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Class 12
Physics

Chapter 24

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FBISE – Class 12 Physics

Climate System & Earth's Energy Budget

Important MCQs & Short Questions

By Fairy (Misbah) ✦

Based on FBISE SLOs: P-12-F-52 to P-12-F-59 | Climate System, Earth's Energy Budget & Ocean Circulation

SECTION A — MULTIPLE CHOICE QUESTIONS (MCQs)

Instructions: Circle/tick the correct option. Each question carries 1 mark.

1. The five interacting components of Earth's climate system are the atmosphere, hydrosphere, cryosphere, lithosphere, and:

(A) Magnetosphere
(B) Biosphere
(C) Exosphere
(D) Ionosphere

✔ Answer: (B) — The biosphere (living things) is the fifth major component of Earth's climate system. (SLO P-12-F-52)

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2. The cryosphere refers to:

(A) The layer of hot gases above the atmosphere
(B) Ice and permafrost on Earth
(C) Liquid water in the oceans
(D) The solid rock layer beneath the soil

✔ Answer: (B) — The cryosphere includes ice and permafrost. (SLO P-12-F-52)

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3. Which component of the climate system includes rivers, lakes, and oceans?

(A) Lithosphere
(B) Cryosphere
(C) Hydrosphere
(D) Biosphere

✔ Answer: (C) — The hydrosphere encompasses all liquid water bodies. (SLO P-12-F-52)

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4. Climate is defined as the statistical characterization of weather typically over a period of:

(A) 1 year
(B) 10 years
(C) 30 years
(D) 100 years

✔ Answer: (C) — Climate is the average weather over 30 years. (SLO P-12-F-53)

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5. Ocean currents and wind patterns are key determinants of a region's:

(A) Soil composition
(B) Climate
(C) Magnetic field
(D) Tidal range

✔ Answer: (B) — Ocean currents and wind patterns determine climate. (SLO P-12-F-53)

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6. Which of the following BEST describes 'climate'?

(A) Day-to-day variation in atmospheric conditions
(B) Long-term average of atmospheric conditions
(C) Instantaneous temperature reading
(D) Short-term precipitation pattern
✔ Answer: (B) — Climate = long-term (30 yr) statistical average. (SLO P-12-F-53)

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7. Climate inertia refers to the:

(A) Rapid response of climate to greenhouse gas reduction
(B) Resistance or slowness of climate systems to significant changes
(C) Acceleration of global temperature rise
(D) Sudden shift in ocean current direction
✔ Answer: (B) — Climate inertia = resistance/slowness to change in significant factors. (SLO P-12-F-54)

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8. Even after stabilization of greenhouse gas emissions, temperatures may continue to rise due to:

(A) Solar flares
(B) Climate inertia and complex feedback systems
(C) Increased volcanic activity
(D) Deforestation
✔ Answer: (B) — Complex feedback systems cause continued warming even after emission stabilization. (SLO P-12-F-54)

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9. A positive feedback loop in climate change:

(A) Reduces the original change
(B) Has no effect on climate
(C) Amplifies the original change
(D) Stabilizes temperature
✔ Answer: (C) — Positive feedback amplifies the original climate change. (SLO P-12-F-54)

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10. Climate change can be categorized into:

(A) Polar and equatorial variations
(B) Internal variations and external forcing
(C) Oceanic and atmospheric variations
(D) Short-term and medium-term changes only
✔ Answer: (B) — Climate change = internal variations + external forcing. (SLO P-12-F-55)

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11. An example of external forcing in climate change is:

(A) El Niño oscillation
(B) Thermohaline circulation shifts
(C) Changes in solar output
(D) Volcanic degassing
✔ Answer: (C) — Changes in solar output are external forcing. (SLO P-12-F-55)

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12. Internal climate variability refers to changes that arise:

(A) From beyond the Earth system
(B) Within the climate system itself without external drivers
(C) Due to human industrial activity
(D) From extraterrestrial impacts
✔ Answer: (B) — Internal variability originates within the climate system. (SLO P-12-F-55)

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13. The term 'Earth Energy Budget' refers to:

(A) The economic cost of renewable energy
(B) The balance between incoming solar radiation and outgoing terrestrial radiation
(C) The total fossil fuel reserves on Earth
(D) The gravitational potential energy of Earth
✔ Answer: (B) — Earth energy budget = balance of incoming vs. outgoing radiation. (SLO P-12-F-56)

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14. Energy imbalance between the poles and the equator primarily drives:

(A) Tectonic plate movement
(B) Atmospheric and ocean circulation
(C) Soil erosion
(D) Magnetic pole reversal
✔ Answer: (B) — Pole–equator energy imbalance drives atmospheric circulation. (SLO P-12-F-56)

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15. The main source of energy for Earth's climate system is:

(A) Geothermal energy
(B) Tidal energy
(C) Solar radiation
(D) Nuclear energy from the core
✔ Answer: (C) — Solar radiation is the primary energy source. (SLO P-12-F-56)

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16. Global climate is primarily determined by energy transfer from:

(A) The Moon
(B) The Sun
(C) Jupiter
(D) Cosmic rays
✔ Answer: (B) — Energy transfer from the Sun governs global climate. (SLO P-12-F-56)

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17. Which region of Earth receives the most direct solar radiation per unit area?

(A) The poles
(B) The mid-latitudes
(C) The equator
(D) The sub-polar regions
✔ Answer: (C) — The equator receives the most direct solar radiation. (SLO P-12-F-56)

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18. Due to the conservation of angular momentum, Earth's rotation deflects air to the _____ in the Northern Hemisphere:

(A) Left
(B) Right
(C) Upward
(D) Downward
✔ Answer: (B) — Coriolis effect deflects air to the right in the Northern Hemisphere. (SLO P-12-F-57)

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19. The Coriolis effect deflects air to the left in the:

(A) Northern Hemisphere
(B) Equatorial belt
(C) Southern Hemisphere
(D) Stratosphere
✔ Answer: (C) — Coriolis deflection is to the left in the Southern Hemisphere. (SLO P-12-F-57)

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20. Distinct atmospheric circulation cells form because of:

(A) Gravitational pull of the Moon
(B) Conservation of angular momentum due to Earth's rotation
(C) Magnetic field variations
(D) Differences in crustal thickness
✔ Answer: (B) — Angular momentum conservation + Earth's rotation creates distinct atmospheric cells. (SLO P-12-F-57)

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21. The three major atmospheric circulation cells in each hemisphere are (from equator to pole):

(A) Ferrel, Hadley, Polar
(B) Hadley, Ferrel, Polar
(C) Polar, Ferrel, Hadley
(D) Hadley, Polar, Ferrel
✔ Answer: (B) — Order: Hadley (0–30°), Ferrel (30–60°), Polar (60–90°). (SLO P-12-F-57)

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22. Ocean water with more salt has:

(A) Lower density
(B) Higher density
(C) The same density as fresh water
(D) Neutral buoyancy
✔ Answer: (B) — Higher salinity → higher density. (SLO P-12-F-58)

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23. Differences in density of ocean water play an important role in:

(A) Earthquake generation
(B) Ocean circulation
(C) Volcanic eruptions
(D) Ozone depletion
✔ Answer: (B) — Density differences drive thermohaline/ocean circulation. (SLO P-12-F-58)

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24. Cold, salty water tends to:

(A) Rise to the ocean surface
(B) Remain at mid-depth
(C) Sink to the ocean floor
(D) Evaporate quickly
✔ Answer: (C) — Cold, dense, salty water sinks — driving deep ocean circulation. (SLO P-12-F-58)

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25. The thermohaline circulation transports heat from:

(A) Poles to the equator
(B) Tropics to the polar regions
(C) Equator to the stratosphere
(D) The seafloor to the atmosphere
✔ Answer: (B) — Thermohaline circulation carries heat from tropics to polar regions. (SLO P-12-F-59)

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26. 'Thermohaline' refers to ocean circulation driven by differences in:

(A) Temperature only
(B) Salinity only
(C) Temperature and salinity
(D) Pressure and wind
✔ Answer: (C) — 'Thermo' = temperature, 'haline' = salt. (SLO P-12-F-59)

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27. The thermohaline circulation is sometimes called the:

(A) Jet stream
(B) Global ocean conveyor belt
(C) Trade winds
(D) Ekman spiral
✔ Answer: (B) — The thermohaline circulation acts as a global ocean conveyor belt. (SLO P-12-F-59)

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28. A sudden weakening of the thermohaline circulation would most likely:

(A) Warm the polar regions significantly
(B) Cool Western Europe by reducing heat transport
(C) Increase equatorial rainfall
(D) Strengthen the Coriolis effect
✔ Answer: (B) — Weaker thermohaline → less heat to Western Europe → cooling. (SLO P-12-F-59)

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29. The lithosphere as a component of the climate system refers to:

(A) All liquid water
(B) Earth's upper rock layer
(C) Ice caps and glaciers
(D) The gaseous envelope of Earth
✔ Answer: (B) — Lithosphere = Earth's upper rock layer. (SLO P-12-F-52)

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30. Which of the following is an example of climate inertia?

(A) An immediate drop in temperature after volcanic eruption
(B) Rapid cooling following emission cuts
(C) Continued sea-level rise after carbon emissions are stabilized
(D) Sudden onset of an ice age
✔ Answer: (C) — Continued sea-level rise after stabilization = classic climate inertia. (SLO P-12-F-54)

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31. Earth's atmosphere circulates because of unequal heating between:

(A) The crust and mantle
(B) The poles and the equator
(C) The ocean floor and the surface
(D) Day and night sides
✔ Answer: (B) — Pole–equator temperature gradient drives atmospheric circulation. (SLO P-12-F-56/57)

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32. Wind patterns are largely a result of:

(A) Tidal forces and lunar gravity
(B) Energy imbalance + Coriolis effect
(C) Ocean salinity gradients alone
(D) Geomagnetic field variations
✔ Answer: (B) — Wind = energy imbalance + Coriolis. (SLO P-12-F-53/57)

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33. The phenomenon by which rising warm air at the equator creates a convection cell is associated with the:

(A) Ferrel Cell
(B) Polar Cell
(C) Hadley Cell
(D) Walker Cell
✔ Answer: (C) — Hadley Cells are convection cells near the equator. (SLO P-12-F-57)

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34. Which component of Earth's climate system is MOST responsible for absorbing solar radiation and moderating temperature?

(A) Lithosphere
(B) Biosphere
(C) Hydrosphere (oceans)
(D) Cryosphere
✔ Answer: (C) — Oceans have high heat capacity and absorb ~70% of solar radiation. (SLO P-12-F-52/58)

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35. If Earth's albedo increases (more reflection of sunlight), the global average temperature would:

(A) Increase
(B) Stay the same
(C) Decrease
(D) Fluctuate randomly
✔ **Answer: (C) — Higher albedo → more sunlight reflected → cooling. (SLO P-12-F-56)**

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36. The energy imbalance that drives atmospheric circulation is primarily because:

(A) The poles receive more solar energy than the equator
(B) The equator receives more solar energy than the poles
(C) Solar energy is uniform across the globe
(D) Night-time radiation equals daytime absorption everywhere
✔ **Answer: (B) — Equator receives far more solar energy → drives circulation. (SLO P-12-F-56)**

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37. Internal climate variations are DIFFERENT from external forcing in that they:

(A) Originate outside the climate system
(B) Originate within the climate system itself
(C) Are always caused by human activity
(D) Result from changes in solar output
✔ **Answer: (B) — Internal variations arise within the climate system. (SLO P-12-F-55)**

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38. Complex feedback systems in climate science can:

(A) Only dampen climate change effects
(B) Only amplify climate change effects
(C) Either amplify (positive) or dampen (negative) climate changes
(D) Have no net effect on global temperature
✔ **Answer: (C) — Feedbacks can be positive (amplify) or negative (dampen). (SLO P-12-F-54)**

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39. Ocean currents influence regional climates primarily by:

(A) Blocking solar radiation
(B) Transporting heat across large distances
(C) Generating rainfall directly
(D) Reducing wind speed
✔ **Answer: (B) — Ocean currents redistribute heat → affect regional climate. (SLO P-12-F-53)**

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40. The correct sequence for thermohaline circulation at high latitudes is:

(A) Water warms → becomes less dense → sinks
(B) Water cools and becomes saltier → increases in density → sinks
(C) Water cools → becomes less dense → rises
(D) Water warms → becomes saltier → sinks
✔ **Answer: (B) — Cooling + salt concentration → density increase → sinking. (SLO P-12-F-58/59)**

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41. Which factor does NOT directly contribute to thermohaline circulation?

(A) Water temperature
(B) Water salinity
(C) Water density
(D) Earth's magnetic declination
✔ **Answer: (D) — Magnetic declination does not drive thermohaline circulation. (SLO P-12-F-58/59)**

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42. A region experiencing persistent high pressure at subtropical latitudes (≈30°N/S) is associated with:

(A) Rising air and heavy rainfall
(B) Descending dry air from the Hadley Cell
(C) Polar vortex incursions
(D) Strong westerly winds
✔ **Answer: (B) — Subtropical high pressure = descending dry air from Hadley Cell. (SLO P-12-F-57)**

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43. Which term describes the portion of solar radiation reflected back by Earth's surface and clouds?

(A) Emissivity
(B) Albedo
(C) Insolation
(D) Irradiance
✔ **Answer: (B) — Albedo = fraction of solar radiation reflected. (SLO P-12-F-56)**

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44. The MAIN reason climate systems show inertia is:

(A) Lack of solar energy
(B) The large thermal mass and complex feedbacks within the climate system
(C) Rapid changes in Earth's orbit
(D) High albedo of tropical forests
✔ **Answer: (B) — Large thermal mass + feedbacks create climate inertia. (SLO P-12-F-54)**

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45. If the thermohaline circulation were to stop completely, which region would experience the MOST dramatic climate change?

(A) Sahara Desert
(B) Equatorial rainforests
(C) North Atlantic / Western Europe
(D) Central Asia
✔ **Answer: (C) — North Atlantic and Western Europe depend heavily on thermohaline heat transport. (SLO P-12-F-59)**

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46. The Coriolis effect is caused by:

(A) Differences in surface temperature
(B) Earth's rotation and conservation of angular momentum
(C) Variations in atmospheric pressure
(D) Gravitational attraction of the Moon
✔ **Answer: (B) — Coriolis = Earth's rotation + angular momentum conservation. (SLO P-12-F-57)**

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47. Solar energy reaching the top of the atmosphere is called:

(A) Albedo
(B) Emissivity
(C) Solar constant / insolation
(D) Radiative forcing
✔ **Answer: (C) — Insolation (solar constant) = solar energy at the top of the atmosphere. (SLO P-12-F-56)**

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48. In which climate component does carbon get stored in the form of coal and oil?

(A) Hydrosphere
(B) Atmosphere
(C) Biosphere and lithosphere
(D) Cryosphere
✔ **Answer: (C) — Fossil fuels are stored in the lithosphere; living carbon in the biosphere. (SLO P-12-F-52)**

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49. Climate change driven by human greenhouse gas emissions is an example of:

(A) Internal climate variability
(B) External forcing
(C) Climate inertia
(D) Thermohaline reversal
✔ **Answer: (B) — Anthropogenic emissions are an external forcing on the climate system. (SLO P-12-F-55)**

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50. An increase in Arctic ice melting reduces albedo, causing further warming. This is an example of a:

(A) Negative feedback loop
(B) External forcing
(C) Positive feedback loop
(D) Climate inertia effect

✔ Answer: (C) — Ice-albedo feedback is a classic positive feedback loop. (SLO P-12-F-54)

FBISE – Class 12 Physics

Climate System & Earth's Energy Budget

Important MCQs & Short Questions

By Fairy (Misbah) ✦

SECTION B — SHORT QUESTIONS

Instructions: Answer in 3–6 sentences. Each question carries 3 marks.

Q1. What are the five components of Earth's climate system? (SLO P-12-F-52)

Earth's climate system has five interacting components:

1. Atmosphere (air) – the gaseous envelope regulating temperature and weather.
2. Hydrosphere (water) – all liquid water including oceans, rivers, and lakes.
3. Cryosphere (ice & permafrost) – frozen water in glaciers, ice sheets, and permafrost.
4. Lithosphere (upper rock layer) – Earth's solid outer shell influencing surface processes.
5. Biosphere (living things) – all organisms that interact with other climate components.

Q2. Define 'climate' and distinguish it from 'weather'. (SLO P-12-F-53)

Weather refers to short-term, day-to-day atmospheric conditions (temperature, rain, wind).
Climate is the long-term statistical characterization of weather, typically averaged over 30 years.
It is determined by ocean currents, wind patterns, and other processes within the climate system.

Q3. What is meant by 'climate inertia'? Give one example. (SLO P-12-F-54)

Climate inertia is the resistance or slowness of the climate system to respond to significant changes.
Example: Even after greenhouse gas emissions are stabilized, global temperatures may continue rising for decades because of complex positive feedback systems (e.g., ice-albedo feedback).

Q4. How can climate change be categorized? (SLO P-12-F-55)

Climate change can be categorized into two types:

1. Internal Variations – changes originating within the climate system itself (e.g., El Niño).
2. External Forcing – changes caused by factors outside the climate system (e.g., solar output variations, volcanic eruptions, or human greenhouse gas emissions).

Q5. Explain the Earth's energy budget. (SLO P-12-F-56)

The Earth's energy budget refers to the balance between incoming solar radiation and outgoing terrestrial (infrared) radiation. The Sun transfers energy to Earth; the poles receive less solar energy per unit area than the equator. This imbalance creates an energy gradient that drives atmospheric and ocean circulation. When incoming energy equals outgoing energy, Earth is in radiative equilibrium.

Q6. Why is there an energy imbalance between the poles and the equator, and what does it cause? (SLO P-12-F-56)

The equator receives direct, concentrated solar radiation, while the poles receive oblique, spread-out radiation. This creates a temperature and energy gradient. The imbalance drives large-scale atmospheric circulation (wind systems) and ocean currents that redistribute heat from the tropics toward the poles.

Q7. Describe how Earth's rotation produces distinct atmospheric circulation cells. (SLO P-12-F-57)

Due to conservation of angular momentum, Earth's rotation deflects moving air:

- To the RIGHT in the Northern Hemisphere (Coriolis effect).
- To the LEFT in the Southern Hemisphere.

This deflection, combined with thermal convection driven by the pole-equator energy imbalance, produces three distinct atmospheric cells in each hemisphere:

1. Hadley Cell (0°–30°) – warm air rises at the equator, moves poleward, sinks at 30°.
2. Ferrel Cell (30°–60°) – mid-latitude indirect circulation cell.
3. Polar Cell (60°–90°) – cold air sinks at the poles and moves equatorward.

Q8. How does salinity affect ocean water density and circulation? (SLO P-12-F-58)

Ocean water with higher salt concentration has greater density than fresher water.
Similarly, colder water is denser than warm water.
These density differences cause cold, salty water to sink in polar regions, displacing warmer water and driving large-scale deep ocean (thermohaline) circulation.

Q9. What is thermohaline circulation and why is it important? (SLO P-12-F-59)

Thermohaline circulation (also called the 'global ocean conveyor belt') is the large-scale ocean current system driven by differences in water temperature and salinity.
It transports warm water from the tropics to the polar regions and carries cold, dense water from the poles back toward the tropics at depth. This process:

- Moderates global climate by redistributing heat.
- Keeps regions like Western Europe significantly warmer than their latitude would suggest.

Q10. What is the Coriolis effect and what causes it? (SLO P-12-F-57)

The Coriolis effect is the apparent deflection of moving objects (air, water) due to Earth's rotation and the conservation of angular momentum.

- In the Northern Hemisphere, objects deflect to the RIGHT.
- In the Southern Hemisphere, objects deflect to the LEFT.

It is responsible for shaping wind patterns, ocean currents, and distinct atmospheric cells.

EARTH'S CLIMATE SYSTEM

- It is defined as a complex system with five interacting components; The atmosphere, hydrosphere, cryosphere, lithosphere and biosphere.
- It is influenced by the factors including the sun, earth's position in space and human made factors such as greenhouse gas emissions

1. The Atmosphere (Air)

- The atmosphere is the layer of air that surrounds the Earth.
- It is made of different gases and protects us by giving oxygen, controlling temperature, and blocking harmful rays from the Sun.
- It primarily consists of 78% nitrogen, 21% oxygen and 0.9% argon.

Role of Atmosphere

- Shielding: Atmosphere protects life on Earth by shielding it from incoming ultraviolet radiations
- Insulation: It insulates the planets, acting as an insulated layer that prevents extreme temperature variations.
- Greenhouse effect: The atmosphere traps some of the Sun's heat using gases like carbon dioxide and water vapor. This trapped heat keeps the Earth warm enough to live on.

Layers of Atmosphere

Atmosphere is divided into 5 layers:

- **Troposphere:** The lowest most player is known as troposphere It extends from the ground to about 16 km. In this layer weather occurs.
- **Stratosphere:** Stratosphere starts above the troposphere, from 16 to 50 km. This layer contains the ozone layer which prevents from harmful ultraviolet radiations coming from the sun.
- **Mesosphere:** After stratosphere, mesosphere extends from 50 to 136 km. It is the layer where meteors burn out.
- **Thermosphere:** Thermosphere extends from 136 to about 600 km. In this layer Auroras occurs due to the solar radiations.
- **Exosphere:** Exosphere is the outermost layer that extends from 600 km and merge into the space. It is the layer in which satellites orbits.

2. The Hydrosphere (Water)

- The hydrosphere is all the water present on Earth, in any form; liquid (oceans, rivers), solid (ice, snow), or gas (water vapor in the air).
- Earth's surface contains approximately 70% water due to this large amount of water, it show it's "blue glow" appearance.

Role of Hydrosphere

- Stores Heat: Oceans absorb and store a lot of the Sun's heat, helping keep Earth's temperature steady.
- Moves Heat Around: Ocean currents carry warm and cold water to different places, affecting weather and climate.
- Water for Rainfall: Water evaporates from oceans and forms clouds, which bring rain and snow.

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- Controls Temperature: Water heats up and cools down slowly, helping prevent sudden changes in Earth's temperature.

Water Balance Equation:- The water balance equation is a fundamental tool used to understand the moment and distribution of water in the hydrosphere our time.

$$\Delta S = P - E - Q$$

Where;

- P = Precipitation: Water that falls from the sky such as rain, snow, sleet, and hail. It is the main input of water.
- Q = Runoff (Discharge): Water that flows on the Earth's surface into rivers, lakes, and oceans. It is an output of water from land.
- E = Evapotranspiration: Loss of water to the atmosphere through evaporation (from water bodies and soil) and transpiration (from plants).
- ΔS = Change in Storage: Increase or decrease of water stored in soil, groundwater, lakes, glaciers, and reservoirs.

3. The Cryosphere (Ice)

- The cryosphere is the part of the Earth where water is frozen due to low temperature.
- Found mainly in polar regions (Arctic and Antarctic) and high mountains.

Role of Cryosphere

- Reflects Sunlight: Ice and snow reflect sunlight (albedo effect), keeping Earth cooler.
- Stores Fresh Water: Holds large amounts of Earth's fresh water.
- Regulates Sea Level: Melting ice increases sea levels; freezing lowers them.
- Influences Weather and Ocean Currents: Cold regions affect air and ocean circulation, impacting climate worldwide.

Components of Cryosphere

There are three main components of cryosphere:

Snow

- Frozen water falling from the sky that accumulates on the ground.
- Exists in cold regions and high mountains where temperatures are low.
- Role in climate: reflects sunlight (keeps Earth cool), stores fresh water, affects weather patterns.

Ice

- Includes glaciers, ice sheets, and sea ice (large masses of frozen water).
- Exists in polar regions and high mountains where ice accumulates over long periods.
- Role in climate: reflects solar energy, regulates sea levels, influences ocean currents and air temperature.

Permafrost

- Soil, rocks, or sediment that stays frozen all year round.
- Exists in polar and subpolar regions with permanently cold ground.
- Role in climate: stores carbon and methane, affects soil and ecosystems, keeps local areas cold.

4. The Lithosphere (Earth's Upper Rocky Layer)

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- The lithosphere is outermost solid shell, consisting of the crust and the uppermost part of the mantle, composed of various rocks and minerals.
- It forms the basis for continents, ocean basins and landforms by interacting with others components of earth's climate system.

Major Processes of Lithosphere (Components)

Land Surface:

- Provides the physical surface where climate processes occur.
- Different land types (deserts, forests, plains, mountains) influence climate in different ways.
- Deserts heat up quickly, forests add moisture, and mountains change wind and rainfall patterns.

Carbon Cycle:

- Rocks weather and erode, releasing carbon dioxide into the atmosphere.
- Some rocks like limestone store carbon for millions of years.
- Acts as a long-term carbon sink that helps balance Earth's climate over geological time.

Tectonic Activity:

- Movement of tectonic plates shapes Earth's surface over long time scales.
- Formation of mountain ranges affects atmospheric circulation and precipitation.
- Slow movement of continents influences global climate patterns.

Volcanic Activity:

- Volcanic eruptions release gases and particles into the atmosphere.
- Ash and particles can block sunlight and temporarily cool the climate.
- Gases like CO_2 released during eruptions can impact long-term climate.

5. The Biosphere (Living Things)

- The biosphere is the thin layer of life on Earth. It spreads from a few kilometers into the air to the deep sea floor.
- It includes all living things (plants, animals, fungi, microorganisms) and the non-living factors they depend on for energy and nutrients.
- Living organisms interact with the environment and affect Earth's climate system through processes like breathing, growing, and decomposing.

Role of Biosphere

- **Climate Regulation:** Plays a crucial role in regulating Earth's temperature by absorbing sunlight, releasing moisture, and keeping air gases in balance.
- **Carbon Cycle:** Acts as an integral reservoir in the carbon cycle as plants absorb carbon dioxide (CO_2) and reduce it in the atmosphere.
- **Energy Flow:** Plays an essential role in energy flow because plants capture solar energy and pass it through the food chain.
- **Water Cycle:** Helps drive the water cycle by releasing water vapor through transpiration, which supports cloud formation and rainfall.
- **Nutrient Cycle:** Acts as a key system in nutrient cycling by breaking down and recycling nutrients that support life and influence climate.

Ocean Currents and Winds

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Ocean currents and wind patterns are the interconnected phenomena that play crucial roles in regulating Earth's climate and distributing heat globally.

Ocean Currents

- Ocean currents are large movements of seawater that flow like rivers within the ocean, carrying warm or cold water across the globe.
- They help regulate Earth's climate by moving heat from warm areas to cooler areas, keeping temperatures balanced.
- They also influence weather and marine life, as warm and cold currents affect rainfall, storms, and the distribution of sea animals and plants.
- They are categorized into two types:
  - (i) Surface Ocean Currents
  - (ii) Deep Ocean Currents

1) Surface Ocean Currents

- Surface ocean currents are movements of water in the upper, shallow layer of the ocean.
- They carry warm and cold water across long distances, helping to shape climate and weather patterns.

Factors:

- **Wind** plays a major role by pushing the surface water and setting it into motion.
- **Subtropical gyres** (large rotating systems) help guide these currents, moving warm water toward the poles and collecting floating materials like plastic.

2) Deep Ocean Currents

- Deep ocean currents are large movements of water found below 500 meters in the ocean.
- They form due to differences in water temperature and density and help move cold and warm water around the globe, affecting climate over long time scales.

Factors:

- **Warm Water Moving Northward:** Warm surface water travels toward the poles, cools down, and sinks, helping drive deep ocean circulation.
- **Density Differences:** Water becomes denser when it is colder and saltier, causing it to sink to the ocean depths. This sinking creates deep circulation, moving cold, dense water along the ocean floor toward the equator. This process, known as the global conveyor belt, distributes heat and nutrients worldwide and influences Earth's climate.

Coriolis Effect

Definition: The Coriolis effect is the deflection of moving water or air caused by Earth's rotation.
Cause: Earth rotates from west to east, which makes moving water bend to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
Effect on Ocean Currents: This deflection creates loops in ocean gyres — clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere.
Role in Climate: It guides surface ocean currents, distributing heat and influencing regional climate and weather patterns.

Earth's Angular Momentum and Wind Patterns

Angular Momentum of Earth:

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- Angular momentum is the tendency of a rotating body (like Earth) to keep spinning unless acted upon by an external force.
- Earth's rotation gives the atmosphere and oceans a conserved angular momentum, which affects the motion of air and water.
- This rotation is the fundamental reason why the Coriolis effect exists.
- **Coriolis Effect:** The Coriolis effect is the apparent deflection of moving objects (like air or ocean currents) caused by Earth's rotation.
- It is a direct consequence of Earth's angular momentum, as moving air tries to conserve momentum while Earth rotates beneath it.
- Effect by hemisphere:
  Northern Hemisphere: deflection to the right
  Southern Hemisphere: deflection to the left
- **Coriolis Force:** The Coriolis force is the actual force acting on a moving mass due to Earth's rotation.
- Formula: $F = 2mv\omega\sin\theta$

Where: F = Coriolis force, m= mass of moving air/water, v= velocity of the air/water, ω = angular velocity of Earth and θ = latitude.

- Variation with latitude: Maximum at the poles ($\theta=90°$) , Zero at the equator ($\theta=0°$).

- **Influence of moment of inertia:** The distribution of Earth's mass affects how fast regions rotate, influencing wind speed and deflection.
- **Influence on wind speed:** Faster winds experience a stronger Coriolis force, resulting in more pronounced deflection.

Formation of Atmospheric Circulation Cells

Earth's rotation and the Coriolis force divide the atmosphere into three main circulation cells per hemisphere:

1. Hadley Cells (0°–30°): Warm air rises at the equator, moves poleward, cools, and sinks at ~30° latitude.
2. Ferrell Cells (30°–60°): Air circulates between Hadley and Polar cells; winds move opposite to Hadley and Polar cells.
3. Polar Cells (60°–90°): Cold air sinks at the poles, flows toward ~60° latitude, and rises to complete the loop.

Global Influence on Climate and Weather

- Hadley cells create tropical rainforests and deserts (~30° latitude).
- Ferrel and Polar cells influence temperate and polar climates, including storms and precipitation.

Wind Patterns:

- Wind is the movement of air from high-pressure to low-pressure areas.
- Wind patterns are shaped by Earth's rotation, pressure differences, and friction.
- **Geostrophic wind** is a wind that flows parallel to isobars due to a balance between two main forces.

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- **Isobars:** Lines on a map connecting points of equal pressure; the closer the isobars, the stronger the wind.
- **Forces Involved:**

a. Horizontal Pressure Gradient Force (PGF): Pushes air from high-pressure to low-pressure regions.
b. Coriolis Force: Deflects moving air due to Earth's rotation (right in Northern Hemisphere, left in Southern Hemisphere).

When these two forces balance exactly, the wind flows along the isobars, not directly from high to low pressure this is called **geostrophic balance.**

Influence on Climate and Weather

Heat Transport: Winds move warm air from tropics toward poles and cold air from poles toward the equator, balancing global temperatures.

Moisture Transport: Winds carry water vapor, influencing rainfall patterns, storms, and monsoons.

Pollutant Dispersion: Wind spreads air pollution, dust, and aerosols across regions.

Pollen Distribution: Winds aid in spreading pollen and seeds, affecting ecosystems and agriculture.

Climate Inertia

- Climate inertia is the resistance or slowness of the climate system to respond to changes in factors like greenhouse gas emissions, even when the cause of change is reduced or stopped.
- **Positive Feedback:** A process that amplifies climate change, e.g., melting ice reduces albedo, causing more warming and more ice melt.
- **Negative Feedback:** A process that reduces or slows climate change, e.g., more clouds reflect sunlight, slightly cooling the Earth.
- **Short-Term Inertia:** Climate responds slowly over months or years due to oceans' heat capacity and seasonal cycles.
- **Long-Term Inertia:** Climate changes very slowly over decades to centuries because ice sheets, deep ocean currents, and carbon storage in rocks take a long time to respond.
- **Importance for Adaptation:** Understanding climate inertia is essential for planning mitigation and adaptation strategies, as some effects of climate change cannot be reversed immediately.
- **Mitigation Steps:** Reduce greenhouse gas emissions, enhance carbon sinks (forests, soils), adopt renewable energy, and improve urban planning to cope with slow climate response.

Internal Variations of Climate

Internal variations are natural fluctuations within the climate system, caused by interactions between components like the atmosphere, oceans, and biosphere.

Examples:

- Solar Radiation: Natural changes in sunlight affect temperatures seasonally and over decades.
- Volcanic Eruptions: Large eruptions release ash and gases, temporarily cooling the climate.
- Ocean Oscillations: Phenomena like El Niño and La Niña change sea surface temperatures and rainfall patterns.
- Atmospheric Circulation Patterns: Shifts in wind belts and jet streams can redistribute heat and moisture, creating wet or dry periods.

External Forcing of Climate

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External forcing refers to factors outside the climate system that drive long-term changes.

Examples:

- Greenhouse Gas Concentration: Higher CO_2, methane, and nitrous oxide trap more heat, warming the Earth.
- Solar Variability: Changes in solar output over years or centuries affect global temperatures.
- Orbital Variations: Slight changes in Earth's orbit and tilt alter the distribution of sunlight and cause ice ages.
- Aerosols, Dust, and Pollution: Particles in the atmosphere reflect or absorb sunlight, affecting temperatures.

Earth Energy Budget

The Earth's energy budget is the balance between incoming energy from the Sun and outgoing energy from Earth. This balance determines Earth's overall temperature and climate.

Components of Earth's Energy Budget

Incoming Solar Radiation:

Energy from the Sun reaches Earth in the form of shortwave radiation (visible light, UV, and some infrared). Part of it is reflected by clouds, ice, and surfaces back to space.

Atmospheric Absorption:

Some solar energy is absorbed by the atmosphere (clouds, water vapor, and gases), heating the air before it reaches the surface.

Outgoing Terrestrial Radiation:

Earth's surface absorbs solar energy and re-emits it as longwave infrared radiation. Some of this energy escapes to space, helping maintain Earth's temperature.

Greenhouse Effect

The greenhouse effect is the warming of Earth's surface caused by greenhouse gases trapping heat in the atmosphere.

Four Steps of the Greenhouse Effect:

1. Sunlight penetrates the atmosphere and reaches the Earth's surface.
2. The heated surface emits infrared radiation (longwave heat energy) back toward the atmosphere.
3. Greenhouse gases (CO_2, methane, water vapor) absorb some of this infrared radiation.
4. Greenhouse gases re-radiate part of this energy back toward Earth, keeping the surface warm enough to support life.

Without the Greenhouse Effect, Earth would be extremely cold, with an average temperature around -18°C, instead of the current ~15°C. Life as we know it would not survive without this natural warming process.

Solar Variability and Climate

Solar variability refers to changes in the Sun's energy output, which can affect Earth's climate over short and long periods.

Solar Cycles:

- The Sun undergoes approximately 11-year solar cycles, with fluctuations in sunspots and solar activity.

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- These cycles slightly change the amount of energy reaching Earth, causing minor warming or cooling effects.

Long-Term Trends:

- Over the past 40 years, observations show that the Sun's energy output has remained relatively stable.
- These long-term changes account for less than 0.1% of the warming observed since 1750.
- Therefore, solar variability cannot explain the rapid global warming seen in recent decades.

Human-Induced Warming:

- Modern global warming is primarily caused by human activities, especially emissions of greenhouse gases.
- The warming effect of these gases is about 270 times greater than any warming caused by changes in sunlight.
- This highlights that while the Sun influences climate slightly, human impact dominates current climate change.

Energy Imbalance

Earth receives unequal solar energy at different latitudes, causing an energy imbalance between the equator and the poles.

Energy Distribution

Equator: Receives more solar energy because sunlight strikes it directly. This heats the surface strongly, creating warm air that rises.

Poles: Receive less solar energy because sunlight comes at a slanted angle, spreading energy over a larger area. The surface remains cold, and air is dense and sinks.

Effects of Energy Imbalance

The difference in temperature and pressure between equator and poles creates pressure gradients that drive winds and circulation.

Atmospheric Circulation Patterns:

- Warm air rises at the equator → moves toward poles in the upper atmosphere → cools and sinks at ~30° and 60° latitudes.
- Creates Hadley Cells, Ferrel Cells, and Polar Cells.
- Trade winds, westerlies, and polar easterlies form due to Coriolis deflection.

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