

1. THE 5 INTERACTING SPHERES OF THE EARTH

The Earth functions as a single, complex, interconnected system driven by energy flow (solar & geothermal) and cycling of matter across 5 major spheres:

Sphere	Scientific Definition & Components	Indian & Real-World Examples
Geosphere	Solid rocks, soil, landforms, and Earth's interior structure.	Deccan Plateau, Thar Desert, Western Ghats.
Hydrosphere	All liquid water: surface oceans, rivers, lakes, and groundwater.	Ganga-Brahmaputra river system, Indian Ocean, Arabian Sea.
Cryosphere	Solid frozen water: ice sheets, glaciers, snow caps, and permafrost.	Himalayan glaciers, Siachen, snow cover in Ladakh & Spiti.
Atmosphere	Gaseous envelope surrounding Earth held by gravity (78% N ₂ , 21% O ₂).	Troposphere weather, Stratospheric Ozone layer shield.
Biosphere	All living organisms and their habitats across land, water, and air.	Sundarbans mangroves, Western Ghats, ocean plankton, coral reefs.

INTERCONNECTEDNESS & DISTURBANCE CASCADE

A disturbance in one sphere triggers a ripple effect across all other spheres:

- **Local Level:** Less winter snowfall (Cryosphere) —> lower summer lake levels (Hydrosphere) —> reduced grass growth for livestock (Biosphere).
- **Global/Regional Level:** Warmer Arabian Sea (Hydrosphere) —> increased evaporation —> southwest monsoon fluctuations —> extreme floods in some Indian regions and severe droughts in others.
- **Sea Level Rise:** Melting Himalayan glaciers & polar ice caps (Cryosphere) —> sea level rise —> coastal flooding in cities like Mumbai & Chennai —> coastal habitat destruction (Biosphere).

2. SOLAR RADIATION & ELECTROMAGNETIC SPECTRUM

Solar Radiation: Primary external energy source reaching Earth as Electromagnetic (EM) waves traveling at light speed ($c = 3 \times 10^8$ m/s).

EM SPECTRUM: Gamma Rays ▶ X-Rays ▶ UV ▶ Visible Light ▶ Infrared ▶ Microwaves ▶ Radio Waves (Short Wavelength / High Energy) ←————→ (Long Wavelength / Low Energy)

Spectrum Breakdown (99% Sun Energy):

- **Gamma & X-Rays:** High frequency/harmful; filtered out by upper atmosphere.
- **Ultraviolet (UV) (100–400 nm):** Absorbed by stratospheric **Ozone Layer**. Excess UV causes eye damage & skin cancer.
- **Visible Light:** Drives **Photosynthesis** (primary food source) and warms land & oceans.
- **Infrared (IR):** Re-radiated as heat from Earth surface;

trapped by greenhouse gases (CO₂, CH₄, H₂O vapor).

SOLAR CONSTANT & INSOLATION

- **Insolation:** Amount of solar radiation reaching Earth's surface.
- **Solar Constant:** Average solar energy received per unit area per unit time perpendicular to Sun's rays at top of atmosphere = **1.4 kW/m²** (or **1400 J/(s·m²)**).
- **Clear Sky Surface Insolation:** Reduced to **~1.0 kW/m²** due to atmospheric scattering & absorption.

3. NUMERICAL CALCULATION & SCIENTIFIC CONTRIBUTIONS

EXAMPLE 13.1: NUMERICAL SOLVED

Question: Energy received by 1 m² area in 1 hour with surface insolation 1 kW/m²?

Calculation:

$$E = \text{Intensity} \times \text{Area} \times \text{Time}$$

$$E = 1000 \text{ J/(s·m}^2\text{)} \times 1 \text{ m}^2 \times 3600 \text{ s} = \mathbf{3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}}$$

Note: Equivalent to 1 unit of household electricity or energy needed to melt 5 kg ice & heat water to 100°C.

Pioneering Scientist: Anna Mani

- India's pioneering atmospheric scientist mapped solar insolation across India in the 1950s.
- Published *Solar Radiation Over India* (1982) with S. Rangarajan, creating India's first Insolation Atlas.
- Laid the foundation for India's modern solar energy revolution.

4. ALBEDO & URBAN HEAT ISLAND EFFECT

Albedo: The fraction of incoming solar radiation reflected by a surface (Latin *albus* = whiteness). Range: 0 to 1 (or 0% to 100%).

Surface Material	Albedo Range	Thermal Effect
Fresh Snow	0.80 – 0.90 (80-90%)	Reflects high heat —> Polar regions stay cold.
Glacier Ice	0.50 – 0.70	High reflection; melting reduces albedo.
Crushed Rock	0.25 – 0.30	Moderate absorption.
Light Coloured Soil	0.20 – 0.35	Moderate reflection.
Black Soil / Ocean Water	0.06 – 0.15	Absorbs most light —> Warms up significantly.

URBAN HEAT ISLAND (UHI) EFFECT

Cities are significantly warmer than surrounding rural areas, especially at night.

- **Cause:** Steel, concrete, brick, and asphalt roads have **low albedo**, absorbing and retaining solar heat during daylight.
- **Re-radiation:** Absorbed heat re-radiates at night, raising urban temperatures and boosting AC energy demand.
- **Rural Difference:** Vegetation & forests stay cool via shade and plant **transpiration**.

5. LATITUDE, EARTH'S SHAPE & ATMOSPHERIC LAYERS

Spherical Shape & Insolation Angle:

- **Equatorial Regions:** Sun's rays strike vertically over a smaller surface area —> concentrated intense heating year-round.
- **Polar Regions:** Sun's rays strike at slant angles spread over a much larger area —> weak heating & extreme cold.
- Uneven equatorial-polar heating drives global atmospheric winds & ocean currents.

Atmospheric Composition:

- **Nitrogen (N₂):** 78% | **Oxygen (O₂):** 21%
- **Trace Gases:** Argon (0.93%), Carbon Dioxide (0.04%), Water Vapour, Ozone.
- Held around Earth by gravity force.

Layer	Altitude	Temperature Trend & Key Features
Troposphere	0 – 12 km	Temp DECREASES with height (~6.5°C/km Lapse Rate). Contains all weather phenomena (clouds, rain, storms). Height highest at equator, lowest at poles.
Stratosphere	12 – 50 km	Temp INCREASES with height due to Ozone Layer absorbing harmful UV rays. Calm, dry air with no vertical turbulence (ideal for jet aircraft).
Mesosphere & Thermosphere	50 – 100+ km	Mesosphere is coldest layer; Thermosphere absorbs high energy X-rays. Outer space begins at ~100 km (Kármán line).

6. OZONE LAYER SHIELD & MONTREAL PROTOCOL

OZONE HOLE & MONTREAL PROTOCOL

- **Ozone Loss:** Synthetic **Chlorofluorocarbons (CFCs)** used in refrigerators and aerosols destroyed stratospheric ozone, forming the "Ozone Hole" over Antarctica.
- **Impact:** Increased UV-B reaching Earth causes skin cancer, eye cataracts, and damages marine plankton.
- **Montreal Protocol (1987):** Global treaty phasing out CFCs; ozone layer is now recovering.

Pioneering Scientist: K.R. Ramanathan

In 1934, Indian scientist K.R. Ramanathan climbed to 18,000 feet in the Himalayas to measure atmospheric ozone levels. His research laid the groundwork for UV absorption dynamics and early Indian monsoon forecasting.

7. LOCAL WINDS: VALLEY & MOUNTAIN BREEZES

Local winds in hilly regions (Shimla, Dehradun, Himalayan valleys) are driven by differential heating rates between mountain slopes and valley floors:

DAYTIME: VALLEY BREEZE

- Mountain slopes heat up rapidly under sunlight —> Air warms & rises —> **Low Pressure** on slopes.
- Valley floor remains cooler —> **High Pressure** in valley.
- Cool air flows **UP the slopes from valley** —> **Valley Breeze**.

NIGHTTIME: MOUNTAIN BREEZE

- Mountain slopes lose heat rapidly after sunset —> Air cools & becomes dense —> **High Pressure** on slopes.
- Valley floor retains heat longer —> **Low Pressure** in valley.
- Heavy cold air flows **DOWN into valley from slopes** —> **Mountain Breeze**.

8. PLANETARY WINDS & PRESSURE BELTS

Uneven latitudinal heating creates 4 major global pressure belts that generate large-scale planetary wind systems:

Equatorial Low (0°)

Sub-Tropical High
(30° N/S)

Sub-Polar Low (60°
N/S)

Polar High (90° N/S)

- **Equatorial Low (Doldrums):** Intense solar heat causes warm air to rise, creating low pressure at 0°.
- **Sub-tropical High (30° N/S):** Rising equatorial air cools at high altitude, sinks at 30°, creating high pressure.
- **Sub-polar Low (60° N/S):** Warm surface air moving poleward meets cold polar air and rises.
- **Polar High (90° N/S):** Extreme cold causes dense air to sink at poles.

CORIOLIS EFFECT & WIND DEFLECTION

Because the Earth rotates on its axis, planetary winds do NOT blow in straight north-south lines.

- **Northern Hemisphere:** Winds deflect to the **RIGHT**.
- **Southern Hemisphere:** Winds deflect to the **LEFT**.

9. OCEAN CURRENTS & CLIMATE REGULATION

Ocean Currents: Continuous directional movement of large ocean water masses driven by wind friction, temperature, salinity differences, and Earth's rotation.

- **Surface Currents:** Driven by planetary trade winds & westerlies.
- **Thermal & Density Circulation:** Warm equatorial surface water flows poleward; cold, dense, high-salinity polar water sinks and flows back at deep levels.
- **Gyres:** Large circular current loops rotating **Clockwise in N. Hemisphere** and **Counter-clockwise in S. Hemisphere**.

GULF STREAM & NORTH ATLANTIC DRIFT

The **Gulf Stream / North Atlantic Drift** carries warm equatorial water across the Atlantic to Northwestern Europe.

Impact: Keeps European ports (e.g., UK, Norway) **ice-free during harsh winters** at high latitudes, supporting trade & commerce.

INDIA'S MONSOON MODELLING AT IITM PUNE

Scientists at the **Indian Institute of Tropical Meteorology (IITM), Pune** run supercomputer climate models coupling atmosphere, ocean, land, and cryosphere data from satellites and Antarctic stations to forecast the Indian Monsoon and study global warming impacts.

10. BIOGEOCHEMICAL CYCLES OVERVIEW & WATER CYCLE

Biogeochemical Cycle: The continuous cyclic movement of matter and energy between abiotic (air, water, soil, rocks) and biotic (living organisms) components across Earth's spheres.

Water Cycle Key Processes:

- **Evaporation & Transpiration:** Liquid water —> atmospheric water vapour.
- **Condensation & Precipitation:** Cloud formation —> rain, snow, hail.
- **Infiltration & Run-off:** Water recharges groundwater or flows into rivers & oceans.

CLIMATE CHANGE IMPACT ON WATER CYCLE

Warmer air holds more moisture —> causes heavy rain bursts, severe floods in some regions, and droughts elsewhere. Melting glaciers increase run-off initially but reduce long-term river flows, accelerating soil erosion and threatening coastal cities (Mumbai, Chennai).

11. CARBON CYCLE & THE KEELING CURVE

Carbon forms the structural backbone of life (proteins, carbs, lipids, DNA). **71% of global carbon is stored in oceans;** atmosphere holds only ~1%.

Fast Carbon Cycle (Days to Years)

- **Photosynthesis:** Plants convert atmospheric CO₂ into Glucose (C₆H₁₂O₆).
- **Respiration:** Plants & animals release CO₂ back into air.
- **Decomposition:** Microbes break down dead organic matter, releasing CO₂.

Slow Carbon Cycle (Millions of Years)

- Dead organic matter buried under high pressure —> **Fossil Fuels** (Coal, Oil, Gas).
- **Oceanic Reservoir:** Dissolved CO₂ forms carbonates & marine shells —> sinks to ocean floor as limestone rocks.

THE KEELING CURVE & CO₂ RISE (315 ppm —> 420+ ppm)

- **Keeling Curve (Fig 13.14):** Shows atmospheric CO₂ concentration from 1960 to 2025.
- **Unprecedented Rise:** CO₂ increased by ~35% (from 315 ppm in 1960 to over 420 ppm today) due to fossil fuel combustion & deforestation.
- **Sawtooth Pattern:** Seasonal dips caused by yearly plant growth absorbing CO₂ during Northern Hemisphere spring/summer.

12. OXYGEN CYCLE

Oxygen Reservoirs & Forms:

- Atmosphere contains **21% free O₂ gas**.
- Combined form in water (H₂O), CO₂, and Earth's crust (metal oxides & silicates).

Consumption vs Restoration:

- **Consumption:** Respiration by living organisms, Combustion of fuels, and Metal oxidation.
- **Restoration:** Oxygen gas is restored to atmosphere almost exclusively by **Photosynthesis** in green plants & phytoplankton.

13. NITROGEN CYCLE (5 MANDATORY STEPS)

Atmospheric Nitrogen ($N_2 = 78\%$) is chemically inert and cannot be absorbed directly by plants. It must undergo transformation:

1. N_2 Fixation

2. Nitrification

3. Assimilation

4. Ammonification

5. Denitrification

Step	Biological / Chemical Mechanism	Key Bacteria & Agents Involved
1. Nitrogen Fixation	Conversion of inert atmospheric N_2 $\longrightarrow$ Ammonia (NH_3).	Rhizobium (legume root nodules), Azotobacter (soil), Lightning.
2. Nitrification	Two-step conversion: (i) $NH_3 \longrightarrow NO_2^-$ (Nitrite) (ii) $NO_2^- \longrightarrow NO_3^-$ (Nitrate)	(i) Nitrosomonas (Ammonia $\longrightarrow$ Nitrite) (ii) Nitrobacter (Nitrite $\longrightarrow$ Nitrate)
3. Assimilation	Plants absorb nitrates/nitrites to synthesize proteins & nucleic acids. Animals eat plants.	Plant roots & Animal digestion.
4. Ammonification	Decomposers break down dead organic matter and waste, converting nitrogen back to ammonia.	Decomposing Bacteria & Fungi.
5. Denitrification	Conversion of nitrates (NO_3^-) back into inert N_2 gas, returning it to atmosphere.	Pseudomonas denitrifying bacteria.

HABER-BOSCH PROCESS ("BREAD FROM AIR")

- Invented in early 1900s to synthesize industrial ammonia fertilizer from atmospheric N_2 .
- **Significance:** Fueled India's Green Revolution; **over 50% of nitrogen atoms in human bodies today come from Haber-Bosch!**
- **Environmental Drawback:** Consumes 1-2% of global energy; fertilizer overuse causes severe soil & water pollution.

14. HUMAN IMPACT: EUTROPHICATION & DEFORESTATION

EUTROPHICATION (ALGAL BLOOMS)

Overuse of nitrogen fertilizers $\longrightarrow$ rain washes excess nitrates into lakes/rivers $\longrightarrow$ explosive growth of algae (**Algal Bloom**) $\longrightarrow$ algae die & decompose $\longrightarrow$ bacteria consume all dissolved oxygen $\longrightarrow$ massive fish kill and aquatic ecosystem death.

Deforestation Multi-Sphere Impact

- **Atmosphere:** Decreased photosynthesis (CO_2 rises) & lower transpiration (rainfall drops).
- **Geosphere:** Loss of tree roots increases soil erosion.
- **Biosphere:** Massive habitat loss & extinction of species.

15. MISSION LIFE & GLOBAL CLIMATE TREATIES

Mission LiFE (Lifestyle for Environment)

India-led global movement introduced at UN Climate Conference (2021). Encourages individual actions: energy saving, water conservation, waste reduction, and sustainable living.

Global Treaties

- **Montreal Protocol:** Phased out CFCs $\longrightarrow$ Ozone layer recovering.
- **Kyoto Protocol & Paris Agreement:** Treaties aiming to limit global CO_2 emissions and restrict global warming.

16. HIGH-YIELD NCERT EXERCISE QUESTIONS WITH ANSWERS

Q1: Explain how climate change affects the water cycle with examples. (3 Marks)

Answer: Climate change increases global temperatures, causing:

1. **Atmospheric Moisture:** Warmer air holds more moisture, causing extreme rainfall events and severe floods in some regions while causing severe droughts elsewhere.
2. **Glacial Melting:** Rapid melting of Himalayan glaciers increases river run-off initially, accelerating soil erosion, and leading to long-term sea-level rise that threatens coastal cities (Mumbai, Chennai).
3. **Groundwater Recharge:** Intense rainfall bursts result in high surface run-off and reduced soil infiltration, lowering groundwater levels.

Q2: How are mountain and valley breezes formed? (3 Marks)

Answer: Driven by differential heating of mountain slopes and valley floors:

1. **Valley Breeze (Day):** Mountain slopes heat faster than valley floor under sunlight → warm air rises on slopes → cool air from valley flows UP slopes.
2. **Mountain Breeze (Night):** Slopes lose heat faster at night → cold dense air sinks DOWN into the valley.

Q3: Describe the processes involved in the nitrogen cycle. (4 Marks)

Answer:

1. **N₂ Fixation:** *Rhizobium* & *Azotobacter* convert atmospheric N₂ → NH₃.
2. **Nitrification:** *Nitrosomonas* converts NH₃ → NO₂⁻; *Nitrobacter* converts NO₂⁻ → NO₃⁻.
3. **Assimilation:** Plants absorb nitrates to make proteins.
4. **Ammonification:** Decomposers convert dead matter back to NH₃.
5. **Denitrification:** *Pseudomonas* converts nitrates back into N₂ gas.

17. QUICK 2-MINUTE REVISION CHECKLIST

- ✓ **5 Earth Spheres:** Geosphere, Hydrosphere, Cryosphere, Atmosphere, Biosphere.
- ✓ **Solar Constant:** 1.4 kW/m² (1400 J/(s·m²)) at top of atmosphere; ~1.0 kW/m² at surface.
- ✓ **Anna Mani:** Mapped India's solar insolation atlas in 1982.
- ✓ **Albedo:** Fresh Snow = 0.80-0.90 (high reflection); Black soil/Ocean = low albedo.
- ✓ **Urban Heat Island:** Concrete/asphalt low albedo retains heat in cities.
- ✓ **Atmosphere Layers:** Troposphere (0-12 km, lapse rate -6.5°C/km); Stratosphere (12-50 km, Ozone layer).
- ✓ **Breezes:** Valley Breeze (Day, Upward) | Mountain Breeze (Night, Downward).
- ✓ **Coriolis Effect:** Deflects winds Right (Northern) & Left (Southern).
- ✓ **Gulf Stream:** Warm current keeping NW European ports ice-free.
- ✓ **Carbon Reservoir:** 71% in oceans; Atmosphere holds 1%; Keeling Curve = 315 to 420+ ppm.
- ✓ **Nitrogen Bacteria:** Fixation (*Rhizobium*), Nitrification (*Nitrosomonas*, *Nitrobacter*), Denitrification (*Pseudomonas*).
- ✓ **Haber-Bosch:** Synthetic ammonia ("Bread from Air"); Eutrophication = Algal bloom → Oxygen depletion.