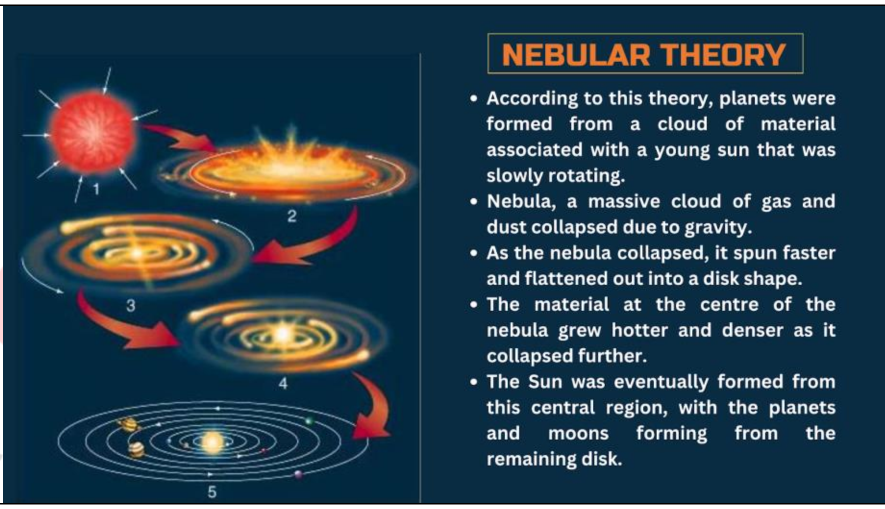
LECTURE 3 – CLIMATOLOGY I

ATMOSPHERE

- The Earth is enveloped by a layer of gases extending thousands of kilometers above the surface, known as the atmosphere. It plays a crucial role in sustaining life by regulating temperature, filtering radiation, and enabling weather phenomena. The atmosphere, though appearing thin relative to Earth's radius, is held by gravity and cannot escape into space.

EVOLUTION OF EARTH'S ATMOSPHERE

- The Earth's atmosphere has undergone significant changes over billions of years, evolving from a primitive composition unsuitable for life to the oxygen-rich environment we depend on today.

<table>
<tr><th>Stages</th><th>Evolution</th></tr>
<tr><td>Nebular theory</td><td>
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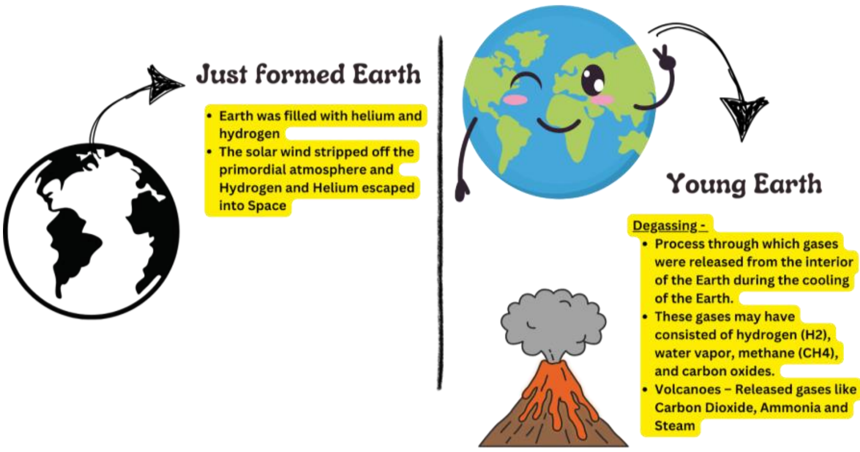
<tr><td>Just formed Earth and Young Earth</td><td>
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<tr><td>Present Earth</td><td>✓ With time Carbon Dioxide dissolved in the Oceans and bacteria fed on it to release oxygen as by-product
✓ Ammonia molecules were split into Nitrogen and Hydrogen by Sun Rays
✓ Process of Photosynthesis flooded the oceans and atmosphere with Oxygen</td></tr>
</table>

COMPOSITION OF EARTH'S ATMOSPHERE

- The atmosphere consists of a mixture of gases, suspended particles, and water vapor. While some gases remain in fixed proportions, others vary based on location and time.

Constituent	*Formula*	*Percentage by Volume*
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon dioxide	CO_2	0.036
Neon	Ne	0.002
Helium	He	0.0005
Krypto	Kr	0.001
Xenon	Xe	0.00009
Hydrogen	H_2	0.00005

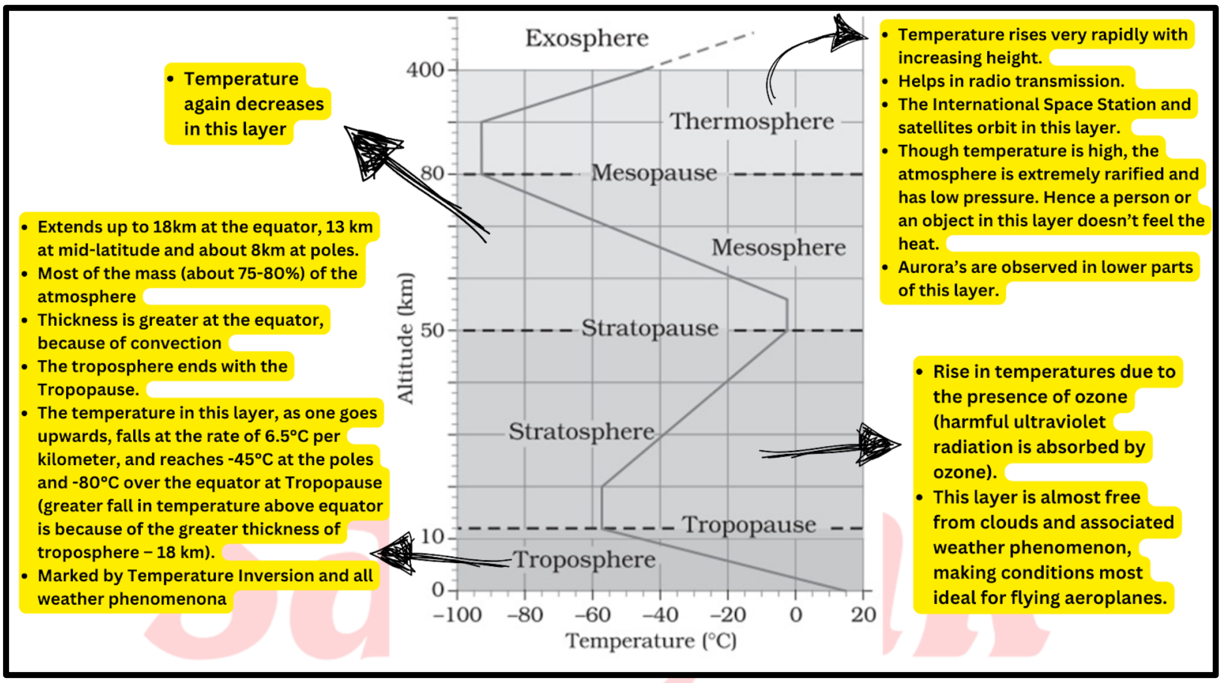
MAJOR GASES IN DRY AIR AND THEIR ROLES

Gas	Role
Nitrogen (N_2)	➢ Constituting the largest share of the atmosphere, nitrogen plays a vital role in biological processes, particularly in protein synthesis. ➢ It also acts as a diluting agent, moderating the combustion rate by reducing the concentration of oxygen.
Oxygen (O_2)	➢ Essential for respiration in living organisms. ➢ Supports combustion processes, making it a crucial element for energy production.
Carbon Dioxide (CO_2)	➢ Acts as a critical component in photosynthesis, enabling plants, algae, and certain bacteria to produce food. ➢ Functions as a greenhouse gas, trapping heat in the atmosphere and regulating Earth's temperature by absorbing and re-emitting infrared radiation..
Ozone (O_3)	➢ Found primarily in the stratosphere (10–50 km above Earth's surface), forming the ozone layer. ➢ Shields life on Earth by absorbing harmful ultraviolet (UV) radiation from the Sun.
Water Vapor (H_2O)	➢ The most variable atmospheric component, contributing up to 4% of the total atmospheric volume, depending on location and climate conditions. ➢ Concentration decreases with altitude and is nearly absent in arid desert regions due to dry winds. This occurs because water vapor primarily originates from **evaporation** at the Earth's surface, particularly from oceans, seas, and lakes. As altitude increases, **temperature decreases**, reducing the air's capacity to hold moisture. ➢ Plays a significant role in weather patterns, cloud formation, and the hydrological cycle.
Dust Particles	➢ Predominantly found in the lower atmosphere but can be lifted to higher altitudes by convection currents.

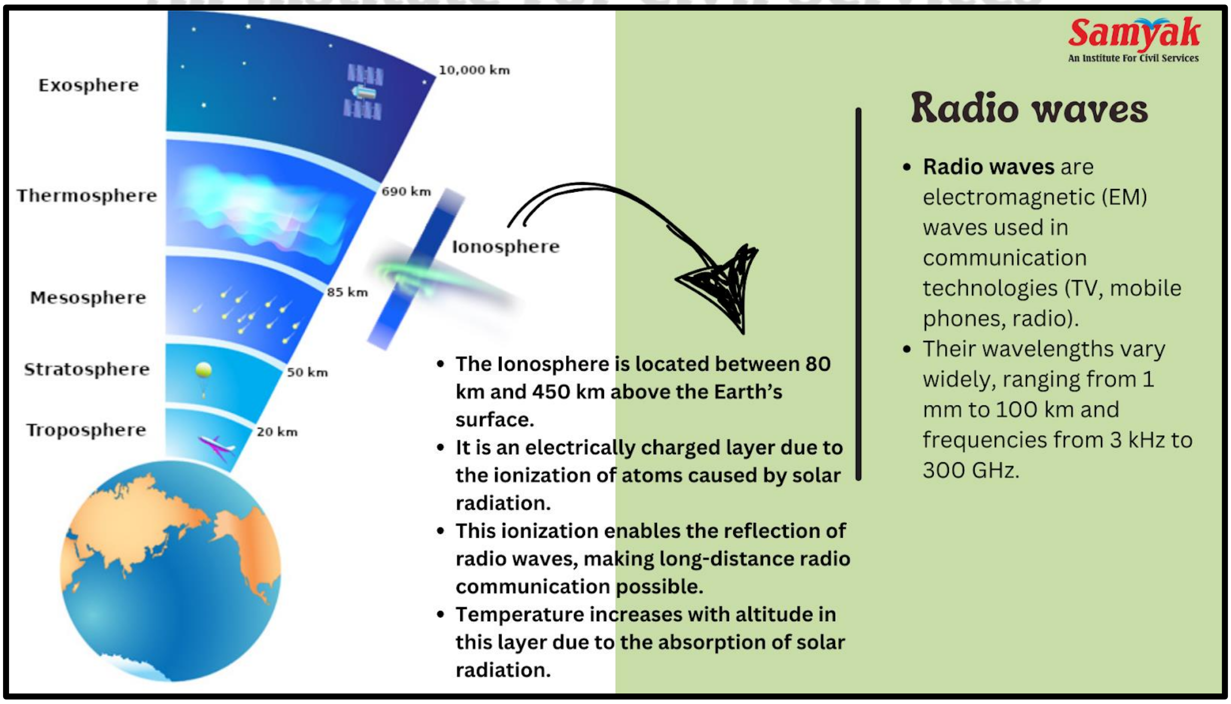
	➢ More abundant in subtropical and temperate regions compared to equatorial and polar areas.\Influences weather by aiding cloud formation and acting as condensation nuclei for precipitation.

STRUCTURE OF ATMOSPHERE

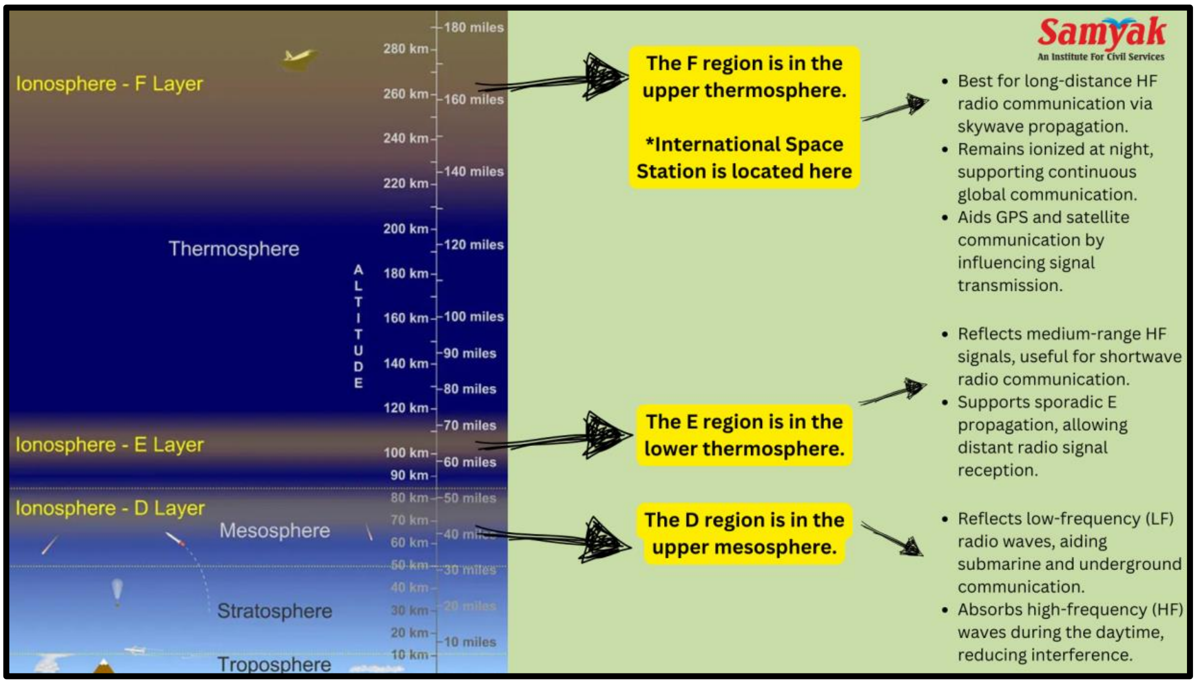
BASED ON CHANGE IN TEMPERATURE AND DENSITY

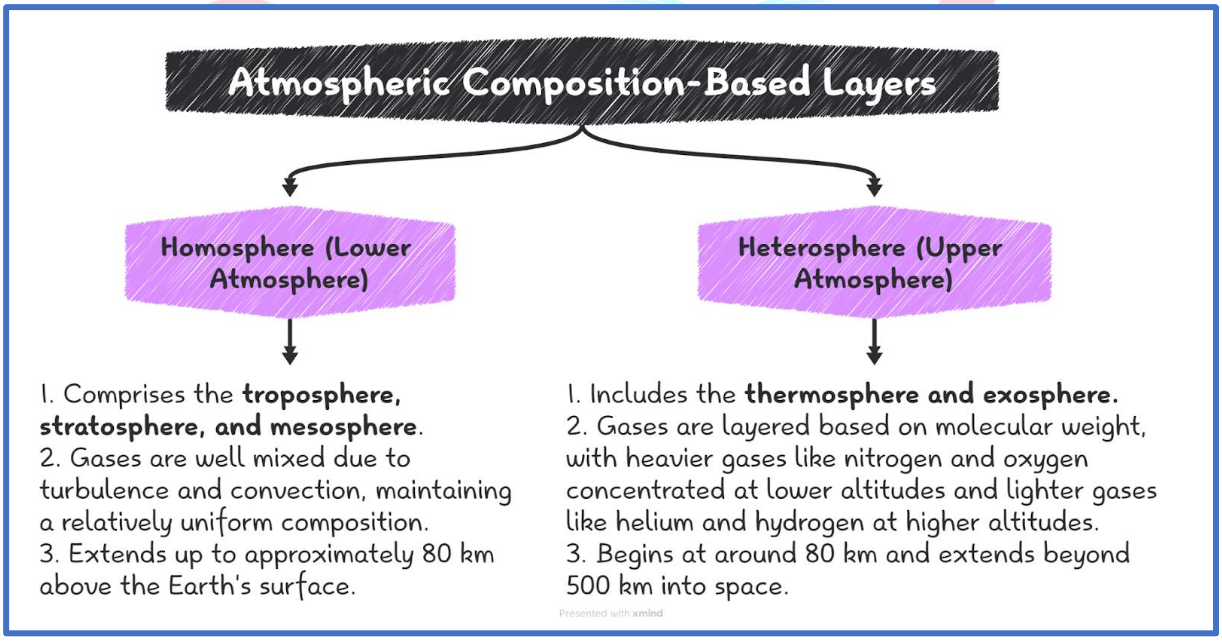


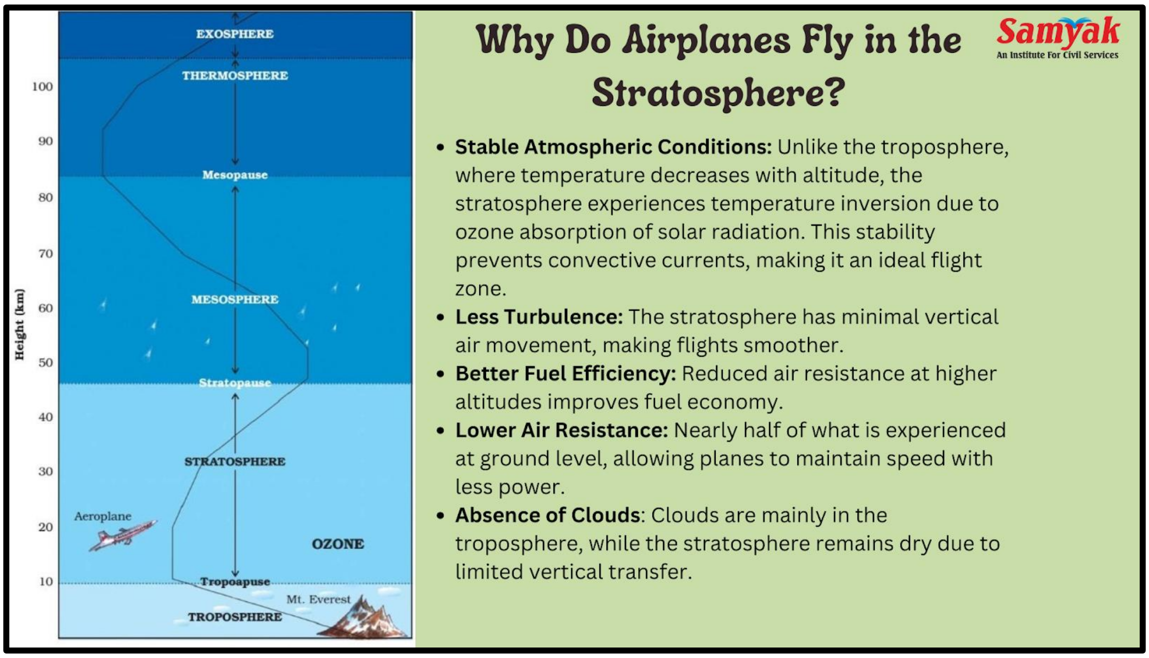
MORE ABOUT IONOSPHERE



REGIONS WITHIN IONOSPHERE



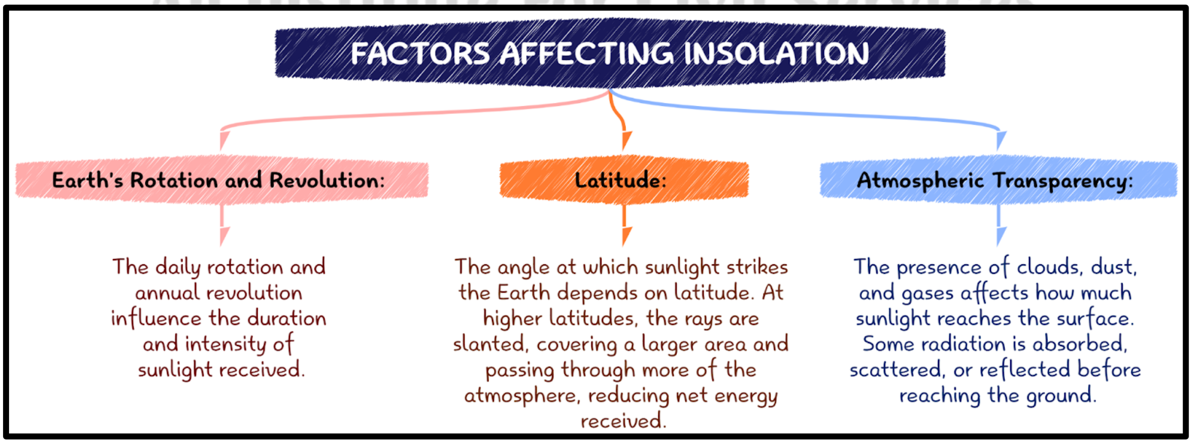




INSOLATION AND HEAT BUDGET

- **Solar Radiation (Insolation) -** The Earth receives energy from the Sun in the form of **shortwave radiation**, also known as **insolation**.
  - Due to the Earth's spherical shape, only a fraction of the Sun's energy is intercepted.
  - At the top of the atmosphere, the average incoming solar radiation is approximately **1.94 calories per square cm per minute**.

FACTORS AFFECTING INSOLATION



THE DETAILS

Factors	Causes
Rotation of the Earth on its Axis	✓ As Earth rotates while being tilted at its axis, the amount of insolation received varies.
Angle of incidence of the Sun Rays	**Higher Latitudes – Less Insolation** ✓ Sun rays are slanting and take longer path through atmosphere. Thus, gets more reflected and absorbed by the atmosphere and covers larger area on the surface.

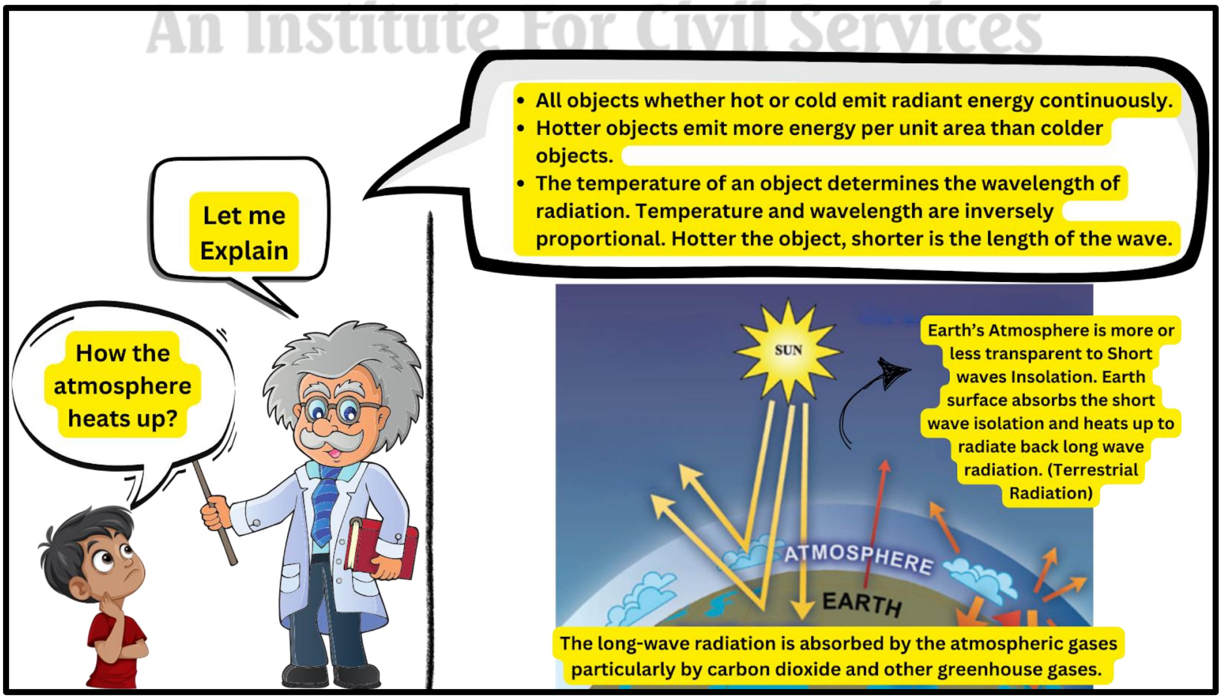
	Lower Latitudes – More insolation ✓ Sun rays are vertical and is more concentrated on the surface
Duration of the Day	✓ Longer the duration of the day, greater the amount of the insolation received
Transparency of the Atmosphere	✓ **Reflection** – by thick cloud ✓ **Absorption -** Water vapour ✓ **Scattering -** Very small suspended particles in the troposphere. **The red colour of the rising and the setting sun and the blue colour of the sky** are the results of scattering of the light within the atmosphere.
Revolution of the Earth	✓ **Perihelion-** As earth is closest to the Sun, more insolation is received. ✓ **Aphelion** – Less Insolation is received

DISTRIBUTION OF INSOLATION

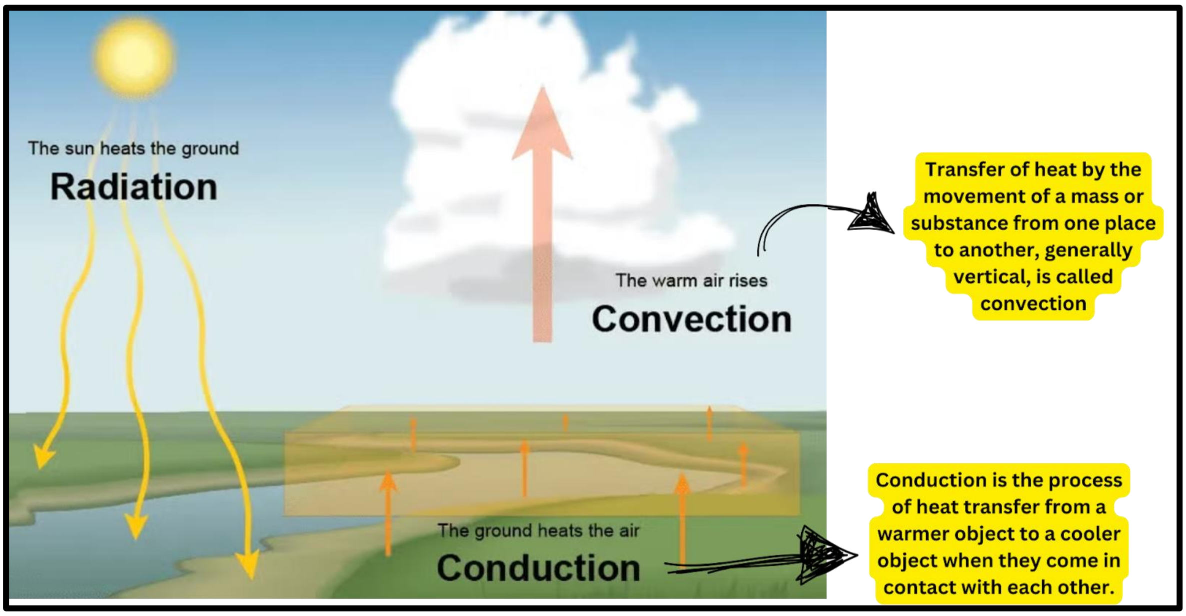
- ✓ The **amount of insolation received on the earth's surface is far less than that is radiated from the sun** because of the small size of the earth and its distance from the sun.
- ✓ **Earth's Atmosphere receives more insolation** than the Earth's Surface
- ✓ **Insolation is more in summers** than in winters
- ✓ **Amount of insolation decreases from Tropics towards the Poles**
- ✓ **Maximum insolation is received over the subtropical desert, where the cloudiness is the least**. The equator receives comparatively less insolation than the tropics.
- ✓ Generally, at the same latitude, the insolation is more over the continent than over the oceans.

HEATING AND COOLING OF THE ATMOSPHERE

1. TERRESTRIAL RADIATION



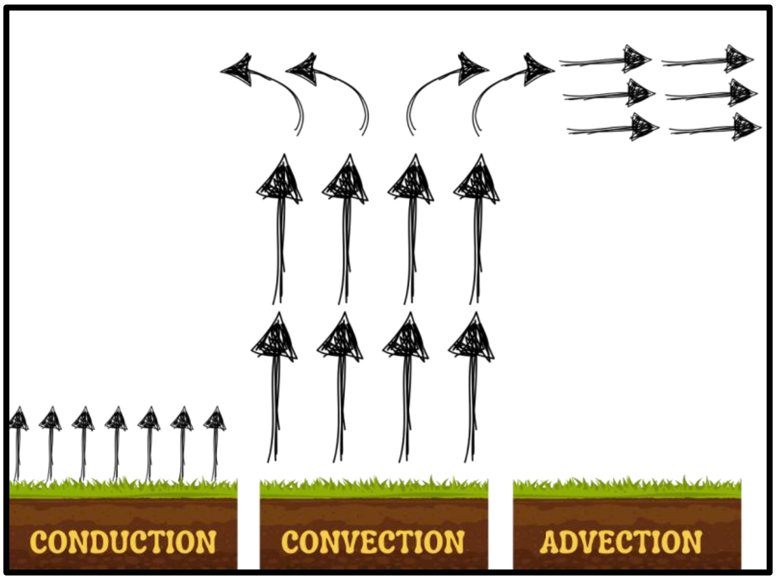
2. CONDUCTION (TRANSFER OF HEAT BY CONTACT) AND CONVECTION (VERTICAL TRANSFER OF HEAT)



- ✓ The air of the lower layers of the atmosphere gets heated either by the earth's radiation or by conduction. The heating of the air leads to its expansion. Its density decreases and it moves upwards.
- ✓ The continuous ascent of heated air creates a vacuum in the lower layers of the atmosphere. As a consequence, cooler air comes down to fill the vacuum, leading to convection.
- ✓ The convection transfer of energy is **confined only to the troposphere.**

4. ADVECTION (HORIZONTAL TRANSFER OF HEAT)

- ✓ The transfer of heat **through horizontal movement of air (wind)** is called advection.
- ✓ **Horizontal movement of the air is relatively more important than the vertical movement.**

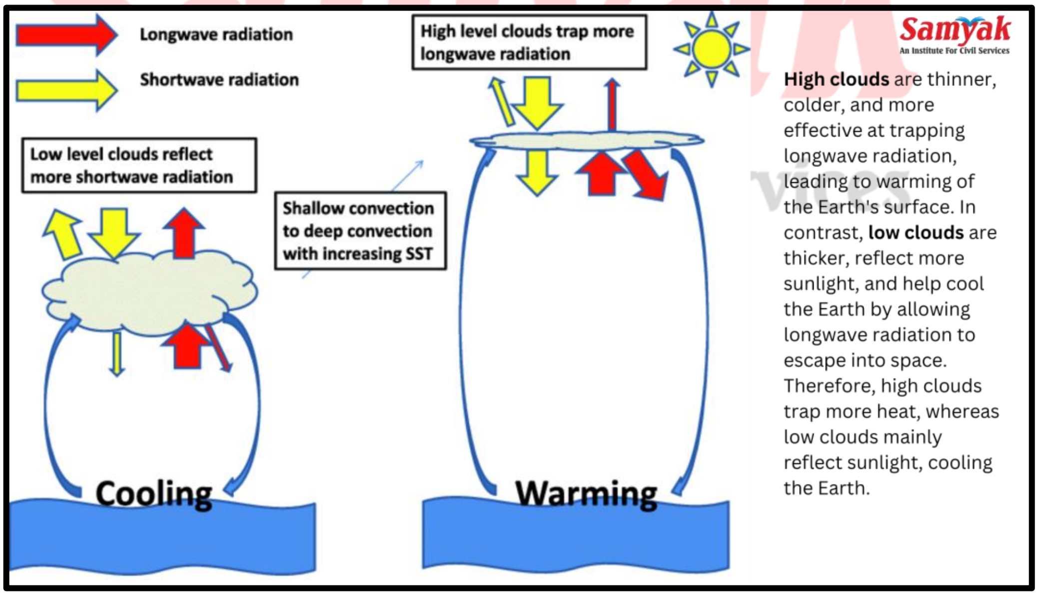


ALBEDO

- The **Albedo Effect** refers to the ability of a surface to **reflect a portion of incoming solar radiation**. It is expressed as a **reflection coefficient** with a value between **0 and 1**—where **0 represents complete absorption (no reflection)** and **1 indicates total reflection**.
- Surfaces with **higher albedo, such as snow and ice, reflect more sunlight**, whereas **darker surfaces like asphalt or forests absorb more heat**, influencing local and global temperatures.

TYPES OF ALBEDO

- **Terrestrial Albedo**
  - It refers to the measurement of Earth's overall reflectivity.
  - The Earth's **average albedo is approximately 0.31**, meaning **31% of incoming solar radiation is reflected back into space**.
  - **Factors Influencing Terrestrial Albedo**:
    - **Cloud Cover**: Thick clouds have a **higher albedo (70-80%)**, reflecting more sunlight.
    - **Deserts and Ice Sheets**: Light-colored surfaces like **sand (30-45%)** and **snow (80-90%)** contribute to a higher terrestrial albedo.
    - **Forests and Oceans**: Darker surfaces, such as **dense vegetation (10-20%)** and **deep oceans (5-10%)**, absorb more sunlight, reducing albedo.



- **Astronomical Albedo**
  - It measures the reflectivity of celestial bodies like **planets, asteroids, and moons**.
  - **Importance**:
    - Helps in **studying planetary compositions and atmospheres**.
    - Determines **surface properties**—for example, icy planets have a **higher albedo** than rocky or gaseous ones.
    - Used in **climate modeling** by comparing Earth's albedo with other planets.

Albedo of different surfaces

Surface	Albedo (%)
Fresh Snow	80-90
Thick Cloud	70-80
Water near Horizon	50-80
Old Snow	45-50
Desert	30-45
Light Soil	20-45
Thin Cloud	25-35
Grasses	20-25
Soil	20-25
Crops	10-25
Forest	10-20
Asphalt	5

Albedo of different planets

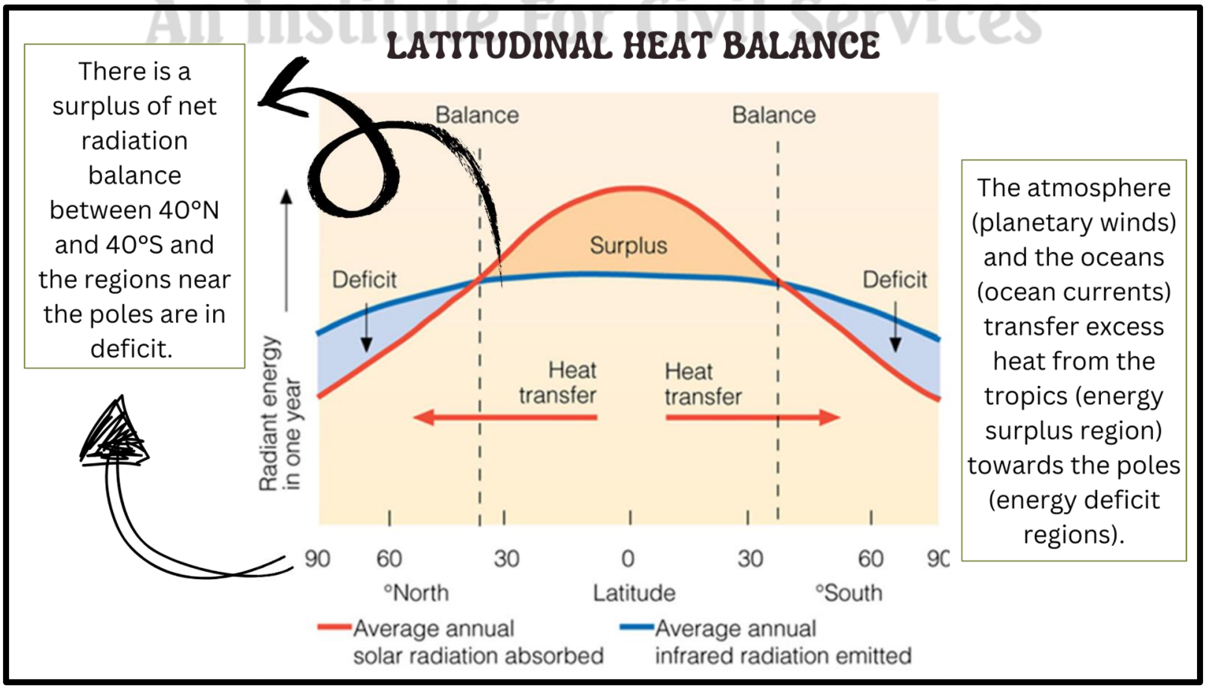
1. Mercury – 0.06
2. Mars – 0.17
3. Earth – 0.38
4. Venus – 0.71
5. Jupiter – 0.73
6. Saturn – 0.76
7. Neptune – 0.84
8. Uranus – 0.93

Mercury has the lowest albedo, reflecting very little sunlight, while Uranus has the highest, reflecting most of the sunlight it receives.

THE ROLE OF ALBEDO IN CLIMATE REGULATION

- **Albedo directly impacts Earth's temperature** by regulating the amount of solar energy absorbed.
- A **decline in global albedo** (due to melting ice caps and deforestation) results in **higher absorption of solar radiation**, contributing to **global warming**.
- Continuous monitoring of Earth's albedo through **satellites** helps track **climate changes** and predict future temperature trends.

LATITUDINAL HEAT BALANCE



Heat Budget

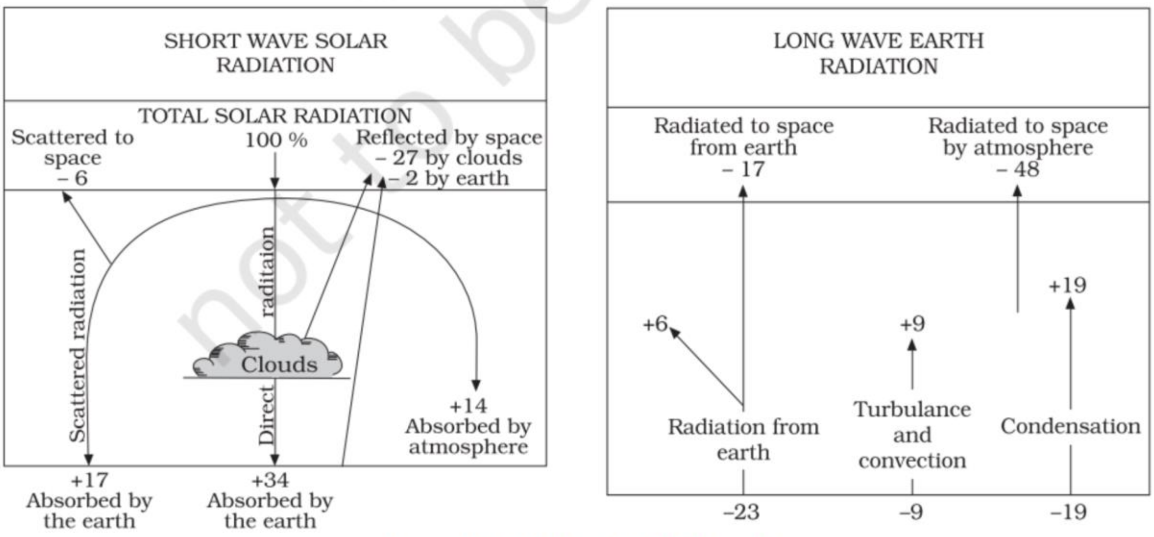


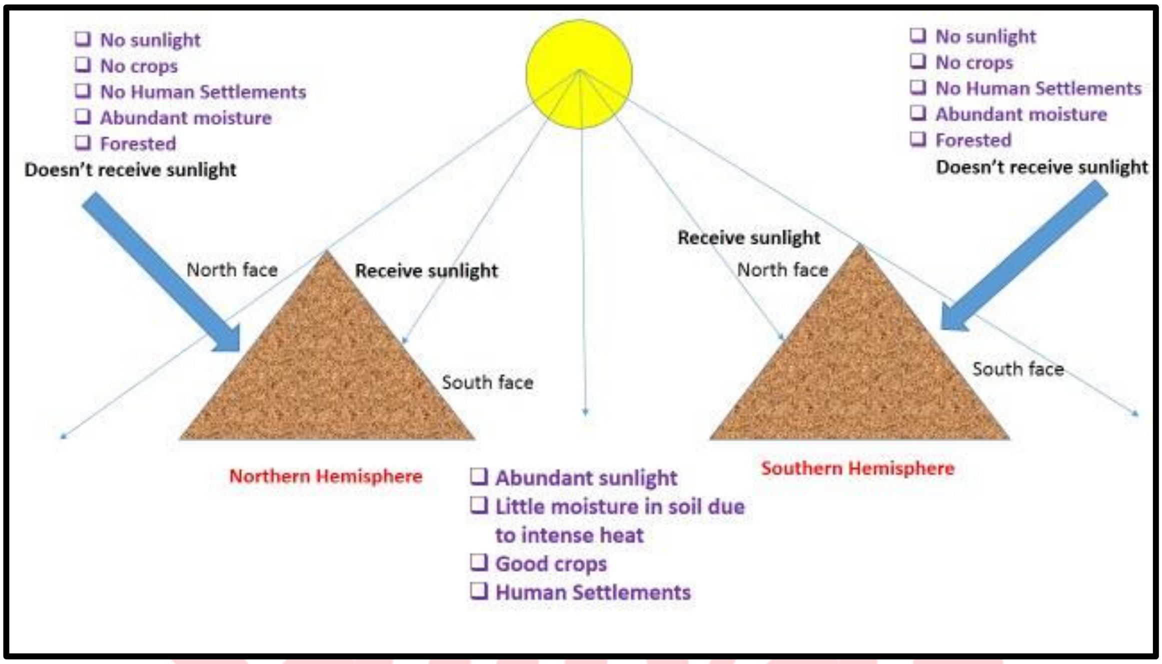
Figure 8.2 : Heat budget of the earth

<u>TEMPERATURE</u>

<u>FACTORS AFFECTING TEMPERATURE DISTRIBUTION</u>

Factors	Explanation
Latitude	➢ **Temperature decreases from Tropics towards Poles** ➢ **Note-** Maximum Temperature is found not at equator but at the Sub-Tropical Regions
Altitude	➢ **Troposphere -** With increase in height, pressure falls, the effect of greenhouse gases decreases and hence temperature decreases ➢ **Stratosphere** – Temperature increases ➢ **Mesosphere** – Temperature Decreases ➢ **Thermosphere** – Temperature Increases
Effects of Oceans and Seas	**Land cools or becomes hot more rapidly compared to oceans because** ➢ **Albedo of land is much greater** than albedo of oceans and water bodies. ➢ **Average penetration of sunlight is more in water** – up to 20 metres, than in land – where it is up to 1 metre only. ➢ **Specific heat of water is 2.5 times higher** than landmass
Local Winds	➢ Winds transfer heat from one latitude to another. ➢ They also help in exchange of heat between land and water bodies.
Continentality	**Maritime Influence** ➢ When the sea is cooler than the land in summer, it lowers the temperature of the coastal place. ➢ However, during the winter the sea is warmer than the land and keeps coastal places warmer. **Continental Influence** ➢ Places Located in the interior of large continents tend to have hot summers than areas near the coast in similar latitudes.
Ocean Currents	➢ Ocean currents can raise or lower the temperature of the nearby coastal areas.
Transparency of	**Already covered under Insolation**

Atmosphere and Distance from the Sun	
Slope Aspect	➢ Slopes more exposed to the sun receive more solar radiation than those away from the sun's direct rays.



DISTRIBUTION OF TEMPERATURE

- Distribution of temperature across the latitudes over the surface of the earth is called its horizontal distribution.
- On maps, the horizontal distribution of temperature is commonly shown by **isotherms**.

ISOTHERMS

- ✓ Isotherms are line connecting **points that have an equal temperature.**
- ✓ **General characteristics of isotherms**
  - **Generally, follow the latitudes** mainly because the same amount of insolation is received by all the points located on the same latitude.
  - **Sudden bends at ocean-continent boundaries**: Due to differential heating of land and water.

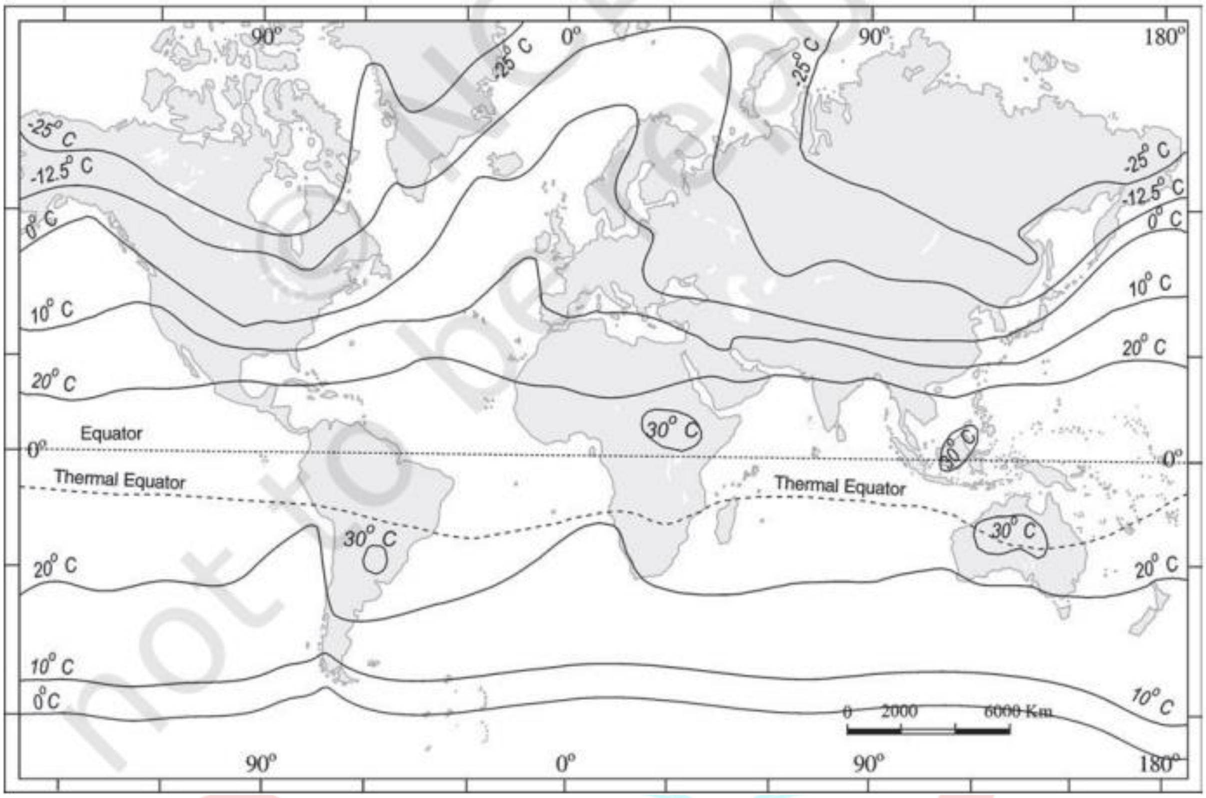


Figure 1: The distribution of surface air temperature in the month of January

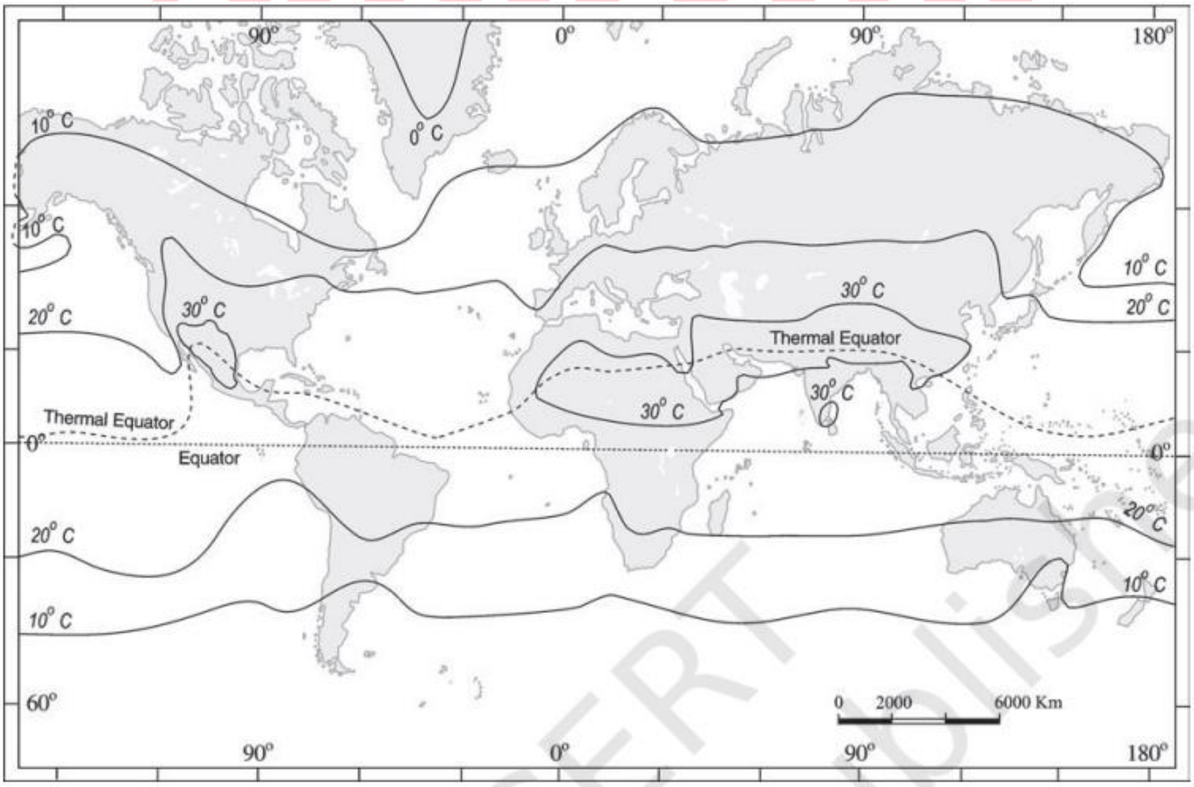


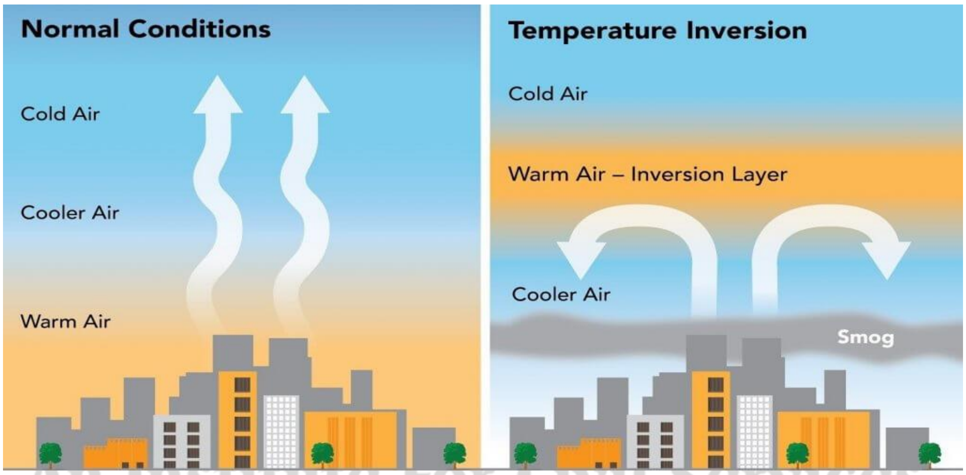
Figure 2: The distribution of surface air temperature in the month of July

GENERAL TEMPERATURE DISTRIBUTION

- The **highest temperatures occur over tropics and sub-tropics** (high insolation). The **lowest temperatures occur in polar and subpolar regions.**
- **The diurnal and annual range of temperatures is highest in the interiors of continents** due to the effect of continentality.
- The **diurnal and annual ranges of temperature is least in oceans.** [high specific heat of water and mixing of water keep the range low]

TEMPERATURE INVERSION

- ✓ Under normal conditions, the temperature usually decreases with an increase in altitude in the troposphere at a rate of 6.5 deg Celsius/km.
- ✓ But on some occasions, the situations get reversed and the **temperature starts increasing with height rather than decreasing. This is called temperature inversion.**

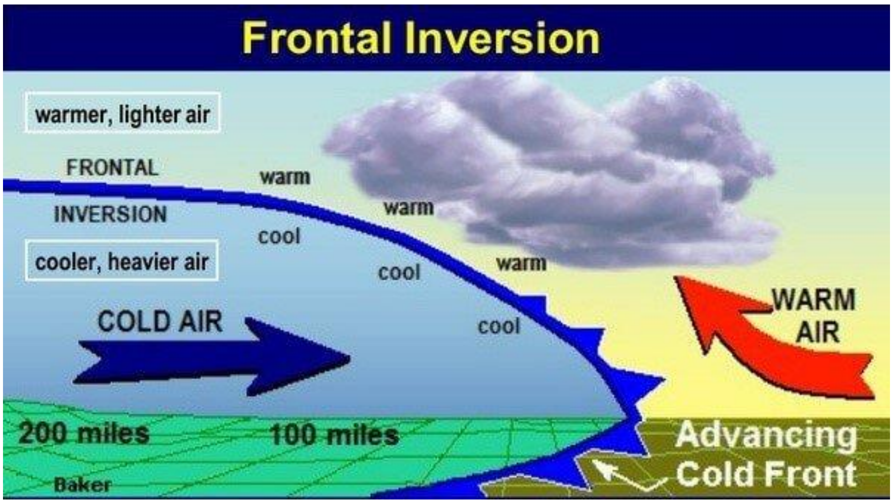


IDEAL CONDITIONS FOR TEMPERATURE INVERSION

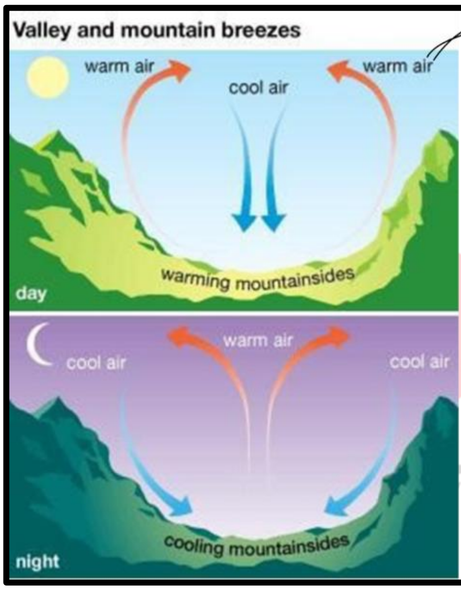
1. **Long nights**, so that the outgoing radiation is greater than the incoming radiation.
2. **Clear skies**, which allow unobstructed escape of radiation.
3. **Calm and stable air**, so that there is no vertical mixing at lower levels.

TYPES OF TEMPERATURE INVERSION

1. **Frontal inversion**
    - It is caused by **the horizontal and vertical movement of air when warm airmass converge with the cold airmass**.
    - This kind of inversion has a **considerable slope, whereas other inversions are nearly horizontal.**



2. **Temperature Inversion in Intermontane Valley (Air Drainage Type of Inversion)**



Temperature Inversion in Intermontane Valley

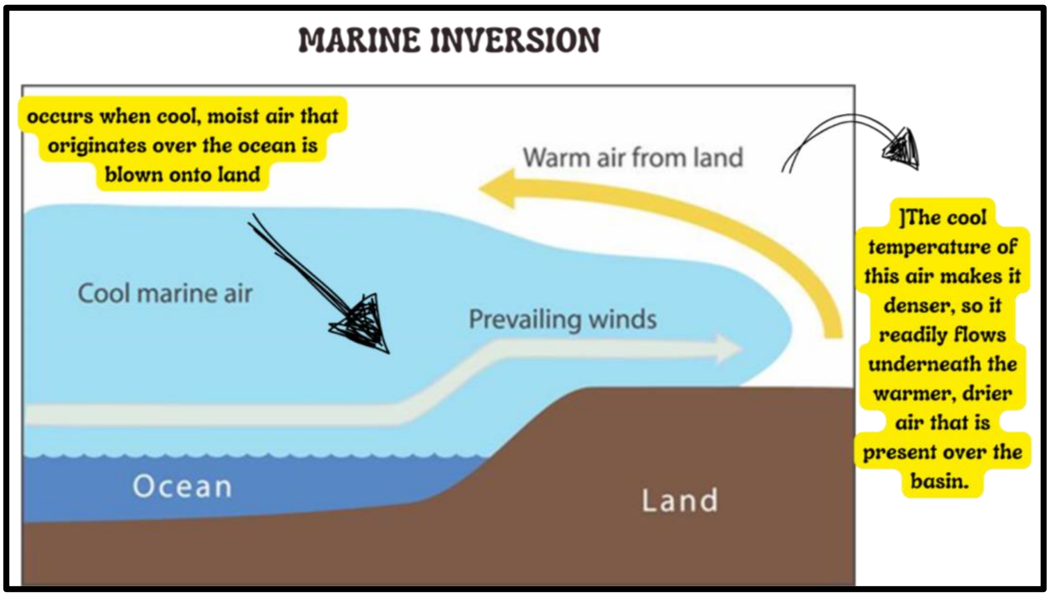
- In high mountains or deep valleys, sometimes, the temperature of the lower layers of air increases instead of decreasing with elevation along a sloping surface.
- Cold air at the hills and mountains, produced during the night, flows under the influence of gravity.
- Being heavy and dense, the cold air acts almost like water and moves down the slope to pile up deeply in pockets and valley bottoms with warm air above. This type of inversion of temperature is called valley inversion.

3. **Ground Inversion (Surface Temperature Inversion)**

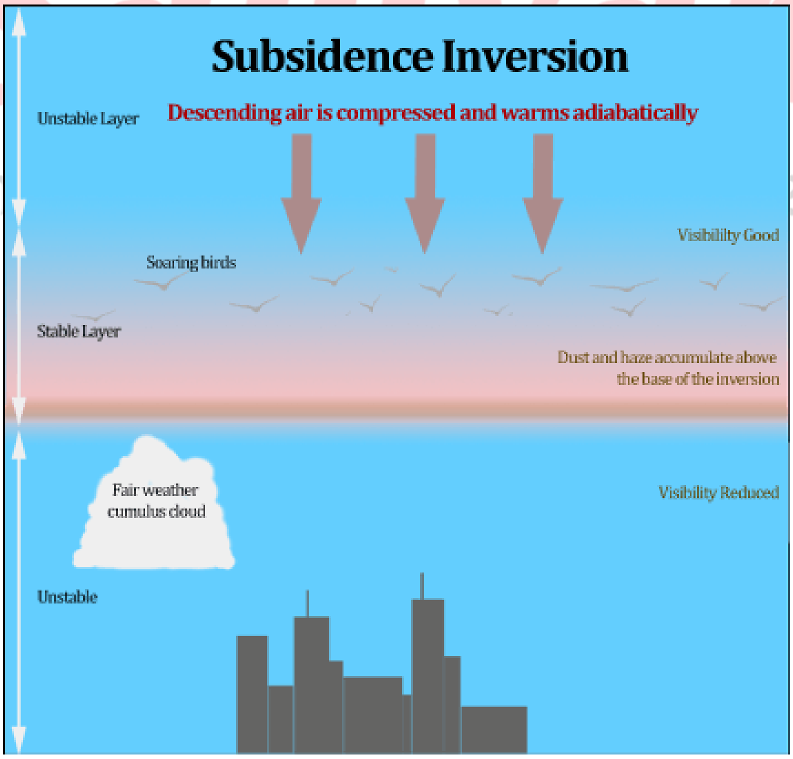
Ground Inversion (Surface Temperature Inversion)

- A ground inversion develops when air is cooled by coming in contact with a colder surface until it becomes cooler than the overlying atmosphere; this occurs most often on clear nights when the ground cools off rapidly by radiation.
- This inversion, however, disappears with sunrise. The duration and height of surface inversion increase polewards.

4. **Marine Inversion**



5. **Subsidence Inversion (Upper Surface Temperature Inversion)**
   - A subsidence inversion develops **when a widespread layer of air descends.**
   - The layer is compressed and heated by the resulting increase in atmospheric pressure.
   - If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion.



EFFECTS AND SIGNIFICANCE OF TEMPERATURE INVERSION

- **Visibility:** Cooler air trapped, forms low clouds (smog), and reduces visibility. This can lead to increased accidents. Also, on the other hand this may help the appropriate stakeholders to predict the location for installation of smog towers.

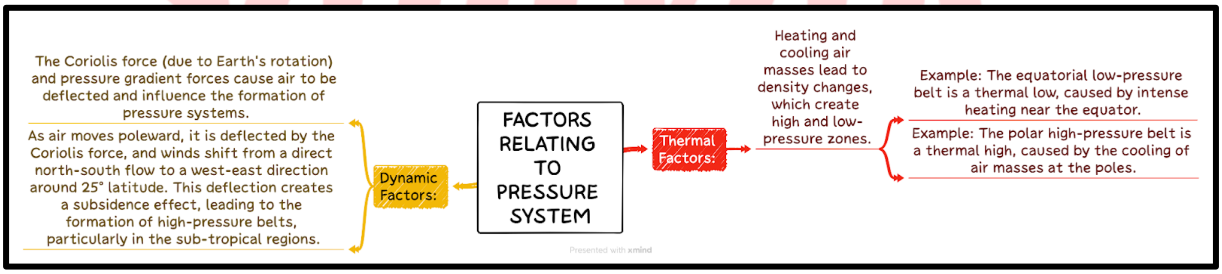
- **Precipitation:** Inverted conditions hinder rain development, impacting agriculture and Farmer's income.
- **Temperature Variations:** Disruption of daily temperature fluctuations. This may lead to increased vulnerability to diseases.
- **Severe Weather:** Contributes to intense thunderstorms and tornadoes. This may turn as an indicator for the government to make suitable policies.
- **Pollutant Trapping:** Smoke, dust, pollutants confined, forming hazardous substances. This may increase vulnerability to respiratory disease.
- **Overall Impact:** Affects visibility, precipitation, temperature patterns, severe weather, and pollutant accumulation.

PRESSURE BELTS

- Air, when heated, expands, reducing its density and leading to **low-pressure areas**. Conversely, cooled air contracts, increasing its density and creating **high-pressure areas**. This differential pressure drives air movement, influencing climate and weather patterns globally.

FORMATION AND ROLE OF PRESSURE SYSTEMS

- Pressure systems are created due to both **thermal** and **dynamic factors**.
- These pressure differences cause air to move from high to low-pressure areas, creating winds that redistribute heat and moisture, which regulates the planet's temperature and influences precipitation patterns.



HORIZONTAL AND VERTICAL VARIATIONS OF PRESSURE

Pressure is not uniform across the Earth's surface or with altitude:

- **Vertical Pressure Distribution**: Pressure decreases with height due to the thinning of the atmosphere. At higher altitudes, such as near **Mount Everest**, air pressure is much lower than at sea level.
- **Horizontal Distribution**: **Isobars**, or lines connecting points of equal pressure, help represent the horizontal distribution of pressure. The spacing between isobars indicates the **pressure gradient**, which in turn determines wind speed and direction.
  - Close isobars represent a **steep pressure gradient**, leading to stronger winds.
  - Wide spacing indicates a **gentler gradient**, resulting in calmer conditions.

AIR PRESSURE

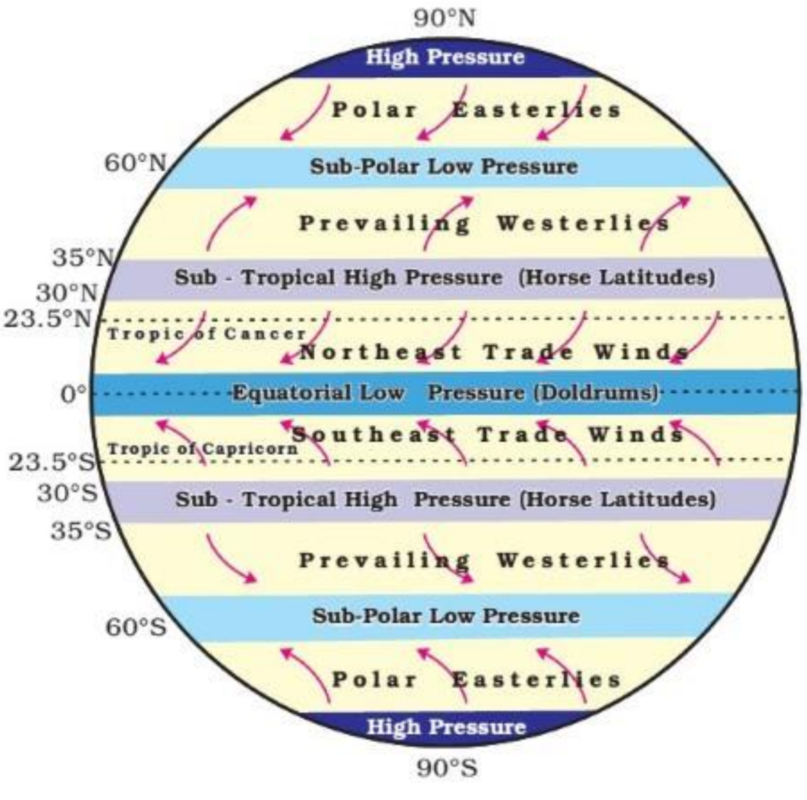
- A force exerted in all directions by virtue of the weight of all the air above it.
- The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the atmospheric pressure.

MEASUREMENT OF AIR PRESSURE

- It is measured by means of an instrument called barometer.
- The units used by meteorologists for this purpose are called millibars (mb).
- The normal pressure at sea level is taken to be about (1013.25 millibars).

PRESSURE BELTS

- Pressure belts are regions of the Earth where air pressure is relatively uniform and distinct from surrounding areas. These belts play a key role in global weather patterns, ocean currents, and the distribution of climate zones.
- They are the result of complex interactions between solar heating, Earth's rotation, and atmospheric circulation.
- There are **seven primary pressure belts** on Earth, which are crucial in determining the movement of air and moisture around the globe.
- These pressure belts are **not permanent** in nature. **They oscillate with the apparent movement of the sun.**
- In the northern hemisphere in winter, they move southwards and in the summer northwards.



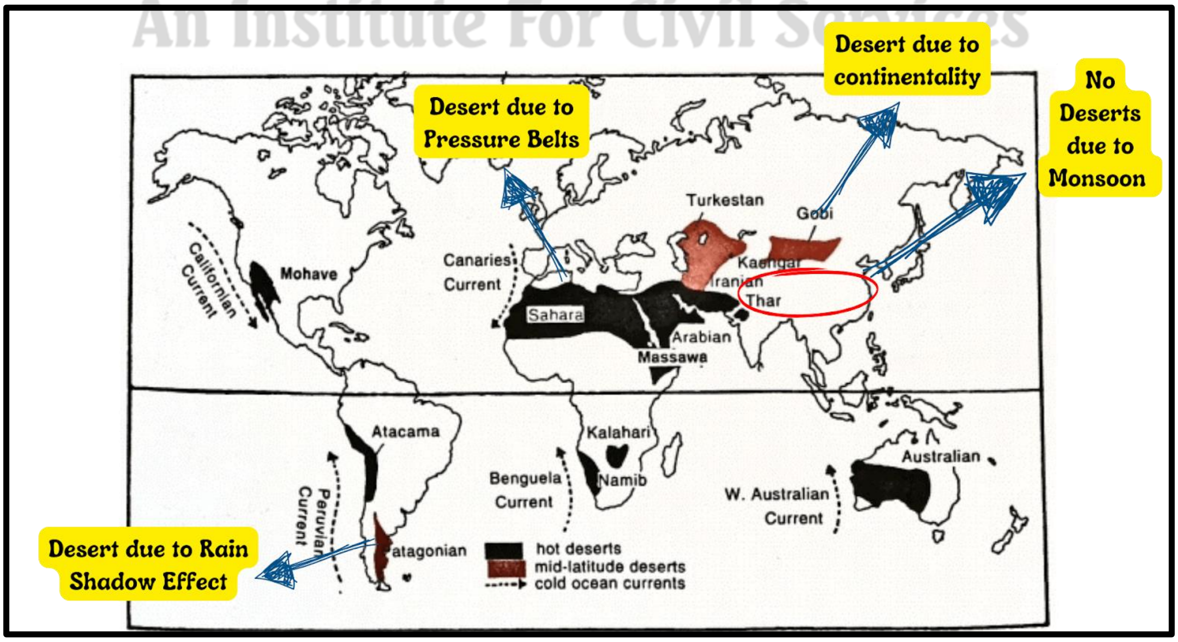
Major Pressure Belts and Wind System

EQUATORIAL LOW PRESSURE BELT OR 'DOLDRUMS'

Extent	Formation	Features
Lies between 10°N and 10°S latitudes. Varies with the apparent movement of the Sun	It receives highest amount of insolation. ➔ Due to intense heating, air gets warmed up and rises over the equatorial region (convection). ➔ Whenever there is vertically upward movement of air, the region at the surface will be at low pressure	➢ **Inter Tropical Convergence Zone-** as Trade Winds converge here ➢ **Doldrums** – extremely calm air movements ➢ **Cyclones are not formed at the equator because of 'zero' coriolis force**

SUB-TROPICAL HIGH PRESSURE BELT OR HORSE LATITUDES

Extent	Formation	Features
25° - 35°N and S in both Hemispheres Varies with the apparent movement of the Sun	At Equator, air rises upward due to convection ➔ At the upper Troposphere, the rising air moves towards tropics and becomes cold ➔ This air coming from the equatorial region subsides and descends around the Sub-tropical regions	➢ **Calm condition (anticyclonic)** with feeble winds ➢ **Most of the deserts are present along this belt**, in both hemisphere ➢ **Trade winds** (move towards Equator) and **Westerlies** (move towards Sub- Polar regions) originate around these regions



SUB-POLAR LOW PRESSURE BELT

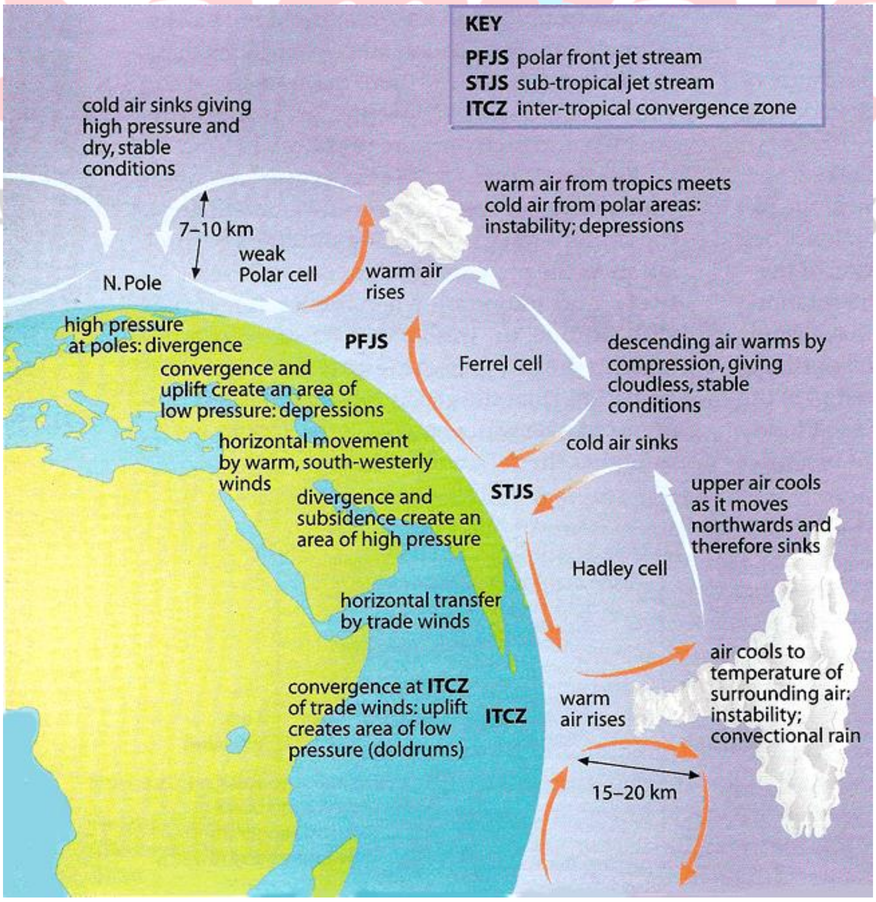
Extent	Formation	Features
Between 45°and 66.5° latitudes in both hemisphere	Air after descending on surface near Sub-tropical zone move away from it (Westerlies) towards the Equator and Sub – Polar Regions ➔ These winds then converge with Polar Easterlies around Sub Polar regions	➢ Temperate Cyclones ➢ Polar Jet Stream

POLAR HIGH PRESSURE BELT

Extent	Formation	Features
Around both the Poles – between 80 and 90° latitudes in both the hemisphere	**Air from the Sub – polar region subsides at the Polar regions**	Polar Easterlies winds originate from this region and move towards the Sub- Polar belts

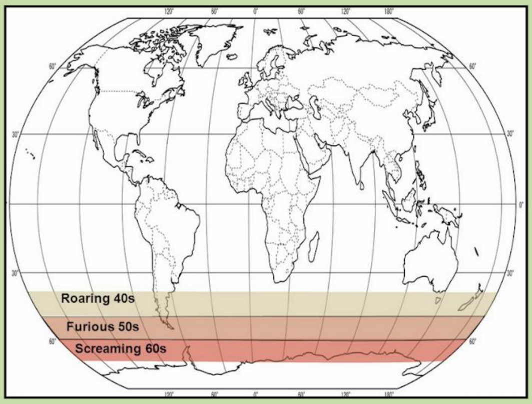
ATMOSPHERIC CIRCULATION

- It is large scale movement of air which helps in redistributing thermal energy around the Earth.

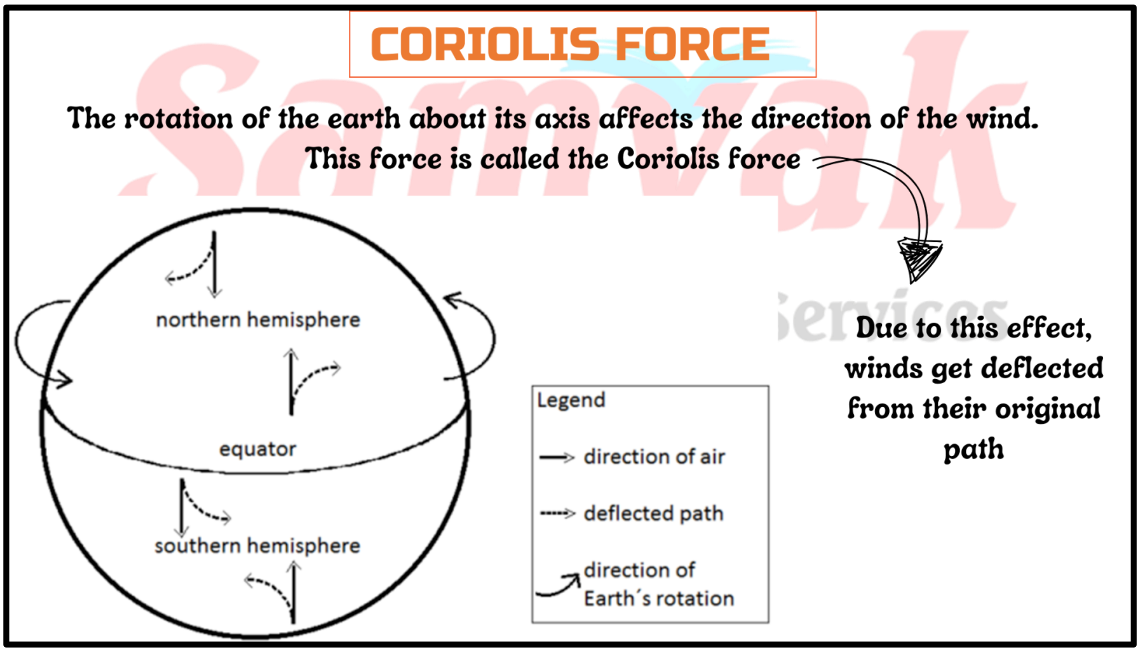


The Roaring 40s, Furious 50s, and Screaming 60s

- **The Roaring 40s, Furious 50s, and Screaming 60s** are fierce winds found in the Southern Ocean, near the fringes of Antarctica. Named after the latitudes at which they occur in the Southern Hemisphere, these winds are notorious for their intensity and power.
- **Historical Discovery:** Dutch sailor Hendrik Brouwer was the first to harness the power of the Roaring 40s. In the 17th century, he realized that by utilizing these winds, he could cross the Indian Ocean more swiftly, reducing travel time to Java in South Africa.
- **Wind and Weather Conditions:** The winds in these latitudes range from 15 to 25 knots. Coupled with extreme weather conditions, they often generate waves reaching heights of 10 meters.
- **Unique Location:** Wellington, the capital of New Zealand, is one of the rare cities situated between these extreme latitudes.



CORIOLIS FORCE



CHARACTERISTICS OF CORIOLIS FORCE

- Coriolis force **becomes effective on any object which is in motion** (i.e., wind, flying birds, aircrafts, ballistic missiles, long-range artillery fire etc.).
- Coriolis force **affects wind direction and not the wind speed.**
- It becomes **maximum at the poles** due to minimum rotational speed of the earth while it becomes **zero at the equator.**
- It always **acts at right angles to the horizontally moving air** and other moving objects.
- **The magnitude of deflection (Coriolis effects) is directionally proportional to:**
  - the sine of the latitude (sin 0° =0, 90° = 1)
  - the mass of the moving body, and

- Horizontal velocity of the wind.