covered continents in the Arctic and Antarctica.
- Accordingly, following types of airmasses are recognised:
    - Maritime tropical (mT);
    - Continental tropical (cT);
    - Maritime polar (mP);
    - Continental polar (cP);
    - Continental arctic (cA).

Airmasses and Frontogenesis

- When two different air masses meet, the boundary zone between them is called a front. The process of formation of the fronts is known as frontogenesis.
- There are four types of fronts: (a) Cold; (b) Warm; (c) Stationary; (d) Occluded.
- When the front remains stationary, it is called a stationary front.
- When the cold air moves towards the warm air mass, its contact zone is called the cold front, whereas if the warm air mass moves towards the cold air mass, the contact zone is a warm front.



- If an air mass is fully lifted above the land surface, it is called the occluded front.

The fronts occur in middle latitudes and are characterized by steep gradient in temperature and pressure. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation.

Student Notes:

14. *What do you understand by seasonal shifting of pressure belts? What impact does it have on the formation of various climatic regions across the globe? Discuss its socio-economic significance.*

Student Notes:

Approach:

- To start with, directly explain shifting of pressure belts and its cause.
- Link various climatic phenomena with associated regions which are influenced by shift of the belts
- Discuss socio-economic significance through their impact on livelihood.

Answer:

Pressure belts on earth's surface appear to move along with the Sun. This is because of inclination of earth to its axis. With the apparent shift of the Sun between the tropics, both the thermally formed pressure belt (EQLP) and the dynamically formed pressure belt (STHP - North and South) move along. For example, in summers, when Sun is directly above tropics, rather than at equator, the entire belt system (EQLP and STHP) shifts northwards. As such, the High Pressure belt which is generally found at 25-30 degrees latitude also shifts northwards to up to 30-35 degrees. Similarly the Equatorial low also shifts upwards, varying considerably over the landmass and the ocean. On the Indian landmass, it can reach up to 20-22 degrees North because of immense heating of North Indian landmass and the consequent low pressure. On Oceans, the belts are fairly stable because the variances in temperature are not much pronounced.

Impact on formation of climates:

- Most significant impact is in form of inhibition of cloud formation under the HP Belt. As HPBs move over an area, it experiences lesser rainfall.
- STHP lies over Mediterranean region in summers, leading to aridity. When it moves south along with the apparent shift of the Sun, the region receives rainfall. During winters, Westerlies prevail and cause rain, where as in summers, the dry trade winds blow offshore.
- On Monsoon: Only on the northward shifting of the EQLP in the form of ITCZ (Inter-tropical Convergence Zone) do the south-east trade winds cross the equator and reach as monsoon winds.
- Besides convergence, convectional uplifting which causes rainfall in the northern plains also occurs in the shifted EQLP i.e. ITCZ.
- Sahara desert remains almost entirely in the region where STHP is found. The edges of Sahara experience some rainfall and therefore a transitional climatic zone has developed there.

Socio-economic significance:

- Mediterranean climate is conducive for growing citrus fruits and therefore it has developed as major supplier of fruits as well as wine worldwide.
- Similar climate in Natal (South Africa), Southern Australia and California has given to similar social setup there based on vineyards and fruit production.
- Monsoon determines the socio-economic setup of India via its agricultural economy.

15. Despite continuous incidence of solar energy, earth's average temperature remains almost constant. Explain the reasons behind this. In this regard, discuss the heat budget of earth and enumerate the factors that control the distribution of temperature on earth's surface.

Student Notes:

Approach:

- With the help of concept of heat budget, discuss how earth is balancing out incoming and outgoing solar energy.
- Then discuss how earth's average temperature remain constant.
- Then briefly discuss factors that control the distribution of temperature on earth's surface.

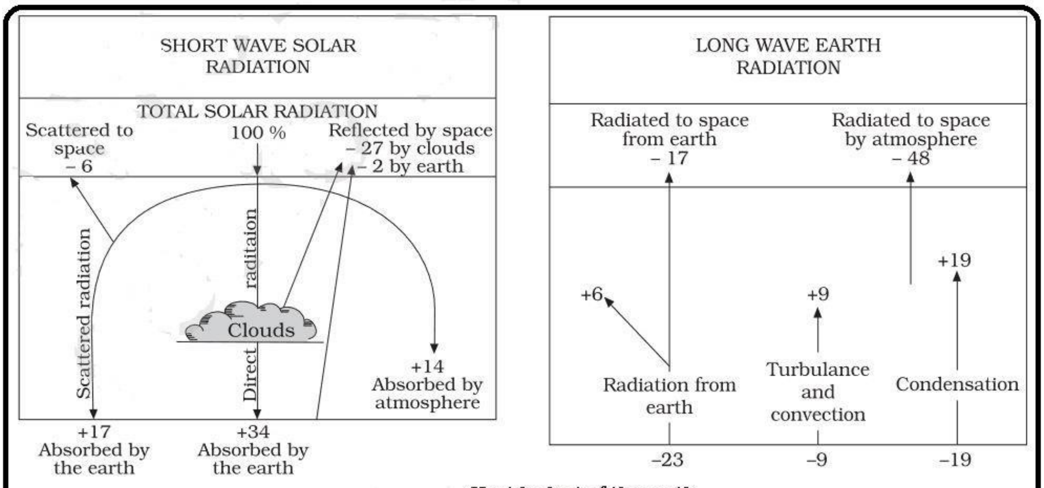
Answer:

Despite continuous incidence of solar energy, the earth as a whole does not accumulate or lose heat. Incoming heat being absorbed by the Earth in the form of short wave radiations and outgoing heat escaping the Earth in the form of long wave radiation are balanced. This balance is known as Earth's heat budget.

Earths Heat Budget:

Considering that the insolation received at the top of the atmosphere is 100 percent. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed. Only the remaining part reaches the earth's surface.

- Roughly 35 units are reflected back to space even before reaching the earth's surface owing to albedo effect of clouds and snow and ice covered surfaces.
- The remaining 65 units are absorbed, 14 units within the atmosphere and 51 units in the form of terrestrial radiating i.e. long wave radiation.
- Of this 17 units are radiated to space directly and remaining 34 units are absorbed by the atmosphere.
- 48 units absorbed by the atmosphere (14 from insolation + 34 units from terrestrial radiation) are also radiated back into space balancing 65 units received.



Heat budget of the earth

Factors that control the distribution of temperature on earth's surface:

- **Earths Heat Engine-** There are variations in the amount of radiation received at earth's surface due to nearly spherical shape of the earth. Thus, there is surplus of net radiation balance between 40 degree North and South though the regions near the poles have deficit. However, atmospheric and oceanic systems (viz. global wind system and Ocean currents) work to even out solar heating imbalances, collectively

Student Notes:

called Earth's heat engine, by taking away heat from surplus region to the deficit one.

- **Latitude-** as latitude increases from equator towards poles, insolation decreases.
- **Altitude-** The atmosphere is indirectly heated by terrestrial radiation from below thus making the places near the sea level hotter than the places situated at higher elevations.
- **Distance from sea-** Compared to land, the sea gets heated slowly and loses heat slowly. The places situated near the sea come under the moderating influence of the sea and land breezes.

16. What are air masses? Highlight their role in affecting the local climate.

Approach:

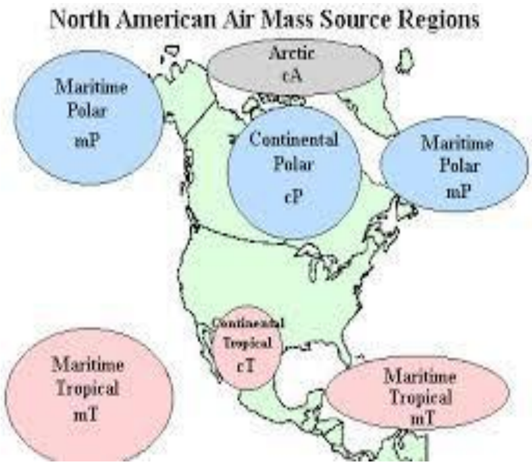
- In the introduction define and explain the formation of air masses.
- Also mention the types of air masses.
- Then discuss how various air masses influence the local climate.

Answer:

Air Masses: When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains. The air with distinctive characteristics in terms of temperature and humidity is called an air mass.

The homogenous surfaces, over which air masses form, are called the source regions. The air masses are classified according to the source regions. Tropical air masses are warm and polar air masses are cold. There are five major source regions. These are:

- Warm tropical and subtropical oceans
- The subtropical hot deserts
- The relatively cold high latitude oceans
- The very cold snow-covered continents in high latitudes
- Permanently ice-covered continents in the Arctic and Antarctica.



Accordingly, following types of air-masses are recognized:

- Maritime tropical (mT
- Continental tropical (cT)
- Maritime polar (mP)
- Continental polar (cP)
- Continental arctic (cA)

Air mass being a large unit of the lower atmosphere exert significant meteorological and climatic influence such as:

- **Change in local weather:** An air mass on the move begins to transform as it passes over new landscapes, while at the same time retaining enough of its original conditions to alter local weather. For example, a cP air mass move south in winters and brings frigid temperatures to the central United States. While dry in its source region, such an air mass often picks up substantial moisture during an early-winter transit of the Great Lakes, allowing it to dump 'lake effect snow' on leeward coasts.

Student Notes:

- **Cyclones and Anti-cyclones:** collision of two air masses leads to formation of fronts. For instance, when polar and tropical air masses merge in the mid-latitudes, prevailing westerly winds funnel along alternating low- and high-pressure centers causing cyclones and anticyclones, respectively.
- **Rainfall:** It also causes precipitation and temperature change in many regions. Maritime-tropical air sourced over warm waters of the Atlantic Ocean, Caribbean Sea and Gulf of Mexico is the main contributor of precipitation for much of North America east of the Rocky Mountains.
- **Cooling effect:** Maritime air masses also contribute to a moderating climatic influence on coastal temperatures, as oceans heat up and cool down more slowly and less dramatically than landmasses.

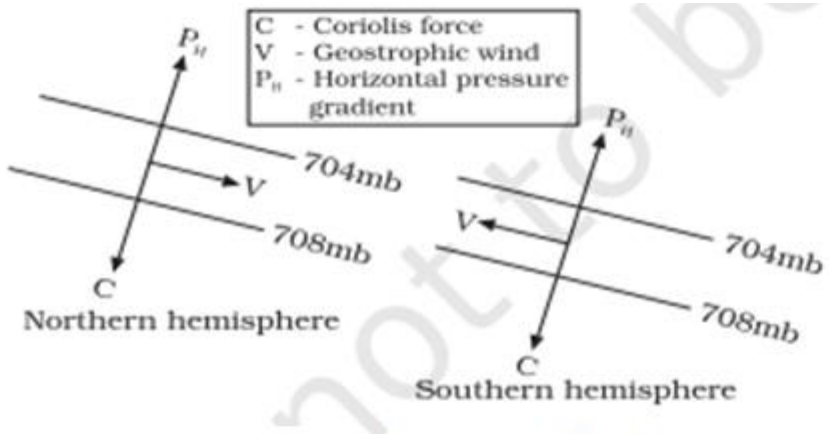
17. ***Describe Geostrophic winds with the help of a diagram. Where and how are they formed? Also, explain how they affect climate.***

Approach:

- Give the definition of Geostrophic winds. Illustrate with a diagram.
- Describe how they are formed.
- Discuss their impact on the weather systems globally.

Answer:

The Geostrophic wind is the theoretical wind that would result from an exact balance between the Coriolis force and the Pressure Gradient Force. As a result, geostrophic wind flows parallel to isobars.



Geostropic Wind

The velocity and direction of the wind are the net result of the wind generating forces. The geostrophic winds are found in the upper atmosphere (2-3 km above the earth's surface) where the frictional effect of the surface is minimal and only the **Pressure Gradient** and the **Coriolis force** act**.** Air naturally moves from areas of high pressure to areas of low pressure, due to the pressure gradient force. As the air starts to move, the Coriolis force deflects it to the right in the Northern Hemisphere, and to the left in the southern hemisphere. In the upper atmosphere, these winds flow at great speeds due to low friction. As the wind gains speed, the deflection increases until the Coriolis and pressure gradient forces are in geostrophic balance.

Impact of Geostrophic winds on climate

1. Jet streams are circumpolar, concentrated bands of meandering geostrophic streams flowing in upper troposphere. They significantly affect weather phenomena globally –

a. Impact the movement of air masses that may cause prolonged flood or drought conditions.

b. Influence the weather of mid-latitudes by influencing the temperate cyclones and the distribution of precipitation.

c. Impact the rainfall pattern in India – steer tropical depressions into India, and transport western disturbances originating over the Mediterranean Sea bringing rain to northwestern regions of India.

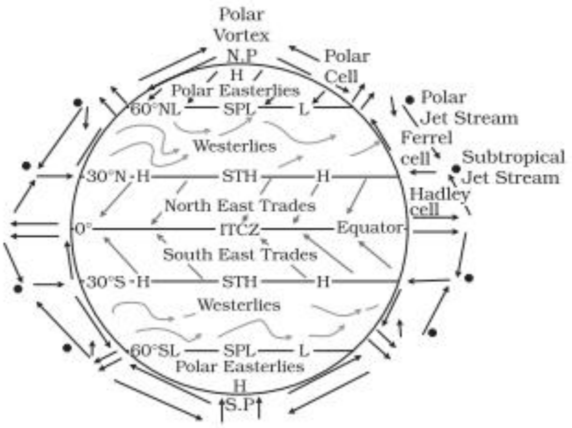


Figure 10. 6 : Simplified general circulation of the atmosphere

2. Geostrophic winds from tropical high pressure to polar low in the upper troposphere flow at great speeds due to low friction and are subjected to greater Coriolis force. So, they deflect greatly giving rise to three distinct cells in atmospheric air circulation – Hadley, Ferrel and Polar cells, instead of one single cell. This impacts the latitudinal heat exchange.

18. Describe the mechanism of formation, movement and dissipation of tropical cyclones. In this context, explain why the recent 'Titli' cyclone was termed as 'rarest of rare' by IMD.

Approach:

- Start with very briefly mentioning the nature of tropical cyclones.
- Describe the mechanism of its formation and movement.
- Explain the factors that cause it to dissipate.
- Discuss the rare feature of Titli cyclone.

simagn27@gmail.com

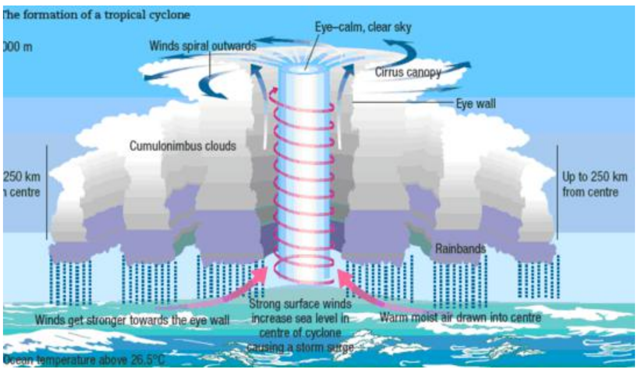
Answer:

A tropical cyclone is a rotational low pressure system in tropics when the central pressure falls by 5 to 6 hPa from the surrounding and maximum sustained wind speed reaches 34 knots (about 62 kmph). They bring about large-scale destruction caused by violent winds, very heavy rainfall and storm surges, thereby making them most devastating natural calamities.

Formation and movement of Tropical Cyclones

Tropical cyclones originate and intensify over warm tropical oceans. The conditions favourable for the formation and intensification of tropical storms are:

- Large sea surface with temperature higher than 27° C;
- Presence of the Coriolis force;
- Small variations in the vertical wind speed;



Student Notes:

- A pre-existing weak low-pressure area or low-level-cyclonic circulation;
- Upper divergence above the sea level system.

Student Notes:

Since, tropical cyclones are part of the trade-winds they move along with the circulation in trade-winds, generally hitting the east coast in the northern hemisphere and the west coast in the southern hemisphere.

Dissipation of tropical cyclones

The energy that intensifies the storm, comes from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. With continuous supply of moisture from the sea, the storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the landfall of the cyclone.

Reasons for Titli Cyclone being termed as 'rarest of rare' by IMD

The recent Titli cyclone which hit Odisha is regarded as the rarest of rare because of its recurvature after landfall. Titli cyclone changed its path after landfall, retained its destructive potential and made a recurvature away from the coastal areas for more than two days. The reason may lie in the point of landfall which was about 20 degree north of the equator.

sihagn27@gmail.com

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PRECIPITATION AND RELATED PHENOMENA

Student Notes:

Contents

sihagn27@gmail.com

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1. Introduction

Student Notes:

Precipitation is vital for life on Earth, but it can also be an inconvenience. Precipitation is any product of the condensation of atmospheric water vapour that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, graupel and hail. Let us first discuss some basic concepts

2. Water vapour

Water is present in the atmosphere in three forms namely – gaseous, liquid and solid.. The water vapour constitute about 2 per cent of the total composition of the atmosphere. This percentage varies from zero per cent in cold dry air of the Arctic regions during the winter season to as much as 5 per cent of the volume in warm humid equatorial regions.

The temperature of the atmosphere is the most important factor, as the capacity of the warm air to hold water vapour is more than that of the cold air. About half of the total moisture present in the atmosphere is concentrated in the lower layer of the atmosphere up to a height of about 2 kilometres.

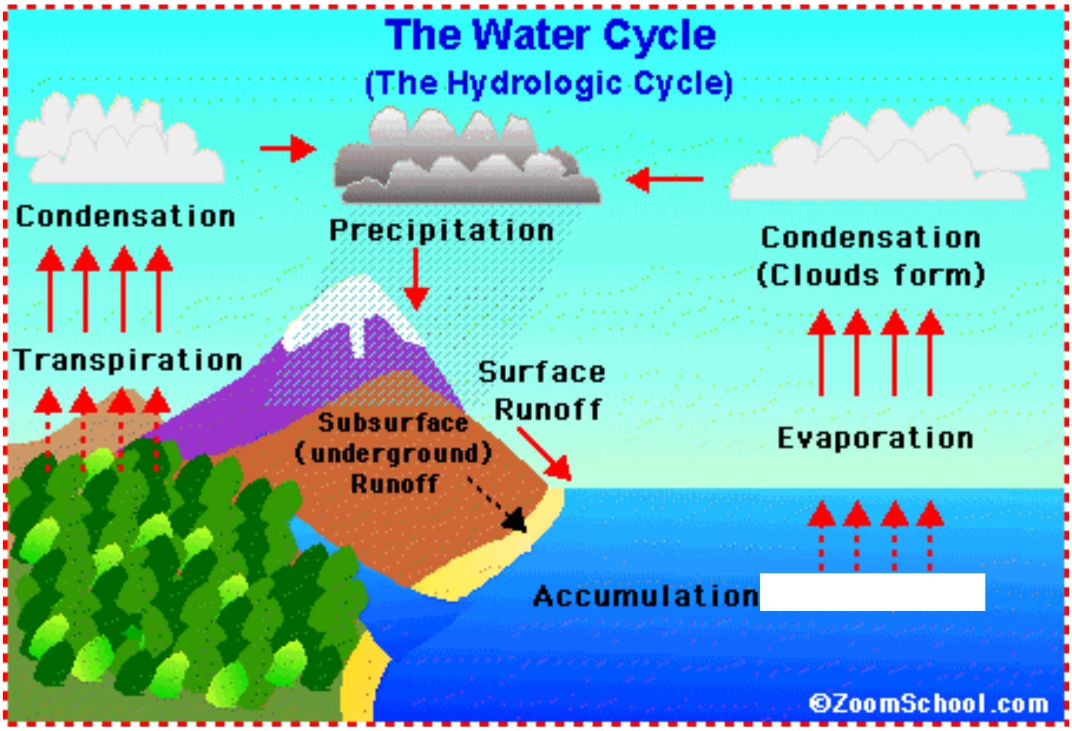
2.1. Importance of Water Vapour

The water vapour present in the atmosphere is an important factor for the weather conditions in a particular region. The amount of water vapour present in the atmosphere influences the nature and amount of precipitation, the amount of loss of heat through radiation from the earth's surface, the surface temperature, the latent heat of the atmosphere, the stability and instability of the air masses. Necessary energy for the development of storms (cyclones, hurricanes etc.) is provided by the water vapour in the form of latent heat energy.

3. The Water Cycle

There is a constant and continuous circulation of water from the Earth's surface to the atmosphere and back to the Earth's surface. This circulation of water is called the water cycle or the hydrological cycle. The water cycle has no beginning or end, rather it is an intricate combination of evaporation, transpiration, air mass movement, condensation, precipitation, run-off and groundwater movement.

The Sun's heat provides energy to evaporate water from the Earth's surface (oceans, lakes, etc.). Plants also lose water to the air (this is called transpiration). The water vapor eventually condenses, forming tiny droplets in clouds. When the clouds meet cool air over land, precipitation (rain, sleet, or snow) is triggered, and water returns to the land (or sea). Some of the precipitation soaks into the ground. Some of the underground water is trapped between rock or clay layers; this is called groundwater. But most of the water flows downhill as runoff (above ground or underground), eventually returning to the seas as slightly salty water.



Student Notes:

4. Humidity

Humidity refers to the amount of water vapour present in the atmosphere at a particular time and place. Humidity in the air is due to the various processes of evaporation from the land and water surfaces of the Earth. It can be expressed as an absolute, specific or a relative value.

4.1. Absolute Humidity

The Absolute Humidity is the **weight** of actual amount of water vapour present in a **unit volume** of air. Generally it is expressed as **grams per cubic meter** of air. The absolute humidity varies from place-to-place and from time-to-time. It decreases from the equator towards the poles. . Generally, the absolute humidity changes as air temperature or pressure changes. However, if temperature increases but there is no excess water for evaporation then absolute humidity will not change.

4.2. Specific Humidity

The Absolute Humidity is the weight of actual amount of water vapour present in a unit weight of air. Generally it is expressed as grams per kilogram of air.

4.3. Relative Humidity

Relative humidity is a better way of expressing the level of humidity in the air. It is the ratio of actual amount of water vapour present in air at a given temperature to the amount of water vapour air can hold at the same temperature. The Relative Humidity is expressed in percentages.

$$Relative\ Humidity = \frac{\begin{matrix}Absolute\ Humidity\\(Actual\ amount\ of\ water\ vapour\ present\ in\ the\ air\ at\ a\ given\ temperature)\end{matrix}}{\begin{matrix}Humidity\ Retentive\ capacity\\(Amount\ of\ water\ vapour\ that\ can\ be\ held\ by\ the\ same\ at\ the\ same\ temperature)\end{matrix}}$$

Generally capacity to hold water vapour increases with increase in temperature and decreases with decrease in temperature. Thus, the relative humidity of the air decreases with increase in

sihagn27@gmail.com

temperature and vice versa Changes in the Relative Humidity of Air[1]

Student Notes:

Changes in Relative Humidity can occur in the following three ways:

I. The temperature remaining the same and amount of water vapour in air increases. Its relative humidity will also increase.
II. When the temperature of air rises its humidity retentive capacity also rises correspondingly and the Relative Humidity decreases.
III. If the temperature of air decreases its humidity retentive capacity also decreases and Relative Humidity increases.

4.3.1. Significance of Relative Humidity

The absolute humidity determines the **amount of precipitation** while the relative humidity tells us about the **possibility of precipitation**. The high and low relative humidity indicates the possibility of wet and dry conditions respectively. Evaporation decreases when there is high relative humidity and vice versa. Relative humidity is directly related to human health. That is why, the equatorial region with high temperature and high relative humidity, and the tropical hot deserts with very low relative humidity are unfavourable for human health.

Absolute Humidity	Relative Humidity
It helps us to know the actual amount of water vapour present in air.	It shows the ratio of water vapour actually present in the air at a given temperature to the retentive capacity of humidity of the same parcel of air at the same temperature.
It does not take temperature into account.	It takes temperature into account.
It is expressed in grams per cubic metre.	It is expressed in percentages.
It Is not a useful measure of humidity because it does not tell us the amount of water vapour required for the air to become saturated.	It is a useful measure of humidity because it can show how far the air is humid.

4.3.2. The Horizontal Distribution of Relative Humidity

The equatorial region is characterized by the highest relative humidity. Relative humidity gradually decreases towards the Tropical high pressure belts (between 25°—35° latitudes) . After this, the relative humidity again increases polewards. The zones of high and low relative humidity shift northward and southward with the apparent migration of the Sun, during the summer and winter solstices respectively. **Relative humidity is maximum in the mornings and minimum in the evenings.**

5. Evaporation

The process of transformation of liquid (water) into gaseous form (water vapour) is called evaporation. The amount and rate of evaporation at a particular place depend upon the aridity (vapour pressure), temperature and the movement of air. Evaporation is faster in dry air than in the wet air. There is more evaporation from the ocean than from the land. A special case of evaporation is **transpiration** which entails loss of water from the leaves and stems of the plants.

[1] If any question based on change of a property(say temperature) is asked consider other factors (say moisture) as constant unless otherwise specified.

Student Notes:

6. Condensation

The process of transforming of water vapour into water (liquid) and ice (solid) is called condensation. Condensation takes place due to the loss of heat and can occur in one of the following ways: a. When the warm moist air rises upwards and expands. b. When the warm moist air comes in contact with the cold surface. c. When the warm moist air mixes with the air coming from the colder regions.

6.1. Latent Heat

At the time of evaporation, heat is absorbed and conserved in water vapour (This is why Evaporation leads to cooling). It is known as latent heat. It is this same heat which is released when water vapour again changes into water through the process of condensation. Latent heat is essential for development of typhoons (storms, cyclones).

6.2. Saturated Air

If at any given temperature the humidity retentive capacity of air equals its absolute humidity the air is said to be saturated. In other words the same parcel of air can no longer absorb or accept any further amount of water vapour at the same temperature. 100 per cent humid air is called saturated air.

6.3. Hygroscopic Nuclei

Condensation always takes place around some particles present in air. These may be dust particles, smoke, oceanic salts or carbon dioxide which act as nuclei to hold water. They are thus called condensation nuclei or hygroscopic nuclei.

6.4. Dew point

Condensation of water vapour in the atmosphere begins when the saturated air mass reaches the dew point. This is level at which the air is not in a position to take up any more moisture. Any further fall in temperature, beyond the dew point, would cause the condensation of the moisture present in the air. In the atmosphere, the nuclei for the condensation of the moisture is provided by the smoke and the dust particles.

sihag...@gmail.com

Once the condensation of water vapour in the atmosphere has taken place, the moisture present in the atmosphere may take one of the following forms— dew, frost, fog, mist, clouds, etc. This will be according to the conditions prevalent in the atmosphere.

7. Dew

When the relative humidity of the air is low, even a drop in temperature during the winter nights fails to saturate the air. Hence condensation does not take place in free air but on some solid objects like leaves, flowers, grass blades, pieces of rocks, etc., which become comparatively cool due to the quick radiation at night. When the cool air comes in contact with these objects, the dew point is reached and condensation takes place. The deposition of water droplets on these objects is called ***dew.***

Some favourable conditions for the formation of dew are the following:

1) **Long Nights**: During long nights earth's surface is cooled. With the coming into contact of humid air with this surface, condensation occurs.
2) **Cloudless Clear Sky**: On account of cloudless and clear sky there is more heating during the day. Hence evaporation will also be more and also rapid cooling of surface at night due to terrestrial radiation.
3) **Calm Air**: Calm air remains in contact with the surface for longer duration. It is a favourable condition for condensation.

4) **Relative Humidity**: High relative humidity promotes more condensation. That is why condensation can be more in the months of August -September in India.

Student Notes:

8. Frost

Frost is actually frozen dew. It is formed when temperature of dew point fall below freezing point. Under such conditions droplets of condensation near or on the ground are frozen. Generally for formation of dew and frost the conditions are similar. Only temperature should fall below freezing point for the formation of frost

Dew	Frost
It can be seen as droplets of water on leaves of small plants or blades of grass.	It can be found on solid surfaces of earth's crust as ice or snow crystal.
It Is formed when temperature of dew point is above freezing point.	It is formed when temperature is below freezing point.
It is useful for plants.	It is harmful for plant growth.

9. Fog

Fog is a special type of thin cloud consisting of very small water droplets which remain suspended in air close to the surface of the Earth. Fog is formed due to condensation of water droplets suspended in the atmosphere in the vicinity of the earth's surface under certain conditions, such as low temperature and high relative humidity.. During the winter season, excessive radiation at night results in the fall of air temperature. The condensation of water vapour takes place around the dust and smoke particles that remain suspended in the air. It is called **fog.** The formation of fog near the surface of the Earth does not involve ascent and consequent expansion of air. The visibility is greatly reduced (less than one km).

Fog is of three types:

1) **Radiation Fog:** The surface is cooled at night due to terrestrialradiation and the air which come into contact with it also gets cooled. Consequently tiny droplets forming the clouds are called radiation fog. It is not very thick and this thickness varies from 10 to 30 metres.
2) **Advection Fog:** It is formed when there is fall in temperature of warm moist air moving horizontally over a cold surface. It is cooled by contact and sometimes by mixing with cold air prevailing over cold surfaces.
3) **Frontal or Precipitation Fog:** The dividing line separating cold and warm air masses are known as fronts. At these fronts convergence of warm and cold air takes place and fog is formed. The warm air in the frontal area is light and rises above the cold air mass. It then begins to cool and when the temperature reaches dew point, frontal fog is formed.

sihagnz7@gmail.com

9.1. Impact of Fog

Fog hinders travel by land, air and sea. When the fog is polluted it becomes poisonous and causes serious health hazards. Agriculture sector is also affected since fog adversely hits late-sowing crops. Fog is beneficial to the tea and coffee plants as it protects them from the scorching sunlight on the hill slopes.

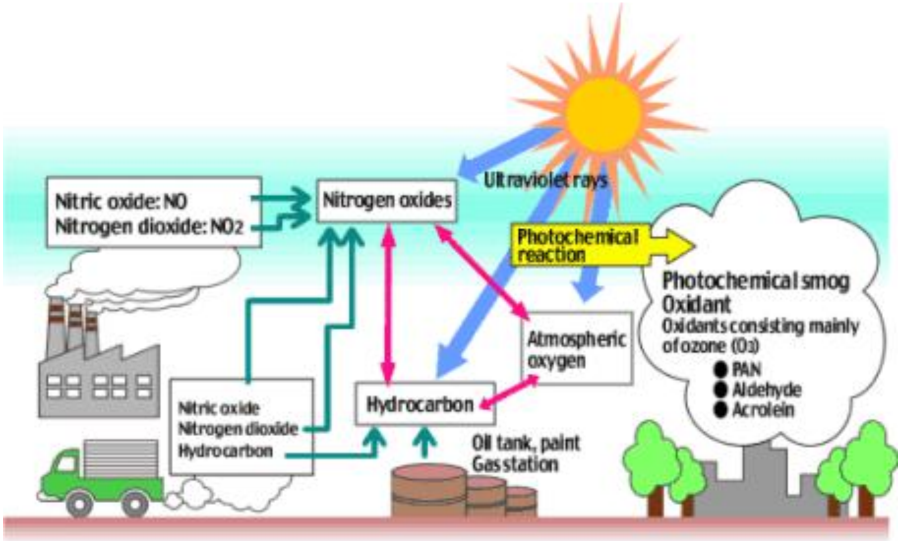
10. Mist

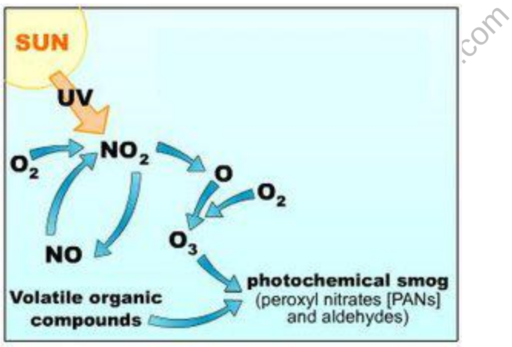
It is also a type of fog but is relatively less dense. The only difference between mist and fog is density and its effect on visibility. A cloud that reduces visibility to less than 1 km is called fog, whereas it's called mist if visibility range is between 1 and 2 km. Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface. Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents. Mist can occur as part of natural weather or volcanic activity or could be created artificially.

11. Smog

It refers to a mixture of smoke and fog. It also results from sun's effect on certain pollutants in the air, notably those from automobile exhaust. There are two main types of smog—photochemical and industrial.

The **photochemical smog** is a mixture of primary and secondary pollutants. The primary pollutants are hydrocarbons and **nitrogen oxides** and their main source is the motor vehicles. The secondary pollutants are formed when sunlight acts upon motor vehicle exhaust gases to form harmful substances such as ozone (O3), aldehydes and peroxyacetylnitrate (PAN). Photochemical smog formation requires (1)a still, sunny day and (2)temperature inversion (pollutants accumulate in the lower inversion layer). The photochemical smog directly affect lungs and eyes, causing irritation in these organs.





FORMATION OF PHOTOCHEMICAL SMOG

The **industrial smog** is a mixture of sulphur dioxide and a variety of solid and liquid particles suspended in air.It comes from the stationary sources, such as furnaces, power plants, etc., than from motor vehicles. Sulphur dioxide in combination with water and oxygen can turn into sulphuric acid in the atmosphere and falls on the earth as acid rain. It can dissolve marble and eat away iron and steel. In human it can affect the respiratory system.

Name:	**Industrial smog** (New York smog, gray smog)	**Photochemical smog** (Los Angeles smog, Denver smog, brown smog)
Weather:	cool, damp	sunny
Content:	particulates, sulfur oxides	NO_x, ozone, hydrocarbons, PAN
Sources:	coal, etc.	gasoline(Petrol), combustion.

Student Notes:

Student Notes:

12. Haze

is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky. The World Meteorological Organization manual of codes includes a classification of horizontal obscuration into categories of fog, ice fog, steam fog, mist, haze, smoke, volcanic ash, dust, sand and snow. Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires. One way to distinguish between smog and naturally-occurring haze is by color. Natural haze is typically white, gray or even blue. Smog is almost always yellowish or brown in color.

The international definition of fog is a visibility of less than 1 kilometre; mist is a visibility of between 1 kilometre and 2 kilometres and haze from 2 kilometres to 5 kilometres . Fog and mist are generally assumed to be composed principally of water droplets, haze and smoke can be of smaller particle size.

13. Atmospheric Brown Cloud (ABC)/Asian Brown Cloud

The ABC originally referred to the enormous blanket of pollution spreading across Asia, distorting normal weather patterns in the region and threatening to devastate many countries' economies. It was called the 'Asian Brown Cloud' in 2002, when a UN report first warned of this layer of pollution comprising ash, acids and aerosols. At that time, the two-mile thick haze extended ominously across the most densely populated areas of the world: southern, south-eastern, and eastern Asia. Subsequently, however, similar patterns were detected elsewhere in the world and it was renamed 'Atmospheric Brown Cloud'.

Asia is particularly vulnerable as the ABC causes changes in the winter monsoon season, sharply reducing rain over northwestern parts of the continent and increasing rain along the eastern coast. However, India's scientific community have said the atmospheric brown clouds over Asia are a seasonal, temporary phenomena which may look bad, but have none of the catastrophic implications mentioned in the UN report.

sbhagn2@gmail.com

14. Clouds

When the moist air ascends, it expands, loses temperature, becomes cool, and gets saturated. With further decrease in temperature beyond the dew point, condensation of the moisture takes place high up in the air and it results in the formation of clouds. **Clouds are droplets of water or tiny ice crystals which collect around the dust particles present in the atmosphere**. The water droplets and tiny ice crystals that remain suspended in the air can be disturbed by the slightest movement of the air. **All forms of precipitation occur from the clouds**. It should be noted that **not all clouds yield precipitation but no precipitation is possible without the clouds**. The clouds play a major role in the heat budget of the Earth and the atmosphere, as they reflect, absorb and diffuse some part of the incoming solar radiation. They also absorb a part of the outgoing terrestrial radiation and then re-radiate it back to the Earth's surface. Whenever there are clouds in the sky, some sort of precipitation always occurs, although we do not feel it on the Earth. Much of it is re-evaporated during its descent through the warm and dry air. Clouds are more common on the windward slopes of the mountains than on the leeward slopes. Clouds are more frequent during the cyclones than during the anticyclones.

15. Types of Clouds

Luke Howard, an English biologist, was the first to classify clouds in 1803. He used Latin names which are still in vogue. Clouds are usually classified on the basis of altitude, shape, expanse, density, colour, transparency, opaqueness, moisture content, etc. They exist at various elevations from the sea level to about 20 km above the sea level. There are three basic groups depending upon the height and shape of clouds. These are the **cirrus clouds**, the **cumulus clouds** and the **stratus clouds**.

Student Notes:

15.1. Cirrus (Curl of Hair) Clouds

Cirrus clouds are formed at high altitudes (8,000 - 12,000m). Being at considerable height these clouds are formed of **ice crystals** and therefore are **white** and **thin**. They are detached, fibrous, **feathery**, often with silky sheen in direct sunlight.

15.2. Cumulus (Heap) Clouds

Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000 -7,000 m. They exist in patches and can be seen scattered here and there. With a flat base on rising they appear like domes at the top. Their appearance and structure is like that of a Cauliflower.

15.3. Stratus (Layer) Clouds

As their name implies, these are layered clouds covering large portions of the sky. These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

The rain bearing clouds are generally the low level clouds and are given the prefix or suffix- 'nimbus', a Latin word meaning a rainy cloud.

Note: Whichever clouds you see in the sky these might be one or more of their types or their combinations or even in changed appearances.

16. International Classification of Clouds

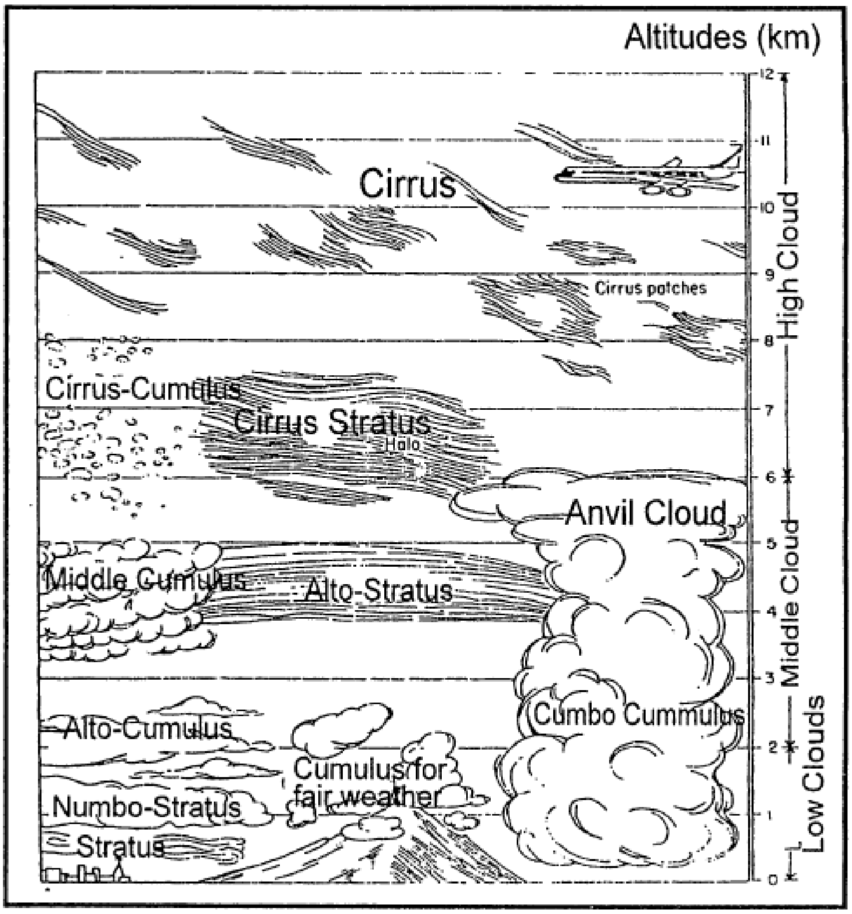
The World Meteorological Organisation presented a detailed International Atlas of Clouds mentioning three main groups and ten main types of clouds.

Cloud Group	Height in meters	Cloud Types	
High Clouds = **Cirrus**	6000-12000	1. Cirrus 2. Cirrostratus[2] 3. Cirrocumulus	High-level clouds form above 6,000 meters and since the temperatures are so cold at such high elevations, these clouds are primarily composed of ice crystals. High-level clouds are typically thin and white in appearance, but can appear in a magnificent array of colors when the sun is low on the horizon.
Middle Clouds = **Alto**	2000-6000	4. Altostratus 5. Altocumulus	The bases of mid-level clouds typically appear between 2,000 to 6,000 meters. Because of their lower altitudes, they are composed primarily of water droplets, however, they can also be composed of ice crystals when temperatures are cold enough.

[2] Sun's Halo is produced by the ice crystals in cirrostratus clouds high (5–10 km) in the upper troposphere.

Student Notes:

Low Clouds = **Stratus**	below 2000	6. Stratus 7. Stratocumulus 8. Nimbostratus	Low clouds are of mostly composed of water droplets since their bases generally lie below 2,000 meters. However, when temperatures are cold enough, these clouds may also contain ice particles and snow.
Clouds with Vertical Growth	9. Cumulus 10. Cumulonimbus		Probably the most familiar of the classified clouds is the cumulus cloud. Generated most commonly through either thermal convection or frontal lifting, these clouds can grow to heights in excess of 12,000 meters, releasing incredible amounts of energy through the condensation of water vapor within the cloud itself.
Special Clouds	Mammatus Lenticular Fog Contrails		



17. Precipitation

The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as *precipitation*. This may take place in liquid or solid form. The precipitation in the form of water is called ***rainfall***, when the temperature is lower than the 0^0C, precipitation takes place in the form of fine flakes of snow and is called ***snowfall***. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Usually the amount of snowfall is included in the rainfall figures. Besides rain and snow, other forms of precipitation are *sleet* and *hail*, though the latter are limited in occurrence and are sporadic in both time and space.

Student Notes:

Sleet: Snow is not frozen rain. The term **sleet** is used for the frozen raindrops and the re-frozen melted snow water in the cold layer of the air near the Earth's surface. Sleet also refers to a mixture of snow and rain.

Hailstones: Sometimes, drops of rain after being released by the clouds become solidified into small rounded solid pieces of ice and which reach the surface of the earth are called *hailstones*.

Hailstone mostly in the cumulo-nimbus clouds. Small droplets of water are formed in the lower part of the clouds due to condensation. Many of these small droplets join together to form large ones. The strong rising convection current carries these raindrops to the higher levels, which causes freezing and gives rise to small ice pellets. The strength of the vertical current is highly variable. Thus the ice pellets are not taken up continuously. They fall for some distance, slightly melt at the lower levels and are carried up again. This happens several times until the weight of the ice pellets becomes so heavy that they cannot be carried up by the current. Ultimately these ice pellets fall as hailstones on the Earth. Hailstones have several concentric layers of ice one over the other. The size of the halistones depends upon the amount of ice it collects during its ascent and descent in the atmosphere by the convection current.

Hailstones occur widely in the world, except in the polar regions, the hot deserts and the equatorial region. The occurrence of hailstones is common during the spring and the early summer in the sub tropical and the temperate regions.

18. Necessary Conditions for RAINFALL

(a) there should be sufficient amount of evaporation from the water bodies (airmass must be saturated with water vapour)
(b) there should be wind to carry the water vapour from one place to another, and
(c) there should be some way of decreasing the temperature of the moist air.

The rainfall does not occur unless these cloud droplets become so large that the air is not able to hold them in suspension. Rainfall occurs only when the cloud droplets change to raindrops. The diameter of a raindrop is about 5 mm and one raindrop contains about 8 million cloud droplets.

sihagn2@gmail.com

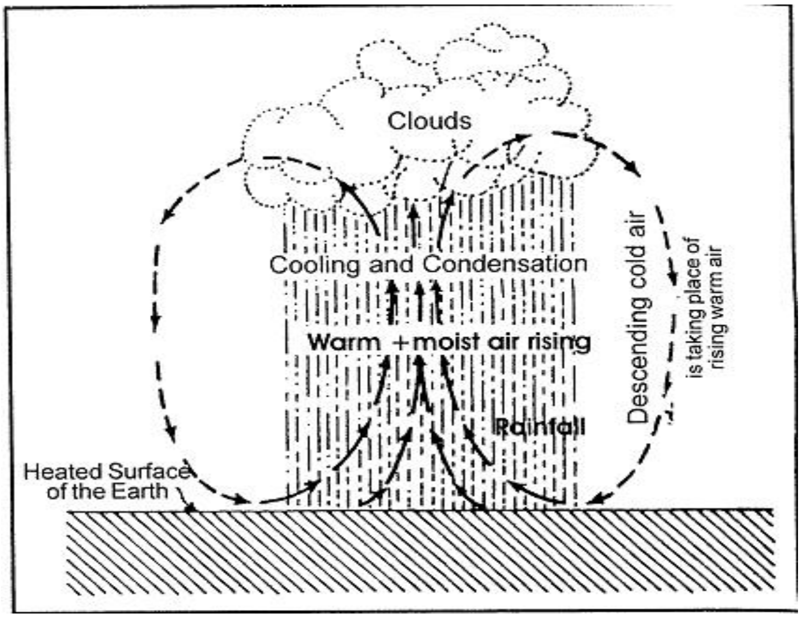
19. Types of Rainfall

According to the way, the cooling of the warm moist airmass takes place, the rainfall can be of the following three types: -

19.1. Convectional Rainfall

As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. With thunder and lightening, heavy rainfall takes place but this does not last long. Such rain is common in the summer or in the hotter part of the day. It is very common in the equatorial regions and interior parts of the continents, particularly in the northern hemisphere.

In the equatorial regions convectional rainfall is received almost daily in the afternoons. In these regions ground starts heating up early morning and by afternoon convectional currents start rising. The whole sky soon is overcast with clouds. Late in the afternoon thunderstorms and lightning occur. It generally happens regularly at 4 P.M. throughout the year. For this reason it is also called 4'O clock rainfall.



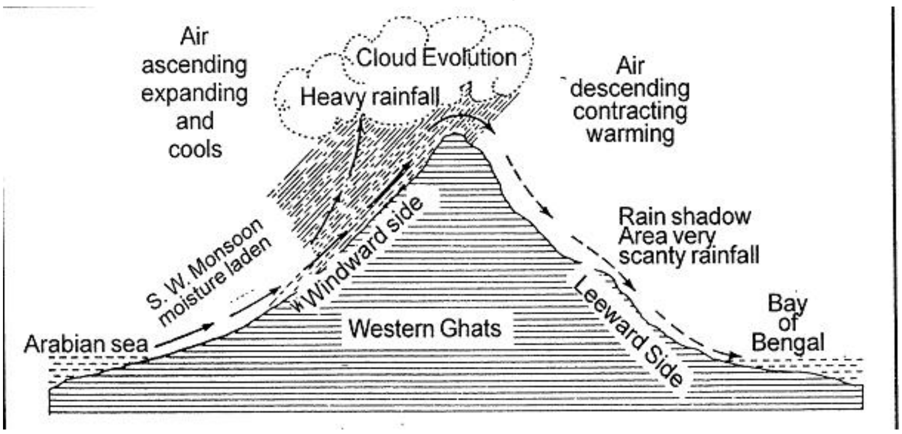
19.2. Orographic Rain

It is also known as the relief rain. When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands; the temperature falls, and the moisture is condensed. The chief characteristic of this sort of rain is that the windward slopes receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these leeward slopes remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the rain-shadow area. For example, Mahabaleshwar lying on the windwardside of Western Ghats receives annual rainfall of about 622 cm as against Pune on the leeward side only 70 km away from Mahabaleshwar receives only 66 cm annual rainfall.

The windward slope of a mountain, at the time of rainfall, has cumulus clouds while the leeward slope has stratus clouds. The orographic rainfall may occur in any season. It is longer duration. The orographic rainfall is supported by convectional and cyclonic processes of condensation. Most of the precipitation in the world is orographic in nature.

sihag27@gmail.com

In India, Cherrapunji in Meghalaya plateau, the Western Ghats and the entire Himalayan region receive Orographic Rainfall.



19.3. Cyclonic or Frontal Rainfall

Cyclones have low pressure at the centre, surrounded by high pressure. When wind from all directions blow towards centre, air masses of different characteristics meet creating fronts. The

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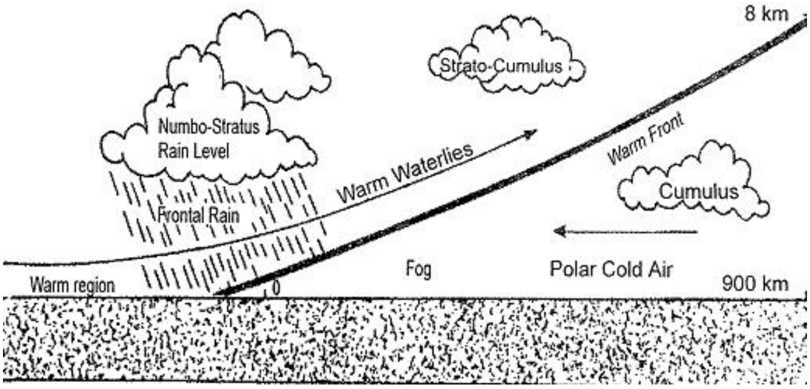
Student Notes:

warm air being the lighter, rises above the cold air. The rising warm air cools and condensation takes place, causing rainfall.

This type of rainfall is associated with temperate and tropical cyclones. Since the lifting of warm air along the warm front of the temperate cyclone is slow and gradual, the condensation is also slow and gradual. Thus the precipitation occurs in the form of **drizzle**[3], It is widespread and continues for a longer duration. Most of the rainfall in the temperate region is received through frontal or cyclonic rains.

The tropical cyclone, regionally known as typhoons, hurricanes, tornadoes, etc., yield heavy downpour in China, Japan, Southeast Asia, India, USA, etc.



20. Distribution of Precipitation

The mean annual rainfall on Earth is about 100 cm but different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons. **Factors** controlling the distribution of rainfall over the earth's surface are the belts of converging-ascending **air flow** (doldrums; polar front etc.), air **temperature**, **moisture**-bearing winds, ocean currents, **distance inland** from the coast, and **mountain ranges**. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily. The coastal areas of the world receive greater amounts of rainfall than the interior of the continents. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water. Between the latitudes 350 and 400 N and S of the equator, the rain is heavier on the eastern coasts and goes on decreasing towards the west. But, between 450 and 650 N and S of equator, due to the westerlies, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east. Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.

On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.

Areas of Heavy Rainfall: The regions receiving more than 200 cm of annual precipitation are included in this belt. The main areas are the **equatorial belt**, the mountain slopes along the western coasts in the cool temperate zone and the coastal areas of the monsoon lands.

Areas of Moderate Rainfall: The regions receiving 100 cm to 200 cm of annual precipitation are included in this belt. The main areas lie adjacent to the regions of heavy rainfall. The coastal areas in the warm temperate zone also receive moderate precipitation.

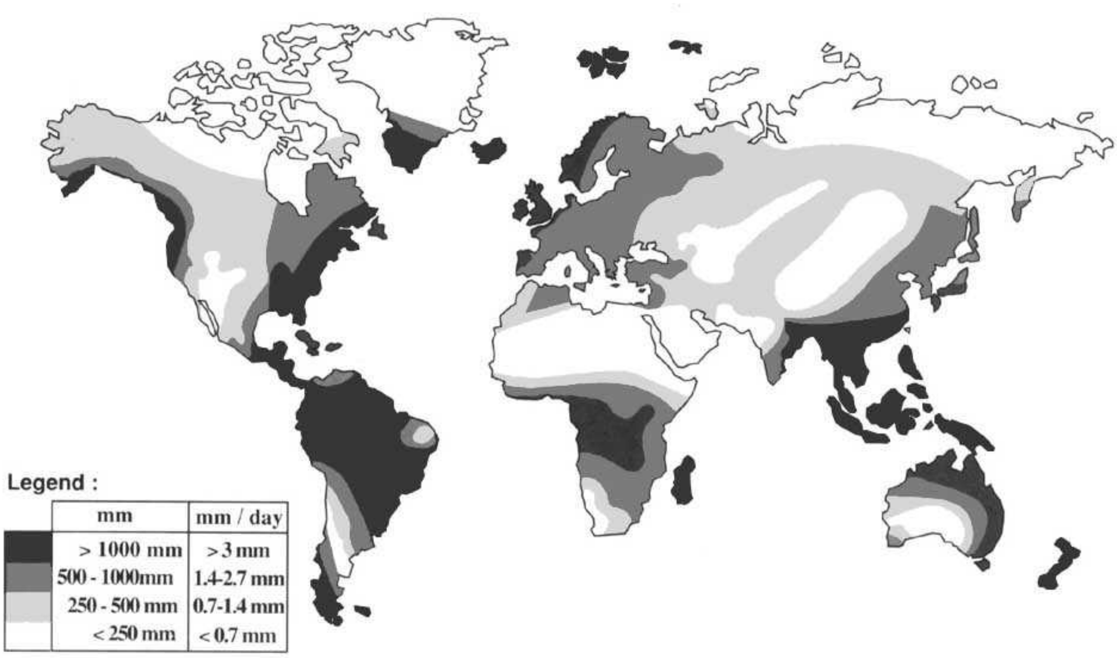
Areas of Low Rainfall: The regions receiving 50 cm to 100 cm of annual precipitation are

[3] When the drops of rain are very small, it is called drizzle.

included in this belt. The main areas lie in the central part of the tropical lands and in the eastern and the interior parts of the temperate lands.

Student Notes:

Areas of Scanty Rainfall: The regions receiving less than 50 cm of annual precipitation are included in this belt. The main areas are the rain shadow areas on the leeward slopes of the mountain ranges, the interior of the continents, the lands in the high latitudes, western margins of the continents in the tropical areas and the arid deserts.



20.1. Seasonal Distribution of Rainfall

The conditions, which can cause precipitation, do not exist in the same combination throughout the year. This leads to the variations in the seasonal distribution of rainfall. However, most of the areas in the world receive a major part of the precipitation during the summer season.

The main characteristics of the seasonal distribution of rainfall

- Heavy rainfall occurs throughout the year in the equatorial region.
- A few degrees north or south of the equator have wet summers and dry winters.
- The monsoon circulation brings more seasonal contrasts resulting in wet summers, as the wind blows onshore, and dry winters as the wind blows offshore.
- Seasonal variation, due to the monsoons, is well-developed in the Indian Subcontinent and in Southeast Asia.
- Most of the western coastal areas in the mid- latitudes have dry summers and wet winters due to the presence of the sub-tropical high pressure belts.
- In the temperate region the precipitation is cyclonic in nature and the cyclones are more common in the winter season. Thus heavy rainfall occurs in winters and not in summers.

The monthly distribution of precipitation throughout the year is often more significant than the average annual precipitation because rainfall is important for the various human activities, especially agriculture. The dependence on rainfall is a matter of great concern to farmers in the sub-humid and semi-arid lands where any departure from the normal regime may result in crop failure.

21. Previous Years Vision IAS Test Series Questions

Student Notes:

1. ***"Distribution of precipitation is the function of pressure and temperature variations in different climatic types". Discuss and justify it with an example from any world climate type.***

Approach

- How temperature and pressure variations are related to the precipitation types
- Describe three types of precipitation and their distribution in various climate types.

Interpretation

Precipitation is the product of interaction between temperature and pressure in combination with other climatic phenomenon. This gives rise to three types of precipitation **convective, orographic and frontal**.

Convective rainfall is a predominant phenomenon in the tropical and sub-tropical climatic zones. It is caused due to the overheating of ground due to which a low pressure center is developed and air which is in contact with the heated surface warms up. The above process leads to instability in the atmosphere. Warm, moist air ascends rapidly into the atmosphere giving rise to torrential rain from the cumulonimbus clouds.

[You can give a diagram of convective rainfall process]

In the case of **orographic** rainfall, the mountain forms a barrier on the windward side and lifts the warm moist air mechanically. Air when cools and expand due to change in atmospheric pressure and adiabatic cooling, gives rise to rainfall when it reaches at due point temperature. This air descends on the lee ward side creating the dry condition due to rise in pressure and temperature of the air.

[You can give a diagram of orographic rainfall]

Frontal rainfall is a dominant phenomenon in mid-latitude regions where the warm moist air and the cold dry air forms the cold and warm fronts respectively. Formation of these fronts also produces the contrasting temperature and pressure conditions that changes with the movement of this frontal formation. There are two types of rainfall conditions: the heavy short period rainfall in the warm front through cumulonimbus clouds, and long term mild rainfall along the cold front through the nimbus and nimbo-stratus clouds.

sihag07@gmail.com

[You can give a diagram of frontal rainfall]

From the above analysis we can say that temperature, pressure and precipitation are related to each other. The change in one leads to a change in the other climatic phenomenon and provides a variation in climate type and its associated features.

2. ***Precipitation, temperature and soil are three important factors which influence the natural vegetation of an area. In this context, discuss the different types of natural vegetation in India along with their distribution.***

Approach:

- Briefly introduce what is natural vegetation and the factors affecting the growth of natural vegetation.
- Now in three different headings of precipitation, temperature and soil, discuss how each factor will affect the natural vegetation, the variation of natural vegetation in India with the variation in each factor and the distribution of natural vegetation.

Answer:

Student Notes:

Natural vegetation is the primeval plant cover unaffected by man either directly or indirectly. Some types of natural vegetation are forests, tundra, grasslands and rainforests. Precipitation, temperature and soil are the three important factors, which influence the growth of natural vegetation.

India being a geographically vast and diverse country, variation in these three factors has resulted in various types of natural vegetation across the different regions:

Precipitation

- The amount of annual rainfall has a great bearing on the type of vegetation. Areas of western side Western Ghats, Andaman and Nicobar, Meghalaya, Arunachal Pradesh, which receive 200 cm or more rainfall per annum have stands of **evergreen rain forests.**
- The **moist deciduous forests** dominate in areas of Madhya Pradesh, Chhattisgarh, Manipur, Mizoram with rainfall between 100 and 200 cm.
- In areas of Karnataka, Maharashtra, Telangana, Rajasthan receiving 50 to 100 cm rainfall there are **drier deciduous** or **tropical Savannah** grading into open thorny scrub.
- The regions of Rajasthan and Gujarat with less than 50 cm rainfall have only dry **thorny scrub** and low open bush merging into semi desert.

Temperature

- Temperature is another important factor that affects natural vegetation. High temperature conditions in the regions of Western Ghats, Andaman and Nicobar islands have resulted in hot and wet equatorial climate with **moist evergreen forests**.
- .As the temperature falls with altitude in the Himalayan region the vegetal cover changes from tropical to **sub-tropical**, **temperate** and finally **Alpine**.
- The range of temperature also influences the natural vegetation. In the southern states of Kerala, Karnataka, Tamil Nadu and Maharashtra, with low annual range of temperature, **evergreen and deciduous forests** are predominant. In the regions of Uttar Pradesh, Bihar, Madhya Pradesh, Haryana and Punjab, with high annual range of temperatures, **Sub-tropical and temperate forests** are common.

sihagn27@gmail.com

Soil

- Different types of soil provide for different conditions, facilitating particular kind of vegetation.
- In the coastal regions of West Bengal, Odisha, Andhra Pradesh and Kerala, where the swampy and saline soils are predominant, **mangrove forests**, **littoral and swamp forests**, and beach and swampy coastal forests are common.
- In the regions of arid and sandy soils of Rajasthan, vegetation of **dry thorn,** bushes are prevalent.
- Topography of the land is also responsible for certain minor variation in vegetation. Regions of Himalayas with higher altitude and steep slope slopes have **Alpine vegetation**. The hill slopes with some depth of soils have **coniferous** or **deciduous** trees.

Student Notes:

3. What is the difference between condensation and precipitation? Elaborate upon the various forms of condensation.

Approach:

- First of all define condensation and its formation process with examples.
- Then define precipitation. Give examples about its types and forms.
- Elaborate about various forms of condensations

Answer:

Condensation is conversion of water from gaseous to either liquid or solid state (in which case it is also called deposition). Two conditions are necessary: *i)* Availability of hygroscopic nuclei, and *ii)* Relative Humidity greater than 100%. Any surface, such as aerosols, plant leafs, etc. can act as condensation nuclei. Cooling of air column below its dew point temperature or addition of water above the holding capacity of air column develops saturation. E.g. Clouds, fog, dew.

Precipitation is the process of falling of moisture from the base of cloud in different **forms** like rain, snow and hail. Various **types** of precipitation are- *i)* Convectional (convective rise of warm air), *ii)* Orograhic (Rise caused by mountain barrier), and *iii)* Frontal.

Variable forms of condensation are demarcated on the basis of location of condensation.

a) At ground: In winter season, long winter nights facilitate contact cooling. The cooling of the moist air column below its dew point temperature makes the ground object as hygroscopic nuclei facilitating condensation. This category includes dew and frost.
   - Dew- It is typical to lower latitudinal and altitudinal locations. These are the deposited water droplets. (Dew point temperature: the temperature to which moist air is cooled at constant pressure and at constant water vapor to reach saturation with respect to water).
   - Frost- These are the deposited minute ice-crystals. It occurs in higher latitudes and altitudinal areas where temperature is below the freezing point of water. (Frost point temperature: the temperature to which moist air is cooled at constant pressure and at constant water vapor to reach saturation with respect to ice).

sihag027@gmail.com

b) Near ground condensation
   - Fog- Fog is simply a ground level cloud. It is defined to be the visible aggregate of suspended ice-crystals and water droplets. Various types of fog are radiation, advection, frontal fog etc.

c) Atmospheric condensation: The condensation form that develops throughout the year and throughout the world barring the exception of extreme Polar Regions is clouds. Clouds can be defined as the visible aggregate of the tiny ice crystals and minute water droplets.

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CLIMATE AND DIFFERENT WORLD CLIMATE

Student Notes:

Contents

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Student Notes:

1. Introduction

Climate holds an important place in our own life. Our life and various economic activities (agriculture, industries, commerce, etc.) are affected by climate. Climate has also an important place in physical geography. Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Any independent study of each of these elements does not present any comprehensive view of climate. On the basis of these elements, there could be thousands of types of climates in the world.

2. Climate & Weather

The *difference* between weather and climate is that weather consists of the short-term (minutes to months) changes in the atmosphere while climate is the average of weather over time and space. In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. Climate, however, is the average of weather over time and space.

2.1. Comparison between Weather and Climate

	Climate	**Weather**
Definition	Describes the average conditions expected at a specific place over a long period of time. A region's climate is generated by the climate system, which has **five components**: atmosphere, hydrosphere, cryosphere, land surface and biosphere.	Describes the atmospheric conditions at a specific place at a **specific point in time**. Weather generally refers to day-to-day temperature and precipitation activity
Components	Climate may include precipitation, temperature, humidity, sunshine, and wind velocity, phenomena such as fog, frost, and hail storms over a long period of time.	Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, excessive heat, heat waves and more
Forecast	By aggregates of weather statistics over periods of 30 years	By collecting meteorological data, like air temperature, pressure, humidity, solar radiation, wind speeds and direction etc.
Determining factors	Aggregating weather statistics over periods of 30[1] years.	Real-time measurements of atmospheric pressure, temperature, wind speed and direction, humidity, precipitation, cloud cover and other variables.
Time period	Measured over a long period	Measured for short term
Study	Climatology	Meteorology

2.2. Importance of Climate and Weather

The influence of climate and weather can be seen in day to day activities of human beings. Forces of nature have regulated to a very great extent the sort of food we eat, what we wear, how we live and work. Conditions of temperature, precipitation and humidity may promote or discourage the growth of fungus and diseases which may be injurious to both men and crops.

[1] NCERT mentions 50 years but according to WMO it is 30 years.

Today, our activities are becoming more and more dependent upon meteorological services. Meteorological stations are set up all over the globe to provide weather updates and predict future conditions. A fair knowledge of the weather is not only useful but often essential.

Student Notes:

2.3. Elements of Climate

There are various environmental elements which have *significant influence* on the climate of a region. Among them, *temperature, pressure, precipitation and winds* are the most important because of their far reaching global influence. These elements are affected in different manner by the following climatic factors: *latitude, altitude, continentality, ocean currents, insolation, prevailing winds, slope and aspect, natural vegetation and soil*.

2.4. Factors Affecting Climate

Latitude: Due to the earth's inclination, the mid-day sun is almost overhead within the tropics but the sun's rays reach the earth at an angle outside the tropics. Thus, temperature diminishes from equatorial regions to the poles.

Altitude: Earth's atmosphere is mainly heated through conduction from the surface, so places near the surface are warmer than those higher up. Thus temperature decreases with increasing height above sea level. This rate of decrease in temperature with altitude *(lapse rate)* is never constant, varying from place to place and from season to season. However, for all practical purposes, it may be reckoned that a fall of 6.5°C occurs with an ascent of 1000 meters or *1°C per 165 meters.*

Continentality (**Distance from sea**): Land surfaces have higher specific heat capacity of heat as compared to water bodies i.e. it takes less energy to raise the temperature of a given volume of land by 1°C as compared to same volume of water body. This accounts for temperature extremes in the continental interiors as compared to maritime areas.

Oceans Currents: Marine areas are influenced by the *warm or cold ocean currents*. Ocean currents like the Gulf Stream or the North Atlantic Drift warm the coastal districts of Western Europe keeping their ports ice-free. Ports located in the same latitude but washed by cold currents, such as the cold Labrador Current off north-east Canada, are frozen for several months. Cold currents also lower the summer temperature, particularly when they are carried landwards by on-shore winds.

siragt21@gmail.com

Local winds: If winds are warm i.e. they have been blown from a hot area, they will raise temperatures. If winds have been blown from cold areas, they will lower temperatures. Local winds like Fohn, Chinook, Sirocco and Mistral also produce marked changes in temperature.

Relief and Topography: Climate can be affected by mountains. Mountains receive more rainfall than low lying areas because as air is forced over the higher ground it cools, causing moist air to condense and fall out as rainfall. The higher the place is above sea level the colder it will be. This happens because as altitude increases, air becomes thinner and is less able to absorb and retain heat.

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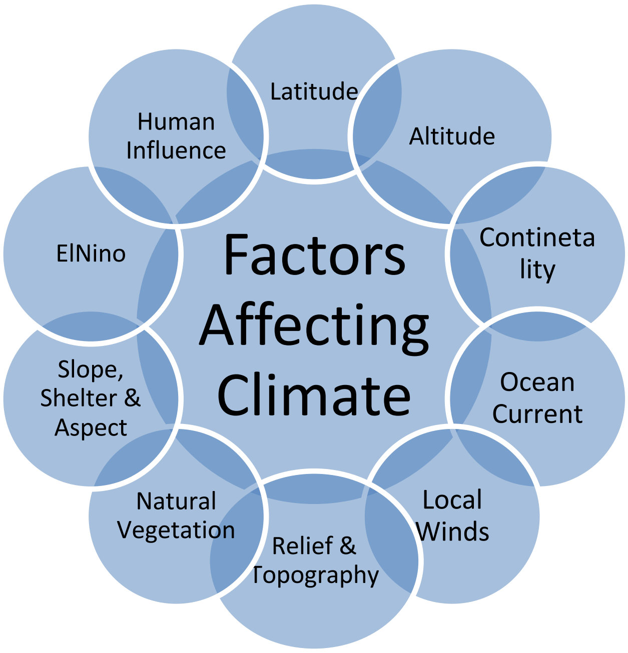


Fig 1: Factors Affecting Climate

Natural Vegetation and Soil: Natural vegetation affects the temperature of the region significantly. Often areas with dense forest cover like areas in thick foliage of Amazon jungles receive less insolation and are, often, cooler than the areas in open space. Light soils reflect more heat than darker soils which are better absorbers. Such soil differences may give rise to slight variations in the temperature of the region. As a whole, dry soils like sands are very sensitive to temperature changes, whereas wet soils, like clay, retain much moisture and warm up or cool down more slowly.

Slope, **Shelter and Aspect**: A steep slope experiences much rapid change in temperature as compared to a gentle slope. Mountain ranges that have an east-west alignment like the Alps show a higher temperature on the *south-facing 'sunny slope'* than the north facing 'sheltered slope'. The greater insolation of the southern slope is better suited for vine cultivation and has a more flourishing vegetative cover. Consequently, there are more settlements and it is better utilised than the 'shady slope'.

El Niño Effect: El Niño, which affects wind and rainfall patterns, has been blamed for droughts and floods in countries around the Pacific Rim. ***El Niño* refers to the irregular warming of surface water in the Pacific**. The warmer water pumps energy and moisture into the atmosphere, altering global wind and rainfall patterns. The phenomenon has caused tornadoes in Florida, smog in Indonesia, and forest fires in Brazil. *El Niño* is Spanish for 'the Boy Child' because it comes about the time of the celebration of the birth of the Christ Child. **The cold counterpart to *El Niño* is known as *La Niña***, Spanish for 'the girl child', and it also brings with it weather extremes.

Human Influence: The factors above affect the climate naturally. However, we cannot forget the influence of humans on our climate. Early on in human history our effect on the climate would have been quite small. However, as populations increased and trees were cut down in large numbers, so our influence on the climate increased. The number of trees being cut down has also increased, reducing the amount of carbon dioxide that is taken up by forests.

2.5. Classification of Climate

If we were to compare the climates of different places on the basis of climatic elements, we would come across many such places which would have similarity between one and more of these elements. On the basis of these very regional similarities and differences of climatic elements, attempts have been made to classify climate for easy understanding, description and analysis.

Student Notes:

Three broad approaches have been adopted for classifying climate. They are empirical, genetic and applied. Empirical classification is based on observed data, particularly on temperature and precipitation. Genetic classification attempts to organise climates according to their causes. Applied classification is for specific purpose.

Heat Zones Classification: The Greek philosophers were the first to present classification of climates. The temperature of the earth was the main bases of their classifications. They had divided the earth into Torrid, Temperate and Frigid zones.

1. ***Tropical or Torrid Zone***: This zone lies between the Tropic of Cancer and the Tropic of Capricorn. In this zone the sunrays are almost vertical throughout the year. The temperature always remains high. There is no winter season in this zone.
2. ***Temperate Zone***: There are two zones lying between the Tropic of Cancer - the Arctic Circle and the Tropic of Capricorn - the Antarctic Circle.

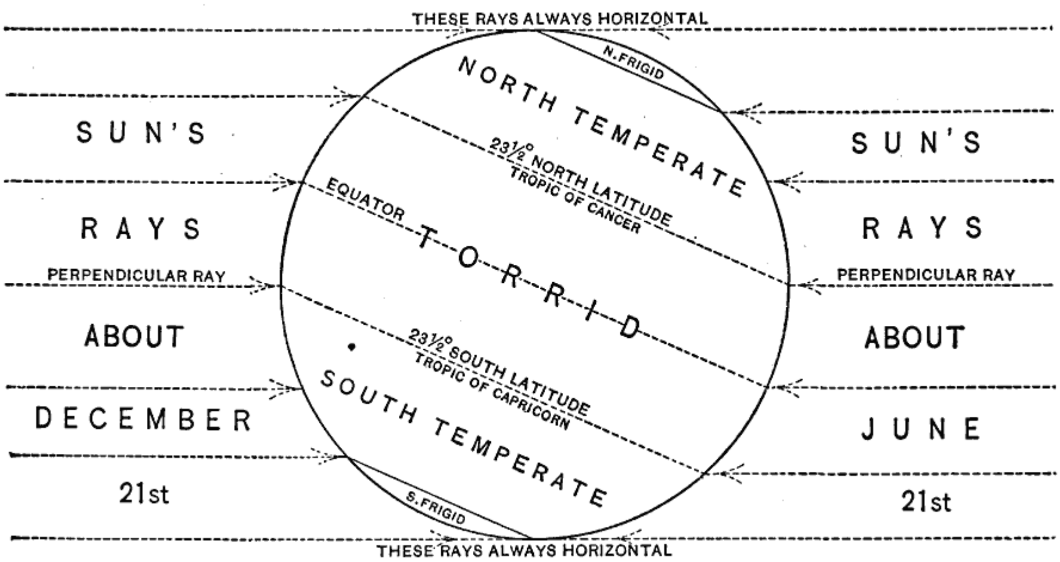


Fig 2: Heat Zones Classifications

3. ***Frigid Zone***: This zone lies between Arctic Circle and North Pole and the Antarctic Circle and the South Pole. The sunrays in these two zones in the Northern and Southern Hemisphere fall in slanting form throughout the year. Therefore these zones experience very low temperature and high degree of coldness. Therefore, these latitudinal zones are known as Frigid Zone.

Koeppen Classification

The most widely used classification of climate is the climate classification scheme developed by German climatologist and plant geographer V. Koeppen. in 1918. The annual as well as monthly *averages of temperature and precipitation* formed the basis of Koeppen classification of climate. He also based his classification on the distribution of weather conditions. This classification is both *empirical and genetic type*. Koeppen in his classification laid great emphasis that all the characteristics of climate can well be expressed through the *distribution of natural vegetation* that's why he tried to associate his climate types with vegetation zones of the world. He made use of annual averages of temperature and precipitation in fixing the climate regions of the world. He presented *five main climate types*. Each of these climate types was represented by capital English alphabets of A, B, C, D and E. He used the letter 'H' for highland type of climates. While keeping temperature and precipitation variations in view these five climate types were further subdivided as shown in the following table:

S.N.	Chief Climatic Groups	Climatic Types
A	Tropical Climate (Average temperature of the coldest month is 18° C or higher)	1. Tropical rain forest type climate 2. Savannah type climate 3. Monsoon type climate
B	Dry Climate (Potential evaporation exceeds precipitation)	4. Desert climate 5. Steppe (Semi-desert) climate
C	Temperate Climate (The average temperature of the coldest month is higher than minus 3°C but below 18°C)	6. Mediterranean climate 7. China type climate 8. West European type climate
D	Continental Climate (The average temperature of the coldest month is minus 3° C or below)	9. Taiga climate 10. Eastern coastal cold climate 11. Continental climate
E	Polar Climate (Average temperature for all months is below 10° C)	12. Tundra climate 13. Snow-capped region type climate
H	Highland Climate (Cold due to elevation)	

Student Notes:

Thornthwaite Classification:

Thornthwaite was an American climatologist. He presented his first climate classification in 1931. In 1931, his classification looked similar to Koeppen. Like Koeppen, Thornthwaite also thought that vegetation is the indicator of climate type. Two basic features of this classification are (i) *Precipitation Effectiveness*, (ii) *Temperature Efficiency*. On the basis of these two indicators, Thornthwaite divided the world into five humidity regions. Each region had its own special type of vegetation as shown in the table below:

Sr. No.	Humidity Region	Special type of Vegetation
A	Very Humid	Rain Forest
B	Humid	Forest
C	Semi Humid	Grassland
D	Semi Dry	Steppe
E	Dry	Desert

On the basis of distribution of seasonal rainfall the above types of humidity regions were further divided into following subdivisions:

Y = Heavy rainfall in all seasons
s = Scarcity of rainfall in summer season
w = Scarcity of rainfall in winter season
d = Scarcity of rainfall in all seasons
After linking precipitation effectiveness and seasonal distribution of rainfall to temperature anomalies, the climates could be of 120 different types.

3. Global Climate Classification

The global climatic conditions can be studied under the following twelve classifications.

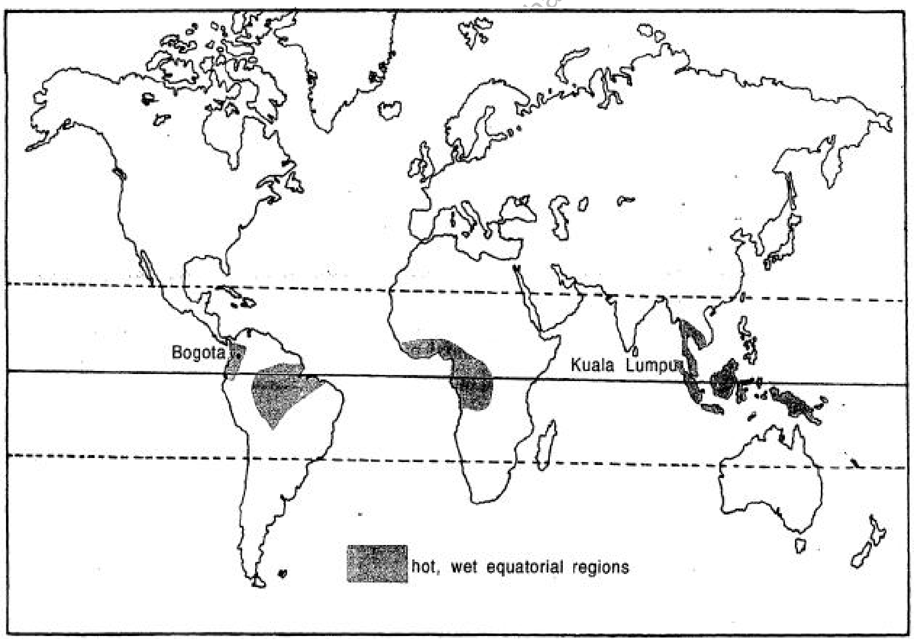
Climatic Zone	*Latitude (Approximate)*	*Climatic Type*	*Rainfall Regime (with approx. total)*	*Natural Vegetation*
Equatorial Zone	0^0-10^0N and S	1. Hot, wet equatorial	Rainfall all year round : 80 inches	Equatorial rain forests

Hot Zone	10^0-30^0N and S	2. a) Tropical Monsoon b) Tropical Marine	Heavy summer rain: 80 inches Much summer rain: 70 inches	Monsoon forests
		3. Sudan Type	Rain mainly in summer: 30 inches	Savanna (tropical grassland)
		4. Desert: a) Saharan type b) Mid-latitude type	Little rain: 5 inches	Desert vegetation and scrub
Warm Temperate Zone	30-^{0}40^0N & S	5. Western Margin (Mediterranean type)	Winter rain: 35 inches	Mediterranean forests and shrub
		6. Central Continental (Steppe type)	Light summer rain: 20 inches	Steppe or temperate grassland
		7. Eastern Margin: a) China type b) Gulf type c) Natal type	Heavier summer rain: 20 inches	Warm, wet forests and bamboo
Cool Temperate Zone	45^0-65^0N & S	8. Western Margin (British type)	More rain in autumn & winter: 30 inches	Deciduous forests
		9. Central Continental (Siberian type)	Light summer rain: 25 inches	Evergreen coniferous forests
		10. Eastern Margin (Laurentian type)	Moderate summer rain: 40 inches	Mixed forests (coniferous and deciduous)
Cold Zone	65^0-90^0 N & S	11. Arctic or Polar	Very light summer rain: 10 inches	Tundra, mosses, lichens
Alpine Zone		12. Mountain climate	Heavy rainfall (variable)	Alpine pastures, conifers, fern, snow

3.1. The Hot, Wet Equatorial Climate

Distribution

The equatorial, hot, wet climate is found between 5° and 10 ° north and south of the equator. Its greatest extent is found in the lowlands of the Amazon, the Congo, Malaysia and the East Indies. Further away from the equator, the influence of the on-shore Trade Winds, gives rise to a modified type of equatorial climate with *monsoonal influences.*



Student Notes:

Student Notes:

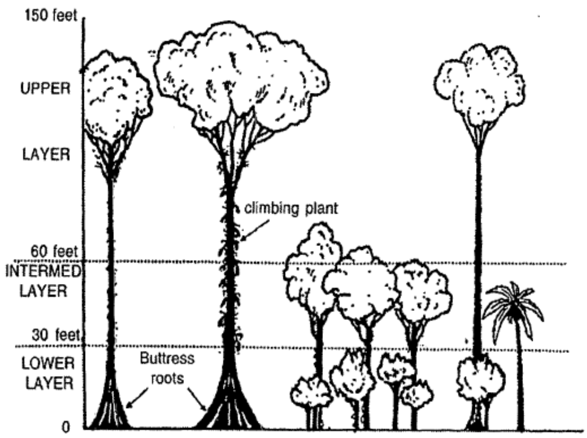
Climatic Conditions

Temperature: The most outstanding feature of the equatorial climate is its great uniformity of temperature throughout the year. The mean monthly temperatures are always around 27°C with very little variation. There is no winter. Cloudiness and heavy precipitation moderates the daily temperature, so that even at the equator itself, the climate is not unbearable. The diurnal range of temperature is small, and so is the annual range.

Precipitation: Precipitation is heavy, between 60 inches and 100 inches, and well distributed throughout the year. There is no month without rain and a distinct dry season like those of the Savannah or the Tropical Monsoon Climates, is absent. Due to the great heat in the equatorial belt, mornings are bright, and sunny. There is much evaporation and convectional air currents are set up, followed by heavy downpours.

Natural Vegetation: It supports a luxuriant type of vegetation – the tropical rain forest. Amazon tropical rain forest is known as Selvas. It comprises a multitude of evergreen trees that yield tropical hardwood, e.g. mahogany, ebony, greenheart, cabinet wood. Lianas, epiphytic and parasitic plants are also found. Trees of single species are very scarce in such vegetation.

Fig. 123 Sketch to show the three distinct layers of an equatorial forest



Life and Development in the Equatorial Regions: The equatorial regions are generally sparsely populated. In the forests most primitive people live as *hunters and collectors* and the more advanced ones practise shifting cultivation. In the Amazon basin, the Indian tribes collect wild rubber, in the Congo Basin the Pygmies gather nuts and in the jungles of Malaysia the Orang Asli make all sorts of cane products and sell them to people in villages and towns. In the clearings for shifting cultivation, crops like manioc (tapioca), yams, maize, bananas and groundnuts are grown.

sinegar27@gmail.com

3.2. The Tropical Monsoon and Tropical Marine Climates

Distribution: It is found in the zones between 5° and 30° latitudes on either side of the equator. These areas are the **tropical monsoon** lands with on-shore wet monsoons in the summer and off-shore dry monsoons in the winter. They are best developed in the Indian sub-continent, Burma, Thailand, Laos, Cambodia, parts of Vietnam and south China and northern Australia.

Outside this zone, the climate is modified by the influence of the on-shore Trade Winds all the year round, and has a more evenly distributed rainfall. Such a climate, better termed the **Tropical Marine** Climate, is experienced in Central America. West Indies, north-eastern Australia, the Philippines, parts of East Africa, Madagascar, the Guinea Coast and eastern Brazil.

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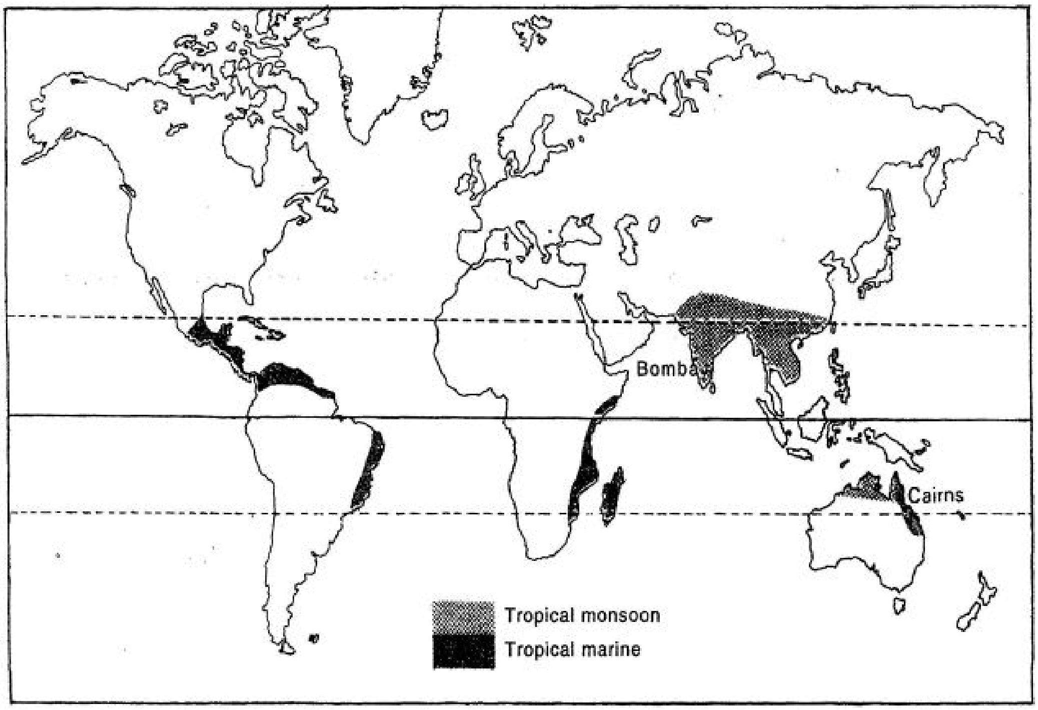


Climatic Conditions:

The basic cause of monsoon climates is the difference in the rate of heating and cooling of land and sea. Average temperature of warm dry summer months ranges between 27°C and 32°C. In the summer, when the sun is overhead at the Tropic of Cancer, the great land masses of the northern hemisphere are heated. The seas, which warm up much slower, remain comparatively cool. At the same time, the southern hemisphere experiences winter, and a region of high pressure is set up in the continental interior of Australia. Winds blow outwards as the South-East Monsoon, to Java, and after crossing the equator are drawn towards the continental low pressure area reaching the Indian sub-continent as the South-West Monsoon. In the winter, conditions are reversed. The sun is overhead at the Tropic of Capricorn, central Asia is extremely cold, resulting in rapid cooling of the land. A region of high pressure is created with out-blowing winds-the North-East Monsoon.

The Seasons of Tropical Monsoon Climate: In regions like the Indian sub-continent which have a true Tropical Monsoon Climate, *three* distinct seasons are distinguishable - The cool, dry season (October to February), the hot dry season (March to mid-June) and the rainy season (mid-June to September).

The Tropical Marine Climate: This type of climate is experienced along the eastern coasts of tropical lands, receiving steady rainfall from the Trade Winds all the time. The rainfall is both *orographic*, where the moist trades meet upland masses as in eastern Brazil, and *convectional* due to intense heating during the day and in summer. Its tendency is towards a summer maximum as in monsoon lands, but without any distinct dry period.

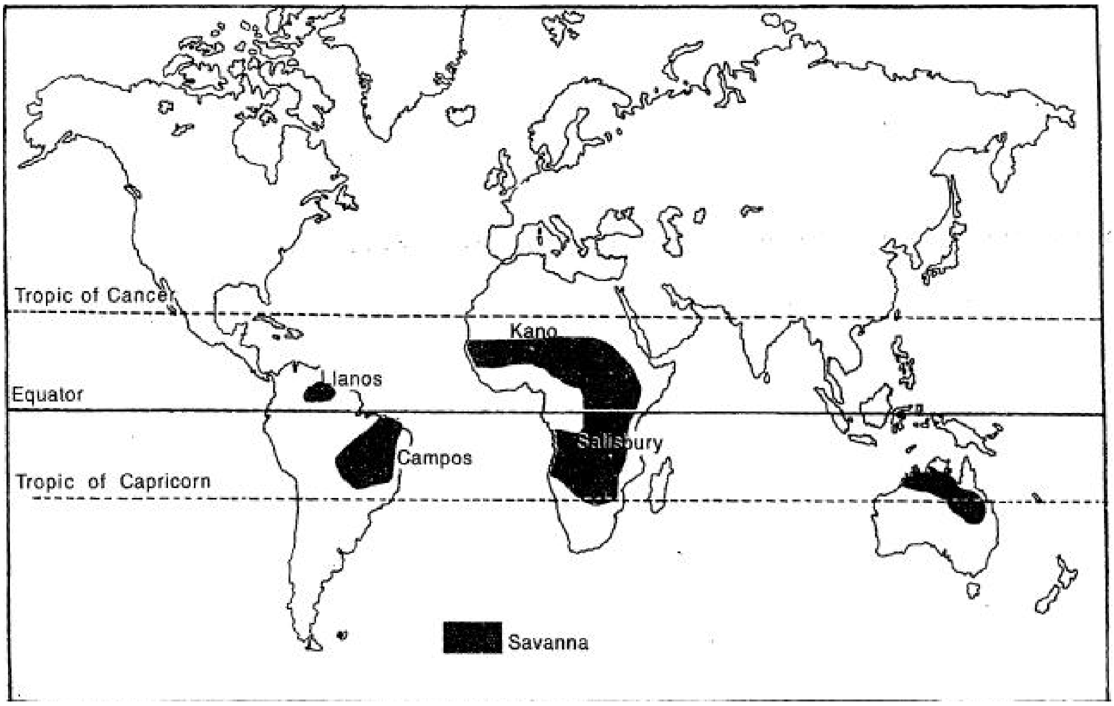
Natural Vegetation: The natural vegetation of tropical monsoon lands depends on the amount of the summer rainfall. Trees are normally deciduous because of the marked dry period, during which they shed their leaves to withstand the drought. Where the rainfall is heavy, e.g. in southern Burma, peninsular India, northern Australia and coastal regions with a tropical marine climate, the resultant vegetation is forest. The forests are more open and less luxuriant than the equatorial jungle and there are far fewer species. Most of the forests yield valuable timber, and are prized for their durable hardwood. Amongst these teak is the best known.

Economy: The main economic activity of the people is agriculture. Major agricrops are rice, cane sugar, jute etc.

Student Notes:

3.3. The Savannah or Sudan Climate

Distribution: The Savannah or Sudan Climate is a transitional type of climate found between the equatorial forest and the trade wind hot deserts. It is confined within the tropics and is best developed in the Sudan where the dry and wet seasons are most distinct, hence its name the Sudan Climate. The belt includes West African Sudan, and then curves southwards into East Africa and southern Africa north of the Tropic of Capricorn. In South America, there are two distinct regions of *savannah* north and south of the equator, namely the *llanos* of the Orinoco basin and the *Campos* of the Brazilian Highlands.



Climatic Conditions:

The Savannah climate is characterized by distinct wet and dry seasons. Mean high temperature throughout the year is between 24°C and 27° C. The annual range of temperature is between 3°C and 8°C, but the range increases as one move further away from the equator. The extreme diurnal range of temperature is a characteristic of Sudan type of climate. The average annual rainfall ranges between 100 cm and 150 cm. The prevailing winds of the region are the Trade Winds which bring rain to the coastal districts.

Natural Vegetation: The savannah landscape is typified by tall grass and short trees. The terms *'parkland'* or *'bush-veld'* perhaps describe the landscape better. Trees grow best towards the equatorial humid latitudes or along river banks but decrease in height and density away from the equator. The trees are deciduous, shedding their leaves in the cool, dry season to prevent excessive loss of water through transpiration, e.g. acacias. Others have broad trunks, with water-storing devices to survive through the prolonged drought such as baobabs and bottle trees. Trees are mostly hard, gnarled and thorny and may exude gum like *gum arabic*.

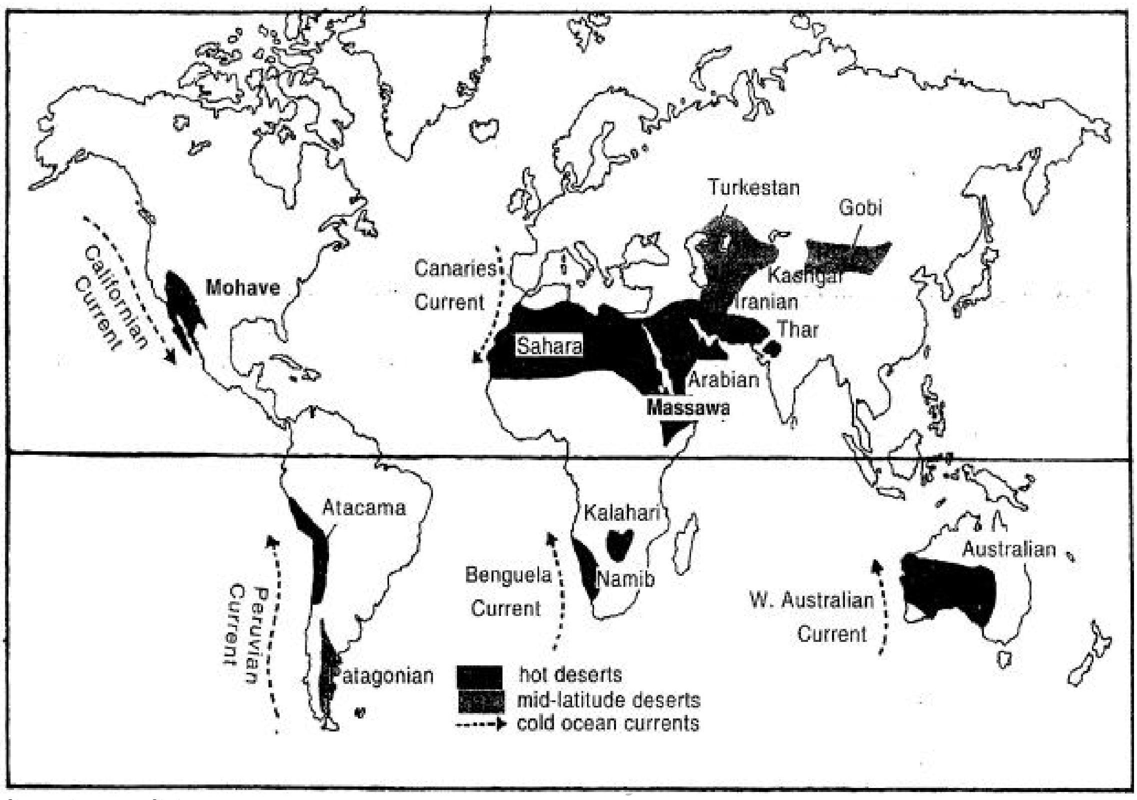
Animal Life of the Savannah: The savannah, particularly in Africa, is the home of wild animals. It is known as the 'big game country' and thousands of animals are trapped or killed each year by people from all over the world. Some of the animals are tracked down for their skins, horns, tusks, bones or hair, others are captured alive and sent out of Africa as zoo animals, laboratory specimens or pets.

Economy: Many tribes live within the Savannah lands. Some tribes live as pastoralists like the Masai and other as settled cultivators like the Hausa of northern Nigeria. However, agriculture is not much developed.

3.4. The Hot Desert and Mid-latitude Desert Climates

Student Notes:

Distribution: Deserts are regions of scanty rainfall which may be hot like the hot deserts of the Saharan type or temperate as are the mid- latitude deserts like the Gobi. The major hot deserts of the world are located on the western coasts of continents between latitudes 15º and 30ºN and S. They include the Sahara Desert, the largest single stretch of desert, which is 3,200 miles from east to west and at least 1,000 miles wide. The next biggest desert is the Great Australian Desert which covers almost half of the continent. The other hot deserts are the Arabian Desert, Iranian Desert, Thar Desert, Kalahari and Namib Deserts. In North America, the desert extends from Mexico to USA and is called by different names at different places, e.g. the Mohave Sonoran, Californian and Mexican Deserts. In South America, the Atacama or Peruvian Desert is the driest of all deserts with less than 0.5 inches of rainfall annually. The Patagonian Desert is more due to its rain- shadow position on the leeward side of the lofty Andes than to continentality.



Climatic Conditions:

Rainfall: The aridity of deserts is the most outstanding feature of the desert climate. Few deserts whether hot or mid-latitude have an annual precipitation of more than 10 inches while in others less than 0.02 inches. The hot deserts lie astride the Horse Latitudes or the Sub-Tropical High Pressure Belts where the air is descending, a condition least favourable for precipitation of any kind to take place. The rain bearing trade winds blow off shore and the Westerlies, that are on-shore, blow outside the desert limits. Whatever winds reaches the deserts blow from the cooler to the warmer regions, and their relative humidity is lowered, making condensation almost impossible.

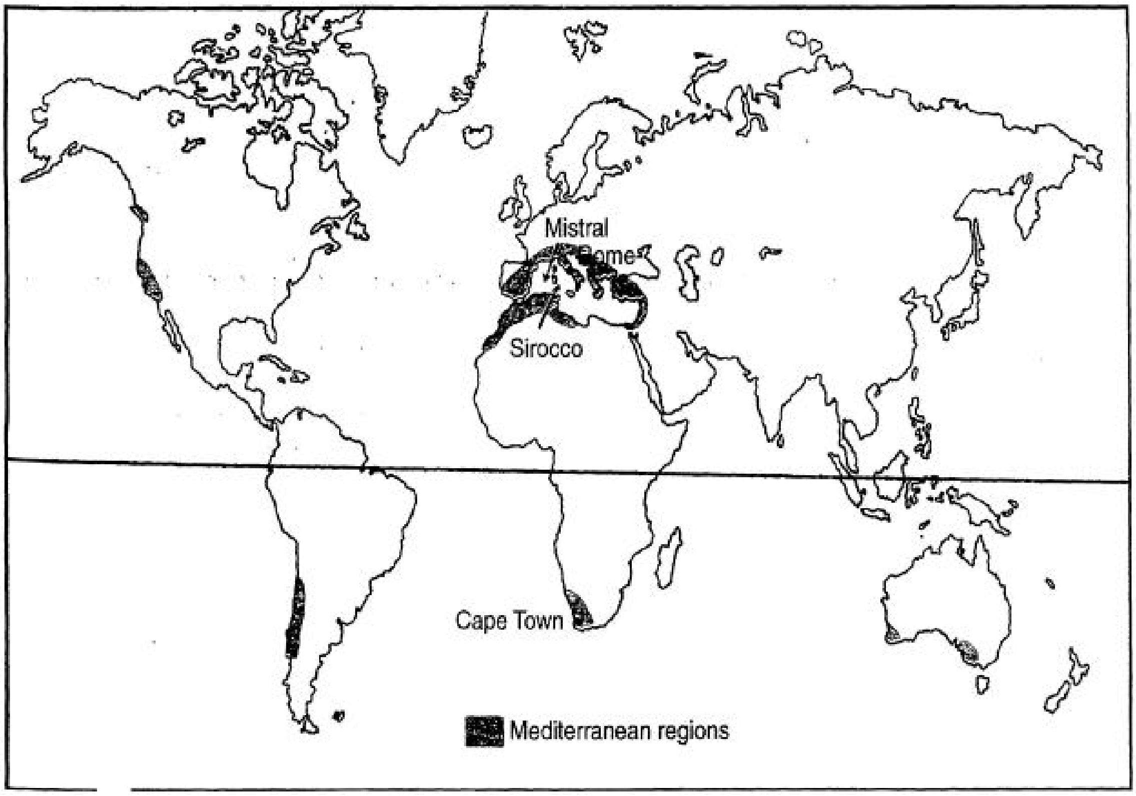
Temperature: The deserts are some of the hottest spots on earth and have high temperatures throughout the year. There is no cold season in the hot deserts and the average summer temperature is around 30°C. The highest shade temperature recorded is 58°C at Al Azizia, 25 miles south of Tripoli, Libya, in the Sahara. The diurnal range of temperature in the deserts is very great.

Natural Vegetation: All deserts have some form of vegetation such as grass, scrub, herbs, weeds, roots or bulbs. Though they may not appear green and fresh all the time, they lie dormant in the soil awaiting rain which comes at irregular intervals or once in many years. The environment, so lacking in moisture and so excessive in heat, is most unfavourable for plant growth and significant vegetation cannot be expected. The predominant vegetation of both hot and mid-latitude deserts is xerophytes or drought-resistant scrub. This includes the bulbous cacti, thorny bushes, long-rooted wiry grasses and scattered dwarf acacia. Trees are rare except where there is abundant ground water to support clusters of date palms.

Life in the Deserts: Despite its inhospitality, the desert has always been peopled by different groups of inhabitants. They struggle against an environment deficient in water, food and other means of livelihood. The desert inhabitants may be grouped under the following categories - The primitive hunters and collectors (The Bushmen and The Bindibu), the nomadic herdsmen (The Tuaregs of the Sahara, the Gobi Mongols and The Bedouin of Arabia), the caravan traders, the settled cultivators and the mining settlers.

3.5. The Warm Temperate Western Margin (Mediterranean) Climate

Distribution: The Warm Temperate Western Margin Climate is found in relatively, few areas in the world. They are entirely confined to the western portion of continental masses, between 30° and 45° north and south of the equator. The basic cause of this type of climate is the shifting of the wind belts. Though the area around the Mediterranean Sea has the greatest extent of this type of 'winter rain climate', and gives rise to the more popular name Mediterranean Climate. Other Mediterranean regions include California (around San Francisco), the south-western tip of Africa (around Cape Town), southern Australia (in southern Victoria and around Adelaide, bordering the St. Vincent and Spencer Gulfs), and south-west Australia (Swanland).



Climatic Conditions: The Mediterranean type of climate is characterized by very distinctive climatic features - a warm summer with off-shore trades, a concentration of rainfall in winter with onshore westerlies, bright, sunny weather with hot dry summers and wet, mild winters

Student Notes:

Student Notes:

and the prominence of local winds around the Mediterranean Sea (Sirocco, Mistral). Since all regions with a Mediterranean climate are near large bodies of water, temperatures are generally moderate with a comparatively small range of temperature res between the winter low and summer high. Areas with this climate receive almost all of their yearly rainfall during the winter season, and may go the summer without having any significant precipitation.

Natural vegetation: Trees with small broad leaves are widely spaced and never very tall. Though there are many branches they are short and carry few leaves. The absence of shade is a distinct feature of Mediterranean lands. Growth is slow in the cooler and wetter season, even though more rain comes in winter. The warm, bright summers and cool, moist winters enable a wide range of crops to be cultivated. The Mediterranean lands are also known as the world's **orchard lands**. A wide range of citrus fruits such as oranges, lemons, limes, citrons and grapefruit are grown. Wine production is another speciality of the Mediterranean countries, because the best wine is essentially made from grapes. Some 85 per cent of grapes produced, go into wine. The long, sunny summer allows the grapes to ripen and then they are hand-picked.

Economy: The area is important for fruit cultivation, cereal growing, wine-making and agricultural industries as well as engineering and mining.

3.6. The Temperate Continental (Steppe) Climate

Distribution

Bordering the deserts, away from the Mediterranean regions and in the interiors continents are the temperate grasslands. Though they lie in the Westerly wind belt, they are so remote from maritime influence that the grasslands are practically treeless. *These grasslands* are so distinctive in their natural vegetation that, although those which occur in the southern hemisphere have a much more moderate climate, they are often dealt with together. In the northern hemisphere, the grasslands are far more extensive and are entirely continental. In Eurasia, they are called the ***Steppes*** and stretch eastwards from the shores of the Black Sea across the Great Russian plain to the foothills of the Altai Mountains, a distance of well over 2,000 miles. There are isolated sections in the *Pustaz* of Hungary and the plains of Manchuria. In North America, the grasslands are also quite extensive and are called **Prairies**. They lie between the foothills of the Rockies and the Great Lakes astride the American Canadian border.

In the case of the **Pampas** of Argentina and Uruguay, the grasslands extend right to the sea and enjoy much maritime influence. In South Africa, the grasslands are sandwiched between the Drakensberg and the Kalahari Desert; and are further subdivided into the more tropical Bush-**veld** in the north, and the more temperate High Veld in the south.

smago27@gmail.com

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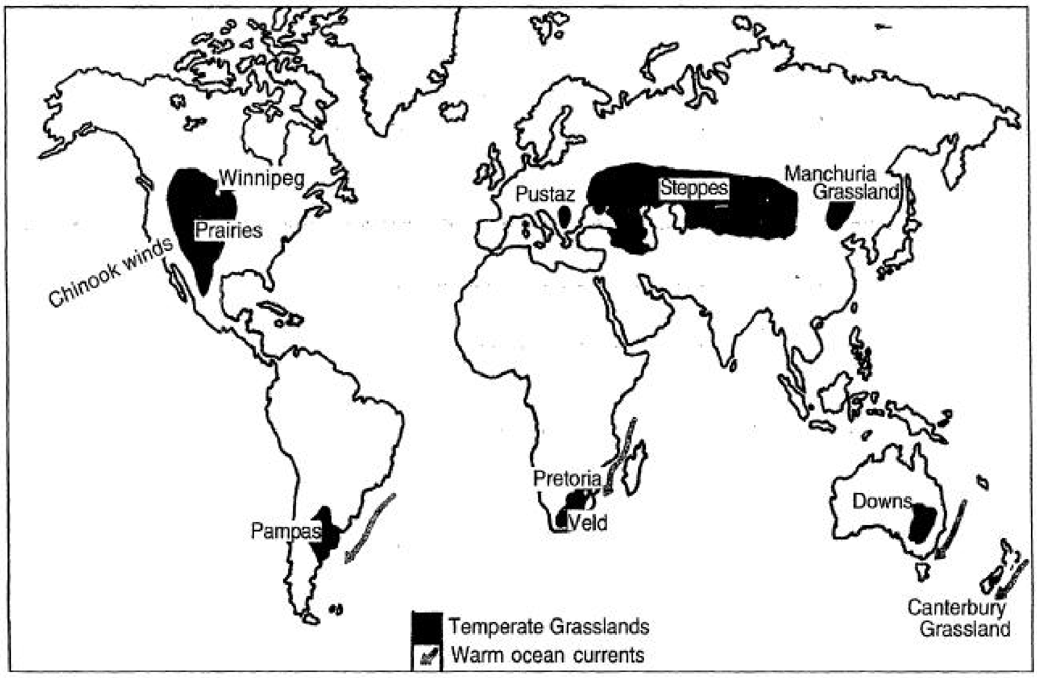

Climatic Conditions

Temperature: Their location in the heart of continents means that they have little maritime influence. Their climate is thus continental with extremes of temperature. **Summers are very warm**, over 19°C. **Winters are very cold** in the continental steppes of Eurasia because of the enormous distances from the nearest sea. The winter months are well below freezing. In contrast, the steppe type of climate in the southern hemisphere is never severe. The winters are mild. Temperatures below freezing point even in midwinter (July in the southern hemisphere) are exceptional.

Precipitation: In its continental position, the annual precipitation of the Steppe Climate is light. The average rainfall may be taken as about 20 inches, but this again varies according to location from 10 inches to 30 inches. The maritime influence in the steppe type of climate of the southern hemisphere is even better brought out by the rainfall regime. Its annual precipitation is always more than the average 20 inches because of the warm ocean currents that wash the shores of the steppe-lands.

Natural Vegetation: The reference to steppe grassland is taken to mean the **temperate grasslands** of the mid-latitudes, the Steppes, Prairies, Pampas, Veld and Downs. The steppes are grass covered, differing only in the *density* and *quality* of the grass. Their greatest difference from the tropical savannah is that they are practically treeless and the grasses are much shorter. Where the rainfall is moderate, above 20 inches, the grasses are tall, fresh and nutritious and are better described as long prairie grass. The *appearance* of the temperate grasslands varies with seasons. Trees are very scarce in the steppes, because of the scanty rainfall, long droughts and severe winters.

Economy: The grasslands have been ploughed up for extensive, mechanized wheat cultivation and are now the 'granaries of the world'. Besides wheat, maize is increasingly cultivated in the warmer and wetter areas. The tufted grasses have been replaced by the more nutritious Lucerne or alfalfa grass.

3.7. The Warm Temperate Eastern Margin (China Type) Climate

Distribution: This type of climate is found on the **eastern margins of continents** in warm temperate latitudes, just outside the tropics. It has comparatively more rainfall than the Mediterranean climate in the same latitudes, coming mainly in the summer. It is, in fact, the climate of most parts of China –a modified form of monsoonal climate. It is thus also called the *Temperate Monsoon or China Type* of climate. In south-eastern U.S.A., bordering the Gulf of Mexico, continental heating in summer induces an inflow of air from the cooler Atlantic Ocean. It is sometimes referred to as the Gulf type of climate. In the southern hemisphere, this kind of climate is experienced along the warm temperate eastern coastlands of all the three continents: in New South Wales with its eucalyptus forests; in Natal where cane sugar thrives; and in the maize belt of the Parana-Paraguay-Uruguay basin.

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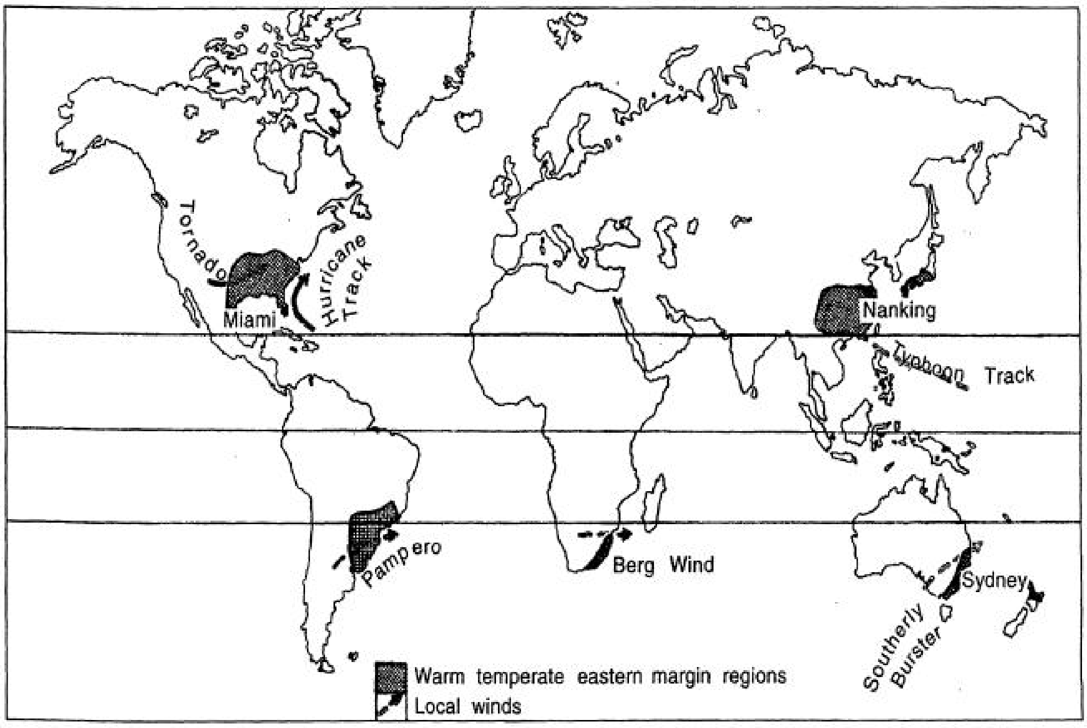


Climatic Condition:

The Warm Temperate Eastern Margin Climate is typified by a **warm moist summer and a cool, dry winter**. The mean monthly temperature varies between 5°C and 25°C and is strongly modified by maritime influence. The relative humidity is a little high in mid-summer. Rainfall is more than moderate, anything from 25 inches to 60 inches. Another important feature is the **fairly uniform distribution of rainfall throughout the year**. There is rain every month, except in the interior of central China, where there is a distinct dry season. Rain comes either from convectional sources or as orographic rain in summer, or from depressions in prolonged showers in winter. Local storms, e.g. typhoons, and hurricanes, also occur.

It can be sub-divided into three main types – a) The China type: central and north China (including southern Japan (temperate monsoonal). b) The Gulf type: south-eastern United States, (slight-monsoonal). c) The Natal type: the entire warm temperate eastern margin (non-monsoonal areas) of the southern hemisphere including Natal, eastern Australia and southern Brazil-Paraguay-Uruguay and northern Argentina.

Natural Vegetation: The eastern margins of warm temperate latitudes have a much heavier rainfall than either the western margins or the continental interiors and thus have luxuriant vegetation. The lowlands carry both evergreen broad-leaved forests and deciduous trees quite similar to those of the tropical monsoon forests. On the highlands, are various species of conifers such as pines and cypresses that are important softwood.

Economy: The warm temperate eastern margins are the most productive parts of the middle latitudes. Besides the widespread cultivation of. Maize and cotton in the Corn and Cotton Belts of U.S.A. fruit and tobacco are also grown. Rice, tea and mulberries are extensively grown in monsoon China.

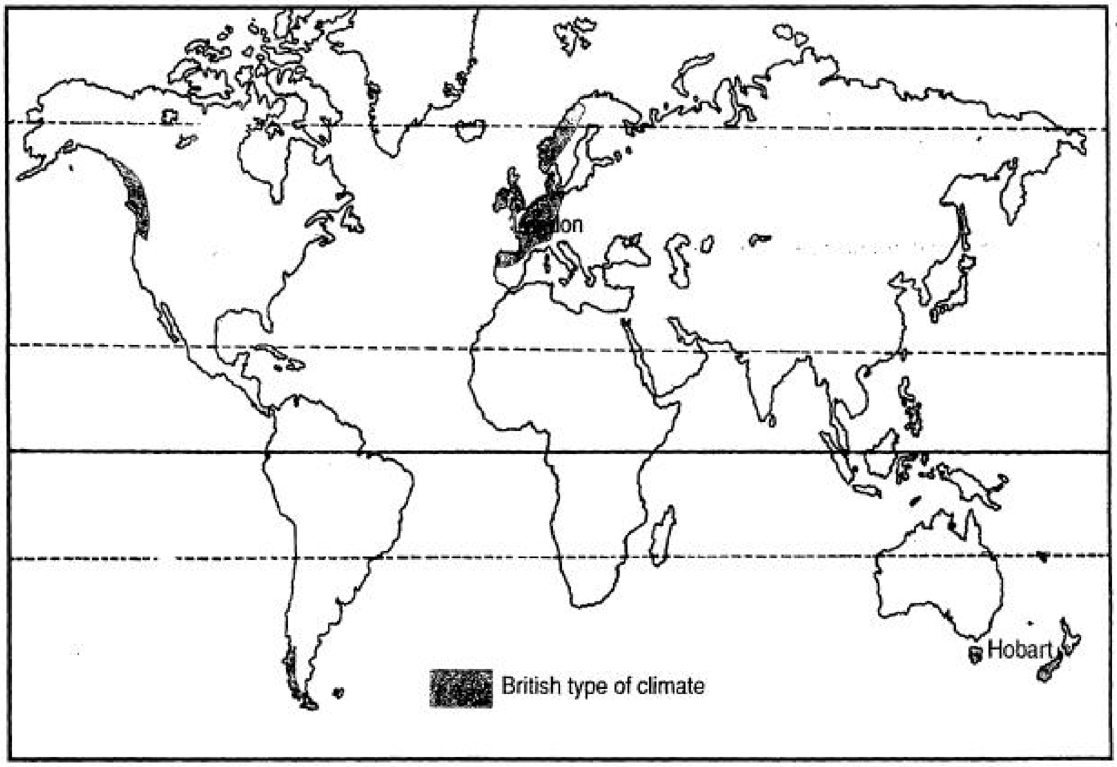
Elsewhere are found other products of economic importance, e.g. cane sugar in Natal, coffee and maize in South America and dairying in New South Wales and Victoria.

Student Notes:

3.8. The Cool Temperate Western Margin (British Type) Climate

Distribution Climate

The cool temperate western margins are under the permanent influence of the Westerlies all round the year. They are also regions of much cyclonic activity, typical of Britain, and are thus said to experience the British type of climate. From Britain, the climatic belt stretches far inland into the lowlands North-West Europe, including such regions as northern and western France, Belgium, the Netherlands, Denmark, western Norway and also north-western Iberia. In the southern hemisphere, the climate is experienced in southern Chile, Tasmania and most parts of New Zealand, particularly in South Island.



Climatic Conditions

Temperature: The mean annual temperatures are usually between 5°C and 15°C. The annual range of temperature is small. Summers are, in fact, never very warm. Monthly temperatures of over 18°C even in mid-summer are rare.

Precipitation: The British type of climate has <u>adequate rainfall throughout the year</u> with a tendency towards a slight winter or autumn maximum from cyclonic sources. Since the rain-bearing winds come from the west, the western margins have the heaviest rainfall. The amount decreases eastwards with increasing distance from the sea.

Natural Vegetation: The natural vegetation of this climatic type is deciduous forest. The trees shed their leaves in the cold season. This is an adaptation for protecting themselves against the winter snow and frost. Shedding begins in autumn, the 'fall' season, during which the leaves fall and are scattered by the winds. Some of the more common species include oak, elm, ash, birch, beech, poplar, and hornbeam. Unlike the equatorial forests, the deciduous trees occur in pure stands and have greater lumbering value from the commercial point of view. The deciduous hardwoods are excellent for both fuel and industrial purposes.

Economy: The region differs from many others in its unprecedented industrial advancement. The countries are

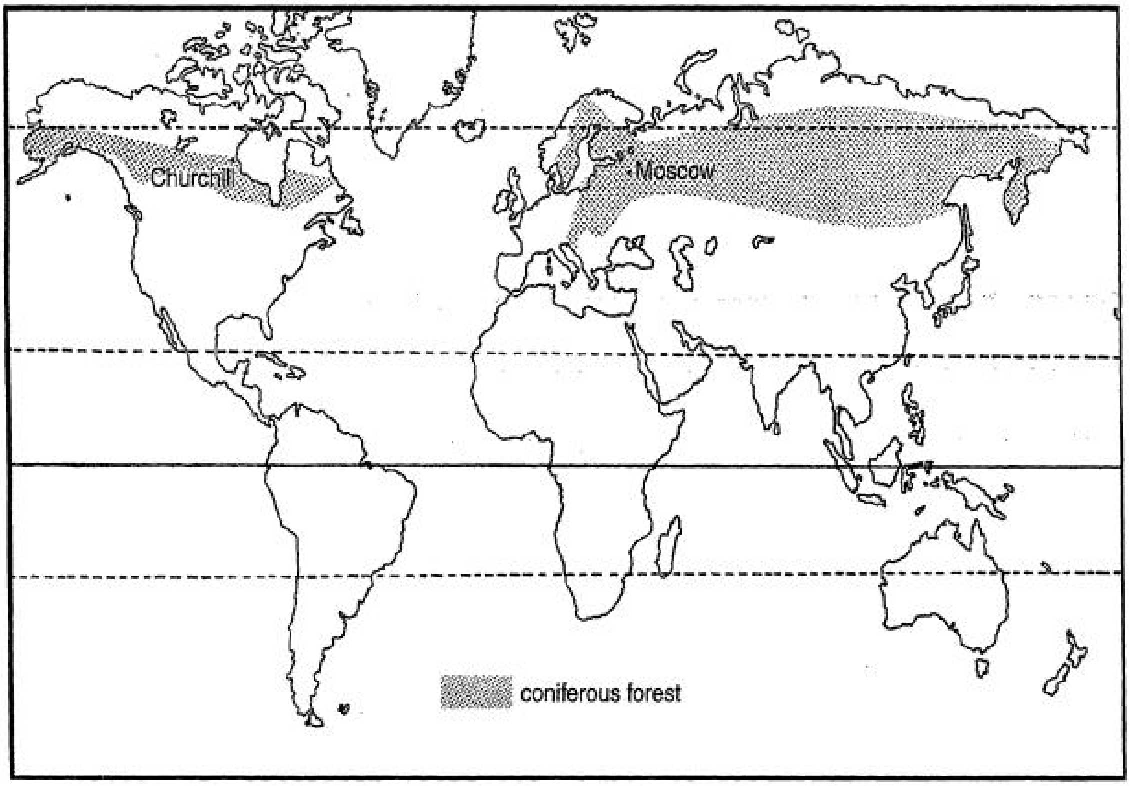
concerned in the production of machinery, chemicals, textiles and other manufactured articles rather than agriculture, fishing or lumbering, though these activities are well represented in some of the countries. Fishing is particularly important in Britain, Norway and British Columbia. A very large part of the deciduous woodlands have been cleared for fuel, timber or agriculture.

Student Notes:

3.9. The Cool Temperate Continental (Siberian) Climate

Distribution

The Cool Temperate Continental (Siberian) Climate is experienced only in the northern hemisphere where the continents within the high latitudes have a broad east-west spread. On its pole ward side, it merges into the Arctic tundra of Canada and Eurasia at around the Arctic Circle. The Siberian Climate is conspicuously absent in the southern hemisphere because of the narrowness of the southern continents in the high latitudes. The strong oceanic influence reduces the severity of the winter and coniferous forests are found only on the mountainous uplands of southern Chile, New Zealand, Tasmania and south-east Australia.



Climatic Conditions:

Temperature: The climate of the Siberian type is characterized by a bitterly cold winter of long duration, and a cool brief summer. Spring and autumn are merely brief transitional periods. The extremes of temperature are so great in Siberia that it is often referred to as the 'cold pole of the earth'. Some of the lowest temperatures in the world are recorded in Verkhoyansk.

Precipitation: The interiors of the Eurasian continent are so remote from maritime influence that annual precipitation cannot be high. Generally speaking, a total of 15 to 25 inches is typical of the annual precipitation of this sub-Arctic type of climate. It is quite well distributed throughout the year, with **a summer maximum** from convectional rain.

Natural Vegetation

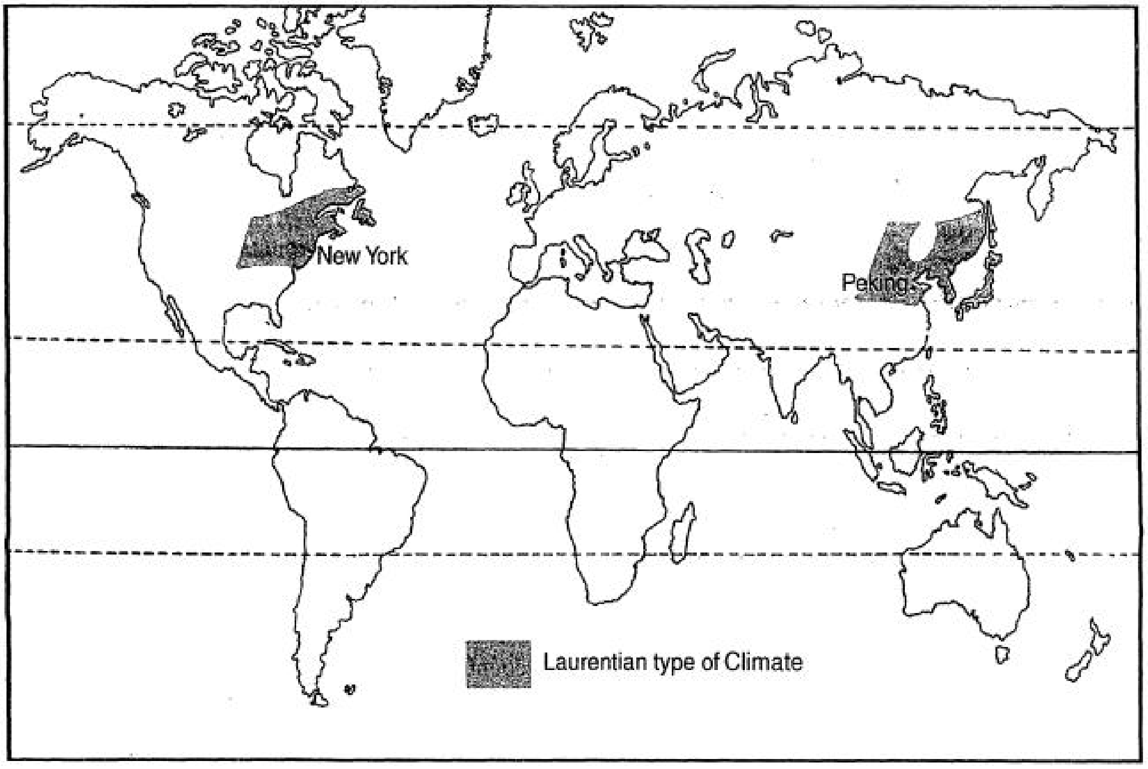
No other trees are as well adapted as the conifers to withstand such an inhospitable environment as the Siberian type of climate. The coniferous forest belts of Eurasia and North America are the richest sources of softwood for use in building construction, furniture, matches, paper and pulp, rayon and other branches of the chemical industry, The world's greatest softwood producers are U.S.S.R, U.S.A., Canada and the Fenoscandian countries (Finland, Norway and Sweden). In the field of newsprint, Canada has outstripped all other producers, accounting for almost half of the world's total annual production. There are four major *species* in the coniferous forests – a) Pine, e.g. white pine, red pine, Scots pine, Jack pine, b) Fir, e.g., Douglas fir and balsam fir, c) Spruce and d) Larch.

Economy: The coniferous forest regions of the northern hemisphere are comparatively little developed. Only in the more accessible areas are the forests cleared for lumbering. There is little agriculture, as few crops can survive in the sub-Arctic climate of these northerly lands. Many of the Samoyeds and Yakuts of Siberia, and some Canadians are engaged in hunting, trapping and fishing.

3.10. The Cool Temperate Eastern Margin (Laurentian) Climate

Distribution

The Cool Temperate Eastern Margin (Laurentian) Climate is an **intermediate type of climate between the British and the Siberian type of climate**. It has features of both the maritime and the continental climates. The Laurentian type of climate is found only in two regions. One is north-eastern North America, including eastern Canada, north-east U.S.A., (i.e. Maritime Provinces and the New England states), and Newfoundland. This may be referred to as the North American region. The other region is the eastern coastlands of Asia, including eastern Siberia, North China, Manchuria, Korea and northern Japan. It may be referred to as the Asiatic region. In the southern hemisphere, this climatic type is absent because only a small section of the southern continents extends south of the latitude of 40° S.



Student Notes:

Climatic Conditions:

The Laurentian type of climate has cold, dry winters and warm, wet summers. Winter temperatures may be well below freezing-point and snow falls to quite a depth. Summers are as warm as the tropics (21° - 27°C) and if it were not for the cooling effects of the off-shore cold currents from the Arctic, the summer might be even hotter. Though rain falls throughout the year, there is a distinct **summer maximum** from the easterly winds from the oceans. Of the annual precipitation of 30 to 60 inches, two-thirds come in the summer. Winter is dry and cold, because the winds are dry Westerlies that blowout from the continental interiors.

Natural Vegetation

The predominant vegetation of the Laurentian type of climate is cool temperate forest. The heavy rainfall, the warm summers and the damp air from fogs, all favour the growth of trees. Generally speaking, the forest tends to be coniferous north of the 50° N. parallel of latitude. The increase in the length and severity of the winter excludes forests that are not adaptable to cold conditions. Oak, beech, maple and birch are the principal trees.

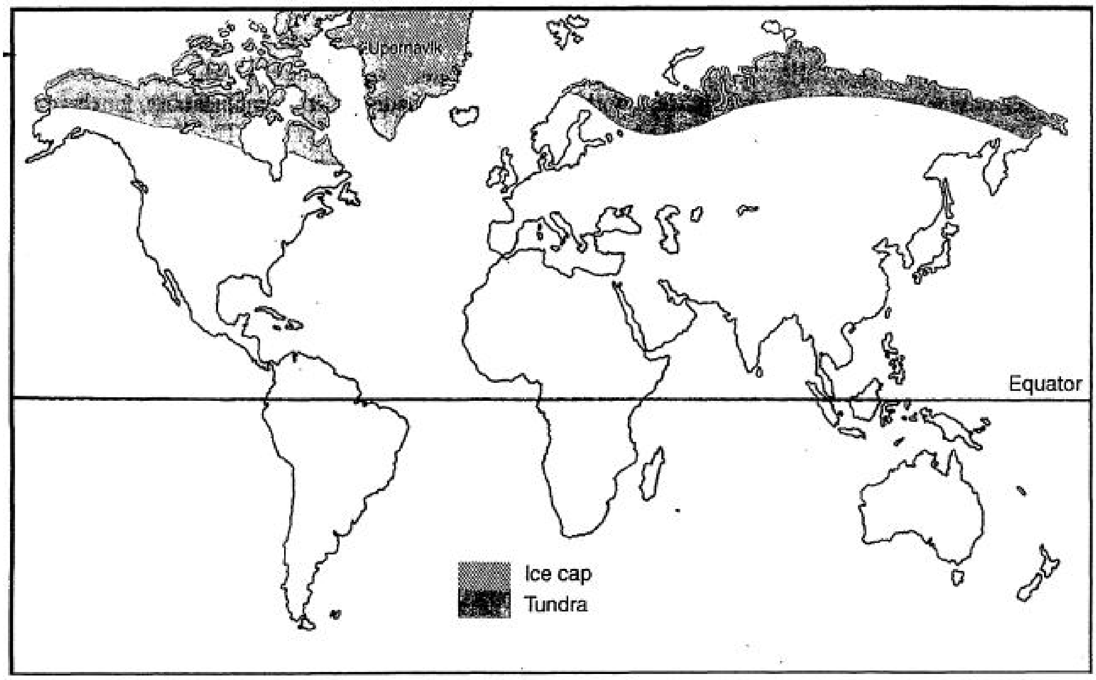
Economy

Lumbering and its associated timber, paper and pulp industries are the most important economic undertaking. Agriculture is less important in view of the severity of the winter and its long duration. Fortunately the maritime influence and the heavy rainfall enable some hardy crops to be raised for local needs. The fertile Annapolis valley in Nova Scotia is the world's most renowned region for apples. Fishing is, however, the most outstanding economic activity of the Laurentian climatic regions.

3.11. The Arctic or Polar Climate

Distribution

The polar type of climate and vegetation is found mainly north of the Arctic Circle in the northern hemisphere. The ice-cap is confined to Greenland and to the highlands of these high-latitude regions, where the ground is permanently snow-covered. The lowlands, with a few months ice-free, have tundra vegetation. They include the coastal strip of Greenland, the barren grounds of northern Canada and Alaska and the Arctic seaboard of Eurasia.



Student Notes:

Climatic Conditions

Temperature: The polar climate is characterized by a very low mean annual temperature and its warmest month in June seldom rises to more than 10°C. In mid-winter (January) temperatures are as low as – *35*°C and much colder in the interior. Winters are long and very severe; summers are cool and brief.

Precipitation: Precipitation is mainly in the form of snow, falling in winter and being drifted about during blizzards. Snowfall varies with locality; it may fall either as ice crystals or large, amalgamated snowflakes. Convectional rainfall is generally absent because of the low rate of evaporation and the lack of moisture in the cold polar air. There is normally a summer maximum, and the precipitation is then in the form of rain or sleet.

Natural vegetation

In such an adverse environment as the tundra, few plants survive. The greatest inhibiting factor is the region's deficiency in heat. With a growing season of less than three months and the warmest month not exceeding 10^{o} C (the tree-survival line), there are no trees in the tundra. Such an environment can support only the lowest form of vegetation, mosses, lichens and sedges. Drainage in the tundra is usually poor as the sub-soil is permanently frozen. Ponds and marshes and waterlogged areas are found in hollows.

Economy:

Human activities of the tundra are largely confined to the coast. Where plateaux and mountains increase the altitude, it is uninhabitable, for these are permanently snow-covered. The few people who live in the tundra live a semi-nomadic life and have to adapt themselves to the harsh environment. The Arctic region, once regarded as completely useless, is now of some economic importance. Apart from the efforts of the various governments in assisting the advancement of the Arctic inhabitants the Eskimos, Lapps, Samoyeds etc., new settlements have sprung up because of the discovery of minerals.

4. Previous Years UPSC Prelims Questions

1. What could be the main reason/reasons of the formation of African and Eurasian desert belt? (2011)
1. It is located in the sub-tropical high pressure cells.
2. It is under the influence of warm ocean currents.

Which of the statements given above is/are correct in this context?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

sivagn27@gmail.com

2. A geographic region has the following distinct characteristics:
1. Warm and dry climate
2. Mild and wet winter
3. Evergreen oak trees

The above features are the distinct characteristics of which one of the following regions? (2010)
(a) Mediterranean (b) Eastern China
(c) Central Asia (d) Atlantic coast of North America

3. Consider the following statements: (2002)
1. In equatorial regions, the year is divided into four main seasons.
2. In Mediterranean region, summer receives more rain.
3. In China type climate, rainfall occurs throughout the year.
4. Tropical highlands exhibit vertical zonation of different climates.

Student Notes:

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3
(c) 1, 2 and 4 (d) 3 and 4

4. The temperature and rainfall of a meteorological station are given below: (2001)
1. Average Temperature: 12.80 degree Celsius
2. Average Rainfall: 54.9 cm per annum

Identify the region having the above climatic pattern from amongst the following:
(a) Mediterranean region (b) Monsoon region
(c) Steppe region (d) N.W. European region

5. Consider the following statements:
1. The annual range of temperature is greater in the Pacific Ocean than that in the Atlantic Ocean.
2. The annual range of temperature is greater in the Northern Hemisphere than that in the Southern Hemisphere.

Which of the statements given above is/are correct? (2007)
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

6. In India, which type of forest among the following occupies the largest area? (2010)
(a) Montane Wet Temperate Forest (b) Sub-tropical Dry Evergreen Forest
(c) Tropical Moist Deciduous Forest (d) Tropical Wet Evergreen Forest

7. Following are the characteristics of an area in India: (2010)
1. Hot and humid climate
2. Annual rainfall 200 cm
3. Hill slopes up to an altitude of 1100 metres
4. Annual range of temperature 15 degrees to 30 degrees

8. Which one among the following crops are you most likely to find in the area described above? (2010)
(a) Mustard (b) Cotton
(c) Pepper (d) Virginia tobacco"

siragn27@gmail.com

9. A geographic region has the following distinct characteristics: (2010)
1. Warm and dry climate
2. Mild and wet winter
3. Evergreen oak trees

The above features are the distinct characteristics of which one of the following regions?
(a) Mediterranean (b) Eastern China
(c) Central Asia (d) Atlantic coast of North America

10. Which one of the following is the characteristic climate of the Tropical Savannah Region? (2012)
(a) Rainfall throughout the year (b) Rainfall in winter only
(c) An extremely short dry season (d) A definite dry and wet season

11. The annual range of temperature in the interior of the continents is high as compared to coastal areas. What is/are the reason/reasons? (2013)
1. Thermal difference between land and water
2. Variation in altitude between continents and oceans

Student Notes:

3. Presence of strong winds in the interior
4. Heavy rains in the interior as compared to coasts

Select the correct answer using the codes given below:

(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2, 3 and 4

12. Climate is extreme, rainfall is scanty and the people used to be nomadic herders. The above statement best describes which of the following regions? (2013)

(a) African Savannah (b) Central Asian Steppe
(c) North American Prairie (d) Siberian Tundra

13. The seasonal reversal of winds is the typical characteristic of (2014)

(a) Equatorial climate (b) Mediterranean climate
(c) Monsoon climate (d) All of the above climates"

14. "Each day is more or less the same, the morning is clear and bright with a sea breeze; as the Sun climbs high in the sky, heat mounts up, dark clouds form, then rain comes with thunder and lightning. But rain is soon over." (2015)

Which of the following regions is described in the above passage?

(a) Savannah (b) Equatorial
(c) Monsoon (d) Mediterranean

5. Previous Years UPSC Mains Questions

1. Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why? (UPSC 2013/10 Marks)

2. As regards the increasing rates of melting of Arctic ice, the interests of the Arctic Council nations may not coincide with those of the wider world. "Explain. (UPSC 2011/12 Marks)

6. Previous Years Vision IAS Test Series Questions

1. List out the differences between the temperate and tropical grasslands.

Answer:

Grasslands are the areas where the vegetation is dominated by the grasses. They are found in all the eco-regions of the world except Antarctica continents. They are classified into two types on the basis of their location and other characteristics such as climatic variations, soil types, vegetation types, fauna and flora type and the type of communities residing.

conditions	Tropical grassland	Temperate grassland
Location	Located in tropical belts, called savannah type, formed due to low rainfall and high temperature	They are located in temperate belts, called mid-latitude type, formed due to continentality
Grass type	Coarse, spiky, not nutritious in nature, height 3 m, parkland topography	Grass isnutritious, soft, height is small, known as bread basket of the world
Soils	laterization is the dominant process, Low fertility oxisols	Calcification is the dominant process, Chernozem is the famous soil
Farming	People practice nomadic herding, big game country known for hunting in ancient times	Commercial farming and commercial herding

Student Notes:

Fauna	High in diversity and grading that is in food chain	Very sparse and low in diversity
Climate type and name in various parts of world	Köppen Aw type climate, known as Savannah in Africa, Downs in Australia, Feld in S. Africa	Bsk type of climate known as Prairies in America, Pustaz in Europe, Steppes in Asia

Student Notes:

2. *How has the vegetation of tropical rainforests adapted to its environment? Illustrate.*

Approach:

- Introduce your answer by explaining climatic conditions of tropical rainforests.
- Discuss the features and characteristics of such vegetation.
- Discuss how climate of these regions influence the vegetation of these regions.

Answer:

High temperature and abundant rainfall in the tropical regions support a luxuriant type of vegetation referred as the tropical rain forest. They have a rich floristic composition. These forests are best developed in tropical America, particularly the Amazon basin, in the East Indies and surrounding areas, Malaysia and the Congo.

Plants there have adapted to the rainforest environment which is dark and wet all year round through various mechanisms. Some such adaptations are:

1. Buttress Roots - Buttress roots are roots above ground which support the tree and encourage growth. The taller the tree becomes the more sunlight it can get from above. Ground root system to ensure stability for the tallest trees and to increase the surface area over which the plant can draw its nutrients.
2. Drip Tips - The leaves are shaped to shed the heavy rainfall. The trees have leaves that have a drip tip so water is collected and dripped down to the roots.
3. Branchless Trees - These plants forget about roots in the soil - they perch high up on branches. The trees put their energy into climbing upwards towards the canopy rather than growing branches at intervals along their trunks.
4. Ferns grow very well on the forest floor as they have adapted to the shady conditions.

sirragn27@gmail.com

3. *"Change in latitude and altitude leads to variation in temperature and vegetation". Analyze.*

Approach:

Clearly mention how change in latitude and altitude changes temperature and vegetation separately. Establish the connection between temperature distribution and vegetation. Appropriate examples should be provided.

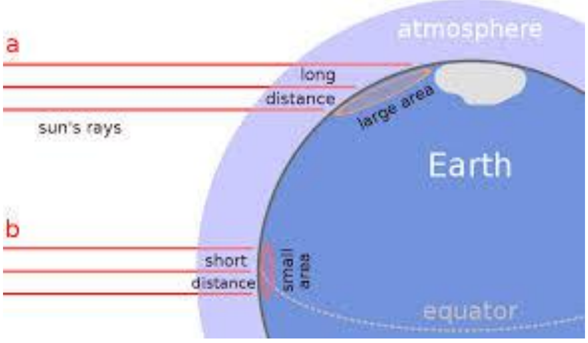
Answer:

***note: Diagrams provided are only for conceptual clarity.**
Temperature and vegetation in any region of earth is governed by multiple factors, latitude and altitude being the prominent ones. These factors can be elaborated as under:

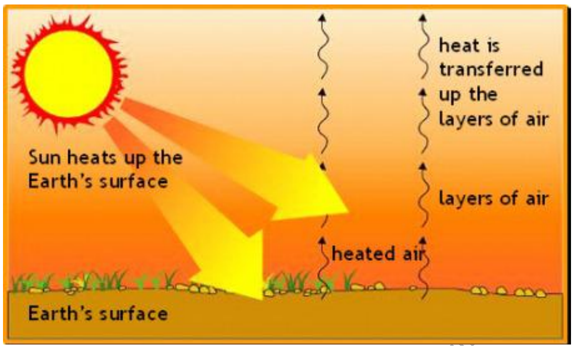
1. Latitude is one of the main factors affecting temperature. With increase in distance from the equator the amount of insolation on an area decreases due to the round shape of the earth so, not every place receives the same amount of sunlight.

2. Another reason is the differing angle of solar incidence. This is the angle at which the Sun's rays strike the Earth's surface. At the Equator, the Sun's rays strike the Earth at a right angle, which makes the heat more intense and concentrated over a small area. Less heat is lost to the atmosphere as the rays travel a shorter distance through the atmosphere.

   At the poles, the Sun's rays strike the Earth at an acute angle; this spreads the heat over a larger area. More heat is lost to the atmosphere as the rays travel a longer distance through the atmosphere as shown in the picture.



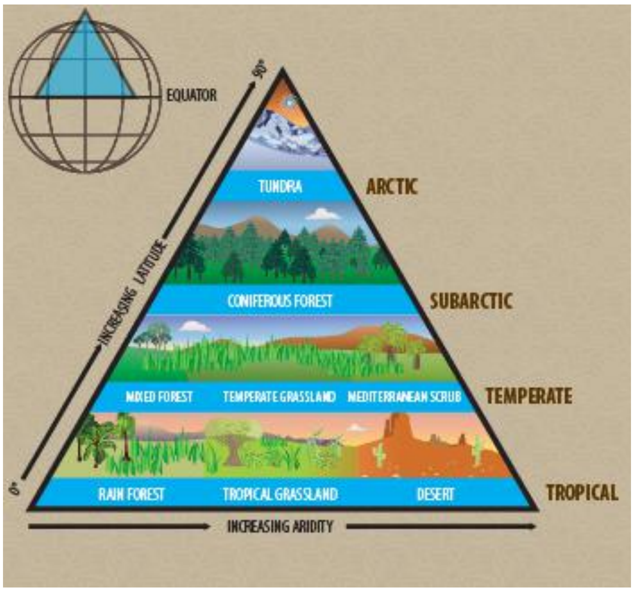
The atmosphere primarily gets heated by the long wave radiation that is emitted by the earth after absorbing solar insolation and not directly by sun's rays. So altitude affects temperature as lower altitude regions are closer to the source of terrestrial radiation than higher altitude.



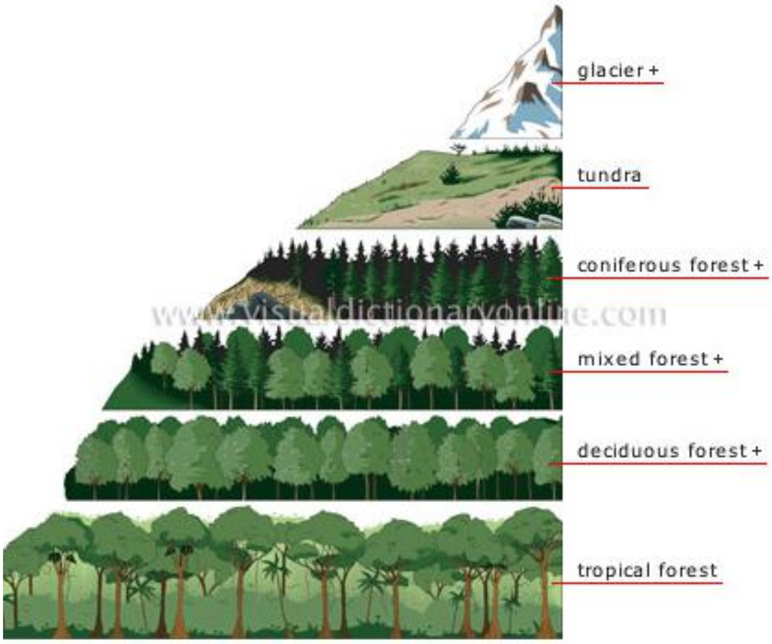
Also, air molecules at low altitudes are crowded together and there subsequent collisions increases their kinetic energy and temperature while at high altitude less air molecules are present in large volume which results into low temperature.
Thus temperature generally decreases with increase in altitude.
The vegetation in an area depends on the prevailing climate which is primarily dependent on the temperature and thus vegetation is also dependent on latitude and altitude. This can be discussed as under:

1. The vegetation around equatorial regions is abundant, diverse and evergreen due to hot and humid climatic conditions due to ample amount of Insolation received in the region.
2. As we move away from the equator towards the tropics, the insolation received decreases. The climate does not provide with torrential rains hence, the vegetation becomes thinner characterized by tropical forest or grasslands depending on the rains the regions receive.
3. Towards the temperate region the vegetation is scantily dispersed, characterized by mixed forests or temperate grasslands.
4. The Sibartctic regions and the regions closer to poles have vegetation with coniferous trees, as we move further closer to poles the vegetation becomes limited to mosses, lichens etc. which can better accommodate to the cold climate. .
   As the latitude increases (towards the poles) the vegetation also generally decreases as shown in the figure:

Student Notes:



Altitude affect the type and amount of sunlight that plants receive, the amount of water that plants can absorb and the nutrients that are available in the soil. As a result, certain plants grow very well in high elevations, whereas others can only grow in middle or lower elevations but in general with increase in altitude the vegetation decrease as shown in the figure.



The vegetation generally decreases with the increasing altitude and the sun facing side of a mountain also has better vegetation growth.

Thus the Latitude and altitude determine the climatic conditions and insolation of a region which in turn determine the vegetation of a region.

4. How do global pressure belts explain the formation of climatic regions across the world?

Approach:

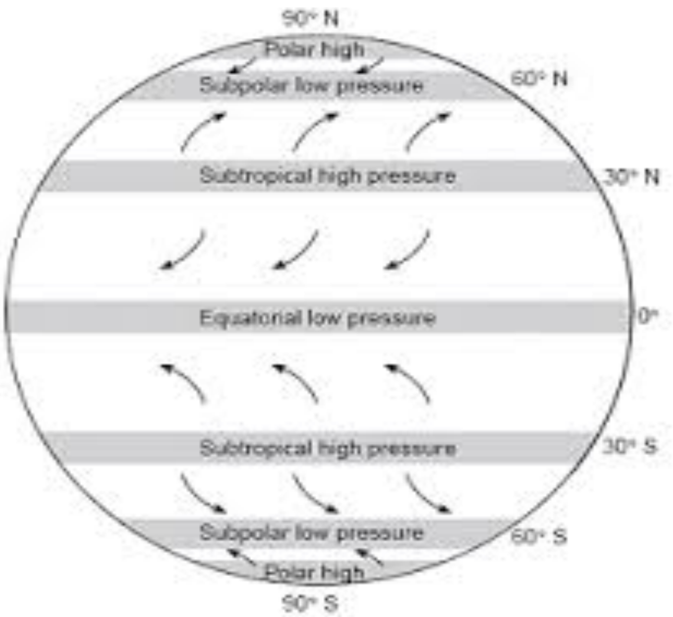
Question seeks to establish the causal link between global pressure belts (which are responsible for causing wind belts) and different climatic regions across the world. It can be done by first introducing global pressure belt and the wind system (with diagram) followed by description of those features of various climatic regions, which are influenced by wind system.

Answer:

Global pressure belts are permanent geo-climatic features on earth produced by the diffential heating of its surface.

These belts exist in pattern of alternate high and low pressure zones over the earth and they are four in numbers: equatorial low pressure belt, sub-tropical high pressure belt, sub-polar low pressure belt and polar high pressure belt (Figure below).

- Within this pattern of pressure belts, winds tend to blow from high pressure belts to low pressure belts as planetary winds.
- Due to Coriolis force winds acquire rightward and leftward tilt in northern and southern hemisphere respectively.



- Pressure and wind belts are dynamic and tend to shifts northward and southwards in response to migration of sun.
- These belts and their shifting play an important role in forming some important features of climatic regions of the world.
    - ***The hot-wet equatorial climate*****:** This region coincides with the equatorial low pressure belt. The condition of low pressure due to high heat results in heavy precipitation and constantly high relative humidity. Hence this climate region supports luxuriant type of vegetation.
    - ***The tropical monsoon climate:*** The shifting of pressure and wind belts produces a unique phenomenon of monsoons in some regions between two tropics. This seasonal shift in winds and consequent precipitation results in south-west monsoon and north-east monsoon in summer and winters respectively.
    - ***The savannah climate:*** This region is confined within tropics in interior of the continents. The prevailing winds of the region, trade winds loose the moisture when it reaches there and create the unique climate of savannah characterized by grasslands.

Student Notes:

Student Notes:

- ***The mid-latitude desert climate:*** This region coincides with sub-tropical high pressure belt where air descends. This condition is least favorable for precipitation. Hence in this climatic region permanently arid conditions prevail.
- ***The warm-temperate Mediterranean climate*****:** This climatic region is confined to the western portion of the continental masses below the high pressure belt that hovers above the region between 30º and 45º north and south of the equator. The shifting of these belts produces rainy winters and dry summers as the region comes under influence of moisture laden westerlies and dry trade winds in winters and summers respectively.
- ***The warm-temperate eastern margin:*** This climatic region experienced wet summer and dry winter as it comes under wet trade winds when pressure belts shifts north in summers.
- ***The cool temperate western margin*****:** these regions remained permanent influence of westerlies that blow from sub-tropical high pressure belt to sub-polar low pressure belt. As a result the precipitation occurs throughout the year.
- ***The cool temperate continental climate*****:** it is found in the interiors of the continent mainly in the northern hemisphere under sub-polar low pressure belts. Hence the rainfall is well distributed throughout the year though it is low due to continental influence.
- ***The cool temperate eastern margin*****:** this region comes under influence of westerlies that blow out from the continental interiors; hence the winter is cold and dry while summers are wet.
- ***The polar climate:*** this climate is found in north of the Arctic Circle in the northern hemisphere. Prevalence of anti cyclonic condition due to high pressure above results in very low precipitation mainly in form of snow.

5. Climate of India not only has regional variations but is also characterized by climatic unity. Substantiate with examples.

Approach:

- Discuss the climatic variations across India
- Write those climatic features which are common across India

Answer*:*

sihagn27@gmail.com

The shape, size, location, latitudinal extent and the sharply contrasting relief features of India has created regional diversities in climatic conditions. The climatic conditions of southern India are a bit different from those of the northern parts with respect to temperature, rainfall and commencement as well as duration of different seasons.

Temperature variation: The range of temperature increases as one moves away from coastal areas to interior parts of the country. As a result, the people living along Konkan and Malabar coasts do not experience extremes of temperatures or marked change in seasons. On the other hand, people living in north western parts of India, experience sharp seasonal contrasts

Precipitation variations: Mausimram, near Cherrapunji in Meghalaya, receives about 1080 cm of rainfall annually, while Jaisalmer in the desert of Rajasthan receives only 20 cm of annual rainfall. The northeastern parts and the coastal plains of Orissa and West Bengal experience spells of heavy rain during July and August while the Coromondel coast of Tamilnadu receive very meager rain during these months

Despite the regional diversities in climatic conditions, there exist weather conditions over different parts of India more or less the same during different seasons round the year leaving minor variations. This is climatic unity on India which is influenced by the overall monsoon regime in following ways:

Student Notes:

- **Latitudes:** India is a vast country that lies entirely in the Northern hemisphere and is characterized by 'Tropical Monsoon' climate.
- The Himalayas, by virtue of their elevation cut off the influence of the cold winds from the north so that the entire country has a tropical monsoon climate. Such a climate is characterized by a uniformly high temperature almost throughout the year particularly in summers.
- **Day-night variations:** The days are generally warm, but the nights are cold almost throughout the country.
- **Seasons:** The four main seasons occur in an almost fixed sequence to form an annual cycle.
- There is distinct **reversal of winds** with alternating seasons and winter season is mostly dry (except in North and Northwestern India due to western disturbances).
- **Local Winds:** Practically almost every part of India experiences hot and dry winds- eg. Loo in North India, and coastal parts of Karnataka, 'Bardoli Chheerha' in Assam, etc.
- **The Southwest Monsoon** provides heavy rainfall in many parts of India. During the onset of the monsoon (i.e. month of June till the end of September), there is hardly any place in India that does not receive continuous rainfall during these four months.
- **Economy and Culture:** The timing of monsoons gives way to the similar patterns in agriculture and same kind of cultural practices eg. 'Pongal' in Tamil Nadu, 'Sankranthi' in Andhra Pradesh, 'Bihu' in North East or 'lohri' in Punjab at the same time. This led to same kind of "Panchanga" and religious practices across India.
- The overall sub-tropical climate in the country maintains the basic food style like the staple food is rice and wheat.

Thus, monsoons lend broad climatic unity due to which cultural unity in India is also witnessed.

sihag...@gmail.com

6. Tropical regions are not only the most resource rich but also one of the most underdeveloped regions of the world. What are the factors responsible for this? How have some of the tropical countries turned their natural limitations to their advantage? Illustrate.

Approach:

- Introduce by stating the condition of the tropical countries and level of their development.
- Bring out that tropical regions are rich but some factors lead to their underdevelopment. List these factors.
- Point out the present trends which have been advantageous for these countries.
- Give examples from India and World.

Answer:

Despite their varied economic, political, and social histories, and rich geographical factors almost all of the tropical countries remain underdeveloped at the start of the 21st century. Only two tropical-zone countries, Hong Kong and Singapore, rank among the 30 countries classified as high-income by the World Bank.

- At the core of long-term growth is the continued development of technology, a process that has benefitted the temperate-zone countries much more than the tropics. Production technology in the tropics has lagged behind temperate-zone technology in the two critical areas of agriculture and consumer industries.

- The burden of disease is considerably higher in the tropics than in temperate climates. Even after controlling for GNP per capita, health outcomes are far better in temperate-zone countries.
- **Rapid deterioration of Tropical soil:** It is a myth that the tropical soils are rich. The torrential downpour in the region washes off all the nutrients from the soil, making agricultural possibilities limited.
- The jungles in these regions are dense and remotely accessed; these are also home to many indigenous people and endangered species. These forests are vital and cannot be exploited for many reasons.
- **Difficulties in lumbering and livestock farming**: Tropical hardwoods are sometimes too heavy to transport in the rivers.

Some of the tropical countries turned their natural limitations to their advantage. Some examples are:

- **Solar Energy**: Non-polluting energies are being promoted as an alternative to the traditional non-renewable types of energies. Some tropical countries like India have abundant solar energy; this is being used by these countries to harness Solar Energy for energy security. India is one such country.
- **Carbon Credits**: Till the time the Tropical countries do not start consuming large scale energy, which is unlikely for many tropical countries at this stage, they can use their unutilized carbon space and trade it with other countries for national profits. Delhi Metro Rail Corporation created a huge profit for itself by trading carbon credits, for the amount of emissions it cut down upon.
- **Ecotourism** is a leading way for developing countries to generate revenue by preserving their rainforests. Kenya in Africa, and Kerela in India are leading examples of tropical region eco-tourism.

The countries in Tropics do face the challenges, but some examples in front of us prove that some disadvantages can be turned into advantages in the coming future and there are examples we can learn from.

sihagnaz7@gmail.com

7. Temperate grasslands are called 'Granaries of the world'. Elucidate. How have the farming practices adopted in these regions impacted the environment?

Approach:

- Discuss the temperate grassland as biome and its agricultural practices.
- Explain the impact of farming practices on environment.

Answer:

The temperate grasslands are located in the interiors of continents where grasses are dominant vegetation. The biome possesses world's most fertile soils such as eastern prairies of the U.S., the pampas of South America, and the steppes of Ukraine.

Temperate grasslands are termed granaries of world because:

- As most of the areas have been cleared and are used to produce crops specially wheat.
- Climate and vegetation represent close relationship thus a suitable climate for crops.
- Soil is world's most fertile supporting the required crops.
- Mechanization of agriculture has facilitated bumper produce to accord the status.

Student Notes:

However farming practices adopted in this region have impacted environment in the following ways:

- Rare occurrence of virgin grassland since most has been changed for pastoralism.
- Use of land for agricultural ecosystem, use of mechanization or through the use of biocides.
- Wheat, corn and dairy farming are practiced widely changing the ecosystem.
- Disappearance of natural habitat or their overall transformation has impacted animal species of the biome.
- There has been an impact in the biodiversity of the area because of introduction of monoculture practices.
- Extensive cultivation of prairies of USA has resulted into loosening of soil which causes great damage during drought to human lives and property.

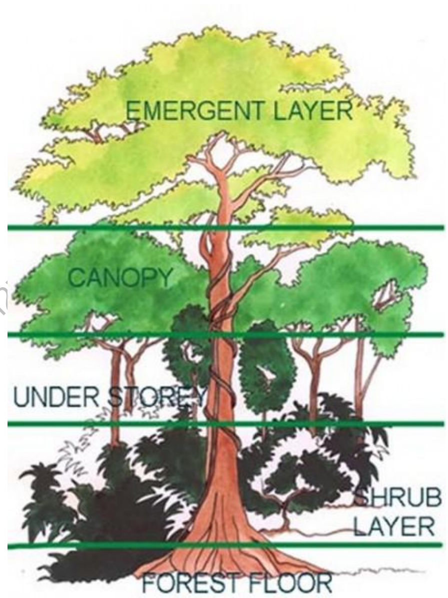
Thus these areas are under huge agricultural pressure due to use of modern techniques which is impacting overall ecosystem of the grassland.

8. ***Elaborate on the characteristic features of vegetation in equatorial regions. Discuss the factors which affect the development of these regions.***

Approach:

- Introduce by describing location and climate of equatorial regions.
- Describe the characteristic features of equatorial vegetation.
- Then explain in some detail factors which affect development of these regions.
- Conclude by suggesting some measures for development.

Answer:



The equatorial hot, wet climate is found between 5 degree and 10 degree north and south of the equator. There is great uniformity of temperature and heavy and well distributed precipitation throughout the year. This conditions support a luxuriant type of vegetation- the equatorial rain forests.

Characteristic Features of Equatorial Vegetation

- A great variety of vegetation- The equatorial vegetation comprises a multitude of tropical hardwood evergreen trees, smaller palm trees, climbing plants like lianas and epiphytic and parasitic plants. Under the trees grow a wide variety of ferns, orchids and lalang (tall grass).
- A distinct layer arrangement- All plants struggle upwards for sunlight resulting in a distinct 5 layered arrangement.
- Multiple Species- The trees of equatorial rainforest are not found in pure stands of a single species.
- Forest Clearings- When the clearings in these forests are abandoned, less luxuriant secondary forests, called 'belukar' in Malaysia, spring up. The trees are short with very dense undergrowth.
- Some plants, known as epiphytes, grow on trees (their roots are not in the soil).

Student Notes:

Student Notes:

Factors which affect development

- Equatorial climate and health- Under conditions of high heat and humidity, Man is subject to serious physical and mental handicaps. Capacity for active work is greatly reduced and vulnerability to diseases is very high.
- Prevalence of bacteria and insect pests- the hot, wet climate encourages spread of insects and pests. Insects and pests not only spread disease but are also injurious to crops.
- Transport and communication networks are built and maintained at a very high cost.
- Rapid deterioration of tropical soil- tropical soils, in their untouched state, are fairly fertile due to thick layer of humus. But once the humus is used and natural vegetation cover is removed, the torrential rains soon wash out most of the soil nutrients.
- Difficulties in lumbering and livestock farming- the region have great potential in timber resources but commercial extraction is difficult. Livestock farming is not developed due to absence of meadow grass.

The equatorial rainforests are lungs of the planet. Their sustainable development is the need of the hour.

9. ***Highlight the characteristic features of Equatorial Climate and Vegetation. What are the reasons that have constrained the development of this region despite abundance of natural resources?***

Approach:

- Briefly state the extent of the hot, wet, equatorial region.
- Mention the characteristic features of the Equatorial climate.
- Similarly, state the characteristic features of vegetation in the Equatorial region.
- State the reasons that have constrained the development of the region despite abundance of natural resources.

Answer:

The hot, wet, equatorial climate is found between 5º to 10º North and South of the Equator, primarily in the Amazon lowlands, the Congo, Malaysia and the East Indies.

Characteristic features of the Equatorial climate include:

- **Temperature and seasons -** Mean monthly temperature is always around 80º F. Diurnal and annual ranges of temperatures are small due to cloudiness, heavy precipitation and land and sea breezes. Thus, there is no winter or summer.
- **Precipitation -** The rainfall is heavy and well distributed throughout the year between 60-100 inches with two periods of maximum rainfall in April and October, shortly after the equinoxes. Least rain falls during June and December solstices. Thunder and lightning often follow convectional rains in the afternoon.

Characteristic features of Equatorial vegetation are:

- **Diversity in vegetation:** It comprises a multitude of evergreen trees that yield tropical hardwood, e.g. mahogany, ebony etc. There are also smaller palm trees, climbing plants, epiphytic and parasitic plants. Under the trees grow a wide variety of ferns, orchids and lalang.
- **Distinct layer arrangement:** As all plants struggle upwards for sunlight.
- **Multiple species:** The trees of the forest are found in multiple strands of different species.

Student Notes:

Factors that constrain the development of the region despite having abundant resources are:

- **Equatorial climate and health:** Due to excessive heat and high humidity, people are subjected to physical and mental handicaps. Diseases like malaria and yellow fever, reduce their capacity to work**.**
- **Prevalence of bacteria and insect pests:** The hot, wet climate is ideal for the survival and spread of insects and pests, which injure crops and plague men and animals.
- **Hindrance to development and maintenance:** Due to luxuriant jungle, tall grass, thick undergrowth, regular weed growth etc., it is difficult to clear the forests for construction and maintenance.
- **Rapid deterioration of tropical soil:** Most of the soil nutrients are washed out due to torrential downpours, leading to soil erosion and impoverishment.
- **Difficulties in lumbering**: Commercial extraction is difficult, as the trees do not occur in homogeneous strands. Further, there are no frozen surfaces to facilitate logging of heavy tropical hardwoods.
- **Difficulties in livestock farming:** Livestock farming is handicapped by absence of meadow grass and frequent attacks by flies and insects.

sihagn27@gmail.com

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OCEAN BASICS AND OCEAN RESOURCES

Student Notes:

Contents

sihagn27@gmail.com

Student Notes:

sihagn27@gmail.com

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Student Notes:

1. Ocean Basics

Water is an essential component of all life forms. The earth fortunately has an abundant supply of water on its surface. Hence, our planet is called the **Blue Planet**. About *97 per cent* of the planetary water is found in the oceans. Oceans account for more than 70 per cent or 140 million square miles of the earth's surface.

Oceanography, the science of the oceans, has become such an important subject in recent years and many researches into the deep seas have been conducted. The oceans, unlike the continents, merge so naturally into one another that it is hard to demarcate them. The geographers have divided the oceanic part of the earth into **four** oceans, namely the **Pacific**, the **Atlantic**, the **Indian** and the **Arctic**.

1.1. Relief of the Ocean Floor

Ocean Floor refers to the land under the waters of the oceans. The ocean floor exhibits complex and varied features similar to those observed over the land. The floors of the oceans are rugged with the world's largest mountain ranges, deepest trenches and the largest plains. These features are formed, like those of the continents, by the factors of *tectonic*, *volcanic* and *depositional* processes.

The ocean floors can be divided into following four major divisions:

1.1.1. Continental Shelf

The continental shelf is the extended margin of each continent occupied by relatively shallow seas. It is the shallowest part of the ocean showing an average gradient of1° or even less. The shelf typically ends at a very steep slope, called the **shelf break**.

The widths of the continental shelves vary from one ocean to another. The average width of continental shelves is about 80 km. The shelves are almost absent or very narrow along some of the margins like the coasts of Chile, the west coast of Sumatra, etc. On the contrary, **the Siberian shelf** in the Arctic Ocean, the largest in the world, stretches to 1,500 km in width. The depth of the shelves also varies. It may be as shallow as 30 m in some areas while in some areas it is as deep as 600 m.

sihag027@gmail.com

The continental shelves are covered with variable thicknesses of sediments brought down by rivers, glaciers, wind, from the land and distributed by waves and currents. Massive sedimentary deposits received over a long time by the continental shelves, become the source of fossil fuels.

1.1.2. Continental Slope

The continental slope connects the continental shelf and the ocean basins (bottom of the ocean). It begins where the bottom of the continental shelf sharply drops off into a *steep slope*. The gradient of the slope region varies between 2-5°. The depth of the slope region varies between 200 and 3,000m. The slope boundary indicates the end of the continents. *Canyons* and *trenches* (discussed later in minor relief features of ocean floor) are observed in this region.

1.1.3. Continental Rise

Where the continental slope ends, the gently sloping continental rise begins. Its general relief is low and with increasing depth, the continental rise becomes virtually flat to merge with the deep sea plains.

1.1.4. Deep Sea Plain

Deep sea plains are gently sloping areas of the ocean basins. These are the flattest and smoothest regions of the world. The depths vary between 3,000 and 6,000m. These plains are covered with fine-grained sediments like clay and silt.

Student Notes:

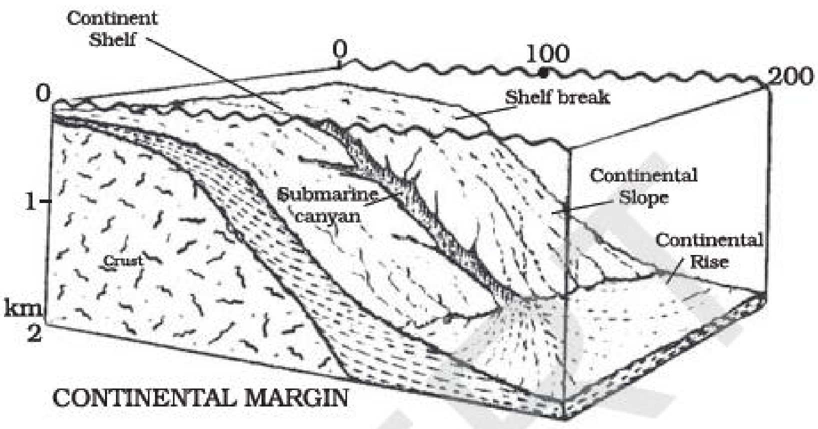
Deep sea plains cover two-thirds of the ocean floor and are also known as **abyssal plains**. They also contain features like ridges, guyots and oceanic islands that sometimes rise above the sea level in the midst of oceans.

1.1.5. Oceanic deeps or Trenches

These areas are the deepest parts of the oceans. The trenches are relatively steep sided, narrow basins. They are some 3-5 km deeper than the surrounding ocean floor. They occur at the bases of continental slopes and along island arcs and are associated with *active volcanoes* and *strong earthquakes*. That is why they are very significant in the study of plate movements.

As many as 57 deeps have been explored so far; of which 32 are in the Pacific Ocean; 19 in the Atlantic Ocean and 6 in the Indian Ocean. The greatest known ocean deep is the **Mariana Trench** near *Guam Island*, which is more than 36,000 feet deep.

Figure 1. Major relief features of the ocean floor.



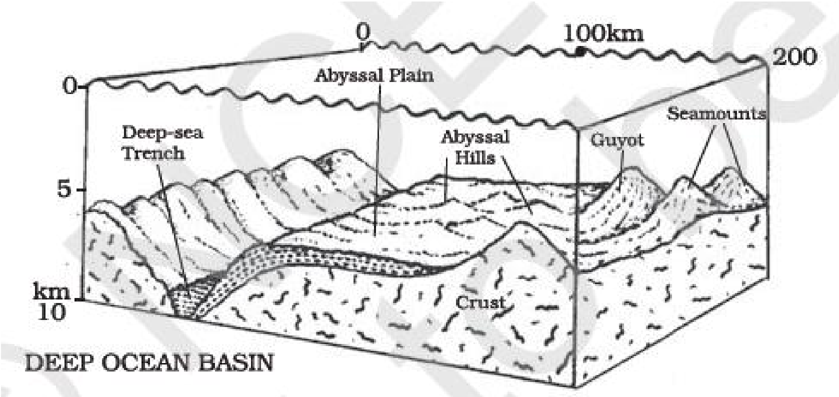
1.2. Minor Relief Features of the Ocean Floor

Apart from the above mentioned major relief features of the ocean floor, following minor but significant features predominate in different parts of the oceans:

1. **Mid-oceanic ridges:** A mid-oceanic ridge is composed of chains of mountains separated by a large depression. Oceanic ridge is also known as an **oceanic spreading center**, which is responsible for **seafloor spreading**. The uplifted sea floor results from *convection* currents which rise in the mantle as magma at a linear weakness in the oceanic crust, and emerge as lava, creating new crust upon cooling. A mid-ocean ridge demarcates the boundary between two tectonic plates, and consequently is termed a **divergent plate boundary**.
   The mountain ranges can have peaks as high as 2,500 m and some even reach above the ocean's surface. **Iceland**, a part of the mid-Atlantic Ridge, is an example.
2. **Seamount:** It is a mountain with pointed summits, rising from the seafloor that does not reach the surface of the ocean. Seamounts are *volcanic* in origin. These can be 3,000-4,500 m tall. The **Emperor seamount**, an extension of the *Hawaiian Islands* in the Pacific Ocean, is a good example.
3. **Submarine canyons:** These are deep valleys, found cutting across the continental shelves and slopes, extending from the mouths of large rivers. **The Hudson Canyon** is the best known submarine canyon in the world.

Student Notes:

Figure 2. Minor Relief features of the ocean floor.



4. **Guyots:** It is a flat topped seamount. They show evidences of gradual subsidence through stages to become flat topped submerged mountains. It is estimated that more than 10,000 seamounts and guyots exist in the Pacific Ocean alone.
5. **Atoll:** These are low islands found in the *tropical oceans* consisting of coral reefs surrounding a central depression. It may be a part of the sea (lagoon), or sometimes form enclosing a body of fresh, brackish or highly saline water.

1.3. The Oceanic Deposits of the Ocean Floor

Materials eroded from the earth which are not deposited by rivers or at the coast are eventually dropped on the ocean floor. The dominant process is *slow sedimentation* where the eroded particles very slowly filter through the ocean water and settle upon one another in layers. All oceanic deposits can be classified as follows:

1. **Muds:** These are terrigenous deposits because they are derived from land and are mainly deposited on the continental shelves. The muds are referred to as blue, green or red muds; their colouring depends upon their chemical content.
2. **Oozes:** These are pelagic deposits because they are derived from the oceans. They are made of the shelly and skeletal remains of marine microorganisms with calcareous or siliceous parts. Oozes have a very fine, flour-like texture and either occur as accumulated deposits or float about in suspension.
3. **Clays:** These occur mainly as red clays in the deeper parts of the ocean basins, and are particularly abundant in the Pacific Ocean. *Red clay* is believed to be an accumulation of volcanic dust blown out from volcanoes during volcanic eruptions.

sihanz7@gmail.com

1.4. Temperature

Like land masses, ocean water varies in temperature from place to place both at the surface and at great depths. Ocean water gets heated by solar energy just as land. The process of heating and cooling of the oceanic water is *slower* than land. This is due to higher *specific heat* of water as compared to land as a result of which greater amount of energy is required to raise the temperature of water as compared to land.

1.4.1. Factors Affecting Temperature Distribution

The factors which affect the distribution of temperature of ocean water are:

1. **Latitude:** The temperature of surface water *decreases* from the equator towards the poles because the amount of **insolation** decreases poleward.
2. **Unequal distribution of land and water:** The oceans in the northern hemisphere receive more heat due to their contact with *larger extent of land* than the oceans in the southern hemisphere.
3. **Prevailing winds:** The winds blowing from the land towards the oceans drive warm surface water away from the coast resulting in the *upwelling* of cold water from below. It results

into the longitudinal variation in the temperature. Contrary to this, the onshore winds pile up warm water near the coast and this raises the temperature.

4. **Ocean currents:** Warm ocean currents raise the temperature in cold areas while the cold currents decrease the temperature in warm ocean areas.

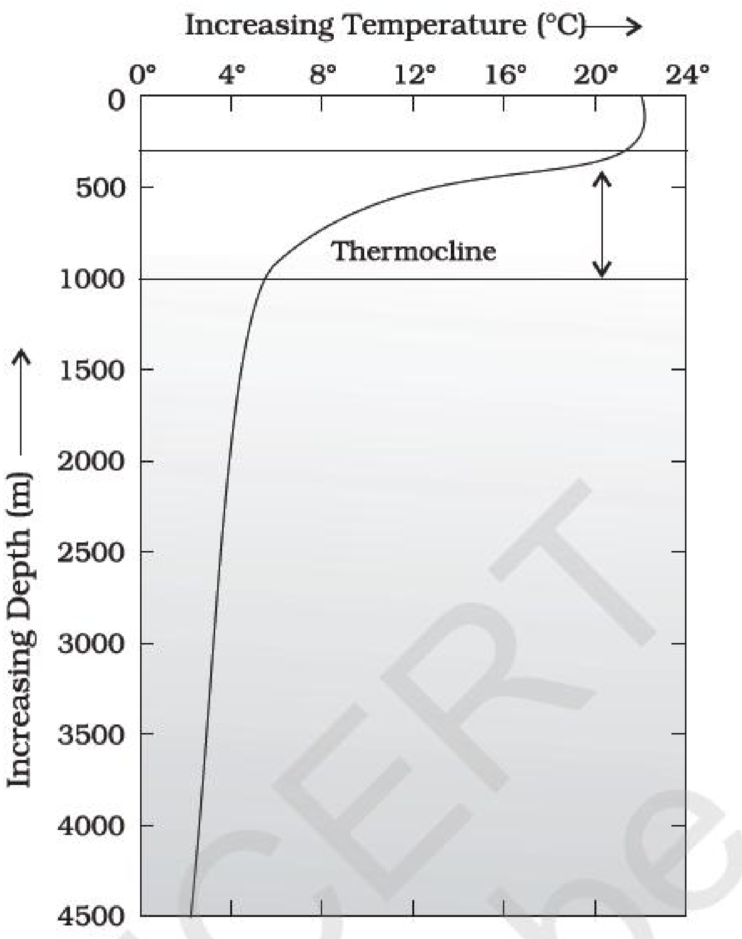
All these factors influence the temperature of the ocean currents locally. The *enclosed seas* in the low latitudes record relatively higher temperature than the open seas; whereas the enclosed seas in the high latitudes have lower temperature than the open seas.

1.4.2. Vertical Distribution of Temperature

It is a well-known fact that the maximum temperature of the oceans is always at their surfaces because they *directly receive the heat from the sun* and the heat is transmitted to the lower sections of the oceans through the process of **convection**. It results into decrease of temperature with the increasing depth, but the rate of decrease is not uniform throughout.

The temperature falls very rapidly up to the depth of 200 m and thereafter, the rate of decrease of temperature is slowed down. The temperature profile of oceans shows a boundary region between the surface waters of the ocean and the deeper layers. The boundary usually begins around 100-400m below the sea surface and extends several hundred of metres downward. This boundary region, from where there is a rapid decrease of temperature, is called the **thermocline**. About 90 per cent of the total volume of water is found below the thermoclinein the deep ocean. In this zone, temperatures approach 0°C.

Figure 3. Variation of temperature with depth in oceans



The temperature structure of **oceans over middle and low latitudes** can be described asa three-layer system from surface to the bottom:

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- The *first layer* represents the top layer of warm oceanic water and it is about 500m thick with temperatures ranging between 20° and25° C. This layer, within the tropical region, is present throughout the year but in mid-latitudes it develops only during summer.
- The *second layer* called the thermocline layer lies below the first layer and is characterized by rapid decrease in temperature with increasing depth. The thermocline is 500 -1,000 m thick.
- The *third layer* is very cold and extends up to the deep ocean floor. Here the temperatures are close to 0° C.

In the **Arctic and Antarctic circles**, surface water temperatures are close to 0° C and so the temperature change with the depth is very slight. Here, *only one layer of cold water exists*, which extends from surface to deep ocean floor.

1.4.3. Horizontal Distribution of Temperature

The average temperature of surface water of the oceans is about 27°C and it *gradually decreases from the equator towards the poles*. The rate of decrease of temperature with increasing latitude is generally *0.5°C per latitude*. The average temperature is around22°C at 20° latitudes, 14° C at 40° latitudes and 0° C near poles.

The oceans in the northern hemisphere record **relatively higher temperature** than in the southern hemisphere. The highest temperature is not recorded at the equator but slightly towards north of it. The average annual temperatures for the northern and southern hemisphere are around 19° C and 16°C respectively. This variation is due to the **unequal distribution of land and water** in the northern and southern hemispheres.

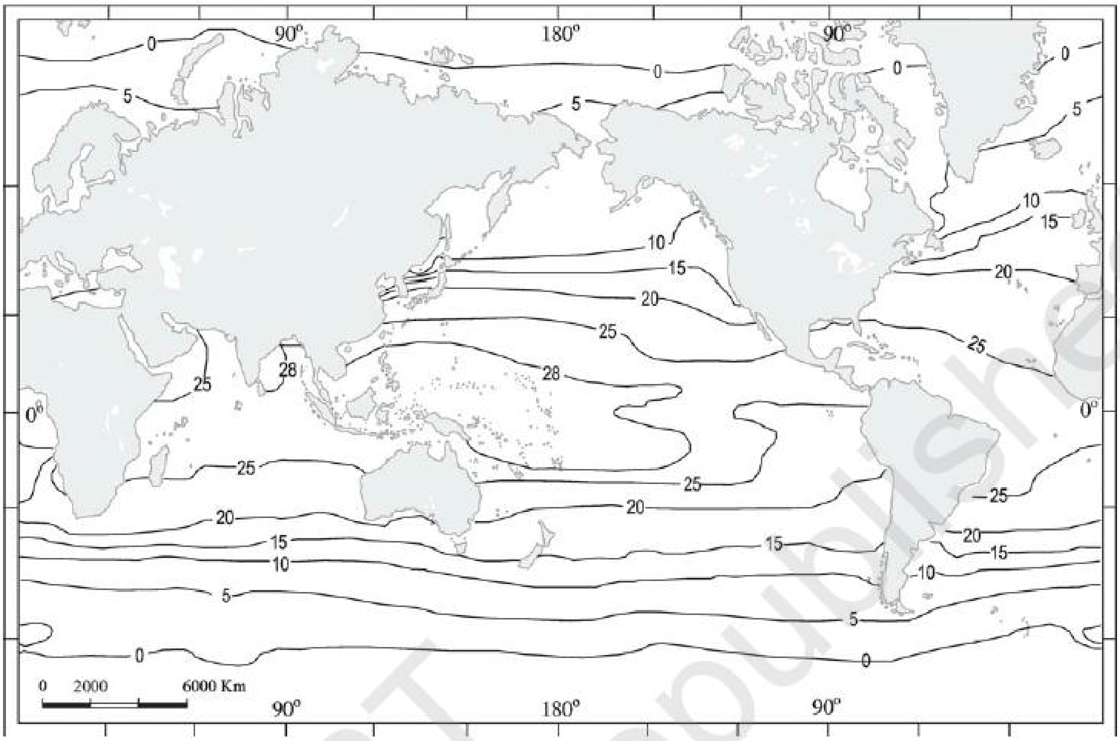

Figure 4. Horizontal Distribution of temperature of oceans around the world

1.5. Salinity

Salinity is used to define the total content of *dissolved salts* in sea water. It is calculated as the amount of salt (in gm) dissolved in 1,000 gm (1 kg) of seawater. It is usually expressed as parts per thousand or ppt. Salinity is an important property of sea water. Salinity of 24.7 ppt has been considered as the upper limit to demarcate *brackish water*(saltier than fresh water, but not as salty as seawater).

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1.5.1. Factors Affecting Ocean Salinity

Major factors are as mentioned below:

- The salinity of water in the surface layer of oceans depends mainly on *evaporation and precipitation.*
- Surface salinity is greatly influenced in coastal regions by the *fresh water* flow from rivers, and in polar-regions by the processes of freezing and thawing of ice.
- *Wind* also influences salinity of an area by transferring water to other areas.
- The *ocean currents* contribute to the salinity variations.

Salinity, temperature and density of water are *interrelated*. Hence, any change in the temperature or density influences the salinity of water in an area.

1.5.2. Vertical Distribution of Salinity

Salinity changes with depth but the way it changes depends upon the *location of the sea*. Salinity at the surface increases by *loss of water to ice or evaporation*, or decreases by the *input of fresh water*, such as from the rivers. Salinity at depth is very much fixed, because there is no way that water is lost, or the salt is added.

There is a marked difference in the salinity between the surface zones and the deep zones of the oceans. The lower salinity water rests above the higher salinity dense water. Salinity, generally, increases with depth and there is a distinct zone called the **halocline,** where salinity increases sharply. Other factors being constant, *increasing salinity of seawater causes its density to increase*. High salinity seawater, generally, sinks below the lower salinity water. This leads to **stratification by salinity**.

1.5.3. Horizontal Distribution of Salinity

The salinity for normal open ocean ranges between 33 ppt and 37 ppt. In the *land locked* **Red sea**, it is as high as 41 ppt, while in the estuaries and the **Arctic**, the salinity fluctuates from 0 – 35 ppt, seasonally. In hot and dry regions, where *evaporation is high*, the salinity sometimes reaches to 70 ppt.

The salinity variation in the **Pacific Ocean** is mainly due to its *shape* and *larger areal extent*. Salinity decreases from 35 ppt - 31 ppt on the western parts of the northern hemisphere because of the influx of *melted water from the Arctic region*. In the same way, after 15° - 20° south, it decreases to 33 ppt

singn27@gmail.com

The average salinity of the **Atlantic Ocean** is around 36 ppt. The highest salinity is recorded between 15° and 20° latitudes. Maximum salinity (37 ppt) is observed between20° N and 30° N and 20° W - 60° W. *It gradually decreases towards the north*. The **North Sea**, in spite of its location in higher latitudes, records higher salinity due to more saline water brought by the *North Atlantic Drift*. **Baltic Sea** records low salinity due to influx of river waters in large quantity. **The Mediterranean Sea** records higher salinity due to high evaporation. Salinity is, however, very low in **Black Sea** due to enormous fresh water influx by rivers.

The average salinity of the **Indian Ocean** is 35 ppt. The low salinity trend is observed in the **Bay of Bengal** due to large influx of river water. On the contrary, the **Arabian Sea** shows higher salinity due to high evaporation and low influx of fresh water.

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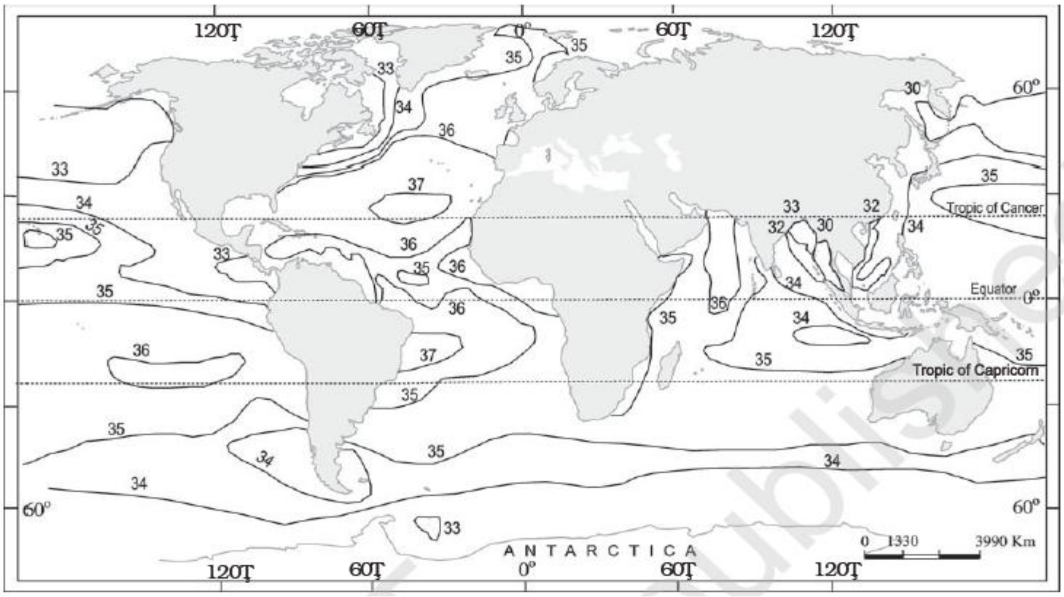

Figure 5. Surface salinity of World Oceans.

2. Movements of Ocean Water

Ocean water is dynamic. The horizontal motion refers to the *ocean currents* and *waves*. The vertical motion refers to *tides*. The *upwelling* of cold water from subsurface and the *sinking* of surface water are also forms of vertical motion of ocean water.

2.1. Waves

Waves are actually the **energy**, not the water as such, which moves across the ocean surface. Water particles only travel in a *small circle* as a wave passes. *Wind provides energy to the waves*. Wind causes waves to travel in the ocean and the energy is released on shorelines.

The motion of the surface water seldom affects the stagnant deep bottom water of the oceans. As a wave approaches the beach, it slows down. This is due to the **friction** occurring between the dynamic water and the sea floor and when the depth of water is less than half the wavelength of the wave, the wave breaks. *The largest waves are found in the open oceans*. Waves continue to grow larger as they move and absorb energy from the wind.

A wave's size and shape reveal its *origin*. **Steep waves** are fairly young ones and are probably formed by *local wind*. **Slow and steady waves** originate from faraway places, possibly from another hemisphere. The maximum wave height is determined by the strength of the wind, i.e. *how long it blows and the area over which it blows in a single direction*.

2.1.1. Characteristics of Waves

Important terms associated with waves are:

- *Wave crest and trough:* The highest and lowest points of a wave are called the crest and trough respectively.
- *Wave height:* It is the vertical distance from the bottom of a trough to the top of a crest of a wave.
- *Wave amplitude:* It is one-half of the wave height.
- *Wave period:* It is the time interval between two successive wave crests or troughs as they pass a fixed point.
- *Wavelength:* It is the horizontal distance between two successive crests.
- *Wave speed:* It is the rate at which the wave moves through the water, and is measured in knots.

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- *Wave frequency:* It is the number of waves passing a given point during a one second time interval.

2.1.2. Wave Motion

Waves travel because wind pushes the water body in its course while gravity pulls the crests of the waves downward. The falling water pushes the former troughs upward, and the wave moves to a new position. The actual motion of the water beneath the waves is circular. It indicates that things are carried up and forward as the wave approaches, and down and back as it passes.

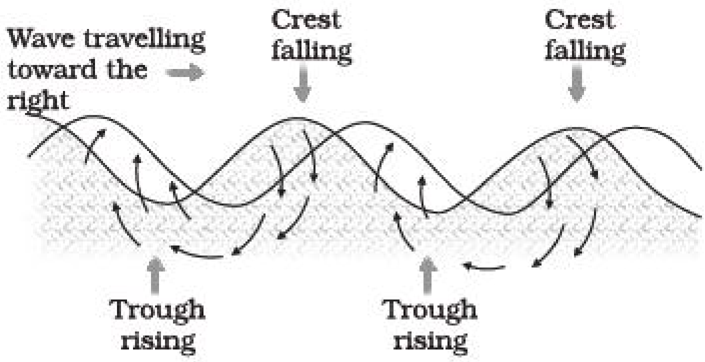

Figure 6. Motion of waves and water molecules

2.2. Tides

The *periodical* rise and fall of the sea level, once or twice a day, mainly due to the attraction of sun and the moon, is called a *tide*. Movement of water caused by meteorological effects (winds and atmospheric pressure changes) are called *surges*. Surges are not regular like tides. The study of tides is very complex, spatially and temporally, as it has great variations in frequency, magnitude and height.

2.2.1. Causes of Tides

The moon's **gravitational pull** to a great extent and to a lesser extent the sun's gravitational pull, are the major causes for the occurrence of tides. Another factor is **centrifugal force**, which is the force that acts to counterbalance the gravity. Together, the gravitational pull and the centrifugal force are responsible for creating the *two major tidal bulges* on the earth.

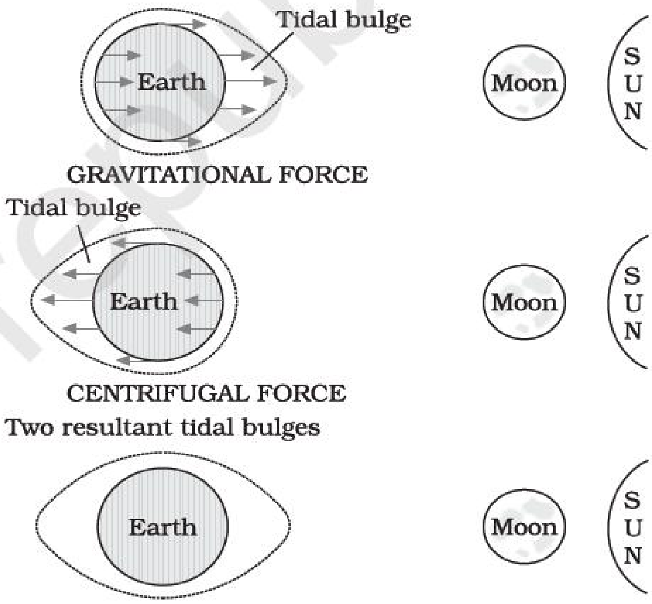

Figure 7. Relation between gravitational forces and centrifugal forces

The 'tide-generating' force is the *difference between the gravitational attraction of the moon and the centrifugal force*. On the surface of the earth, nearest the moon, pull or the attractive force of the moon is greater than the centrifugal force, and so there is a net force causing a bulge towards the moon.

On the opposite side of the earth, the attractive force is less, as it is farther away from the moon, the centrifugal force is dominant. Hence, there is a net force away from the moon. It creates the second bulge away from the moon.

2.2.2. Types of Tides

Tides vary in their frequency, direction and movement from place to place and also from time to time. Tides may be grouped into various types based on their *frequency of occurrence in one day* or based on their *height*.

2.2.3. Tides Based on Rrequency

1. ***Semi-diurnal tide:*** The most common tidal pattern, featuring two high tides and two low tides each day. The successive high or low tides are approximately of the same height.
2. ***Diurnal tide:*** There is only one high tide and one low tide during each day. The successive high or low tides are approximately of the same height.
3. ***Mixed tide:*** Tides having variations in height are known as mixed tides. These tides generally occur along the west coast of North America and on many islands of the Pacific Ocean.

2.2.4. Tides Based on Height

The height of rising water (high tide) varies appreciably depending upon the *position of sun and moon with respect to the earth*:

1. **Spring tides:** On *full moon* and *new moon* days, the Sun, the Moon and the Earth are almost in the *same line*. On these days, the Sun and the Moon exert their *combined gravitational force* on the Earth. Thus on these two days the high tides are the *highest* and are known as spring tides. The height of a spring tide is about 20 per cent more than the normal high tide. They occur twice every month.
2. **Neap tides:** On *half Moon* days (i.e. first and last quarter phases of the Moon), the Sun and the Moon are at *right angles* to the centre of the Earth. The tide producing forces of the Moon and the Sun, work in *opposite directions* and they partly cancel each other's force. In such cases, the high tide is lower than the normal and low tide is higher than the normal. The difference is about 20 per cent. This is known as the neap tide.

singh07@gmail.com

2.2.5. Characteristics of Tides

- **Tidal range:** The difference between the high tide water and the low tide water is called the tidal range. The time between the high tide and low tide, when the water level is falling, is called the **ebb**. The time between the low tide and high tide, when the tide is rising, is called the **flow** or **flood**.

  Once in a month, when the moon's orbit is closest to the earth *(perigee)*, unusually high and low tides occur. During this time the *tidal range is greater than normal*. Two weeks later, when the moon is farthest from earth *(apogee)*,the moon's gravitation force is limited and the tidal ranges are less than their average heights.

  When the earth is closest to the sun (*perihelion*), around 3rd January each year, tidal ranges are also much greater, with unusually high and unusually low tides. When the earth is farthest from the sun (*aphelion*), around 4th July each year, tidal ranges are much less than average.

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- **Tidal current:** Tidal currents (a horizontal motion) are a result of the rise and fall of the water level due to tides (a vertical motion). The effects of tidal currents on the movement of water in and out of bays and harbours can be substantial.
  The tidal bulges on *wide continental shelves*, have greater height. When tidal bulge shit the mid-oceanic islands they become low. The shape of bays and estuaries along a coastline can also magnify the intensity of tides. *Funnel-shaped bays* greatly change tidal magnitudes. The highest tides in the world occur in the **Bay of Fundy in Nova Scotia, Canada**. The tidal bulge is 15 - 16 m.
- **Tidal bore:** When the tide enters the narrow and shallow estuary of a river, the front of the tidal wave appears to be vertical due to the piling up of the river water against the tidal wave and the friction of the river bed. It looks as if a vertical wall of water is moving upstream. This is called a tidal bore. In India tidal bores are common in the *Hugli River*.

2.2.6. Importance of Tides

Since tides are caused by the earth-moon-sun positions which are known accurately, *the tides can be predicted well in advance*. This helps the navigators and fishermen plan their activities. Some of the important activities associated with tides are:

1. Tidal flows are of great importance in **navigation**. Tidal heights are very important, especially harbours near rivers and within estuaries having shallow 'bars' at the entrance, which prevent ships and boats from entering into the harbour. Large ships enter the harbour of a shallow sea during high tide and they go back also at the time of high tide. *London* and I have become important ports due to the tidal nature of the mouths of the *Thames* and *Hugli* rivers respectively.
2. The river mouths and estuaries are kept **clean of sedimentation** due to the action of tidal currents. The force of the outgoing tide and the river current carries the silt away to the open sea. This helps in navigation.
3. The tidal force can also be used as a source for **generating electricity**. A 3 MW tidal power project at *Durgaduani* in *Sunderbans* of West Bengal is under way.
4. The inflow of the salty tidal water, especially along the coast of cold countries, retards the process of freezing and *prevents the harbours from becoming ice-bound*.
5. The fishing industry is helped by the rhythm of high and low tides. The fishermen mostly sail out to the open sea during low tides and return to the coast at high tides.

sihagn27@gmail.com

2.3. Ocean Currents

Ocean currents are like river flow in oceans. They represent a *regular volume of water in a definite path and direction*.

2.3.1. Causes of Ocean Currents

Ocean currents are influenced by two types of forces namely:

- **Primary forces** that initiate the movement of water.
- **Secondary forces** that influence the currents to flow.

The forces that influence the currents are:

1. **Heating by solar energy** causes water to *expand*. That is why, near the equator the ocean water is about 8 cm higher in level than in the middle latitudes. This causes a very *slight gradient* and water tends to flow down the slope.
   There is much difference in the temperature of ocean waters at the equator and at the poles. As *warm water is lighter and rises*, and *cold water is denser and sinks*, warm equatorial waters move slowly along the surface polewards, while the heavier cold waters of the polar regions creep slowly along the bottom of the sea equatorwards.

Student Notes:

2. **Wind** blowing on the surface of the ocean pushes the water to move. *Friction* between the wind and the water surface affects the movement of the water body in its course. Most of the ocean currents of the world follow the direction of the prevailing winds.
3. **Coriolis force** causes the water to move to the *right in the northern hemisphere* and to the *left in the southern hemisphere*. These large accumulations of water and the flow around them are called **Gyres.** These produce large circular currents in all the ocean basins.
4. **Salinity** of ocean water varies from place to place. Waters of high salinity are denser than waters of low salinity. Hence on the surface, waters of low salinity flow towards waters of high salinity while at the bottom, waters of high salinity flow towards waters of low salinity.
5. The **configuration of the coastline** serves as an obstruction for the natural flow of ocean currents and succeeds in changing its direction. This is quite conspicuous in the equatorial region where the landmasses deflect the current towards the north and the south.

2.3.2. Types of Ocean Currents

The ocean currents may be classified based on their *depth* or *temperature*.

2.3.3. Currents Based on Depth

1. **Surface currents** constitute about10 per cent of all the water in the ocean, these waters are the upper 400 m of the ocean.
2. **Deep water currents** make up the other 90 per cent of the ocean water. Deep waters sink into the deep ocean basins at high latitudes, where the temperatures are cold enough to cause the density to increase.

2.3.4. Currents Based on Temperature

1. **Cold currents** bring coldwater into warm water areas. These currents are usually found on the *west coast of the continents in the low and middle latitudes* (true in both hemispheres) and on the *east coast in the higher latitudes in the Northern Hemisphere*.
2. **Warm currents** bring warm water into cold water areas and are usually observed on the east coast of continents in the low and middle latitudes (true in both hemispheres). In the northern hemisphere they are found on the west coasts of continents in high latitudes.

2.3.5. Characteristics of Ocean Currents

siragio7@gmail.com

The currents are *strongest near the surface* and may attain speeds over five knots. At depths, currents are generally slow with speeds less than 0.5knots. The speed of a current is known as its **drift**. Drift is measured in terms of knots. The **strength of a current** refers to the speed of the current. *A fast current is considered strong*. A current is usually strongest at the surface and decreases in strength (speed) with depth. Most currents have speeds less than or equal to 5 knots.

2.3.6. Currents of the Atlantic Ocean

Major currents of the Atlantic Ocean are:

North and South Equatorial Current

- To the north and south of the equator, there are two westward moving currents-the North Equatorial Current and the South Equatorial Current.
- Due to the rotation of the Earth (Coriolis Effect), these currents move almost due west along the equator.
- The North Equatorial Current moves northwards due to the presence of the South American continent and the Coriolis force, and takes the north-west direction. It enters *the Gulf of Mexico* to form the **Gulf Stream**.
- The **South Equatorial Current** originates from the western coast of Africa, from where it moves towards South America.

- The east coast of Brazil obstructs the South Equatorial Current which then bifurcates into two branches.
- The northward branch merges with the North
- Equatorial Current, while the second branch flows along the east coast of Brazil and is known as the Brazilian Current.
- The North Equatorial Current and the South Equatorial Current are warm currents.

Gulf Stream

- The Gulf Stream is one of the largest warm currents. It originates from the Gulf of Mexico (about 20° N) and moves in a north-easterly direction along the eastern coast of North America.
- The average speed is about 33 km per day and its average width is about 70 km.
- Under the impact of the Westerlies, this warm current reaches the western coast of Europe (about 70° N latitude).
- The general direction of flow of the Gulf Stream, north of 30° N latitude, is northward.
- Near Newfoundland, its water mixes with the cold water of the Labrador Current, which forms very dense fog. The foggy conditions around Newfoundland hamper the navigation of ships.
- From here, the Gulf Stream moves northeastwards.
- This current gradually widens and its speed decreases. It becomes a prominent, slow-moving current known as the North Atlantic Drift.
- Near Western Europe, it splits into two parts. One part moves northwards, past UK and Norway, while the other part is deflected southwards as the cold Canary Current.
- The warm water of the Gulf Stream modifies the weather conditions off the eastern coast of North America and the western coast of Europe.
- On the western coast of Europe, the seaports remain open even in the severe winter season due to the warm water of the Gulf Stream.

Labrador Current

- The cold Labrador Current of the North Atlantic Ocean, has its origin in the Arctic Ocean.
- This current flows from north to south between Greenland and the Baffin islands.
- The Labrador Current merges with the Gulf Stream near Newfoundland.
- This helps in the growth of plankton- a feed for fish. Thus the Grand Banks near Newfoundland have become the ideal fishing ground in the world.
- The average speed of the Labrador Current is about 25 km per day.
- This current brings huge icebergs with it from the Arctic Ocean.

Canary Current

- The Canary Current is a cold current and flows along the western coast of Spain and Portugal and the north-west coast of North Africa. .
- The average speed of this current is about 45 km per day.
- The relative coolness of the Canary Current reduces the relative humidity and thus causes scanty rainfall in the greater parts of the Sahara Desert.

Brazil Current

- The Brazil Current is a warm current and flows southward along the east coast of South America (about 40° S latitude).
- The average speed of the Brazil Current is about 30 km per day.
- From 40° S, it is deflected eastwards due to the Earth's rotation and flows in easterly direction.
- It modifies the weather conditions along the eastern coasts of Brazil and Argentina.

Student Notes:

Falkland Current

Student Notes:

- The cold waters of the Antarctic Sea flow as Falkland Current from south to north along the eastern coast of South America up to Argentina.
- The Falkland Current brings huge icebergs from the Antarctic region to the South American coast.

Benguela Current

- The Benguela Current is a cold current which originates in the Antarctic region and flows along the coast of south-west Africa.
- The Benguela Current helps in reducing the relative humidity of the eastward moving warm and moist air masses.
- The Kalahari Desert is largely formed under the influence of this current.
- Further northwards, the Benguela Current merges with the South Equatorial Current.

South Atlantic Drift

- The eastward continuation of the Brazil Current is called the South Atlantic Drift or the West Wind Drift.
- It develops at about 40° S latitude due to the impact of the Westerlies.
- The eastward movement is due to the Earth's rotation.

2.3.7. Currents of the Pacific Ocean

Major currents of the Pacific Ocean are:

North Equatorial Current

- The North Equatorial Current is a warm current which originates off the western coast of Mexico and flows in the westerly direction.
- It runs parallel to the equator and reaches the islands of Philippines after covering a distance of about 12,000 km.
- Near Philippines, under the impact of Coriolis force, it turns northwards.
- One branch of the North Equatorial Current flows northward to join the Kuroshio Current, while the southern branch turns eastwards to form the Counter Equatorial Current.

South Equatorial Current

- The South Equatorial Current is a warm current which originates due to the influence of South-east Trade winds and flows from east to west.
- It bifurcates into northern and southern branches near New Guinea.
- The northern branch turns eastward and joins the Counter Equatorial Current, while the southern branch flows along the north-eastern coast of Australia.

Kuroshio Current

- Kuroshio Current is an important warm current, which develops partly due to the Coriolis force and partly due to the obstruction by the Philippines in the flow of the North Equatorial Current.
- The average velocity is about 30 km per day and the average surface temperature is about 20°C.
- This current keeps the eastern coast of Japan warm even in the coldest month (January), when it is snowing heavily in Honshu and Hokkaido.
- A branch of Kuroshio Current enters the Sea of Japan as Tsushima Current and keeps the western coast of Japan comparatively warm.
- Around 35° N, the Kuroshio current comes under the impact of the Westerlies and flows in the north-east direction to reach the western coast of North America.
- Further northwards, it is known as the Aleutian Current.

Student Notes:

Kurile or Oyashio Current

- The Kurile or Oyashio Current is a cold current which originates from the Bering Strait and moves southwards along the coast of the Kamchatka peninsula to touch the island of Kurile.
- It carries with it the cold water and icebergs from the Arctic Ocean to the coast of eastern Russia and Japan.
- Near 50° N latitude, it is bifurcated into two branches. One of them merges with Kuroshio Current and creates dense fog which is hazardous to navigation, but ideal for abundant growth of plankton.
- Thus the north-eastern coast of the Japanese islands is an important fishing ground in the world.
- The second branch moves up to the Japanese coast.
- The Oyashio Current is comparable to the Labrador Current of the North Atlantic Ocean.

California Current

- The California Currents is a cold current which flows southwards along the Pacific coastline of USA, and is comparable to the Canary Current of the Atlantic Ocean in most of its characteristics.
- After reaching the Mexican coast, it turns westward and merges with the North Equatorial Current.
- Dense sea fogs are experienced off the coast of San Francisco.

Peru Current

- The Peru Current is a cold current, also known as the Humboldt Current, which flows along the western coast of South America.
- It flows from south to north along the coast of Peru and is caused by the northward deflection of the West Wind Drift.
- It affects the coastal climate of Chile and Peru.

East Australian Current

- The East Australian Current is a warm current which is the southern branch of the South Equatorial Current, which flows from north to south along the eastern coast of Australia.
- New Zealand is surrounded by this current.
- It raises the temperature along the east Australian and the New Zealand coasts for considerable distance southwards.

sihagn27@gmail.com

West Wind Drift

- It is a strong, cold current, flowing from between Tasmania and South American coast.
- It flows under the influence of the Westerlies and is largely confined between 40° Sand 50° S latitudes.
- This current becomes very strong due to large volume of water and high velocity winds (Roaring Forties).
- One of its branch enters the Atlantic Ocean through Cape Hom, and the other branch turns northwards and joins the Peru Current.

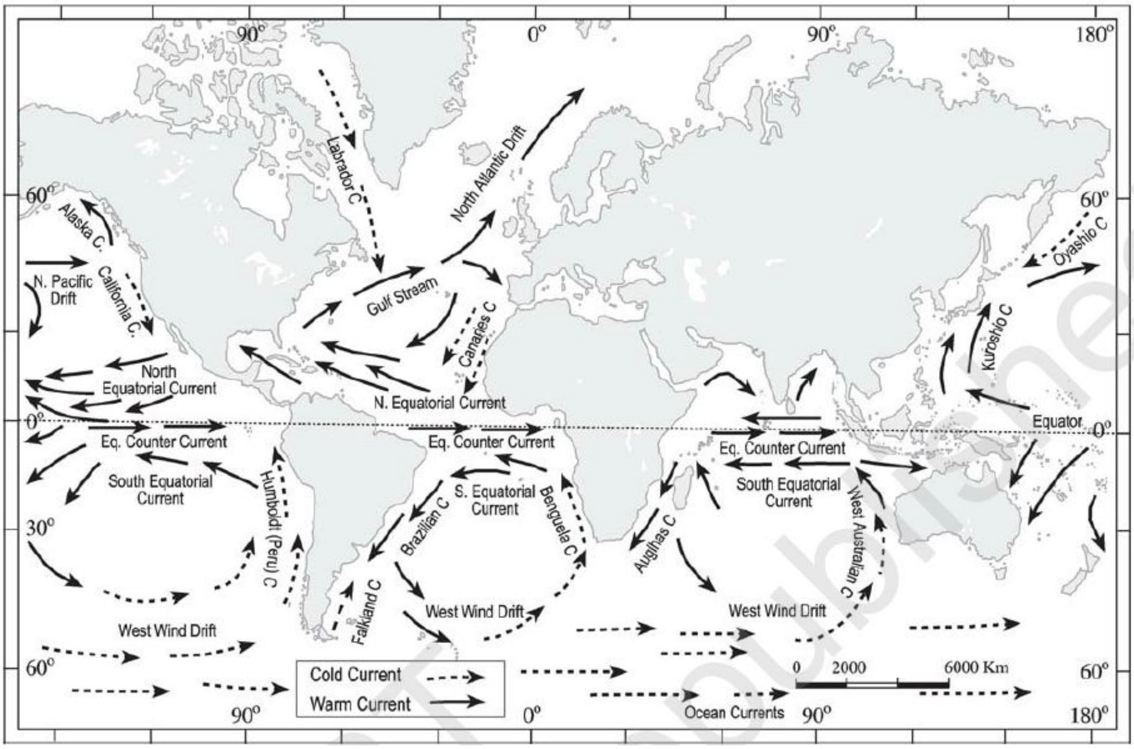


Figure 8. Major Ocean currents

2.3.8. Currents of the Indian Ocean

The ocean currents of the Indian Ocean are largely controlled and modified by the landmasses and the Monsoon winds. The ocean currents of the **North Indian Ocean** flow under the influence of the north-east and the south-west Monsoon winds. Thus the ocean currents change the direction of flow twice a year.

The currents in the **southern Indian Ocean** follow the general pattern of other oceans and are not affected by the seasonal changes in the direction of Monsoon winds.

Major currents of the Indian Ocean are:

North-east Monsoon Current

- In the winter season, the north-east Monsoon winds blow from land to ocean and from the northeast to the south-west in the Northern Hemisphere.
- Under the influence of these winds, the ocean current also flows from the north-east to the southwest.

South-west Monsoon Current

- There is a complete reversat in the direction of Monsoon winds during the summer season and they blow from the south-west to the north-east in the Northern Hemisphere.
- This also reverses the direction of the ocean current. Now the direction of the ocean current also changes from the south-west to the northeast.
- Two branches of the main current move in the Arabian Sea and the Bay of Bengal.

South Equatorial Current

- The warm South Equatorial Current flows from east to west between 10° Sand 15° S latitudes from the western coast of Australia to the coast of Africa.
- After being obstructed by the Madagascar Island, this current is divided into many branches.
- One major branch flows towards the south as the Agulhas Current.

Student Notes:

Student Notes:

Agulhas Current

- The Agulhas Current is a warm current which is a branch of the South Equatorial Current which flows along the eastern coast of Madagascar.
- It continues southwards up to about 30° S, where it merges with the Mozambique Current.
- Around 35° S latitude, it comes under the influence of the Westerlies and flows towards the east.

Mozambique Current

- The Mozambique Current is a warm current which is the northern branch of the South Equatorial Current which enters the Mozambique Channel around 10° S latitude.
- Moving southwards between Mozambique and Madagascar, it joins the Agulhas Current around 30°S latitude.

West Wind Drift

- The West Australian Current is a cold current is in the southern part of the Indian Ocean and moves from west to east around 40° S latitude.
- The West Wind Drift develops under the influence of the Westerlies (Roaring Forties).

West Australian Current

- The West Australian Current is a cold current which flows along the western coast of Australia.
- This current turns towards west and north-west near the Tropic of Capricorn and finally merges with the South Equatorial Current.
- The second branch flows to the south of Australia and finally merges with the West Wind Drift in the Pacific Ocean.

2.3.9. Effects of Ocean Currents

- The oceanic circulation *transports heat from one latitude belt to another* in a manner similar to the heat transported by the general circulation of the atmosphere. The cold waters of the Arctic and Antarctic circles move towards warmer water in tropical and equatorial regions, while the warm waters of the lower latitudes move polewards.
- *West coasts* of the continents in *tropical and subtropical latitudes* (except close to the equator) are bordered by *cool waters*. Their average temperatures are relatively low with narrow diurnal and annual ranges. There is fog, but generally the areas are arid.
- *West coasts* of the continents in the *middle and higher latitudes* are bordered by *warm waters* which cause a *distinct marine climate*. They are characterised by cool summers and relatively mild winters with a narrow annual range of temperatures.
- *Warm currents* flow parallel to the *east coasts* of the continents in *tropical and subtropical latitudes*. This results in *warm and rainy climates*. These areas lie in the western margins of the subtropical anti-cyclones.
- The *mixing of warm and cold currents* help to replenish the oxygen and *favour the growth of planktons, the primary food for fish population*. The **best fishing grounds of the world exist mainly in these mixing zones.**

3. Ocean Resources

The ocean is one of Earth's most valuable natural resources. It provides food in the form of fish and shellfish. It's used for transportation—both travel and shipping. It provides a treasured source of recreation for humans. It is mined for minerals and drilled for crude oil. We discuss all these in greater detail below:

3.1. Fishing

Student Notes:

The oceans have been fished for thousands of years and are an integral part of human society. Fish have been important to the world economy for all of these years. Fisheries of today provide about 16% of the total world's protein with *higher percentages occurring in developing nations*. Marine fisheries are very important to the economy and well-being of coastal communities, providing food security, job opportunities, income and livelihoods as well as traditional cultural identity.

The word fisheries refers to all of the fishing activities in the ocean, whether they are to obtain fish for the commercial fishing industry, for recreation or to obtain ornamental fish or fish oil. Fishing activities resulting in fish not used for consumption are called **industrial fisheries**. Due to the relative abundance of fish on the continental shelf, fisheries are usually marine and not freshwater.

3.1.1. Major Fishing Grounds

The major commercial fishing grounds are located in the cool waters of the *northern hemisphere in comparatively high latitudes*. Commercial fishing is *little developed in the tropics or in the southern hemisphere*. The best fishing grounds are found above continental shelves which are not more than 200 metres below the water surface, where plankton of all kinds are most abundant.

The world's most extensive continental shelves are located in high or mid-latitudes in the northern hemisphere, e.g., **the banks of Newfoundland**, **the North Sea** and **the continental shelf off north-western Europe**, and **the Sea of Japan**.

Plankton are in plentiful supply in polar waters, at *the meeting of cold and warm ocean currents as on the Newfoundland 'banks' and the Sea of Japan, or where cold water from the ocean floor wells up to the surface as it does off the west coast of South America*. The continental shelves of the tropics are relatively less rich in plankton because the water is warm.

The amount of fish available in the oceans is an ever-changing number due to the effects of both natural causes and human developments. It will be necessary to manage ocean fisheries in the coming years to make sure the number of fish caught never makes it to zero.

cihanz7@gmail.com

3.2. Climate Buffer

Water has a very high specific heat capacity. This means that a lot of energy is needed to increase its temperature (energy is needed to overcome the hydrogen bonds). As the Earth is 71% water, energy from the sun causes only small changes in the planet's temperature. This stops the Earth getting too hot or too cold and makes conditions possible for life. *Heat is stored by the ocean in summer and released back to the atmosphere in winter.* Oceans, therefore, *moderate climate by reducing the temperature differences between seasons.*

By far the largest carbon store on Earth is in sediments, both on land and in the oceans, and it is held mainly as calcium carbonate. The second biggest store is the deep ocean where carbon occurs mostly as dissolved carbonate and hydrogen carbonate ions. *About a third of the carbon dioxide from fossil fuel burning is stored in the oceans and it enters by both physical and biological processes.*

3.3. Phytoplankton

Phytoplankton accounts for around 90% of the world's oxygen production because water covers about 70% of the Earth and phytoplankton are abundant in the photic zone of the surface layers. Some of the oxygen produced by phytoplankton is absorbed by the ocean, but most flows into the atmosphere where it becomes available for oxygen dependent life forms.

3.4. Mining

Student Notes:

The oceans hold a veritable treasure trove of valuable resources. **Sand and gravel**, **oil** and **gas** have been extracted from the sea for many years. In addition, minerals transported by erosion from the continents to the coastal areas are mined from the shallow shelf and beach areas. These include *diamonds off the coasts of South Africa and Namibia* as well as deposits of *tin*, *titanium* and *gold* along the shores of *Africa, Asia and South America*.

Natural gas and oil have been extracted from the seas for decades, but the ores and mineral deposits on the sea floor have attracted little interest. Yet as resource prices rise, so too does the appeal of ocean mining.

3.4.1. Deep Sea Mining

Back in the early 1980s there was great commercial interest in marine mining. This initial euphoria over marine mining led to the **International Seabed Authority** (ISA) being established in Jamaica, and the **United Nations Convention on the Law of the Sea** (UNCLOS) being signed in 1982 – the "constitution for the seas". Since entering into force in 1994, this major convention has formed the basis for signatories' legal rights to use the marine resources on the sea floor outside national territorial waters.

After that, however, the industrial countries lost interest in resources. For one thing, prices dropped making it no longer profitable to retrieve the accretions from the deep sea and utilize the metals they contained. Also, new onshore deposits were discovered, which were cheaper to exploit.

The **present resurgence of interest** is due to:

- The sharp increase in resource prices and attendant rise in profitability of the exploration business.
- Strong economic growth in countries like China and India which purchase large quantities of metal on world markets. Even the latest economic crisis is not expected to slow this trend for long.
- The industrial and emerging countries' geopolitical interests in safeguarding their supplies of resources also play a role. In light of the increasing demand for resources, those countries which have no reserves of their own are seeking to assert extraterritorial claims in the oceans.

ishagn27@gmail.com

3.4.2. Major Deep Sea Minerals

The major focus is on **manganese nodules**, which are usually located at depths below 4000 metres, **gas hydrates** (located between 350 and 5000 metres), and **cobalt crusts** along the flanks of undersea mountain ranges (between 1000 and 3000 metres), as well as **massive sulphides** and the **sulphide muds** that form in areas of volcanic activity near the plate boundaries, at depths of 500 to 4000 metres.

Manganese Nodules

Manganese nodules are lumps of minerals covering huge areas of the deep sea with masses of up to 75 kilograms per square metre. Manganese nodules are composed primarily of manganese and iron. *The elements of economic interest, including cobalt, copper and nickel, are present in lower concentrations and make up a total of around 3.0 per cent by weight.* In addition there are traces of other significant elements such as *platinum* or *tellurium* that are important in industry for various high-tech products.

These chemical elements are *precipitated from seawater* or *originate in the pore waters of the underlying sediments*. The greatest densities of nodules occur off the **west coast of Mexico**, in the **Peru Basin**, and the **Indian Ocean**.

Cobalt crusts

These crusts accumulate when manganese, iron and a wide array of trace metals dissolved in the water (cobalt, copper, nickel, and platinum) are deposited on the volcanic substrates. The cobalt crusts also contain relatively small amounts of the economically important resources. Extracting cobalt from the ocean is of particular interest because it is found on land in only a few countries (Congo, Zaire, Russia, Australia and China), some of which are politically unstable.

Cobalt crusts form at depths of 1000 to 3000 metres on the flanks of *submarine volcanoes*, and therefore usually occur in regions with high volcanic activity such as the territorial waters around the island states of the South Pacific.

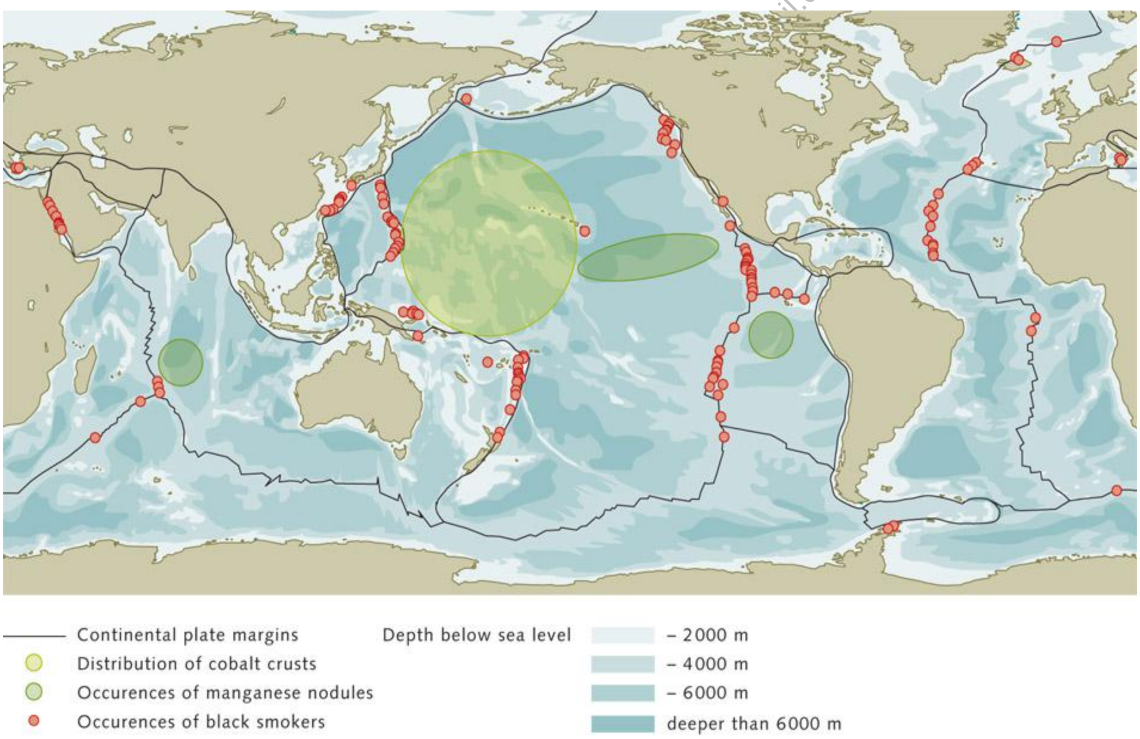
Massive Sulphides

Sulphur deposits produced from **underwater volcanic areas** are known as black smokers. These occurrences of massive sulphides form at *submarine plate boundaries*, where an exchange of heat and elements occurs between rocks in the Earth's crust and the ocean due to the interaction of volcanic activity with seawater.

Cold seawater penetrates through cracks in the sea floor down to depths of several kilometres. Near heat sources such as magma chambers, the seawater is heated to temperatures exceeding 400 degrees Celsius. Upon warming, the water rises rapidly again and is extruded back into the sea. These hydrothermal solutions transport metals dissolved from the rocks and magma, which are then deposited on the sea floor and accumulate in layers. This is how the massive sulphides and **the characteristic chimneys** (black smokers) are produced.

So far only a few massive sulphide occurrences which are of economic interest due to their size and composition are known. While the black smokers along the **East Pacific Rise** and in the **central Atlantic** produce sulphides comprising predominantly ironrich sulphur compounds – which are not worth considering for deep-sea mining – the occurrences in the **southwest Pacific** contain greater amounts of copper, zinc and gold. The *largest known sulphide occurrence* is located in the **Red Sea** Here, the sulphides are not associated with black smokers, but appear in the form of iron rich ore muds.

Figure 9. Distribution of Deep Sea Minerals



Student Notes:

3.4.3. Constraints in Deep Sea mining

Student Notes:

Major problems associated with deep sea mining are:

- The most limiting factors associated with deep-sea marine mining are the political and legal aspects. Legal and political issues surrounding exploration, exploitation, and marketing of sea floor minerals must be resolved.
- The excavation of marine minerals would considerably disturb parts of the seabed. Huge amounts of sediment, water, and countless organisms would be dug up with the nodules, and the destruction of the deep-sea habitat would be substantial. It is not yet known how, or even whether, repopulation of the excavated areas would occur.
- Sea floor mining will only be able to compete with the substantial deposits presently available on land if there is sufficient demand and metal prices are correspondingly high.
- The excavation technology has yet to be developed. There are serious technological difficulties in separating the crusts from the substrate which combined with the problems presented by the uneven sea floor surface further reduce the economic potential of the marine mining.

Despite the challenges, deep sea mining has some **potential benefits over terrestrial mining**:

- The minerals are often much closer to the surface, so operations have to dig and displace less rock, meaning a smaller footprint and fewer carbon emissions.
- Seabed mining infrastructure is both moveable and reusable, unlike roads and buildings often left behind at abandoned mines on land.
- And no residents will be directly displaced by mining.

4. UPSC Previous Years Prelims Questions

1. The acidification of oceans is increasing. Why is this phenomenon a cause of concern:

1. The growth and survival of calcareous phytoplankton will be adversely affected.
2. The growth and survival of coral reefs will be adversely affected.
3. The survival of some animals that have phytoplanktonic larvae will be adversely affected.
4. The cloud seeding and formation of clouds will be adversely affected.

Which of the statements given above is/are correct?

(a) 1, 2 and 3 only (b) 2 only
(c) 1 and 3 only (d) 1, 2, 3 and 4

sihagn27@gmail.com

2. Consider the following factors:

1. Rotation of the Earth
2. Air pressure and wind
3. Density of ocean water
4. Revolution of the Earth

Which of the above factors influence the ocean currents?

(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 4 (d) 2, 3 and 4

3. The most important fishing grounds of the world are found in the regions where:

(a) Warm and cold atmospheric currents meet
(b) Rivers drain out large amounts of freshwater into the sea
(c) Warm and cold oceanic currents meet
(d) Continental shelf is undulating

3. What explains the eastward flow of the equatorial counter-current:

(a) The Earth's rotation on its axis (b) Convergence of the two equatorial currents
(c) Difference in salinity of water (d) Occurrence of the belt of calm near the equator

Student Notes:

4. Tides occur in the oceans and seas due to which among the following?

1. Gravitational force of the Sun
2. Gravitational force of the Moon
3. Centrifugal force of the Earth

Select the correct answer using the code given below.

(a) 1 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

5. With reference to 'Indian Ocean Dipole (IOD)' sometimes mentioned in the news while forecasting Indian monsoon, which of the following statements is/are correct?

1. IOD phenomenon is characterised by a difference in sea surface temperature between tropical Western Indian Ocean and tropical Eastern Pacific Ocean.
2. An IOD phenomenon can influence an El Nino's impact on the monsoon.

Select the correct answer using the code given below:

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

6. Consider the following pairs:

Sea		**Bordering country**
1. Adriatic Sea	:	Albania
2. Black Sea	:	Croatia
3. Caspian Sea	:	Kazakhstan
4. Mediterranean Sea	:	Morocco
5. Red Sea	:	Syria

Which of the pairs given above are correctly matched?

(a) 1, 2 and 4 only (b) 1, 3 and 4 only
(c) 2 and 5 only (d) 1, 2, 3, 4 and 5

7. With reference to Ocean Mean Temperature (OMT), which of the following statements is/are correct?

1. OMT is measured up to a depth of 26°C isotherm which is 129 meters in the south-western Indian Ocean during January–March.
2. OMT collected during January–March can be used in assessing whether the amount of rainfall in monsoon will be less or more than a certain long-term mean.

sivagn27@gmail.com

Select the correct using the code given below:

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

8. Consider the following pairs:

River		**Flows into**
1. Mekong	:	Andaman Sea
2. Thames	:	Irish Sea
3. Volga	:	Caspian Sea
4. Zambezi	:	Indian Ocean

Which of the pairs given above is/are correctly matched?

(a) 1 and 2 only (b) 3 only
(c) 3 and 4 only (d) 1, 2 and 4 only

Student Notes:

5. UPSC Previous Years Mains Questions

1. Critically evaluate the various resources of the oceans which can be harnessed to meet the resource crisis in the world. (2014)
2. Explain the factors responsible for the origin of ocean currents. How do they influence regional climates, fishing and navigation? (2015)
3. Account for variations in oceanic salinity and discuss its multi-dimensional effects. (250 words) (2017)
4. How do ocean currents and water masses differ in their impacts on marine life and coastal environment? (2019)

6. Vision IAS Previous Years Questions

1. "Interaction between the ocean and the atmosphere stabilizes and regulates the climatic variations over the earth". Discuss and give an example to justify the above statement from any climate type of the world.

Approach:

Discuss how the interaction between the ocean and the atmosphere at global, regional and the local level can affect the climate types.

Answer:

The interaction between the oceans and the atmosphere takes place by exchange of heat from the equator towards the poles through the global air circulation and the global surface and sub-surface water currents. This heat exchange act as the engine of earth processes that leads to the interaction of various phenomena with each other and reflects itself in the form of climatic variations. To explain this interaction we are taking an example of Indian monsoon climate that is affected by the global, regional and local climatic interaction.

At global level monsoon is affected by El-Nino, jet streams circulation, Somalian current, and the movement of the inter-tropical convergence north and south of the equator, with the apparent movement of the sun in the north and south of the equator. These phenomenons affect the onset and withdrawal of Indian monsoon to a larger extent.

At regional level, sea surface temperature, temperature in the north-west India and the heating of the Tibetan plateau, and the flow of easterly jet stream over the Indian sub-continent plays an important role in the intensification of monsoon over the Indian sub-continent.

At local level, shifting of the low pressure trough in the Ganga plains and its distance from the base of the Himalayas determine the precipitation amount and distribution.

Thus from the above analysis we can say that the interaction between the oceans and the atmosphere stabilizes and regulate the climatic variations over the earth surface.

2. What are ocean currents? How do they affect the climate of coasts? Illustrate.

Approach:

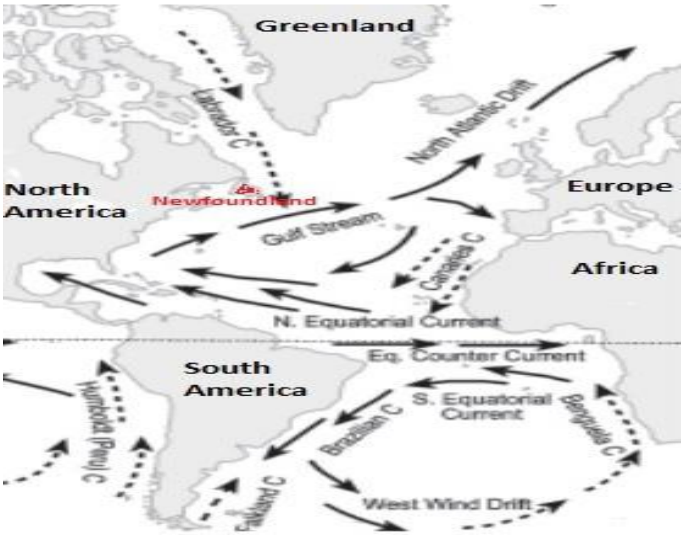
- Describe how currents are formed and their motion along the coast.
- Explain how warm and cold currents changes local climatic conditions.
- Examples – Norway coast, hot deserts, reversal of currents in north Indian oceans

Answer:

An ocean current is the motion of ocean water at a much larger scale. Ocean water is moved in a directed manner at surface as well as deep in the ocean. Such movement is the net result of multiple forces - atmospheric winds, coriolis force, temperature and density gradients in the ocean etc. surface winds are the prime driver of oceanic current.

Because ocean currents circulate water worldwide along the coast, they have a significant impact on the climate of coast. cold currents bring cold water into warm water areas while warm currents bring warm Water into cold water areas.

In North Atlantic Ocean, warm North Atlantic drift reaches the higher latitudes of Europe warms up the coastal water and keeps the ports open throughout the year. While ports located at same latitude on Canada coast are frozen in winters. During La Nina, cold Humboldt current dominates at the coast of Peru which experiences little or no rain. Mixing up of cold Labrador current and warm gulf stream at Newfoundland creates foggy conditions. Thus, ocean currents have remarkable impact on the climate of coast.



Ocean currents – north Atlantic drift, mixing of cold and warm currents at Newfoundland, cold Humboldt current.

sihagn2@gmail.com

3. 'Global warming will result in reduced water circulation around the oceans'. Discuss.

Approach:

- The reasons for reduced circulation should be scientifically linked to the global warming.
- There is no need of a discussion of effect of global warming on oceans or oceanic resources. The question is specific about ocean circulation.

Answer:

- The movement of water around the oceans has two parts which are strongly linked:
  - A **density driven circulation** which is driven by the differences in the density of seawater at different locations. The density of seawater depends on its temperature and how salty it is. As a result, this movement is known as the thermohaline circulation.
  - A **wind driven circulation** which results in huge surface currents like the Gulf Stream.
- Higher temperatures are predicted to increase the input of freshwater into the high latitude oceans. Computer models suggest that this additional freshwater comes from increased rain at mid and high latitudes and from the melting of ice sheets.

Student Notes:

- Ocean circulation is very sensitive to the amount of freshwater entering the system. Freshwater controls the density of seawater and therefore the ability of seawater to sink when it is cooled. If the water is too fresh, cooling won't make it dense enough to sink into the deep ocean. If water doesn't sink at high latitudes there is only wind driven forcing and therefore reduced water circulation around the oceans.

Student Notes:

4. *What are ocean currents? How do they affect the climate of coasts? Illustrate.*

Approach:

- Describe how currents are formed and their motion along the coast.
- Explain how warm and cold currents changes local climatic conditions.
- Examples – Norway coast, hot deserts, reversal of currents in north Indian oceans

Answer:

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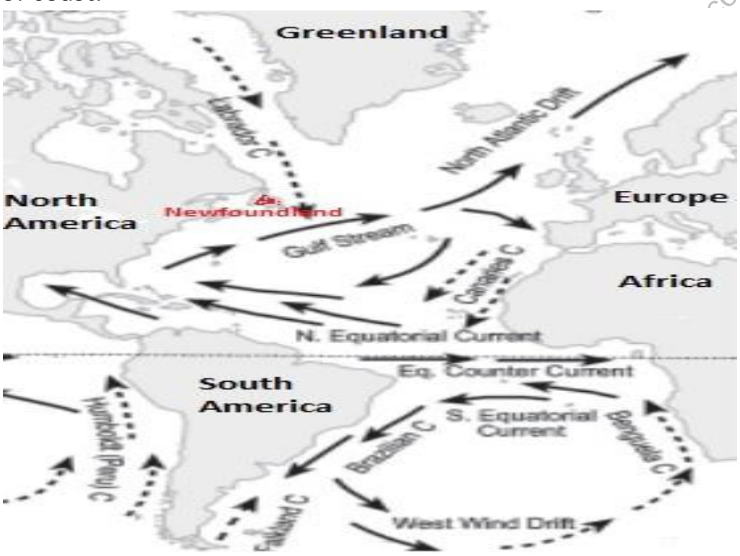

Ocean currents – north Atlantic drift, mixing of cold and warm currents at Newfoundland, cold Humboldt current.

5. ***What is Indian Ocean Dipole? How does it relate to monsoon rains in India? Contrast it with the role of El-Nino on the same.***

Student Notes:

Approach:

- Define Indian Ocean Dipole, explain both positive and negative IOD.
- Highlight the impact of IOD on Monsoon in India.
- Define El Nino and its impact on rains.
- Draw diagram – showing IOD and El Nino.
- Bring out the differences between IOD and El Nino with respect to Monsoon.

Answer:

- The south west monsoon rainfall is influenced by a system of oscillating sea surface temperatures known as the **Indian Ocean Dipole (IOD)** in which the western Indian Ocean becomes warmer than the eastern part of the ocean. Because of warmer conditions over Arabian Sea, it brings more rainfall and therefore an IOD, normally referred to as a positive IOD is favourable for rainfall, monsoons and consequently summer and kharif crops.
- A negative IOD on the other hand during which the temperatures over Arabian Sea are cooler than tropical eastern Indian Ocean brings less rainfall.
- **El Nino,** which leads to warming of the Pacific off the coast of Peru and consequently cooler conditions in Indian Ocean, results in deficient rainfall conditions at times leading into drought. El Nino and Indian monsoon are inversely related. El Nino directly impacts India's agrarian economy as it tends to lower the production of summer crops such as rice, sugarcane, cotton and oilseeds, eventually translating into high inflation and low GDP
- The **Indian Ocean Dipole (IOD) and the El Nino** are independent climatic phenomena but often co-occur. Both IOD and El Nino result in change of global wind patterns. However, it must be noted that the cycle of IOD is shorter, while El Nino condition could last for two years. IOD commences in the month of May and end with the withdrawal of Southwest Monsoon in the Indian sub-continent. If IOD is positive then it lessens the negative impact of El-Nino, because, of creation of low pressure in the Arabian Sea.

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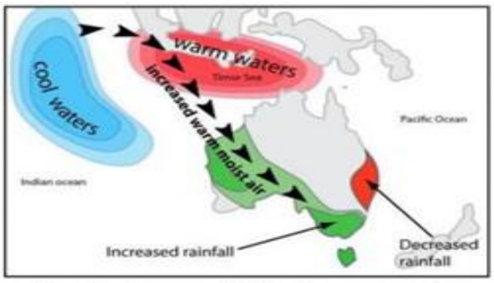
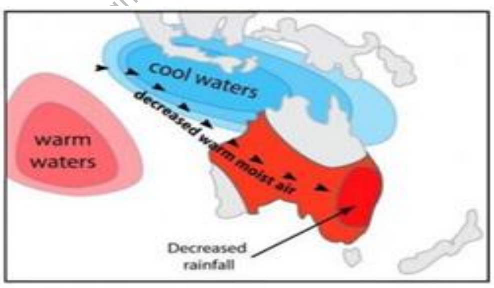


Negative phase: cool Indian Ocean water drives moist warm air and brings normal rainfall.



Positive phase: warm Indian Ocean water leads to weaker, drier winds and less rainfall.

6. ***What factors are responsible for the origin and modification of ocean currents? Explain with examples how ocean current currents affect the climate of surrounding regions.***

Approach:

- First of bring out all factors which are responsible for the origin and modification of the ocean currents and elaborate briefly about them.
- Then, with examples, elaborate how ocean currents determine the climate of surrounding regions.

Answer:

The factors responsible for the origin and modifications of ocean currents can be enumerated as:

- Origin - It is attributed to density differences in different layers of ocean waters. Heavier water sinks and causes the overlying surface water to move in its space. This gives rise to global oceanic circulation.
- Other factors - Accumulation of water on east coasts leads to gravity induced movements down the slope.
- Expansion due to heat - Even though water is considered practically incompressible, minor expansion due to excess solar heat in equatorial regions causes a slight gradient and water tends to flow down the slope.
- Modification - Wind, Coast line and inundation, large river discharge, presence of partially enclosed seas.
- Periodic reversals due to heating and accumulation can also cause modification such as in case of El-Nino current caused by a stronger counter equatorial current.
- Coriolis force- This force intervenes and causes the water to move to the right in Northern Hemisphere and to the left in the Southern Hemisphere. These produce large circular currents in all the Ocean basins. One such circular current is in the Sargasso Sea.

Ocean currents have direct and indirect effects on the climate of the regions. These can be enumerated as:

- West coasts of the continents in Tropical and subtropical are bordered by cold currents. Their average temperatures are relatively low with narrow diurnal and annual ranges. There is fog, but generally areas are arid due to the desiccating effect leading to formation of deserts in the area. Example. Cold Peruvian current-Atacama Desert.
- East coasts of the continents in the lower and middle latitudes are bordered by warm currents which cause a distinct marine climate. They are characterized by cool summer and relatively mild winters. E.g. China type of climate.
- Warm currents flow parallel to east coasts of the continents in tropical and subtropical latitudes. This result in warm and rainy climates. E.g. Florida.
- Foggy weather and drizzle in the mixing zones of warm and cold current.

sihagn2@gmail.com

7. Identify the factors that determine density of ocean waters. Discuss the latitudinal distribution of density and explain the seasonal changes that occur, if any. Also, illustrate its relationship with ocean currents.

Approach:

- Give a general overview of oceanic water density.
- List the factors responsible for it.
- Mention how the density varies with change in latitude.
- Also discuss the change in density with change in season and its relationship with Ocean currents.

Answer:

Density of the ocean water is determined mainly by temperature, salinity and pressure. However, other regional factors also determine the water density. These further govern the vertical movement of ocean water resulting in its stratification according to density.

- **Temperature:** Depends upon the heat exchange between sea surface and atmosphere. At higher temperature water expands reducing its density, while lower

Student Notes:

temperature increases density of water. Thus, the water at poles is denser than in tropics.

- **Salinity:** High salinity seawater is denser and sinks below lower salinity water, leading to stratification.
- **Pressure:** Increasing density values demonstrate the compressibility of seawater under the tremendous pressures present in the deep ocean.
- **Other Factors:** Rainwater, surface run-off brought by rivers flowing into oceans, and melt water from ice and snow are minor factors that lower down density. While, evaporation, cooling of surface water and process of ice formation tend to increase density of the ocean water. Partially or completely enclosed seas don't intermix much with surrounding water. In the tropics they have higher evaporation resulting in higher density while near poles they have lesser evaporation resulting in comparatively low density.

Latitudinal Variation

Between 20 degrees and 30 degree N and S, water has high salinity due to high rate of evaporation, thereby leading to higher density.

- Temperature of surface ocean water decreases between 45-degree N-S and poles. Lower surface temperature corresponds to high water density.
- Salinity is lower than average 35 % in the equatorial waters due to high daily rainfall and and high relative humidity.

Seasonal Variation

As salinity, temperature and density of water are interrelated; any change in one factor influences other. For instance, in Red Sea, salinity is as high as 41 ppt, while in the Arctic, it fluctuates from 0-35 ppt, seasonally. In hot and dry regions, where evaporation is high, the salinity sometimes reaches to 70 ppt. Ocean salinity declines due to rains as well as in summers when ice melts.

Relationship with Ocean Currents

Waters of low salinity and density flow on the surface of waters of high salinity, while waters of high salinity flow at the deep oceans towards waters of low salinity. For example, the less saline waters of the Atlantic flow on the surface into the enclosed Mediterranean Sea, this is compensated for by an outflow of the denser bottom water from the Mediterranean.

sihagn27@gmail.com

In the northern Atlantic Ocean, creation of gyres due to Gulf Stream, Canary Current and North Equatorial Current, increases the salinity.

Also, in areas where convergence of ocean currents occurs, water of relatively higher density moves downwards, while, in areas of divergences, ascending motion of bottom water of higher density and lower temperature towards the surface.

8. What is the global ocean conveyor belt? Discuss its significance for marine ecosystem.

Approach:

- Define global ocean conveyor belt in the introduction.
- Illustrate the phenomenon with suitable diagram.
- Explain the significance of global ocean conveyor belt for marine ecosystem.
- Conclude accordingly.

Answer:

Global ocean conveyor belt is a constantly moving system of water driven by temperature and salinity in the deep ocean and the wind-driven currents on the

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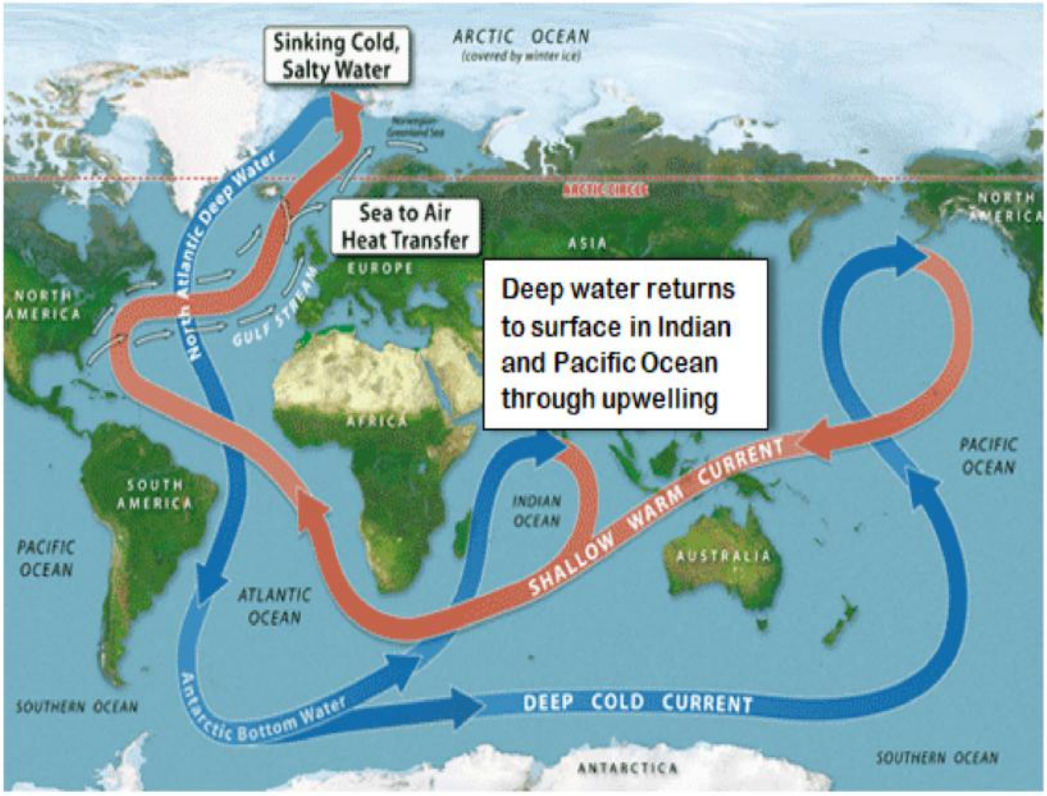
surface. It starts in the Norwegian Sea (North Atlantic) where cold saline water sinks to the bottom of the ocean and moves south of the equator all the way down to Antarctica, and finally upwells in the Indian and the Pacific oceans to complete the cycle as shallow warm surface currents.



Global ocean conveyor belt consists of:

- **Deep water formation:** The evaporative cooling and ice formation in North Atlantic make the water more saline and dense. The surface water, thus sinks to the ocean bottom. Warm surface water from the Gulf Stream moves in to replace the sinking water.
- **Spreading of deep water**: The high latitude cooling and the low latitude heating makes the deep water move southwards as North Atlantic Deep Water current. After reaching Antarctica, the current gets recharged because of strong cooling and sinking of water in the region and forms the Antarctic Circumpolar current. This current splits into two, one move towards Indian Ocean, while the other towards Pacific.
- **Upwelling of deep water:** These aforementioned two sections warm up and become less dense as they travel northward toward the equator, and return to the surface through mixing and wind-driven **upwelling**.
- **Near-surface currents**: Outflowing of cold undersea waters in the Pacific makes the sea level of the Atlantic slightly lower. This gives rise to the near surface currents. The warm, fresher water hence loops back to the South Atlantic, eventually returning to the North Atlantic, where the cycle begins again.

Significance for marine ecosystems:

- **Maintaining Ocean salt budget:** The oceanic circulation helps in balancing the salinity of ocean water across the world.
- **Maintaining Ocean heat budget:** It helps in the distribution of heat from the tropics to the poles and from the depth of the water to the surface.

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* **Influences polar ice formation:** Global conveyor belt supplies heat to the Polar Regions. Therefore, influences the rate of sea ice formation near poles, which in turn affects the climate system, albedo and solar heating.
* **Sink for carbon dioxide**: Before sinking, the water absorbs enormous amounts of gases such as carbon dioxide at the sea surface, and then transports them rapidly to much greater depths. This dissolved carbon dioxide remains buried to the ocean depths for centuries.
* **Facilitates Nutrient circulation:** Warm surface waters are depleted of nutrients and carbon dioxide, but they are enriched again as they travel through the conveyor belt as deep or bottom layers. The base of the world's food chain depends on the cool, nutrient-rich waters that support the growth of algae and seaweed.
* **Oxygen enrichment:** The mixing of warm and cold currents helps to replenish oxygen and favour growth of plankton, the primary food for fish population.
* **Long distance migration in the marine environment:** Ocean gyres and currents help marine animals such as sea turtles to migrate across oceans for spawning and reproduction.

There is a concern that the Global Ocean conveyor belt is getting affected due to global warming. The increased melting of polar ice might disturb this delicate temperature-salinity based circulation which is essential for the marine ecosystem and climate of earth.

sihagn27@gmail.com

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CORAL REEFS AND INDIAN OCEAN

Student Notes:

Contents

sihagn27@gmail.com

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1. Coral Reefs

Coral reefs are some of the *most diverse ecosystems* in the world. Thousands of species rely on reefs for survival. Thousands of communities all over the world also depend on coral reefs for food, protection and jobs.

A **reef** is a strip or ridge of rocks, sand, or coral that rises to or near the surface of a body of water. The best-known reefs are the coral reefs developed through biotic processes dominated by **corals** and calcareous algae.

1.1. Corals

Corals are **animals**, even though they may exhibit some of the characteristics of plants and are often mistaken for rocks. Corals can exist as individual polyps (a small sea animal that has a body shaped like a tube), or in colonies and communities that contain hundreds to hundreds of thousands of polyps. Corals are found throughout the oceans, from deep, cold waters to shallow, tropical waters.

1.1.1. Types of Corals

Corals are classified as under:

1. **Hard Corals:** Hard corals, also known as *stony corals*, produce a rigid skeleton made of *calcium carbonate* in crystal form called aragonite**.** Hard corals are the primary **reef-building** corals. Hard corals consisting of hundreds to hundreds of thousands of individual polyps are cemented together by the **calcium carbonate** 'skeletons' they secrete. Living coral grow on top of the skeletons of their dead predecessors. Hard corals that form reefs are called **hermatypiccoral**.
2. **Soft Corals:** Soft coral, also known **ahermatypic coral**, do not produce a rigid calcium carbonate skeleton and do not form reefs, though they may be present in a reef ecosystem. Soft corals are also mostly colonial i.e. what appears to be a single large organism is actually a colony of individual polyps combined to form a larger structure. Soft coral colonies tend to resemble trees, bushes, fans, whips, and grasses.

1.2. Zooxanthellae

sihag927@gmail.com

Most reef-building corals contain **photosynthetic algae**, called zooxanthellae, that live in their tissues. *The corals and algae have a mutualistic relationship*. The coral provides the algae with a protected environment and compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes.

Zooxanthellae supply the coral with glucose, glycerol, and amino acids, which are the products of photosynthesis. The coral uses these products to make proteins, fats, and carbohydrates, and produce **calcium carbonate**. This is the driving force behind the growth and productivity of coral reefs.

In addition to providing corals with essential nutrients, zooxanthellae are responsible for the *unique and beautiful colors of many stony corals*. Sometimes when corals become physically stressed, the polyps expel their algal cells and the colony takes on a *stark white appearance*. This is commonly described as **coral bleaching**. If the polyps go for too long without zooxanthellae, *coral bleaching can result in the coral's death*.

1.3. Coral Formation and Types

Coral reefs begin to form when free-swimming coral larvae attach to submerged rocks or other hard surfaces along the edges of islands or continents. As the corals grow and expand, reefs take on one of three major characteristic structures:

- **Fringing reefs**, which are the most common, project seaward directly from the shore, forming borders along the shoreline and surrounding islands.
- **Barrier reefs** also border shorelines, but at a greater distance. They are separated from their adjacent land mass by a lagoon of open, often deep water.
- An **atoll** forms if a fringing reef forms around a *volcanic island* that subsides completely below sea level while the coral continues to grow upward. Atolls are usually circular or oval, with a central **lagoon**.

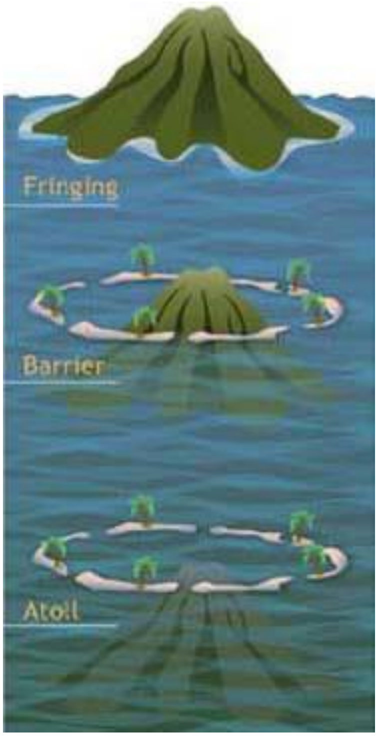

Figure 1. Types of Coral Reefs

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2. Conditions Needed for Growth of Coral Reefs

Corals are found throughout the oceans, from deep, cold waters to shallow, tropical waters. Conditions favourable to growth of corals reefs can be discussed as under:

1. Shallow coral reefs grow best in **warm water** (70–85° F or 21–29° C). It is possible for soft corals to grow in places with warmer or colder water, but growth rates in these types of conditions are very slow.
2. Reef-building corals prefer **clear and shallow water**, where **lots of sunlight** filters through to their symbiotic algae. The most prolific reefs occupy depths of 18–27 m.
3. Corals also need **salt water** to survive, so they also grow poorly near river openings with fresh water runoff.
4. Other factors influencing coral distribution are *availability of hard-bottom substrate* and the *availability of food* such as plankton.

2.1. Location of Coral Reefs

Coral reefs develop in shallow, warm water, usually near land, and **mostly in the tropics**. There are coral reefs off the *eastern coast of Africa*, off the *southern coast of India*, in the *Red Sea*, and off the coasts of *northeast and northwest Australia* and on to *Polynesia*. There are also coral reefs off the coast of *Florida, USA, to the Caribbean, and down to Brazil*.

The **Great Barrier Reef** (off the coast of NE Australia) is the *largest coral reef in the world*. It is over 2000 km long.

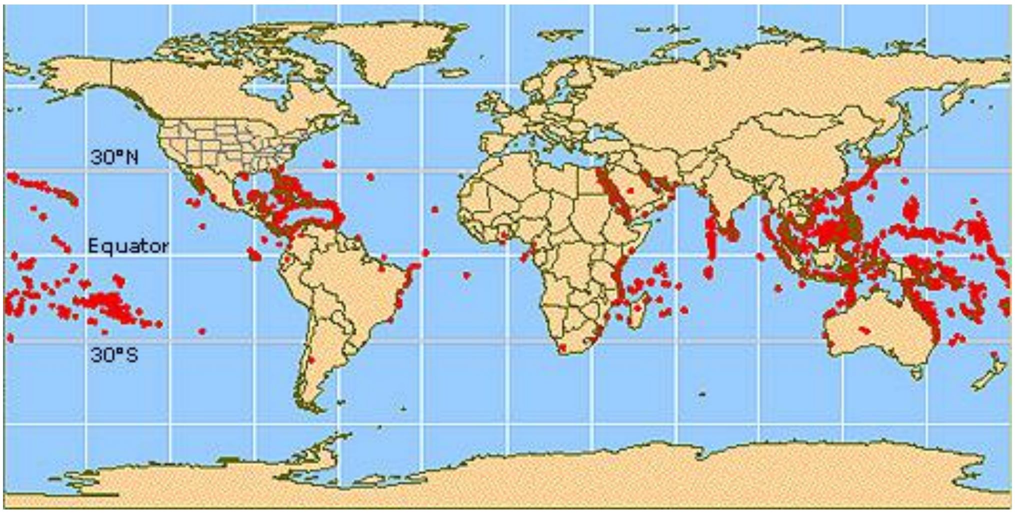

Figure 2. Global distribution of Coral Reefs

2.2. Importance of Coral Ecosystems

- Coral reefs are some of the **most diverse and valuable ecosystems on Earth**. Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals and hundreds of other species. They are often referred to as the **Rainforests of the Sea**.
- Healthy coral reefs have rough surfaces and complex structures that **dissipate much of the force of incoming waves**. This buffers shorelines from currents, waves, and storms, helping to prevent loss of life, property damage, and erosion. Reefs are also a source of sand in natural beach replenishment.
- Being storehouses of immense biological wealth, reefs also provide **economic and environmental services** to millions of people. Healthy reefs contribute to local economies through **tourism**. Diving tours, fishing trips, hotels, restaurants, and other businesses based near reef systems provide millions of jobs and contribute billions of dollars all over the world. Coral reefs serve as habitat for many commercially important species targeted for fishing.
- Coral ecosystems have proven to be beneficial for humans through the identification of potentially **beneficial chemical compounds** and through the development of **medicines**, both derived from organisms found in coral ecosystems. Many drugs are now being developed from coral reef animals and plants as possible cures for cancer, arthritis, human bacterial infections, viruses, and other diseases.

2.3. Threats to Coral Reefs

An estimated 20 per cent of the world's reefs are damaged beyond recovery and about half of the remaining coral reefs are under risk of collapse. The top threats to coral reefs are:

2.3.1. Climate Change

Climate change impacts have been identified as one of the greatest global threats to coral reef ecosystems. As temperature rise, **mass bleaching**, and **infectious disease outbreaks** are likely to become more frequent. Additionally, carbon dioxide absorbed into the ocean from the atmosphere has already begun to *reduce calcification rates in reef-building* and reef-associated organisms by altering sea water chemistry through decreases in pH (**ocean acidification**).

In the long term, failure to address carbon emissions and the resultant impacts of rising temperatures and ocean acidification could make many other coral ecosystem management efforts futile.

Student Notes:

2.3.2. Unsustainable Fishing

Coral reefs and associated habitats provide important commercial, recreational and subsistence fishery resources. But coral reef fisheries, though often relatively small in scale, may have disproportionately large impacts on the ecosystem if conducted unsustainably. *Rapid human population growth, demand for fishery resources, use of more efficient fishery technologies, and inadequate management and enforcement* have led to the depletion of key reef species and habitat damage in many locations.

2.3.3. Pollution

Impacts from land-based sources of pollution (e.g. agriculture, deforestation, storm water, coastal development, road construction, and oil and chemical spills) on coral reef ecosystems include increased *sedimentation*, *nutrients*, *toxins*, and *pathogen introduction*. These pollutants and related synergistic effects can cause disease and mortality in sensitive species, disrupt critical ecological functions, cause trophic structure and dynamics changes (i.e. eutrophic conditions), and impede growth, reproduction, and larval settlement.

These threats—combined with other threats like *coral disease; tropical storms; tourism and recreation; vessel damage; marine debris, and aquatic invasive species*—compound upon each other, making conservation efforts more difficult.

2.4. Coral Reefs in India

The coral reef ecosystems are found in four regions of India which are:

Region	Type of Reef
Andaman & Nicobar Islands	Fringing Reefs
Gulf of Mannar (Tamil Nadu)	Fringing Reefs
Gulf of Kutchh (Gujarat)	Fringing Reefs
Lakshadweep Islands	Atolls

Figure 3. Coral Reefs of India

There are no coral reefs on the central east and west coasts of India. The conditions here, especially **salinity and high sediment load**, are not ideal for coral growth. Most major rivers of India, like the Ganges, flow into the sea on the east coast, bringing in lots of sediments that would not allow the corals to grow. On the west coast, the monsoon is intense from June to

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August. The fresh water flow into the sea at this time reduces salinity to less than half of the normal and the sea water becomes murky brownish with the sediments.

The Indian coral reefs are world famous but least explored, studied and utilised. On the other hand, they are indiscriminately damaged by human exploitation mainly for the cement industry (calcium carbide), road and building material in certain areas like the Gulf of Mannar and the Gulf of Kutch. The other two regions, the Andaman and Nicobar Islands and the Lakshadweep, because of their far-flung location from the mainland, are comparatively less affected by human depredations.

3. Indian Ocean

The Indian Ocean is the third largest of the world's oceanic divisions, covering approximately 20% of the water on the Earth's surface. It is bounded by Asia—*including India, after which the ocean is named on the north*, on the west by Africa, on the east by Australia, and on the south by the Southern Ocean.

As one component of the World Ocean, the Indian Ocean is delineated from the Atlantic Ocean by the **20° east meridian** running south from **Cape Agulhas** (South Africa), and from the Pacific Ocean by the meridian of **146°55' east**. The northernmost extent of the Indian Ocean is approximately **30° north in the Persian Gulf**. The ocean is nearly 10000 km wide at the southern tips of Africa and Australia, and its area is 73556000 km² including the Red Sea and the Persian Gulf.

Island nations within the ocean are *Madagascar, Comoros, Seychelles, Maldives, Mauritius, and Sri Lanka*. The archipelago of Indonesia borders the ocean on the east.

Figure 4. Geography of Indian Ocean

3.1. Significance of Indian Ocean for India

Significance of Indian Ocean for India can be discussed under following heads:

1. **Geopolitical Significance:** The Indian Ocean Region (IOR), comprising the ocean and its littorals, is India's regional or *immediate geo-strategic environment*. It exists on the fringes of our boundaries and has a significant impact on the internal state of affairs.Indian Ocean defines the Indian Navy's primary Area of Maritime Interest, where it seek to address the challenges having a bearing on national security and the nation's overall socio-economic development.

Student Notes:

With substantial economic activity, including 90% trade by volume and bulk of our energy imports, happening over the sea, **maritime security** is central to overall development of our nation. Concurrently, India cannot hope to develop and grow peacefully with an unstable and turbulent neighbourhood. Prevalence of peace in the Indian Ocean Region is therefore a key national security imperative.

Riding on the benefits of globalisation, littorals of the IOR are now re-emerging to achieve their original potential. The emergence of many regional countries, as economic powerhouses, reflects this reality. Consequently, several regional economic groupings such as ASEAN, BIMSTEC, SAARC, IOR-ARC, GCC and few others have evolved over time in the IOR to harness the advantages of economic integration.

India's **geo-strategic location** positions us right at the confluence of major arteries of world trade. The Indian Navy is therefore viewed by some of the littorals as a suitable agency to facilitate regional maritime security in the IOR as a **net security provider**. India's standing as a **benign power** provides credence to this perception, making us a preferred partner for regional security.

Economic security is central to the comprehensive approach to security. In this globalised world, the Indian economy is integrated with, and consequently interdependent on other world economies. The prospect of disruption of trade at critical chokepoints, such as the Strait of Hormuz or Malacca, can be catastrophic for the global economy. The downstream effects of such economic upheaval are certainly disastrous for regional peace. Maintaining unimpeded flow of energy and other commodities over the sea is therefore a prime concern for all nations, including ours.

Maritime terrorism is another grave challenge. The events of 26/11 brought to fore the porosity of our long coastline and its resultant vulnerability to terror attacks perpetrated from the sea. Moreover, the prospect of terror attacks on off-shore infrastructure and sea-borne traffic, close to the coast, puts a premium on ensuring **coastal security**. Consequent to government directives, the Navy is now responsible for overall maritime security of the country, including the coast.

The region's natural bounties and maritime trade carried over its sea lanes drive the global economy. The fact that two-thirds of the world's oil shipments, one-third of its bulk cargo and half of the container traffic transit over its sea lanes, and through its choke points, a large part of which is meant for countries outside the region, underscores the Indian Ocean's importance for the world at large.

In conclusion, maintenance of a peaceful maritime environment is an imperative, for our nation and the region, to sustain our growth trajectories and to achieve our national aspirations. The oceans are vast, challenges too many, and resources limited, for any individual state to assure security of the global commons. This, therefore, calls for a cooperative approach. By virtue of **India's geo-strategic location** in the Indian Ocean and her **maritime capabilities**, the Indian Navy is deemed by many to be the net security provider in the IOR.

2. **Economic Significance:** Economic importance of the Indian Ocean is immense. It can be discussed on the following points:
   a. About 30% of *world trade* is handled in the ports of the Indian Ocean.
   b. Half of the world's *container traffic* passes through Indian Ocean.
   c. *Continental shelves* cover about 4.2% of the total area of the Indian Ocean and are reported to be very Rich in minerals including Tin, Gold, Uranium, Cobalt, Nickel, Aluminium and Cadmium although these resources have been largely not exploited, so far.

Student Notes:

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d. 40 out of 54 types of *raw materials* used by U.S. industry are supplied by the Indian Ocean.
e. Several of the world's *top container ports*, including Port Kelang and Singapore, are located in Indian Ocean as well as some of the world's fastest growing and busiest ports.
f. Indian Ocean possesses some of the *world's largest fishing grounds*, providing approximately 15%of the total world's fish catch (approximately 9 million tons per annum).
g. 55% of known *world oil reserves* are present in Indian Ocean.
h. 40% of the *world's natural gas reserves* are in Indian Ocean littoral states.

4. Previous Years UPSC Prelims Questions

1. Which of the following have coral reefs?
1. Andaman and Nicobar Islands
2. Gulf of Kachchh
3. Gulf of Mannar
4. Sunderbans

Select the correct answer using the code given below. (2014)

(a) 1, 2 and 3 only (b) 2 and 4 only
(c) 1 and 3 only (d) 1, 2, 3 and 4

2. Consider the following statements:
1. Most of the world's coral reefs are in tropical waters.
2. More than one-third of the world's coral reefs are located in the territories of Australia, Indonesia and Philippines.
3. Coral reefs host far more number of animal phyla than house hosted by tropical rainforests.

Which of the statements given above is/are correct? (2018)

(a) 1 and 2 only (b) 3 only
(c) 1 and 3 only (d) 1, 2 and 3

5. Previous Years UPSC Mains Questions

ihagnz7@gmail.com

1. What is the importance of Indian Ocean for India? (UPSC 1999/15 Marks)
2. Mention the advantages which India enjoys being at the end of the Indian Ocean. (UPSC 1996/15 Marks)
3. Describe the ideal conditions for coral reef formation. (Geography Mains 2008)
4. Write short note on formation of coral reefs. (Geography Mains 2001/200 words)
5. Write short note on coral reefs. (Geography Mains 1988/200 words)
6. Examine economic significance of the resources of the Continental Shelf of the Indian Ocean. (Geography Mains 2009/30 marks)
7. Assess the geographical significance of Indian Ocean. (Geography Mains 2008/200 words)
8. Analyse the role of India in the geo-politics of the Indian Ocean Region. (Geography Mains 2003,2000/200 words)
9. Discuss the geopolitical importance of Indian Ocean area. (Geography Mains 1999/200 words)

6. Previous Years Vision IAS Test Series Questions

Student Notes:

1. ***Define corals and reefs. Describe the ideal conditions for coral reef formation? Also give an account of distribution of coral reefs in India.***

Approach:

Questions are very basic and specific in nature. So, specific answers should be provided for each part.

Answer:

A **reef** is a strip or ridge of rocks, sand, or coral that rises to or near the surface of a body of water. The best-known reefs are the coral reefs developed through biotic processes dominated by **corals** and calcareous algae.

Corals are **animals**, even though they may exhibit some of the characteristics of plants and are often mistaken for rocks. Corals can exist as individual polyps (a small sea animal that has a body shaped like a tube), or in colonies and communities that contain hundreds to hundreds of thousands of polyps. Corals are found throughout the oceans, from deep, cold waters to shallow, tropical waters.

Conditions needed for growth of Coral Reefs:

- Shallow coral reefs grow best in **warm water.**
- Reef-building corals prefer **clear and shallow water** with **lots of sunlight.**
- Corals also need **salt water** to survive.
- Other factors influencing coral distribution are *availability of hard-bottom substrate* and the *availability of food* such as plankton.

Coral Reefs in India

The coral reef ecosystems are found in four regions of India which are:

Region	Type of Reef
Andaman & Nicobar Islands	Fringing Reefs
Gulf of Mannar (Tamil Nadu)	Fringing Reefs
Gulf of Kutchh (Gujarat)	Fringing Reefs
Lakshadweep Islands	Atolls

sihagn27@gmail.com

2. ***Lakshadweep has been facing a drastic decline in coral cover in recent years. Discuss various environmental and anthropogenic factors behind this phenomenon. How can El Nino be disastrous for the world's coral reefs? Illustrate.***

Approach:

Answer can be framed simply in three parts. First, brief introduction of the phenomenon. Second, explanation of underlying factors of coral bleaching. Third, description of effects of El Nino on corals, with examples.

Answer:

Lakshadweep is the major area of coral formation in India. Unfortunately it is facing decline in coral reefs as reported that till 2010, the live coral reef cover in the island was recorded at 27 per cent, which dropped to 11 per cent in the subsequent year because of the May 2010 bleaching. This decline is presenting the serious threat to marine ecosystem and livelihood prospects of local community.

The various environmental and anthropogenic factors that are contributing to coral degradation are:

Student Notes:

(i) Environmental

- Climate change: the rise in sea surface temperature due to El-Nino phenomenon during 1998 caused extensive coral reef bleaching impacting over 40 to 90% of live coral cover.
- Coastal erosion: It is a serious problem faced by the islands every year resulting in loss of land.
- Increasing sedimentation and pollution of water is disturbing the delicate balance of coral and their survival need.

(ii) Anthropogenic

- Population pressure: Changing demographic pattern and lifestyle, coupled with resource harvest from the reefs have brought many reefs in the Lakshadweep to various degrees of stress.
- Developmental activities: Overexploitation and mindless mining of coral reef colonies led to degrading of coral reef.
- Coral tourism: Lakshadweep increasingly being promoted as major tourist destination for sea sports like scuba diving. This results in environmental pollution particularly of sea water.

El Nino as an anomaly is not well understood phenomenon but it is cites as major threat to coral by scientists. It raises the sea temperature and sea level disturbing the delicate ecosystem of corals. Further, it is well established that the last big El Niño in 1997/98 caused the worst coral bleaching in recorded history. In total, 16% of the world's coral was lost and some countries like the Maldives lost up to 90% of their reef coverage

3. Explain the importance of coral reefs as an ecosystem. Why are corals rare along the western coast of the continents?

Approach:

- Briefly introduce what are Coral Reefs.
- Then explain the importance of Coral reefs as an ecosystem. The key word is "ecosystem". Concentrate on the role of Coral reefs as an ecosystem. No need to write everything about Coral reefs.
- Then come to the reason behind absence of Coral reefs on the western coast of the continents.

sinagn27@gmail.com

Answer:

Coral reefs are diverse underwater ecosystems formed due to the accumulation and solidification of lime secreting organisms known as Coral Polyps. They are also known as the "tropical rainforests of the sea" for their astounding richness of life.

Importance of Coral reefs as an ecosystem:

- Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals and hundreds of other species.
- Coral reefs are the source of nitrogen and other essential nutrients for marine food chains. They also assist in carbon and nitrogen fixing. They help with nutrient recycling.
- As a healthy and diverse ecosystem, Coral reefs helps in recycling and purification of water and air, the creation of soil, and the break-down of pollutants.

Student Notes:

- Coral are very important in controlling the amount of carbon dioxide in the ocean water. Coral polyp turns carbon dioxide in the water into a limestone shell. Without coral, the amount of carbon dioxide in the water would rise.
- Coral reefs protect coastlines from the damaging effects of wave action and tropical storms.
- Coral reefs with diverse range of species provide a larger gene pool, giving natural communities survival options when environmental conditions and climates change. The greater the number of species and hence genetic diversity in an ecosystem, the lesser will be the impact of removing individual species.

Corals are rare along the western coast of the continents primarily due to upwelling and strong cold coastal currents that reduce water temperatures in these areas. Coral reefs are very sensitive organisms and grow only in particular conditions. They are usually found in the Tropical seas upto a depth of 200-300 ft where Sun rays reach. The ideal temperature for their growth is 20-25 ^{0} C. Both high Salinity and fresh water are harmful for their growth. These ideal conditions required for the growth of Corals are usually absent along the western coast of the continents due to upwelling of cold Currents.

4. ***Coral reefs are the most biologically diverse and economically valuable ecosystems on earth. Elaborate. Discuss the factors responsible for the decline of coral reefs across the world. Also, list some measures that have been taken for their preservation.***

Approach:

- Introduce the answer by bringing out facts to show that coral reefs are the most biologically diverse and economically valuable.
- Enumerate and analyse the factors responsible for the decline of coral reefs, such as rising temperature, sedimentation etc.
- Enumerate the measures taken to save coral reefs, you should bring measures taken both in India and worldwide. The questions demands measures taken, avoid giving suggestions.

Answer:

Coral reefs are some of the most diverse and valuable ecosystems on Earth. Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals and hundreds of other species. They have high productivity and are referred to as 'the Tropical Rainforests of the oceans'.

- Reef building corals lay down the foundation of calcium carbonate which act as home to a wide array of plants and animals.
- Coral ecosystems are a source of food for millions.
- Coral reefs buffer adjacent shorelines from wave action and prevent erosion, property damage and loss of life.
- Healthy reefs contribute to local economies through tourism.
- They provide habitat, spawning and nursery grounds for economically important fish species.
- The coral biodiversity is considered key to finding new medicines for the 21st century.

Factors responsible for decline:

- Coral species live within a relatively narrow temperature margin hence low and high sea temperatures can induce coral bleaching.

sihagnz@gmail.com

Student Notes:

- When corals are exposed to high concentrations of chemical contaminants or pathogens, coral bleaching happens.
- Increasing demand of fish for food and tourism has resulted in over fishing of not only deep-water commercial fish, but key reef species as well.
- The growth of coastal cities and towns generates a range of threats to nearby coral reefs.
- With increased pollution, Carbon Dioxide is absorbed by Ocean leading to rise in Carbonic acid in water. As Coral has Calcium carbonate as main component, it reacts with Carbonic acid and slowly dissolves down.

Measures taken for preservation of coral reefs:

- Chapter 17 of "Agenda 21" specifically addresses the protection and sustainable development of the marine and coastal environment within the context of the United Nations Convention on the Law of the Sea (UNCLOS).
- In 2003, UN-Oceans was created as an inter-agency coordination mechanism on ocean and coastal issues, including coral reefs.
- India has taken steps to protect its coral reefs under Coastal Ocean Monitoring and Prediction system (COMAPS), Land Ocean Interactions in Coastal zones (LOICZ) and Integrated Coastal and Marine Area Management (ICMAM).
- It has notified Coastal Regulation Zones (CRZ) and has setup National Coastal Zone Management Authority and State Coastal Zone Management Authority to protect coral reefs.

5. What are the characteristic features of coral reef ecosystems? Highlighting their importance, identify some of the threats being faced by them.

Approach:

- Briefly, write about the coral reefs.
- List the characteristic features of coral reef ecosystems.
- Discuss their importance.
- Enumerate the some of the threats being faced by them.

smage27@gmail.com

Answer:

Coral reefs are shallow-ocean habitats, built out of coral polyps, which are small marine animals that thrive in colonies. Coral reefs are the outcome of a symbiotic relationship between corals and one-celled algae called zooxanthellae in an oceanic ecosystem. Corals are aquatic animals which provide shelters to algae in exchange of oxygen and nutrients which algae produce by photosynthesis process. Algae also provide beautiful color to coral reefs.

Characteristics Features

- Coral reef shorelines are essentially tropical and virtually confined to within 30 degrees of the equator.
- They survive in **very narrow range of temperature** & adopted to live in warm water.
- Corals can live only in **saline water**, and the average salinity should be between 27 to 40%.
- The growth of corals is confined between **50 m to 200 m** depth in order to ensure availability of sunlight for photosynthesis and also require **sediment-free, clean water**.
- They are **ecologically highly productive regions** occupying less than 1% of the world's ocean surface, while providing shelter for around 25% of all marine species.

Student Notes:

Importance of Coral Reef Systems

- Contribute in CO_2 removal and help nutrient recycling of carbon dioxide.
- Protects the coastal regions from storms and erosion by cyclones and tsunami.
- Provides a source of food for millions of marine species and marine fish catch.
- Provides shelter to large number of marine creatures.
- Also, provide important medicines including anti-cancer drugs.

Threats Faced

- Rising seawater temperature as a result of climate change due to which the relationship between corals and their symbiotic microalgae breaks down.
- Unplanned construction activities in coastal areas disturb sediments.
- Ecologically destructive fishing practices, such as use of dynamite or cyanide in fishing cause physical damage to corals.
- Unregulated and excessive fishing beyond the replenishment capacity.
- Release of nutrient-laden sewage in coastal areas causes algal blooms which block sunlight, stunt coral growth and interfere with reproduction.
- Tourism in ecologically sensitive areas causes physical damage to reefs by construction.
- Recently, ocean acidification has emerged as another potentially serious threat. These acidic conditions dissolve coral skeletons, which make up the structure of the reef, and make it more difficult for corals to grow.

Considering the ecological and economic significance, the restoration of coral reef system should be the priority for the countries with coral reef systems.

sihagn27@gmail.com

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JATIN KISHORE
3 AIR
PRATIBHA VERMA
6 AIR
VISHAKHA YADAV
7 AIR
GANESH KUMAR BASKAR
8 AIR
ABHISHEK SARAF
9 AIR
RAVI JAIN
10 AIR
SANJITA MOHAPATRA
9 IN TOP 10 SELECTIONS IN CSE 2018
1 AIR
KANISHAK KATARIA
2 AIR
AKSHAT JAIN
3 AIR
JUNAID AHMAD
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FOR DETAILED ENQUIRY,
PLEASE CALL: +91 8468022022,
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ENQUIRY@VISIONIAS.IN
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