

**FORTUNE**  
**Prelims Precise**  
**Compilation**  
**Volume I**



**GEOGRAPHY**

January 2025 - December 2025



## Toppers in Top 100



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# PHYSICAL GEOGRAPHY

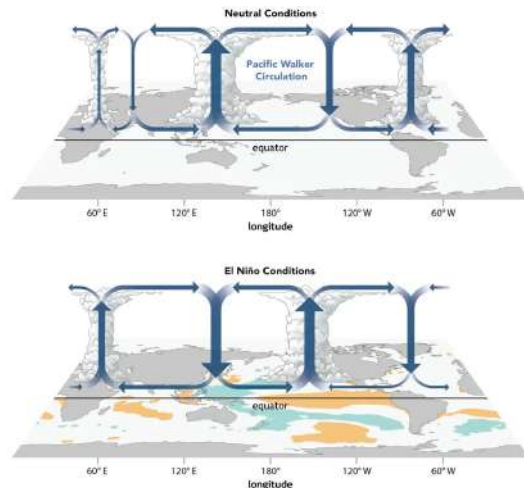
## I. Climatology & Atmospheric Phenomena

### A. Atmospheric Circulation & Climate Systems

#### Madden-Julian Oscillation (MJO)

- The southwest monsoon arrived in Kerala on May 24, eight days earlier than the normal onset date and one of the key drivers was the **Madden-Julian Oscillation (MJO)**, according to the India Meteorological Department (IMD).
- The MJO is a **moving system of winds, clouds, and pressure** that brings rain as it circles around the equator.
- The phenomenon takes its name from the **two scientists who identified it in 1971** — Roland Madden and Paul Julian.
- The system typically travels **eastward at a speed of 4-8 metres per second**.
- It goes around the globe in 30-60 days on average, but can sometimes take 90 days.
- As it moves, **strong MJO activity often splits the planet into two parts** — one in which the **MJO is in active phase** and brings rainfall, and the other in which it suppresses rainfall.
- An active phase is generally **followed by a weak or suppressed phase**, in which there is little MJO activity.
- The effect of the MJO is witnessed mainly in the **tropical region, in the band between 30 degrees North and 30 degrees South** of the equator, even though the mid-latitude regions in both hemispheres also feel its impact.
  - 👉 India falls in this band.
- As the MJO cycle lasts only 30-60 days, there can be multiple MJO events in a season.
- In the tropics, **MJO in its active phase brings frequent cyclonic activity**, and can initiate the onset of the monsoon as was the case of Kerala.

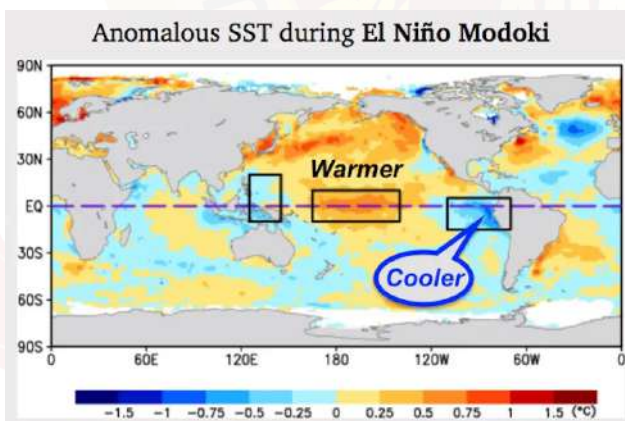
#### El Niño



- Climate models and observations indicate a possible **El Niño** phase in El Niño–Southern Oscillation occurring in the Pacific in 2026.
- **ENSO (El Niño–Southern Oscillation)** is a recurring climate pattern involving fluctuations in ocean temperatures and atmospheric pressure across the equatorial Pacific.
- It has two main phases:
  - 👉 **El Niño (warm phase):** Surface waters in the central and eastern Pacific become unusually warm due to weakened trade winds, altering global weather patterns.
  - 👉 **La Niña (cool phase):** Surface waters in the same region are cooler than normal, with stronger trade winds, producing opposite weather effects.
- El Niño occurs when **weakened trade winds shift warm waters eastward**, altering atmospheric circulation, while La Niña is the opposite (cooler waters, stronger winds).
- El Niño **impacts** include global temperature spikes, weaker monsoons and **droughts in India, floods in South America**, and droughts, heatwaves, and wildfires in Australia and Southeast Asia.

## Dateline El Niño

- **Tropical Pacific sea surface temperature (SST) patterns** have shown an unexpected evolution since early 2024.
- Initial forecasts strongly suggested a **La Niña** developing in the latter half of the year, seemingly supported by early cold SST anomalies in the far eastern Pacific.
- However, **these cold anomalies strangely shifted westward towards the international dateline**, while warm anomalies appeared in the far east by early summer 2024.
- **Unusual wind patterns** accompanied this, with easterly anomalies in the central-western Pacific and westerly anomalies in the far east.
- This unusual configuration of **cold SSTs west of warm SSTs persists**, contrasting with the more common **Dateline or Central Pacific El Niño pattern** of recent decades.
- **Dateline El Niño, also known as “El Niño Modoki”**, refers to climatic phenomena characterized by the warming of sea surface temperatures (SSTs) in the central Pacific Ocean, near the **International Date Line**.
- While La Niña typically has a consistent cold SST pattern in the eastern to central Pacific, El Niños exhibit “flavours” with warm SSTs in either the east or central Pacific.
- The underlying cause of this novel SST anomaly pattern **remains unknown**.



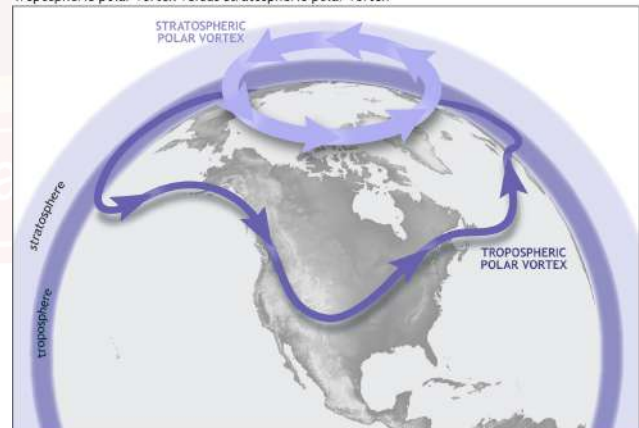
## Sudden Stratospheric Warming (SSW) Event

- Meteorologists have warned that **another Sudden Stratospheric Warming (SSW) event may occur**, potentially **disrupting the polar vortex and sending unusually cold Arctic air into parts of the United States**.
- **SSW** refers to a **rapid rise in stratospheric temperatures** that weakens or distorts the polar vortex (a cold-air mass typically stabilized over the Arctic).
- It begins **with large-scale atmosphere waves (called Rossby waves)** getting pushed higher into the atmosphere.
- These waves can **“break” (like waves in the ocean) on top of the polar vortex and weaken it**. If waves are strong enough, the winds of the polar vortex can weaken so much that they can reverse from being westerly to easterly and this leads to cold air descending and warming rapidly.
- And it can **lead to a displacement or splitting of the polar vortex, so instead of cold air being locked above the polar region it can push further south** into the mid-latitudes.

### Polar Vortex:

- **Polar Vortex** is a large **area of low pressure and cold air** surrounding both of the Earth’s poles.
- It extends from the **tropopause (the dividing line between the stratosphere and troposphere) through the stratosphere and into the mesosphere** (above 50 km).
- It always exists near the poles, but weakens in summer and strengthens in winter.

Tropospheric polar vortex versus stratospheric polar vortex



NOAA Climate.gov  
Data: Waugh et al., 2017

## Polar Cold Wave

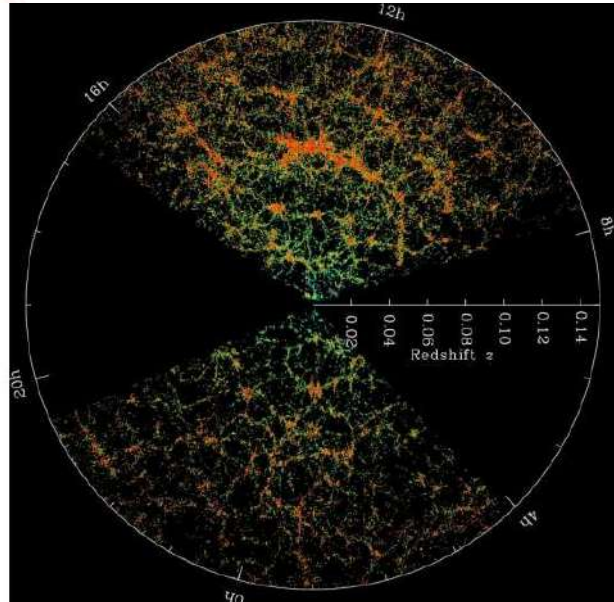
- Temperatures across lower **South America** have **plummeted** as a rare polar cold wave grips the region, the World Meteorological Organization (WMO) reported recently.
- **Chile and Argentina** recorded some of the coldest temperatures due to the **polar-origin anticyclone** (cold wave).
- This leads to a fall in **temperature of 10°C to 15°C** below seasonal averages.
- A **cold wave** is a period of marked and unusual cold weather characterised by a sharp and significant drop in air temperatures near the surface over a large area and persisting below certain thresholds for **at least two consecutive days during the cold season**.
- It was driven by a strong high-pressure system originating near the poles, which brings
- atmospheric stability and clear skies leading to severe frost across wide areas

## Antarctic Ice Growth Linked to Early Indian Monsoon

- Recent research shows a connection between the **formation of Antarctic ice around 34 million years ago** and the **early development of the Indian monsoon**.
- Scientists used the **Climate Leaf Analysis Multivariate Program (CLAMP)**, which is a methodology to study the **size, shape, and structure of fossil leaves** to reconstruct ancient climates.
- A fossil leaf from the **Laisong Formation in Nagaland** indicated that the region was **much warmer and wetter** in the past compared to today.
- The formation and expansion of **Antarctic ice sheets altered wind patterns and the circulation of the atmosphere**, shifting the **Intertropical Convergence Zone (ITCZ)** — Earth's primary tropical rain belt — closer to the tropics.
- This shift **intensified rainfall in India's northeast**, helping shape the monsoon system as it is known today, while also influencing **global precipitation and wind systems**.

- The study also highlights a modern implication: accelerated **Antarctic ice melt** caused by **climate change** could once again **shift the ITCZ**, potentially disrupting rainfall patterns in India and other tropical regions.

## Universe's Clumpiness



- Recent measurements of matter clustering of universe using gravitational lensing and galaxy surveys indicates what scientists call an  $S_8$  tension.
- Scientists have found that **matter in the universe isn't spread out evenly**—it forms **clumps** like galaxies and galaxy clusters, while some areas are mostly empty.
- Early on, the universe was very smooth, as seen in the **cosmic microwave background (CMB)**, the leftover light from the Big Bang.
- Over time, **gravity pulled matter together**, creating the clumps we see today.
- The  **$\Lambda$ CDM (Lambda Cold Dark Matter) model** is considered the standard cosmological model used to explain the structure and evolution of the universe.
- It **assumes the universe is made up of about 5% normal matter, 27% dark matter, and 68% dark energy** (represented by Lambda,  $\Lambda$ ).
- To measure how clumpy the universe is, scientists use a **number called Sigma 8 (S8)**.
  - 👉 A high S8 means matter is very clumpy; a

low S8 means it's more spread out.

- But here's the problem—when scientists measure S8 in different ways, they get different results.
- This mismatch is called the “**S8 tension.**”
- If this difference isn't just a measurement error, it might mean that our current model of the universe, the  $\Lambda$ CDM model, which says most of the universe is made of dark matter and dark energy, might be **incomplete or needs updating.**

## B. Heat & Extreme Weather

### Wet-Bulb Temperature

- The widely accepted **wet-bulb temperature survival threshold of 35°C** is being questioned after recent physiological studies suggest the **limit may actually be closer to 31°C.**
- **Wet-bulb temperature** is a measure that combines heat and humidity to show how well the human body can cool itself by sweating.
  - It's called **wet-bulb temperature** because it's measured using a **thermometer wrapped in a wet cloth (or wick)** over its bulb (the sensing part).
- Normally, when we sweat, the **moisture evaporates and cools our body.**
- But in **hot and very humid conditions**, this evaporation slows down.
- If the wet-bulb temperature reaches the temperature of human skin (**around 35°C**), **sweat can't evaporate at all — meaning the body can't cool itself**, which can quickly lead to heat stroke or death.
- In 2010, scientists suggested **35°C wet-bulb as the maximum survivable limit** for humans.
- But new research shows that people may **start experiencing serious health risks at a lower level** — around 31°C wet-bulb — especially if exposed for long periods.

### Humid Heat Waves

- A new study in *Nature Communications* finds that **rainfall and soil moisture influence the onset of extreme humid heat** in tropical and subtropical regions, with important implications for India.
- **Humid heat waves** are periods when **high temperatures coincide with high humidity levels.**
- This combination makes it difficult for the human body to cool down because **sweating becomes less effective** in evaporating moisture from the skin.
- As a result, the body can overheat, leading to **serious health risks** (heat stress or heat stroke) above **wet-bulb temperatures (Twb)** of 31°C for healthy individuals and lower for vulnerable groups

**Wet-bulb temperature (Twb)** is the lowest temperature air can reach through the evaporation of water at constant pressure. It reflects the combined effect of **temperature and humidity** on how cool the air feels.

When humidity is high, the wet-bulb temperature is close to the actual air temperature, meaning evaporation (and thus cooling by sweating) is less effective. It's an important measure for assessing heat stress on the human body.

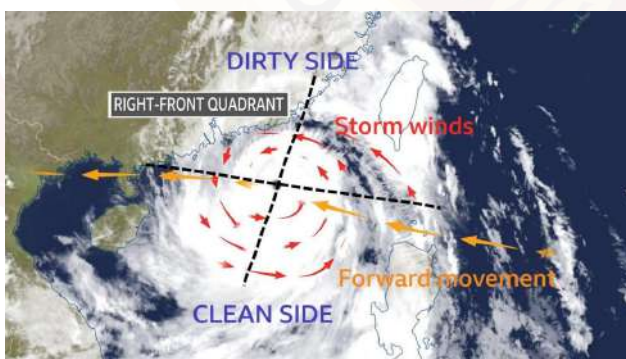
- In **dry regions like northwestern India**, **humid heat waves often follow rainfall**, which adds surface moisture that evaporates and raises humidity.
- In **wetter areas**, such events occur **after at least two days of little or no rain.**

### Super Typhoon

- The **Philippines was hit by Super Ragasa** in 2025, with winds reaching **250–280 km/h**, making it the **strongest tropical cyclone of the year.**
- It is classified as a **Category 5 super** on the **Saffir-Simpson scale**, which ranks cyclones based on sustained wind speed.
- A tropical cyclone has a “**clean**” side and a “**dirty**” side.

- On the **right-hand side** of the storm (relative to its direction of movement), the **forward motion of the storm adds to the rotational wind speed**, making winds **stronger** and more destructive - This is called the **“dirty side”**.
- On the **left-hand side**, the forward motion **subtracts from the rotation**, so winds are **weaker**, making it the **“clean side”**.
- This is why **most damage usually occurs on the right-hand side** of a moving cyclone in the northern hemisphere, while the opposite is true in the southern hemisphere..

### Saffir-Simpson Hurricane Wind Scale

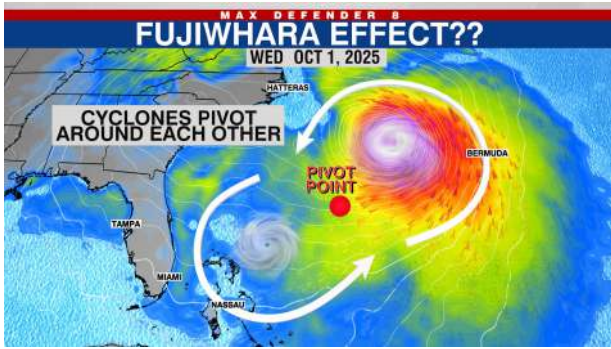


### Hurricane Melissa

- **Hurricane Melissa** was one of the strongest hurricanes to hit the **Caribbean**, rapidly intensifying from a tropical storm to a **Category 4** within a day due to unusually **warm sea temperatures**.
- It made landfall in **Jamaica as a Category 5** hurricane and later struck **eastern Cuba**.
- Tropical cyclones are classified by wind speed using the **Saffir-Simpson Hurricane Scale** (developed in 1971 by Herbert Saffir and Robert Simpson), ranging from **Category 1 to 5**.
- The term **tropical cyclone** is the general name for such storms worldwide, but they are called **hurricanes** in the Atlantic and northeastern Pacific, **typhoons** in the northwestern Pacific, and simply **cyclones** in the Indian Ocean and South Pacific
- **Hurricanes** are named by the **World Meteorological Organization (WMO)** through its **Regional Association IV**, which includes the U.S., Mexico, and Caribbean nations.
- The **National Hurricane Center (NHC)** uses six rotating name lists reused every six years. If a hurricane causes major destruction, its name is **retired and replaced** by the WMO.

### Fujiwhara Effect

- Two potential cyclonic storms are forming in the Bay of Bengal, with global forecast models indicating a possible **Fujiwhara interaction between them**.
- The Fujiwhara effect occurs when **two cyclonic storms in the ocean form in the same region and their wind circulations start interacting with each other** in the middle to upper layers of the atmosphere.
- This interaction of winds **creates a bond between the two storms**, through which they start influencing each other.
- The influence **could be weak or strong** and could lead to either of the storms gaining wind speeds and strength or both storms dissipating.
- In **rare cases, the two systems could merge**, especially when they are of similar size and intensity, to form a bigger storm.
- The Fujiwhara effect was identified by **Sakuhei Fujiwhara**, a Japanese meteorologist in 1921. The first known instance of the effect was in 1964 in the **western Pacific Ocean when Marie and Kathy merged**.



## Blizzard

- A severe blizzard struck the eastern face of **Mount Everest in Tibet** recently, trapping nearly 1,000 trekkers in the remote **Karma valley**.
- Blizzards are dangerous **winter storms that are a combination of blowing snow and wind** resulting in very low visibilities.
- Blizzards **occur when cold air masses, sub-zero temperatures with snow or ground snow, and strong winds** combine to create low visibility and severe winter storm conditions.
- In the Himalayas, when **winds pull cold air toward the equator** from the poles and bring warmer, moist air toward the poles from the equator, **a front is formed causing ideal conditions for blizzards**.
- **Karma valley**, first explored by Western travellers a century ago, is a relatively pristine part of the Everest region.
  - 👉 Unlike the peak's arid north face, it **boasts lush vegetation and untouched alpine forests**, fed by meltwaters from the Kangshung glacier at the foot of the world's highest mountain.

## Roll Cloud



- A rare "roll cloud," a long, tube-shaped cloud formation, was recently spotted rolling over the coastline of **Póvoa do Varzim, Portugal**.
- **A roll cloud, also known as volutus**, is a rare meteorological phenomenon classified under **arcus clouds**, a group of low, horizontal cloud formations often linked to thunderstorms.
- Roll clouds are distinct in their tube-like shape and the way they appear to rotate slowly along a horizontal axis, independent of the parent storm.
- The roll clouds usually form **under very specific conditions**:
  - 👉 Warm, dry air ascends quickly because of strong surface heating (such as in a heatwave).
  - 👉 This rising air collides with cooler, more humid sea breezes coming from the ocean.
  - 👉 The difference between air masses produces turbulence and condensation and thus results in the roll-shaped cloud.
- Roll clouds can also occur **due to coastal breezes, where cooler air** from the land pushes beneath warmer sea air, triggering similar cloud formation.
- Though visually dramatic, roll clouds are **usually harmless**.

## Blood Moon



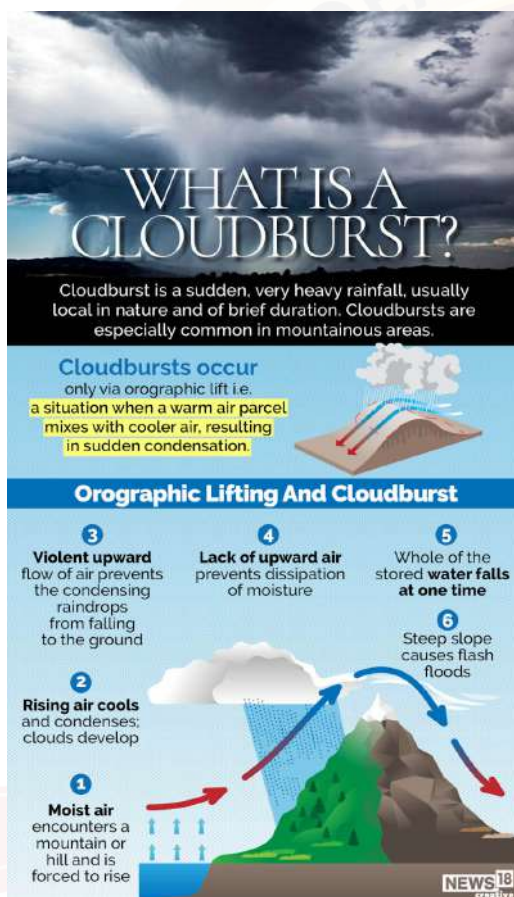
- A **blood moon was visible in India** on September 7, 2025, during a total lunar eclipse, when the moon will **appear dark red due to Earth's shadow**.
- During the eclipse, **the Earth passes directly between the Sun and the Moon**, casting its darkest shadow (the umbra) over the Moon.
- As sunlight filters through Earth's atmosphere, it bends and reaches the Moon, casting it in warm tones by a phenomenon called Rayleigh scattering.

- When sunlight travels through Earth's atmosphere, **shorter wavelengths like blue and violet scatter in all directions** while longer wavelengths, such as **red and orange**, pass through more directly thereby giving the Moon its red hue.
- **Raleigh scattering** is also the phenomenon by which the sky appears blue in colour due to the scattering of light.
- **Note: Rayleigh scattering** is the **elastic scattering of electromagnetic radiation**, such as light, by **particles that are much smaller than the radiation's wavelength**, like atmospheric gas molecules.

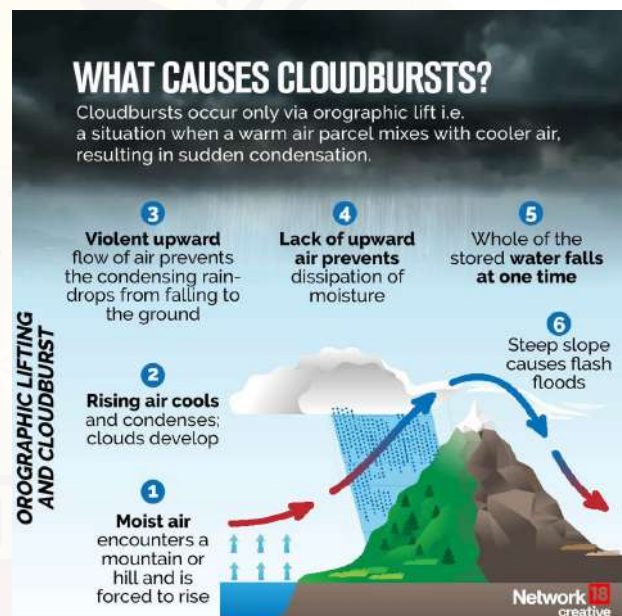
- Short spells of very **heavy rainfall over a small geographical area** can cause widespread destruction, especially in hilly regions where this phenomenon is the most common.
- Rainfall of **10 cm or more in an hour** over a roughly 10 km x 10-km area is classified as a cloudburst event.
- During a cloudburst event, **a place receives about 10% of this annual rainfall within an hour.**
- The **India Meteorological Department forecasts rainfall events** well in advance, but it does not predict the quantum of rainfall.
- The forecasts can be about **light, heavy, or very heavy rainfall**, but weather scientists do not have the capability to predict exactly how much rain is likely to fall at any given place.

### C. Precipitation & Tidal Events

#### Cloudburst



#### Mini Cloudbursts



- Two persons were killed, and over a dozen went missing after cloudbursts led to flash floods in **several districts of Himachal Pradesh.**
- A cloudburst is a localised but intense rainfall activity.

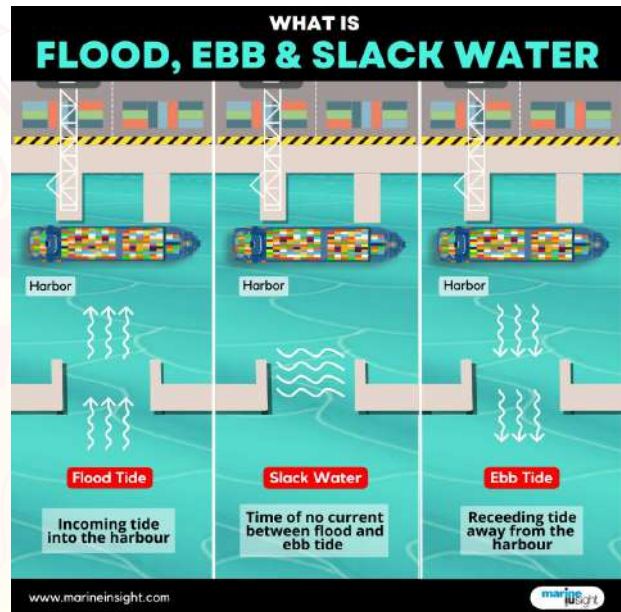
- The **India Meteorological Department (IMD)** clarified that while there is no rising trend in major cloudbursts, instances of “mini cloudbursts” are increasing in India.
- Generally, cloud burst events are **associated with rainfall >10 cm/hr** as per the definition by IMD.
- However, mini cloudbursts are **categorized by IMD as 5 cm of rain per hour**, which is enough to trigger landslides.

- It occurs in
  - June over Western Ghats,
  - July and August over central India and the foot hills of Himalayas.
- These events are generally **found to occur in the early morning hours** at foot hills of Himalaya and along the west coast of India.
- In the interior of the land mass these are observed in the afternoon hours while in the southern peninsula during night hours.

- The extended slack tide allowed water to spread over a wider area causing flooding.
- The cause remains **uncertain**, and its recurrence is **unpredictable**.

### Slack Tide

- A prolonged **high tide slack** in **Kochi, Kerala** caused **severe flooding**, as water remained still for over **two hours** instead of the usual **10-15 minutes**.
- **Slack tide** is a short period when tidal movement **pauses** before changing direction.
- It occurs between **flood (incoming tide)** and **ebb (outgoing tide)**.



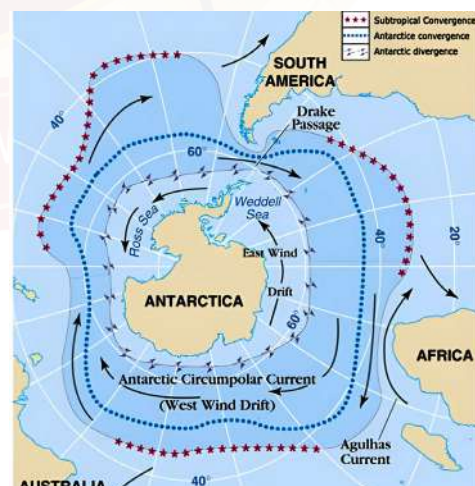
## II. Oceanography

### A. Ocean Currents & Circulation

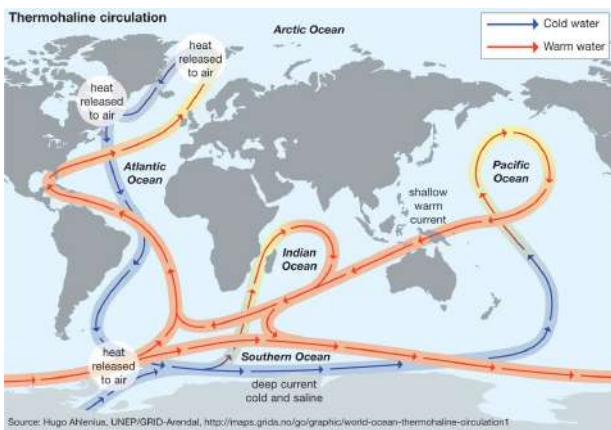
#### Antarctic Circumpolar Current

- A groundbreaking study has revealed that the **Antarctic Circumpolar Current (ACC)**, the world's most powerful ocean current, is slowing down due to melting ice sheets.
- As the **only ocean current connecting the Atlantic, Pacific, and Indian Oceans**, the ACC is five times stronger than the Gulf Stream and over 100 times more powerful than the Amazon River.
- Beyond climate regulation, the ACC acts as a **natural barrier, preventing non-native marine species** from reaching Antarctica.
  - ➔ If it weakens, species like bull kelp, shrimp, and mollusks could invade, disrupting the delicate Antarctic food web and threatening native species such as penguins.
- The melting ice sheets **dump vast quantities of fresh water** into the salty ocean.

- This sudden change in ocean 'salinity' has a **series of consequences** - including the weakening of the sinking of surface ocean water to the deep (called **the Antarctic Bottom Water**), and, based on this study, a weakening of the strong ocean jet that surrounds Antarctica.
- A weaker current may also **allow more warm water to penetrate southwards**, exacerbating the melting of Antarctic ice shelves and contributing to global sea-level rise.
- Faster ice-melting could then lead to further weakening of the current, commencing a **vicious spiral of current slowdown**.



## Atlantic Meridional Overturning Circulation (AMOC)

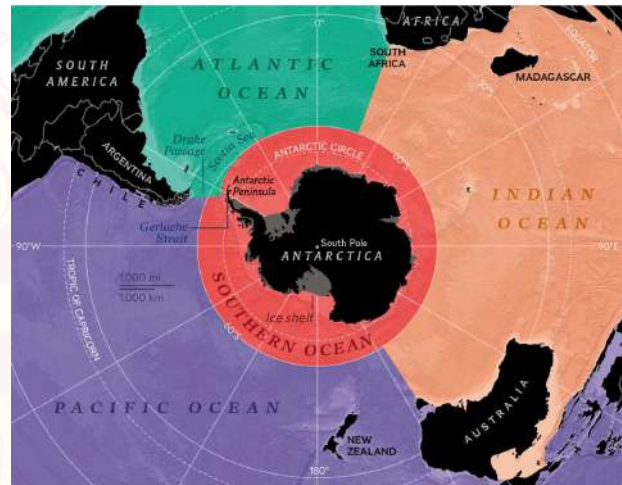


- Recent research indicates that the **Atlantic Meridional Overturning Circulation (AMOC)**, a key component of the global ocean system, could reach a **tipping point for shutdown within a few decades**, though a full collapse may take **50–100 years**.
- AMOC** is a large **system of ocean currents** in the Atlantic Ocean that moves **warm, salty water from the tropics northward** toward Europe and the Arctic.
- When this water cools, it **sinks** and flows back south at deeper levels, helping regulate **global climate and weather patterns**.
  - ☞ This circulation keeps **Europe relatively mild** and affects rainfall and temperature worldwide.
- Thus, **AMOC** acts like a giant **ocean conveyor belt**
- However, **global warming** is threatening this system.
- Rising temperatures make the ocean's **surface water warmer and less dense**, so it **sinks less easily**, weakening the AMOC.
- This reduces the flow of warm water northward, which could have serious consequences:
  - ☞ **Europe:** hotter summers, colder winters, and increased weather extremes.
  - ☞ **Tropical regions:** shifts in rainfall belts, affecting agriculture and water supply.
  - ☞ **Global climate:** disruption of ocean currents that regulate heat and carbon, potentially accelerating climate change.

## Southern Ocean Carbon Anomaly

### Limits of the Southern Ocean

National Geographic now recognizes five world oceans. Most of the waters that surround Antarctica out to 60 degrees south latitude, excluding the Drake Passage and Scotia Sea, constitute the newly acknowledged Southern Ocean.



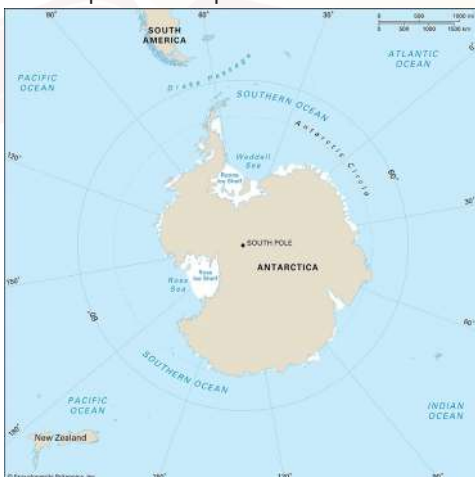
Matthew W. Chwastyk and Greg Ugiasky, NG Staff  
Sources: NASA/JPL; International Hydrographic Organization (IHO)



- New research shows that since the early 2000s, the **Southern Ocean** has absorbed more CO<sub>2</sub> than predicted, a phenomenon called the **Southern Ocean carbon anomaly**.
- The anomaly** due to stronger winds and upwelling, the ocean has continued to absorb carbon.
- Normally, **stronger winds and upwelling** in this region were expected to release CO<sub>2</sub>, but due to changes like melting Antarctic ice and lighter surface waters, the ocean has continued to **trap carbon below the surface**, creating this anomaly.
- Factors causing the anomaly:**
  - ➔ **Freshening of surface waters:** Increased rainfall and meltwater from Antarctic glaciers have reduced surface salinity, making surface waters lighter and more buoyant.
  - ➔ **Enhanced stratification:** Fresher, lighter surface layers sit atop warmer, saltier deep waters, limiting vertical mixing and air–sea gas exchange.
  - ➔ **Trapping of carbon-rich waters below surface:** Upwelled circumpolar deep waters remain 100–200 metres below the surface, preventing CO<sub>2</sub> release.
- They also implied that it **is temporary and there may be a risk of sudden reversal** of this anomaly, i.e. it would weaken and start releasing CO<sub>2</sub>.

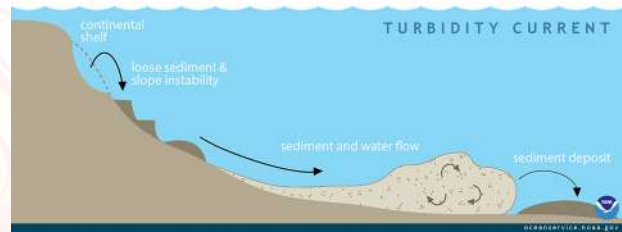
## Ocean Burp

- Studies show that even after global greenhouse gas emissions reach net zero, the **Southern ocean could release a massive amount of trapped heat**, temporarily reversing climate progress in a phenomenon informally called “**ocean burp**”.
- The oceans absorb CO<sub>2</sub> from the atmosphere through physical, chemical, and biological processes.
  - Physical (Solubility Pump):** CO<sub>2</sub> dissolves in cold surface waters, especially in polar regions, and is transported to deep layers via currents.
  - Chemical (Carbonate Chemistry):** CO<sub>2</sub> reacts with water forming bicarbonate and carbonate ions, locking carbon in stable forms.
  - Biological Pump:** Phytoplankton photosynthesize, capturing CO<sub>2</sub>; dead organisms and marine snow sink, storing carbon in the deep ocean.
- For over a century, the ocean has absorbed about a **quarter of human-made CO<sub>2</sub>** and **over 90% of excess heat**, stabilizing the climate.
- When the planet cools after reaching net-zero emissions, the trapped heat will slowly rise to the surface.
- This **upwelling releases heat back into the atmosphere**, temporarily warming the planet again, though most of the stored CO<sub>2</sub> remains dissolved in the ocean.
- The **Southern Ocean** is most affected because its unique currents and connection to the Atlantic, Pacific, and Indian Oceans allow efficient mixing and deep storage of heat and carbon, making it the primary ocean sink and the main source of a potential “ocean burp” when deep waters upwell.



## B. Marine & Coastal Processes

### Turbidity Currents



- A new study has found the **first direct evidence of an underwater microplastics “avalanche”** in **Whittard Canyon**, a deep-sea trench off the southwest coast of Ireland between the Celtic Sea and the Atlantic Ocean.
- This event was caused by a **turbidity current** — a fast, downhill flow of dense, sediment-filled water triggered by things like earthquakes or collapsing slopes.
- These currents carry sediments, nutrients, and now even plastic waste to the deep ocean, changing the seafloor’s shape.
- Turbidity refers to how cloudy or dense the water** is due to particles like sediment or plankton.

### Brine Pools



- Scientists have discovered **deadly brine pools** beneath the Red Sea, located 4,000 feet deep in the **Gulf of Aqaba**.
- These **hypersaline pockets**, up to ten times saltier than surrounding water, instantly kill or stun marine life.
- Brine pools form when **ancient salt deposits leach into the ocean**, creating dense, oxygen-deprived environments.
- Their extreme salinity **prevents mixing with seawater**, making them appear as “underwater lakes.”
- The deepest-known brine pool is in the **Orca Basin**, Gulf of Mexico, at 2,200 m below sea level.

## Ocean Darkening

- A new study, **Darkening of the Global Ocean**, finds that over **20% of the ocean** has darkened in the past two decades.
- **Ocean darkening** refers to the **reduction in sunlight penetration** into the upper layers of the ocean, known as the **photic zone**, the sunlit layer (up to 200m deep), which is critical for **photosynthesis** and marine life.
- Caused by factors like **algal blooms**, **sediment runoff**, **organic matter**, and **climate change** (e.g., warmer waters, altered plankton dynamics).
- It can impact **marine ecosystems**, **food chains**, **carbon cycling**, and **fisheries**, since most ocean life depends on light for survival and biological processes.
- The study used **Calanus copepods**, a genus of small, shrimp-like **zooplankton** found widely in **cold and temperate ocean water**, to detect changes in light availability.
  - They are **highly photosensitive** and respond to faint **light cues** from the Sun and Moon.
  - Their sensitivity to light makes them an ideal **indicator species** to study **changes in ocean light penetration** and **ocean darkening**.
  - Known for their **daily vertical migration**—rising to the surface at night to feed and sinking during the day to avoid predators.



## C. Ocean Governance

### Inter-Governmental Oceanographic Commission (IOC)

- **Indian National Centre for Ocean Information Services (INCOIS)** has been selected by **Inter-Governmental Oceanographic Commission (IOC) of UNESCO** for a major global submarine cable initiative.
- IOC, the only **UN body specialized in ocean science** and services, headquartered in France, launched Ocean Decade Tsunami Programme (ODTP) in 2021.
- Ocean Decade Tsunami Programme (ODTP) as part of the **Decade of Ocean Science for Sustainable Development (2021–2030)** – an effort to **bolster the global tsunami warning system** by reducing response times and enhancing community readiness.
- **INCOIS** was established in Hyderabad **1999** as an autonomous organization under the **Ministry of Earth Sciences** to provide critical ocean information and advisory services.
- INCOIS will now take up 3 of 10 major projects under ODTP

#### Projects:

- **Submarine Cable Observatory:** A 150 km multi-parameter cable west of **Wandoor**, Andaman, at 2,000–2,500 m depth, with real-time monitoring from INCOIS Hyderabad, to study ocean dynamics and seismic activity linked to tsunamis.
- **People Centred Tsunami Early Warning (PCTWIN):** Focuses on improving disaster risk knowledge, detection, forecasting, communication, and preparedness.
- **Tsunami Ready Odisha (TRO):** Enhances coastal community resilience and awareness, linked to UNESCO-IOC's Tsunami Ready Recognition Programme, in collaboration with Odisha's disaster agency.

### III. Geomorphology & Geophysics

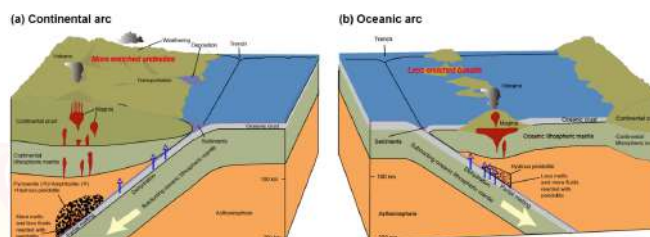
#### A. Volcanism & Tectonics

##### Deccan Volcanism

- Study shows that **Deccan Volcanism** (~66 Million years ago) contributed to faunal extinctions (e.g., dinosaurs, ammonoids) but **promoted tropical rainforest diversification**.
- This massive volcanic event in western and central India **formed the Deccan Traps**, releasing lava, ash, and greenhouse gases for thousands of years.
- While it **wiped out gymnosperms and dinosaurs**, it created fertile, undisturbed habitats ideal for **angiosperms**.
- Despite global warming, **tropical flora recovered rapidly**.
- The study suggests **undisturbed rainforests can regenerate** under favorable conditions, offering insights into climate resilience.

##### Volcanic Arc

- Recently researchers have uncovered a **massive, 400-mile-long** chain of extinct, fossilized volcanoes deep under South China.
- This ancient volcanic arc was formed around **800 million years ago** during the early **Neoproterozoic era**, when two tectonic plates collided during the breakup of the supercontinent Rodinia.
- A volcanic arc is a chain of volcanoes, hundreds to thousands of miles long, that forms above a **subduction zone**.
- They are mainly two types:
  - **Continental Volcanic Arc:** formed when an oceanic plate subducts (slides) beneath a continental plate resulting magma to rise to the **continental crust**. **Eg:** Andes Mountains (Andesitic arc), Cascade Range (in North America) etc
  - **Oceanic Volcanic Arcs (Island Arcs):** formed when one oceanic plate subducts beneath another oceanic plate resulting magma to rise to the **oceanic crust** forming volcanic islands. **Eg:** Aleutian Islands, Japan, and the Philippine Islands.



##### Mud Volcano

- India's only mud volcano at **Baratang in the Andaman and Nicobar Islands** erupted on 2 October 2025 after being dormant for over 20 years.
- Mud volcanoes are natural geological features where **mud, gases like methane and carbon dioxide, and other materials are pushed to the surface** due to underground pressure from overlying rocks or gas deposits.
- This process, called mud volcanism, can **create craters and bubbles**, support unique ecosystems, and indicate the presence of natural resources.
- Baratang's mud volcano is **different from the active volcanic island of Barren Island** and is located about 150 km from Port Blair in the North and Middle Andaman district.



## Effects of Melting Ice Caps on Volcanic Eruptions

- Recent research suggests that melting glaciers could make volcanic eruptions more explosive and frequent.
- Studies cite that the **weight of a glacier puts immense pressure** on a volcano's underground magma chambers.
  - When the glacier melts, this pressure is reduced.
- The reduced pressure allows the **magma and underground gases to expand**, leading to more explosive eruptions.
- A drop in pressure can **also cause rocks to melt at lower temperatures**, potentially increasing the overall production of magma.
- Precipitation** from the melting ice can also seep into the ground and react with the magma system, which can trigger an eruption.
- This indicates that regions like **West Antarctica, parts of North America, New Zealand, and Russia** are most at risk.

## Sagaing Fault

### Myanmar sits on a tectonic fault line



- The Indian plate collides with the Eurasian plate
- Friction builds up along the Sagaing fault
- The fault slips along a 200km section, which releases energy felt as an earthquake

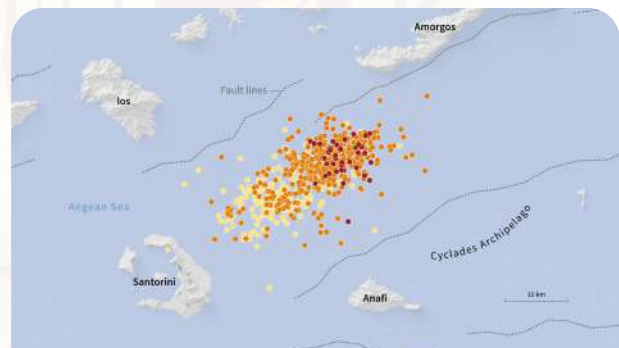
Source: USGS, Advancing Earth and Space Sciences



- The recent earthquake in Myanmar had its source in central Myanmar, about 20 km from Mandalay, the country's second-largest city.
- Mandalay, located on the **east bank of the Irrawaddy river**, is close to one of the most **seismically active faults in the region, called the Sagaing fault**, named after a town not far from Mandalay on the river's opposite side.

- The **north-south running Sagaing fault** forms the tectonic boundary between the **Central Myanmar Lowlands and the Indo-Burman Range**.
- An elongated micro-tectonic block that exists between the Indian plate and the Sagaing fault is commonly called the **Burma plate or the Burma Sliver**.
  - It owes its origin to the strain partitioning occurring at the subduction front.
- Unlike the **vertical motions of fault blocks along the frontal part** of the convergence zone, where one tectonic block is pushed up on the other, the **movement is horizontal on the Sagaing fault**, with the blocks **sliding past each other**.
  - The San Andreas fault in the western U.S. is another such example.
- Classified as a typical **ridge-trench transform fault**, the Sagaing fault system runs **1,400 km between the spreading centre under the Andaman Sea** in the south to the eastern Himalayan bend in the north.

## Earthquake Swarm



### Santorini: seismic activity near the island

The Greek island and its neighbour Amorgos have been hit by a series of tremors. Experts warn that the earthquakes could continue for weeks

Earthquakes registered since January 29, 2025  
 Magnitude  
 ● < 2.5  
 ● 2.5 to 4  
 ● 4 to 4.9

Source: Geodynamic Institute of the National Observatory of Athens, data as of February 4 at 07:30 GMT

Map data: DSM, JAXA, GRIAS AFP

- Greece's Santorini** and nearby islands have declared a state of emergency after a swarm of undersea earthquakes.
- This region lies in the **volcanic arc** of the **Hellenic subduction zone**, where the **African plate** slowly slides beneath the Eurasian plate, creating weak zones in the crust.
- Unlike typical earthquake sequences, **swarms consist of multiple tremors** of similar intensity without a single large mainshock.

- These can last for days, weeks, or even months.
- The swarms are likely **caused by ascending magma fluids**, but their distribution suggests they occur along pre-existing faults.

## Earth's Oldest Meteorite Impact Crater

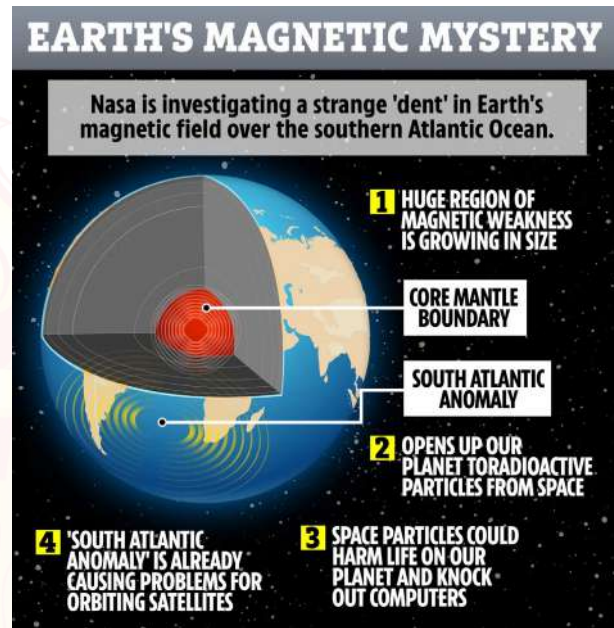
- The oldest meteorite impact crater on Earth was recently discovered in the **Pilbara region of Western Australia**.
- The crater formed **more than 3.5 billion years ago**, making it the oldest known by more than a billion years.
- The impact would have been phenomenal, **creating a crater over 100km (62 miles) wide** and sending debris spinning around the globe.
- The team identified the crater through distinctive rock formations known as **“shatter cones”**.
  - Shatter Cones are distinctive **“hut-like” rock formations**, some several metres tall, which **only form under the intense pressure of a meteorite strike**.
- The energy from these impacts **may have played a crucial role in forming Earth's crust** and contributing to the development of continents.

## OLDEST METEOR CRATER

The ancient strike site was discovered in north-west Australia - just where scientists predicted



## South Atlantic Anomaly (SAA)



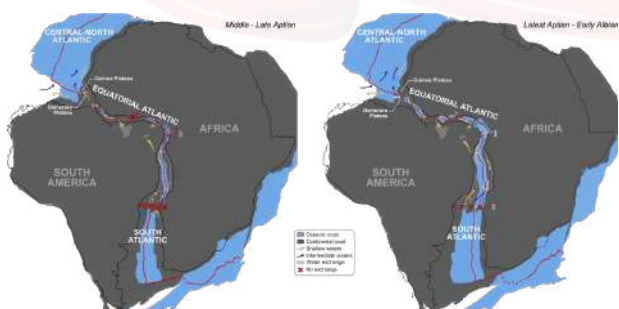
- Recent findings from the **European Space Agency's (ESA) Swarm mission** reveal that the South Atlantic Anomaly (SAA) — the region of weakest intensity in Earth's magnetic field — has expanded by nearly 0.9% since 2014.
- Earth's magnetic field is created by the **molten iron in Earth's outer core** and as it swirls around at a depth of thousands of kilometres.
- It creates a **protective zone around the planet that protects us from the harmful cosmic radiation** and the harmful particles unleashed by the sun.
- But it **doesn't generate an equal layer everywhere**.
  - The SAA is a zone where the magnetic field is weaker.
- The molten iron moves turbulently inside Earth, and this swishing around has resulted in the expansion and shifting of the SAA.
- This creates a weaker magnetic shield that **exposes satellites and spacecraft to higher radiation**, potentially disrupting electronics and damaging hardware.
- While humans on Earth are mostly safe, astronauts on the ISS face increased risks.

## B. Landform & Geological Processes

### Morphological Ridge

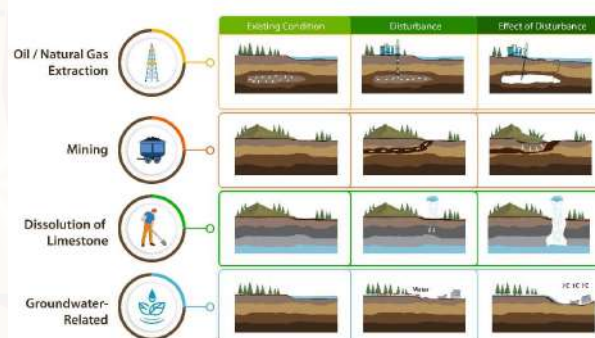
- The Supreme Court issued a show cause notice to Delhi officials for **allegedly violating its 1996 directive in the M.C. Mehta vs Union of India case** by allowing construction in the Morphological Ridge area.
- A **ridge** is a long, narrow elevated landform, usually a chain of hills or mountains, that stands higher than the surrounding terrain.
- The morphological ridge is a** general geological term referring to **ridge-like landforms** identified based on their shape, structure, and physical features (morphology), rather than official forest status or land use.
- The **Aravalli hill range contains the Delhi Ridge** as its tail-end and an ecologically critical zone.
- It works as a **green lung** for the capital and a **natural barrier against hazards** such as desertification and pollution.
- Entering Delhi from **Gurgaon** in the southwest, this Ridge stretches for around **35 km from the south of Mahipalpur to southeast of Tughlakabad**, petering out in Wazirabad on the western bank of Yamuna.
- The **Morphological Ridge**, on the other hand, is a geologically **extended Ridge area**.
- It is **not officially notified as forest land** but enjoys protection under several High Court and Supreme Court rulings over the past decade.
- The extent of the Morphological Ridge is based on a **Delhi Forest Department map**, itself based on the seismic zonation map of Delhi 2006, undertaken under the Geological Survey of India.
- It is marked as **“gair mumkin pahad” (uncultivable rocky hill)** in records.

### Mud Wave



- Scientists have found 117-million-year-old mud waves **beneath the Atlantic seabed near Guinea-Bissau**.
- Mud waves** are large, wave-like sedimentary structures found on the seafloor.
- They are formed by the continuous action of **deep-sea currents** that move fine sediments like mud, clay, or silt across the ocean bottom
- The Atlantic mud waves, over a kilometer long and hundreds of meters high, were formed by **strong underwater currents when salty water from the young North Atlantic spilled** into southern basins.
- They **mark the Equatorial Atlantic Gateway**, created when South America and Africa split, forming the Atlantic Ocean.
- This new seaway **initially reduced ocean carbon burial**, leading to global warming between 117–110 million years ago.
- The study shows how past ocean circulation shaped climate, helping predict future changes.

### Land Subsidence



- Severe land subsidence in Chamoli, Uttarakhand has forced evacuations and triggered panic among residents.
- Land subsidence involves the **gradual submergence or sagging of subsurface material**.
- Unplanned construction, heavy rainfall, landslides, and **river erosion contribute** to ground subsidence in the Himalayan region.
- The young, **tectonically active Himalayan range is prone to such events**, with heavy rains saturating soil and reducing its load-bearing capacity.

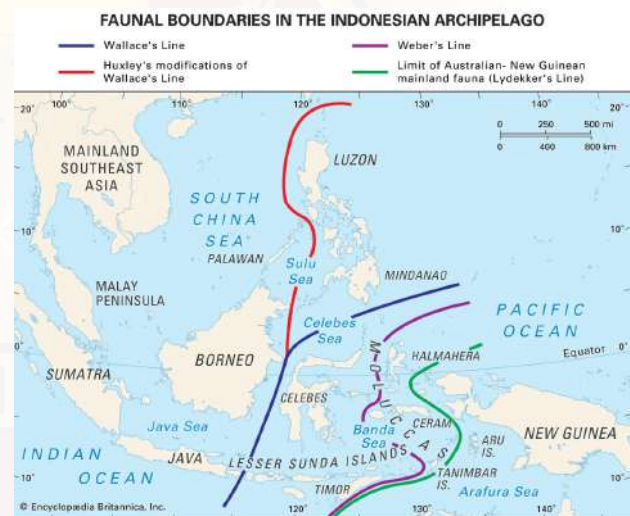
- The excessive **withdrawal of groundwater also increases the pressure** over the clay layer, and the stress subsequently accumulates in the soil structures, which creates cracks and damages the houses.
- **The lack of sudden destruction**, as is the case with other disasters, makes land subsidence pass unnoticed for long periods of time.

## Palaeofires

- Scientists found strong proof of **very ancient wildfires called Palaeofires** that happened about **250 million years ago in the Godavari Basin** in India.
- These old fires affected the Earth's environment and climate long ago.
- When **plants burn**, they leave behind **tiny bits of charcoal** and other organic material that get trapped in layers of rock and soil.
- By studying these layers, scientists can learn about the wildfires that happened millions of years ago.
- They used **special tools to look closely at these tiny particles**, such as pollen, plant bits, and charcoal from fires.
- They found **three main types of particles**:
  - **Plant debris** (Translucent Organic Matter)
  - **Charcoal made by ancient fires** (Palaeofire Charcoal)
  - Charcoal that might have been **moved around after burning** (Oxidised Charcoal)
- The study also showed that **back then, the Earth's atmosphere had more oxygen**, which likely made **wildfires happen more often** and burn more intensely.
- So, by studying these ancient fires, scientists better understand how Earth's climate and ecosystems evolved over millions of years.

## Wallace Line and Biodiversity

- **Rising temperatures and habitat loss** are potentially dissolving the Wallace Line, a biogeographical boundary identified by **Alfred Russel Wallace in the 19th century**.
- This **invisible oceanic barrier**, running between islands like **Bali and Lombok and Borneo and Sulawesi**, marks a sharp division between Asian and Australian fauna.
- Sulawesi is an exception, hosting species from both regions due to its geological history and continental drift theory.
- A 2023 study suggests that **warmer, wetter conditions in Malay's tropical islands** acted as stepping stones for Asian species moving towards Australia, while Australian species, adapted to cooler climates, faced difficulties crossing towards Asia.
- This **historical balance may now be disrupted** by climate change and habitat destruction, facilitating unprecedented species dispersal across the once distinct Wallace Line.



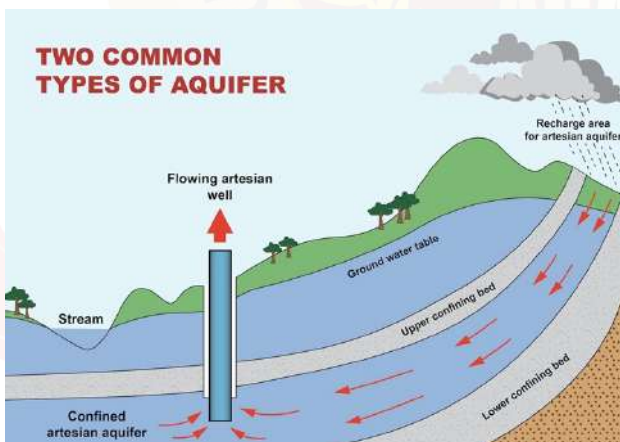
## IV. Hydrology & Water Resources

### Artesian Condition

- In **Taranagar village, Rajasthan**, a rare phenomenon occurred when water gushed out forcefully from the ground after a farmer drilled a tube well up to 850 feet.
- This is known as the '**artesian condition**' or '**confined water**'.
- The **artesian condition** occurs when groundwater is trapped under pressure between layers of impermeable rock or clay which becomes a confining bed.
- This creates an **artesian aquifer**, which is a body of rock or sediment that can hold groundwater.
- They are often found in areas where there are **layers of sedimentary rock**, such as sandstone and limestone

#### How It Works:

- ◆ **Confined Aquifer:** Water is held between two impermeable layers, preventing it from escaping freely.
- ◆ **Hydraulic Pressure:** Water in the aquifer is under pressure due to its elevation difference.
- ◆ **Drilling or Natural Rupture:** When a well or crack reaches the aquifer, the pressure forces the water to rise without pumping, sometimes even flowing to the surface as an **artesian well**.



### Lake Tefe



- **Amazonian lakes like Lake Tefe in Brazil** are being transformed into simmering basins as severe heatwaves and drought grip the region.
- The **shallow waters of Lake Tefé**, which were only two metres deep, reached 41°C. The extreme drought that affected the **lake in 2024 reduced its area by 75%**.
- Hundreds of river dolphins turned up dead in the lake including **pink river dolphins (Inia geoffrensis)** and **tucuxi river dolphins (Sotalia fluviatilis)**.
- Many **fish**, especially Amazonian species, have **narrow temperature tolerances**, making even small increases deadly.
- Higher temperatures also **reduce dissolved oxygen**, adding to their stress.

### Virtual Water Export Crisis

- **The World Economic Forum** recently cited that rice, the world's **largest staple foodstuff**, is **water-intensive** and its cultivation accounts for between 34% and 43% of the world's irrigation water.
- The traditional methods of cultivation produce relatively **large amounts of the greenhouse gas methane** (totalling approximately **10-12% of global methane**).
- It is **climate sensitive** as Yields drop >8% per 1°C temperature rise.

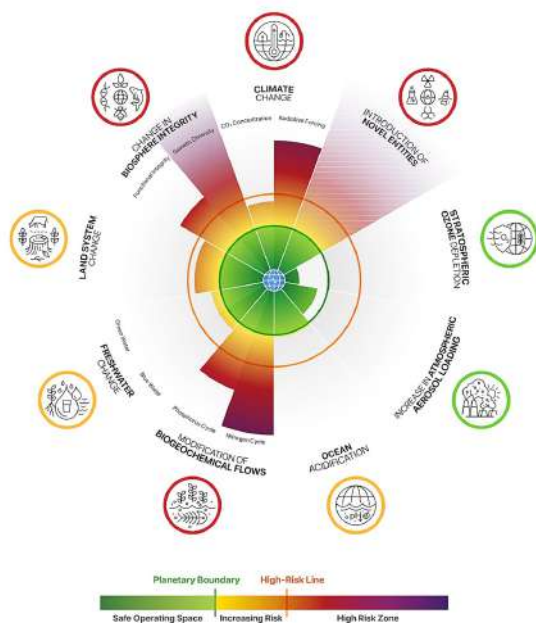
- China is the **largest producer**, followed by India, Indonesia, Bangladesh, Viet Nam and Thailand.
- India's large rice exports ( $\approx 40\%$  of global trade) effectively export **billions of cubic metres of groundwater** from water-stressed regions embedded in these grains, a phenomenon called **virtual water-export**.
- **Punjab and Haryana** particularly face severe depletion; most blocks are **over-exploited/critical** (Central Ground Water Board, 2024–25), with borewell depths rising from  **$\sim 30$  ft to  $80$ –**

**200 ft.**

- Tech-led solutions like **Alternate Wetting and Drying (AWD)** can reduce rice water use by **20–50%**, cut **greenhouse gas emissions up to 70%**, and improve yields.
- **Climate-resilient rice varieties, AI-based water management, carbon market incentives, and low-emission procurement policies** (e.g., Vietnam's 1-million-hectare low-carbon rice target, Thailand's Rice NAMA) together promote sustainable rice cultivation.

## V. Environment, Climate Change & Sustainability

### Planetary Boundaries



- A new report from the Planetary Boundaries Science Lab at the **Potsdam Institute for Climate Impact Research (PIK), Germany** reveals that 7 of the 9 critical Earth system boundaries have now been breached, **one more than last year**.
- The **seven breached boundaries** are:
  - Climate Change, Biosphere Integrity, Land System Change, Freshwater Use, Biogeochemical Flows, Novel Entities & Ocean Acidification (new in 2025).
- **Ocean acidification** has now gone beyond what is considered safe for marine life and cold-water corals, tropical coral reefs, and Arctic marine life are especially at risk.

- **Only two boundaries within safe boundaries: Loading of aerosols (air pollution) and the stratospheric ozone layer** - caused by decades of international action, like the Montreal Protocol and shipping regulation.
- The **nine boundaries together form Earth's operating system by interconnecting life-support processes** that must stay within safe limits to keep humanity safe and the natural world resilient.

### The California wildfires

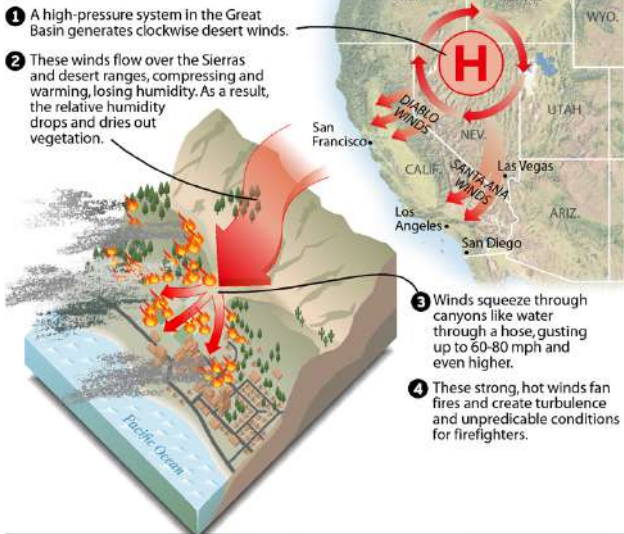
- Ferocious wildfires erupted in California state of The United States, an unusual event for winter, driven by powerful Santa Ana winds and dry conditions.
- **Wet-to-Dry Cycle:** Unusually wet years (2022-23) led to excessive vegetation growth.
  - However, this winter's exceptionally dry conditions turned the vegetation into dry fuel for fires.
- **Santa Ana Winds:** These strong, dry winds from the Great Basin normally blow from October to January towards the Pacific.
  - This year, they were unusually strong, rapidly spreading the flames.
- **Climate Change Impact:** Rising global temperatures have caused longer, more intense dry seasons, early snowmelt, and vegetation moisture stress, increasing wildfire risks.

## Diablo and Santa Ana Winds at a Glance

This is how the hot, powerful Santa Ana winds in Southern California and Diablo winds in Northern California increase the regions' fire risk.

### HOW SANTA ANA AND DIABLO WINDS OCCUR

- 1 A high-pressure system in the Great Basin generates clockwise desert winds.
- 2 These winds flow over the Sierras and desert ranges, compressing and warming, losing humidity. As a result, the relative humidity drops and dries out vegetation.
- 3 Winds squeeze through canyons like water through a hose, gusting up to 60-80 mph and even higher.
- 4 These strong, hot winds fan fires and create turbulence and unpredictable conditions for firefighters.



SOURCES: National Weather Service; Inside Climate News research

PAUL HORN / Inside Climate News

## Plastic Ice VII

- Scientists have experimentally **confirmed the existence of Plastic Ice VII**, a previously theorized phase of water that forms under extreme conditions.
- **Unlike conventional ice, where water molecules are fixed in place**, Plastic Ice VII features a rigid cubic lattice structure allowing the molecules to rotate freely while maintaining solidity.
- This phase **emerges at pressures exceeding 3 gigapascals** (about 30,000 times Earth's atmospheric pressure) and **temperatures above 450 Kelvin (177°C)**.
- Researchers utilized **quasi-elastic neutron scattering (QENS)** to observe this phenomenon, revealing that water molecules in Plastic Ice VII exhibit rapid rotational motion akin to liquid water, despite being in a solid state.
- This discovery **enhances our understanding** of water's behavior under extreme conditions and has significant implications for planetary science, suggesting that such ice phases may exist in the interiors of icy moons and exoplanets.
- The designation "**Ice VII**" refers to a **specific crystalline phase of ice** identified in the sequence of ice polymorphs, each assigned a Roman numeral as they were discovered

### QENS:

Quasielastic incoherent neutron scattering (QENS) is a key tool for the exploration of complex systems, such as liquids, polymers, glasses, and biomolecules.

The technique uses **neutrons to study the dynamic processes of atoms and molecules** in materials, particularly their motions and diffusion, by measuring the small changes in neutron energy during scattering events.

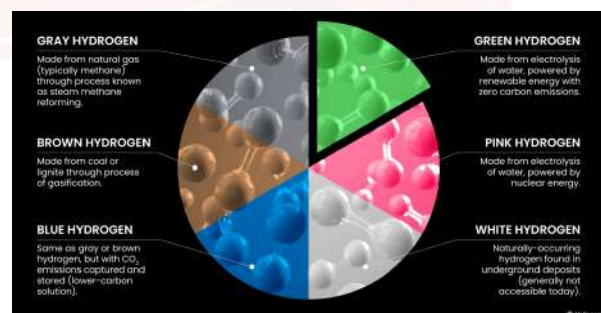
## Drought Hotspots Around the World 2023–2025 Report

- The **UN Convention to Combat Desertification (UNCCD)** and the **U.S. National Drought Mitigation Centre (NDMC)** with the support of the **International Drought Resilience Alliance (IDRA)** released the Drought Hotspots Around the World 2023-2025 Report.
- It identifies the regions of the world that were most severely affected by droughts in 2023–2024, with some continuing into 2025
- It states that the combined effects of the **El Niño Southern Oscillation (ENSO)** and **climate change** intensified drought in many parts of the world.

### Key Highlights :

- **Global Escalation:** Droughts have intensified across Africa, the Mediterranean, Latin America, and Asia, termed "slow-moving catastrophes."
- **Panama Canal Disruption:** Drought reduced daily transits from 38 to 24 ships, disturbing global trade and food prices.
- In India drought leads to monsoon variability, food price vulnerability, hydrological stress and socioeconomic impact.

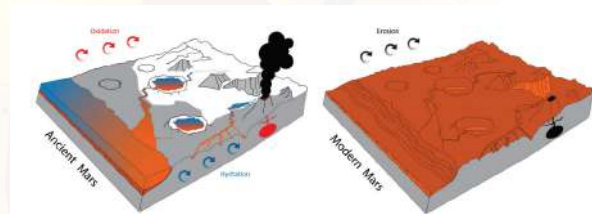
## White Hydrogen



- French scientists have discovered a **significant deposit of natural hydrogen**, known as white hydrogen, approximately 1,250 meters underground in **Folschviller, Lorraine’s Moselle area**.
- Initially searching for methane, researchers found **hydrogen concentrations increasing with depth**—14% at 1,100 meters and 20% at 1,250 meters—suggesting a substantial reservoir.
- **White hydrogen is naturally occurring** and does not require industrial processing, distinguishing it from green hydrogen, produced using renewable energy, and gray hydrogen, derived from fossil fuels.
- This discovery could **bolster France’s economy** by creating thousands of jobs and positioning the nation as a leader in **Europe’s clean energy transition**.
- This suggests that Mars became rusty during a period when liquid water was present on its surface, several billion years ago.
- Earlier, Mars’ red color was thought to come from **hematite**, forming under dry conditions without water.
- Unlike hematite, ferrihydrite forms quickly in cool, wet environments, suggesting Mars had **liquid water much earlier** than thought, perhaps billions of years ago.
- The latest study suggests Mars **had a wetter past**, which could have supported microbial life that once existed.
- Mars is believed to have initially started as a **‘gray’ planet** and then acquires its characteristic red hue by erosion of altered ferrihydrite-rich rocks and dispersal of dust by aeolian processes
- Future missions, including **NASA’s Perseverance and ESA’s Rosalind Franklin rover**, aim to analyze Martian dust for further insights into its wet history.

### Ferrihydrite in Mars

- New research **challenges** the belief that Mars’ red color is due to iron minerals rusting in dry conditions.
- Combining **ESA and NASA spacecraft data** with lab experiments, scientists found that **ferrihydrite**—an **iron oxide requiring water**—better explains the planet’s hue.



## VI. Space, Astronomy & Planetary Science

### Planet Parade



- A rare **planet parade** occurred recently, with **Venus, Saturn, Jupiter, and Mars** forming a stunning arc in the night sky.
- **Uranus and Neptune** were also visible with a telescope.
- A “planet parade,” also sometimes called a **planetary alignment**, is a celestial event where several planets **appear close together** in the same area of the sky due to their unique orbits around the Sun.
- It’s **not a perfect line-up**, but rather a grouping where the planets are visually clustered when viewed from Earth.
- The last such alignment was in **May-June 2024**, when all solar system planets were visible.

## Study on Age of Saturn's Rings

- A new study by researchers challenges the idea that **Saturn's rings** are young.
- Saturn, mostly **hydrogen and helium**, has bright-white rings made of ice and rock.
- NASA's **Cassini Orbiter** found them unusually clean, suggesting they are only 100 million years old, as older rings should have accumulated dust.
- However, new computer models show **dust particles evaporate and disperse** when colliding with ice, keeping the rings clean regardless of age.
- The study also highlights **Enceladus**, Saturn's geologically active moon, whose cryovolcanic water plumes contribute material to the rings, impacting their composition and age estimation.

**Four planets in our Solar System have rings:** Saturn, Jupiter, Uranus, and Neptune. Saturn has the most prominent and extensive ring system, composed mainly of ice and rock. Jupiter's rings are faint and made of dust from its moons, while Uranus has thin, dark rings consisting of ice and rock. Neptune's rings are also faint and fragmented, with some bright arcs. Among these, Saturn's rings are the most visible, whereas the others require telescopes to observe.

## Iron Opacity in Sun

- New research has found that **scientific theories have underestimated iron's opacity in Sun.**
- The sun primarily consists of **hydrogen** (about 74%) and **helium** (about 24%), with only about **2%** of its composition being heavier elements like iron, oxygen, carbon, and nitrogen.
- When light interacts with materials like **iron**, some of the light is absorbed, and some is scattered, influencing how energy moves in the star.
- How much **light an object absorbs is called its opacity:** the more it absorbs, the more opaque it is.

- Researchers subjected a **plasma containing iron to conditions expected at the star's radiation/convection zone boundary**, a layer about 30% of the way from the surface to its centre.
- They reported that depending on the frequency of radiation striking it, **iron's opacity was found to be 30-400% higher than predicted.**
- In essence, iron's higher opacity means less radiation can pass through certain layers, which could affect how the sun generates energy, possibly leading to changes in **temperature profiles** and the **overall dynamics** of the sun's interior.

## Helium in Sun

- Researchers from the **Indian Institute of Astrophysics (IIA)** in a new study have been able to accurately **estimate the abundance of helium in the sun's photosphere** for the first time.
- Astronomers have traditionally assumed the abundance of Helium in the photosphere of Sun-like stars to be **one tenth of that of Hydrogen.**
- This is assumed by **extrapolating from hotter stars, or from the outer atmosphere** of the Sun (solar corona, solar wind), or from seismology studies of the interior of the Sun.
- **None of these methods are based on direct observations** of the photosphere due to the absence of Helium spectral lines.
- The abundance of various elements in our Sun, or in any other star, is estimated from their absorption spectral lines.
- Since **Helium does not produce any observable spectral lines** from the visible surface, or the photosphere, of the Sun, its abundance has usually been estimated through indirect means.
- Now, the IIA researchers have used **magnesium and carbon features in the observed high-resolution spectrum** of the sun and have accurately calculated the abundance of Hydrogen.
- Since Helium is the **second most abundant element in the Sun after Hydrogen**, the abundance of Helium is linked to the abundance of Hydrogen.

## The Rare Earth Hypothesis

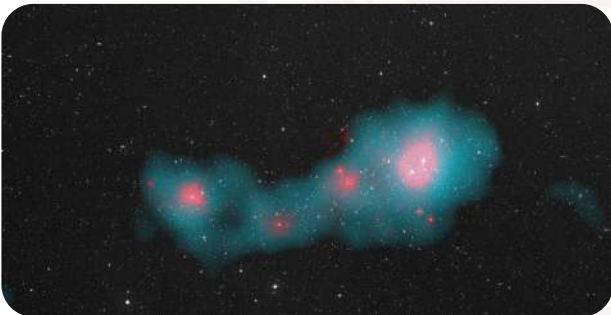


- Recent data from **NASA's** Kepler and James Webb Space Telescopes (JWST) show **Earth-sized planets in habitable zones are common**, but **conditions for complex life are extremely rare**.

- The **Rare Earth hypothesis** argues that while simple microbial life may be abundant, the specific combination of factors needed for complex organisms are extremely rare.
- Proposed by Peter Ward and Donald Brownlee in 2000**, the Rare Earth hypothesis argues that **Earth's unique combination of factors**—stable galactic location, suitable star, plate tectonics, a large moon, and protective atmosphere and magnetic field—makes complex life extremely rare.
- Earth is thus considered a “Goldilocks planet,”** with just the right conditions for complex life, making similar planets in the universe extremely rare..

## VIII. History / Ancient Knowledge Systems

### Quipu



- Astronomers have discovered **Quipu**, the largest known structure in the universe, named after the **Incan system of measurement**.
- Spanning **1.3 billion light-years** and containing **200 quadrillion times the Sun's mass**, Quipu is visible in sky maps without specialized detection methods.
- The Quipu superstructure contains around 68 galaxy clusters and stretches from high northern latitudes to nearly the southern end of the sky,
- Previously, the **Hercules Corona-Borealis Great Wall** was considered the largest structure, though its existence is debated.

- Alongside Quipu, researchers identified four other massive superstructures: **Serpens-Corona Borealis**, **Hercules**, **Sculptor-Pegasus**, and **Shapley** (previously the largest known).
- Together, these structures **occupy 13% of the universe's volume** and influence the **cosmic microwave background (CMB)**, affecting measurements of the **Hubble constant** and **gravitational lensing**.

The name Quipu references the **Incan knotted-string system**, a decimal-based recording method where knots represent numerical values.

The **Inca civilization (1438–1533 CE)** emerged in the Andes across modern-day Peru, Ecuador, Bolivia, Chile, Argentina, and Colombia.

Their empire, Tawantinsuyu, built roads, agricultural terraces, and cities like Machu Picchu.

The empire thrived until the **Spanish conquest** in 1532.

# INDIAN GEOGRAPHY

## I. Climatology & Atmospheric Phenomena

### A. Atmospheric Circulation & Climate Systems

#### Early onset of Monsoon:

- The southwest monsoon arrived in Kerala on **May 24**, eight days earlier than the normal onset date, according to the India Meteorological Department (IMD).
- The IMD uses a **3 fold criteria** to declare the arrival of Monsoon.
  - Rainfall:** At least 60% of the 14 designated southern meteorological stations (including Thiruvananthapuram, Kochi, Mangalore, etc.) must report >2.5 mm rainfall for two consecutive days.
  - Wind Field:** Westerly winds must dominate up to 600 hPa pressure level, and wind speed at 925 hPa must range between 15–20 knots (27–37 km/h).
  - Outgoing Longwave Radiation (OLR):** OLR values must be below 200 W/m<sup>2</sup>, indicating active convection and cloud cover, which is favorable for monsoon onset.
- This is the **earliest arrival of Monsoon since 2009** and IMD has forecast an above normal monsoon for this year.
- However, **an early on-set does not guarantee a surplus monsoon** as 2009 ended up being a deficient year.

- The department defines average or normal rainfall as ranging between 96% and 104% of a 50-year average of **87 cm (35 inches) for the four-month (June-September) season**.
- These four-months deliver **over 70% of overall rainfall** in India.
- Interestingly, IMD only counts the rainfall within these 4 months as monsoon rainfall and the rain falling in May is counted as **part of pre-monsoon rainfall**.

#### Cyclone Shakhti and Montha

- The India Meteorological Department (IMD) confirmed **Cyclone Shakhti** over the northeast **Arabian Sea** and issued alerts for **Cyclone Montha over the southeast Bay of Bengal**, the third severe storm after Asani (2022) and Michaung (2023) to hit Andhra Pradesh.
- Tropical cyclones** are low-pressure storms that form over warm waters above 27°C.
- While the Bay of Bengal sees more cyclones due to higher sea surface temperatures, the **Arabian Sea has become increasingly active**, with warmer waters causing rapid intensification of storms like **Tauktae (2021) and Biparjoy (2023)**.
- In the Indian Ocean, cyclones are named from a pre-approved list contributed by countries in the region under the **World Meteorological Organization (WMO) – ESCAP Panel on Tropical Cyclones (PTC)**.
- Names are **used sequentially and retired if a cyclone is particularly destructive**.

## II. Oceanography

### B. Marine & Coastal Processes

#### India's Coastline Measurement

- India's coastline has been remeasured at **11,098 km**, up from **7,516 km**, showing a **48% increase** due to more accurate methods. The earlier measurement used **low-resolution maps at**

a scale of **1:4,500,000**, which missed finer coastal features.

- The revised length is based on **high-resolution data (1:250,000 scale)** and modern **Geographic Information System (GIS)** technology, which maps land features precisely and includes previously excluded **offshore islands**.
- India's coastline **expanded by almost half in just over five decades** according to a Ministry of Home Affairs report.

- The expansion is due to a **new measurement approach** that accounts for complex coastal features like **bays, estuaries, and inlets**, replacing older straight-line methods.
- Accordingly, India's coastline expanded by **47.6%**, growing from **7,516 km (1970) to 11,098 km (2023-24)**.
  - Gujarat** saw the largest increase, nearly doubling from **1,214 km to 2,340 km**.

- West Bengal** had the highest percentage rise (**357%**), from **157 km to 721 km**.
- Puducherry's** coastline shrank by **10.4%**.
- Unlike older methods that relied on **straight-line distance measurements**, the scientifically updated approach incorporates the **measurement of complex coastal formations** such as bays, estuaries, inlets, and other geomorphological features.

Length of India's coastline along states	
State/UT	Coastline length (in km)
Gujarat	2,340.62
Maharashtra	877.97
Goa	193.95
Karnataka	343.3
Kerala	600.15
Tamil Nadu	1,068.69
Andhra Pradesh	1,053.07
Odisha	574.71
West Bengal	721.02
Daman and Diu	54.38
Pondicherry	42.65
Lakshadweep	144.8
Andaman and Nicobar	3,083.50

Source: Ministry of Ports, Shipping and Waterways

## NEW PARAMETERS

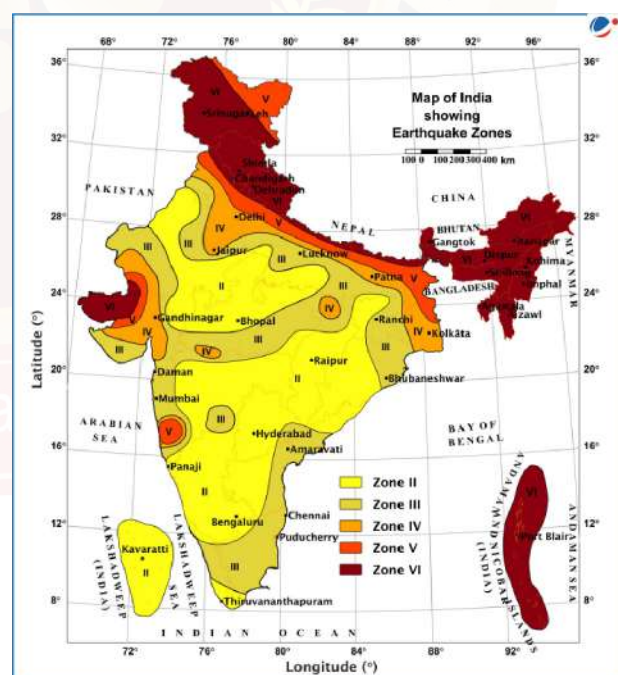
- While earlier method relied on straight-line distance, new one **factored in complex coastal formations such as bays, estuaries and inlets**
- Tamil Nadu's coast, with a revised length of 1,068km, has overtaken Andhra (1,053km)
- Puducherry's coastline shrinks 4.9km**, a departure from general upward revision

### III. Geomorphology & Geophysics

#### C. India-Specific Geology

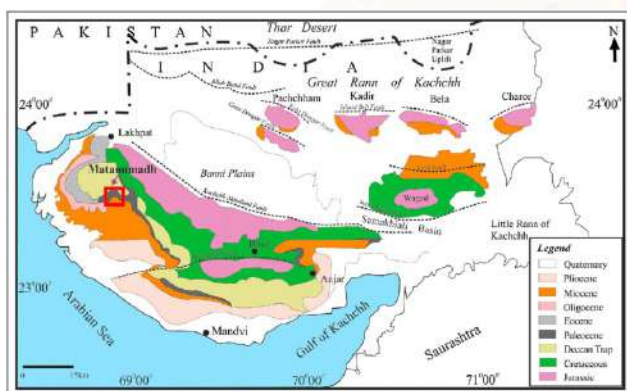
##### India's seismic zonation map

- India's **updated 2025 seismic zonation map** places the entire **Himalayan arc** in the new **highest-risk Zone VI**, with 61% of the country now in moderate to high hazard zones.
- The revision **accounts for long-unruptured fault segments**.
- The new code introduces an **"exposure window"** using the **PEMA (Population, Exposure, Mitigation, and Assessment) method**, factoring in population, infrastructure, and vulnerability to reflect both hazard and community impact.
- The Himalayas face major reclassification, while the **southern peninsula sees minor changes due to stable tectonics**.

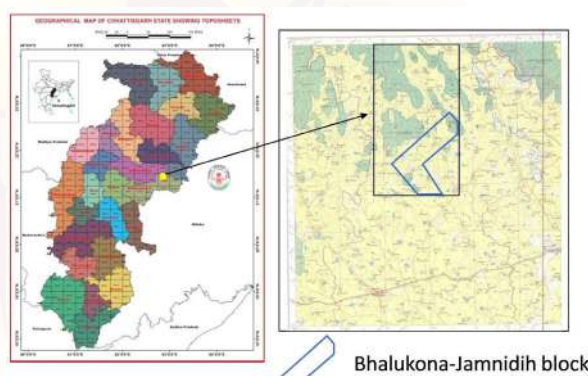


## Jarosite Discovery in Kutch

- **Matanomadh**, a remote village in **Gujarat's Kutch district**, has been identified by ISRO as a potential **test bed for its Mangalyaan-2 mission**.
- Located 100 km west of Bhuj, its **harsh terrain and sparse vegetation** make it similar to Mars.
- The village contains **jarosite**, a **rare iron-rich sulfate mineral** also found on Mars, formed millions of years ago from **volcanic ash mixing with marine water**.
- While **ISRO's Ladakh HOPE mission** simulates Mars-like living conditions at high altitude for crewed experiments, Matanomadh provides a site to study Martian-like geology and minerals.



- The Ni–Cu–PGE-associated block spans 3,000 hectares, around 70 km from Raipur.
- Geophysical surveys indicate the presence of **sulphide mineralization** extending up to 300 meters in depth, pointing to substantial resource potential,
- Adjacent to this discovery zone lies the **Kelwardabri Ni, Cr and PGE Block**.
- Ni–Cu–PGE deposits are formed from **magnas, specifically mafic (like basalt) and ultramafic (like komatiite)** rocks, which originate from the Earth's mantle.
- The Platinum Group Elements include platinum, palladium, rhodium, ruthenium, iridium, and osmium.
- These deposits are globally significant resources, with their **metals essential** for stainless steel, high-strength alloys, electrical infrastructure, catalytic converters, electronics, and emerging technologies like electric vehicle batteries.



## Bhalukona–Jamnidih Block

- A potential **Nickel–Copper–Platinum Group Elements (Ni–Cu–PGE) mineral zone** has been recently discovered in the Bhalukona–Jamnidih block of **Chhattisgarh**.

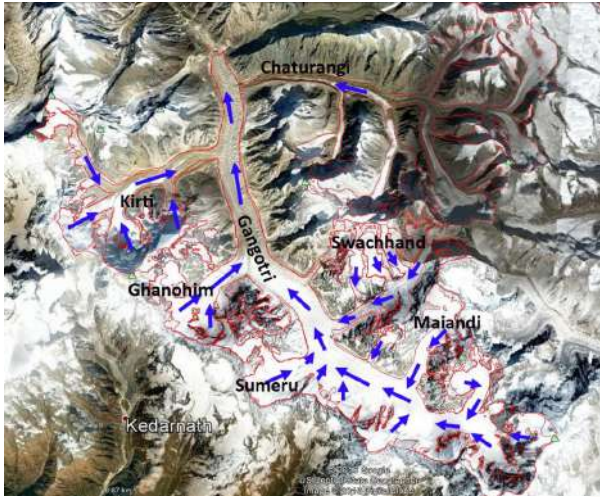
## IV. Hydrology & Water Resources

### Gangotri Glacier System (GGS)

- A study by IIT Indore and ICIMOD (Nepal) reveals that the Gangotri Glacier System (GGS), the **primary source of the Ganga**, has lost 10% of its snowmelt flow over 1980–2020 due to rising temperatures and climate change.
- It is located in **Uttarkashi** district of Uttarakhand within **Gangotri National Park**, is **one of the largest Himalayan glaciers**

originating from the northern slopes of the **Chaukhamba range**.

- It is a **compound valley glacier**, fed by several tributary glaciers like **Meru, Raktvarn, Chaturangi**, and **Swachand** glaciers.
- It is fed by peaks including **Shivling, Thalay Sagar, Meru**, and **Bhagirathi III** and it **terminates at Gaumukh**, from where the Bhagirathi River emerges and later joins the Alaknanda to form the Ganga at Devprayag.



## Groundwater Contamination in India

- The 2024 **Annual Groundwater Quality Report** by the **Central Ground Water Board (CGWB)** reveals alarming findings.
- Despite India's rivers and seasonal monsoons, it is groundwater that sustains most of the nation's domestic and agricultural needs.
- Over 85% of rural drinking water and 65% of irrigation water come from below the surface.

### Key Findings:

- Nitrates:** More than 20% of samples from 440 districts were contaminated with nitrates, largely due to the overuse of chemical fertilisers and leaching from septic systems.

- Fluoride:** Excessive fluoride was detected in over 9% of samples, causing widespread dental and skeletal fluorosis—particularly in Rajasthan, Andhra Pradesh, and Telangana.
- Arsenic:** Arsenic levels in parts of Punjab and Bihar far **exceeded the World Health Organization (WHO) limit of 10 µg/L**, increasing the risk of cancer and neurological disorders.

## Greening of Thar Desert

- The recent **“Greening of the Thar Desert”** report by researchers from India reveals a 38% rise in greening annually over the last two decades.
- It is largely driven by increased **monsoon rainfall, agricultural expansion, and groundwater resources.**
- Groundwater contributed 55%, while precipitation accounted for 45%.
- The **Thar Desert**, spanning **200,000 square kilometers** across **northwestern India** (Rajasthan, Gujarat, Punjab, and Haryana) and **southeastern Pakistan**, is known for hosting the world's highest population density for a desert.
- The region saw a **64% rise in precipitation** between 2001 and 2023.
- Additionally, there was significant agricultural growth, with **crop area** increasing by **74%** and **irrigated area** by **24%** from 1980 to 2015.

## Indian Bureau of Standards guidelines for contaminants levels in drinking water

Analyte	Unit	Limits		Health effects
		Acceptable	Permissible*	
Chloride (Cl)	mg/L	250	1000	Eye/nose irritation; stomach discomfort
Fluoride (F)	mg/L	1	1.5	Bone disease; children may get mottled teeth
Iron (Fe)	mg/L	1	None	Anesthetic effect; promotes iron bacteria
Nitrate (NO <sub>3</sub> )	mg/L	45	None	Blue baby syndrome
Arsenic (As)	µg/L	10	No relaxation	Skin damage; increased risk of cancer
Uranium (U)	µg/L	30	No relaxation	Increased risk of cancer; kidney toxicity
Electrical Conductivity (EC)	µS/cm at 25°C	750	3000	Anesthetic effect; cardiovascular complications



Source: Annual Ground Water Quality Report (2024) \* in absence of alternative source.

MONGABAY  
INDIA

## V. Environment, Climate Change & Sustainability

### Urban Aerosol Pollution and Clean Islands in Indian Cities

- A recent study on aerosol levels of 141 cities in India from **2003 to 2020** by IIT Bhubaneswar, has shed new light on **urban aerosol pollution patterns across India**.
- Urban aerosol pollution is the presence of **aerosols, ie, small, solid, or liquid particles suspended in the atmosphere within cities**.

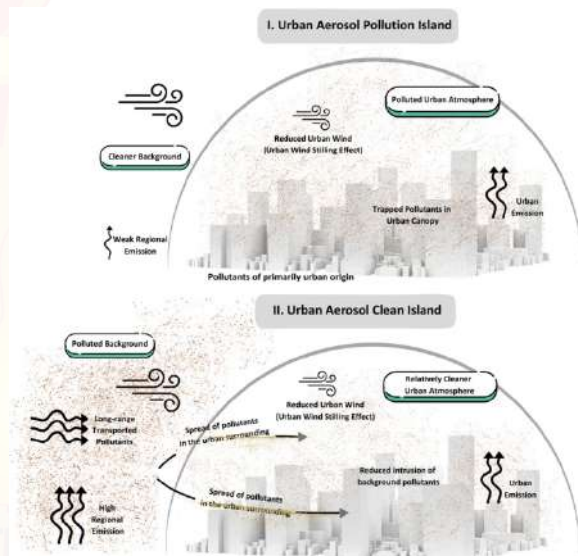
They are two types:

#### Urban aerosol pollution island :

- Cities with **higher aerosol levels** than their surroundings.
- This is caused by local pollution sources (like vehicles and industries) that get trapped by meteorological conditions, forming a “pollution dome.”
- These are primarily found in **south and southeast India**.

#### Urban aerosol clean island:

- Cities with **lower aerosol levels** than their surroundings.
- This is due to the “**wind stalling effect**,” where buildings weaken surface winds, slowing the entry of external pollutants from the highly polluted surrounding areas.
- These are mainly found in the northern Indo-Gangetic Plain (**IGP**) region.



## VII. Indian Institutions, Missions & Forecasting

### 150 years of IMD

- The India Meteorological Department (IMD), under the **Ministry of Earth Sciences**, celebrates 150 years of service since its establishment in **1875**.
- It was founded after disasters like the **1864 Calcutta cyclone** and monsoon failures (1871) highlighted the need for centralized meteorological services.
- IMD is one of the **six Regional Specialized Meteorological Centers (RSMCs)** recognized by the **World Meteorological Organization (WMO)** for issuing cyclone advisories in the **Indian Ocean region**.
- IMD uses **Doppler Radars** for real-time weather monitoring that feeds the **Numerical Weather Prediction** to prepare forecasts for short to medium range forecasts (up to 10 days) and extended range.

- IMD's **Vision-2047** aims for **zero-error** severe weather forecasts at the block level by 2047.

#### Advancements in Forecasting:

- ✓ **40% improvement** in forecast accuracy over the last decade.
- ✓ **INSAT 3DR & 3DS** provide round-the-clock weather monitoring.
- ✓ **Heatwave prediction** accuracy rose from 50% (2014) to **95%** (now).
- ✓ **Thunderstorm detection** improved from 50% (2017) to **86%** (hourly).
- ✓ **Heavy rainfall prediction** accuracy increased from 50% to **78%** (3 days in advance).
- ✓ **Cyclone track prediction** improved by **35-40%**, reducing human casualties to near zero.

## The Bharat Forecast System

### Precision technology

The BFS developed by the Indian Institute of Tropical Meteorology, aims at improving weather forecast models

#### EXISTING FORECAST MODELS

- Use square grids of 12-km sides to map a region
- Use equal-sized grids to map regions
- Able to give block-level forecasts 5 days ahead



#### BFS MODEL

- Breaks down a region into 6-km sides for mapping, leading to a four-fold improvement
- Uses a triangular-cubic octahedral structure
- Able to give forecasts up to the level of panchayats

- The India Meteorological Department (IMD) has adopted the **Bharat Forecast System (BFS)**, an advanced, indigenously developed weather model with a 6 km resolution—better than global models (9–14 km).
- Developed by **Indian Institute of Tropical Meteorology (IITM), Pune**, BFS replaces the older 12 km model and uses **powerful computers 'Arka' and 'Arunika'**.
- It offers 64% better accuracy, especially for **extreme weather, and delivers short-term (3 days), medium-term (7 days), and nowcasting (2 hours) forecasts**.
- The system **utilizes a Triangular-Cubic Octahedral (TCO) grid structure**, focusing higher resolution over tropical regions like India.
- It also includes data from a network of **40 Doppler Weather Radars (expandable to 100)**.

## Mission Anveshan

- The Centre is considering extending **Mission Anveshan** to incentivize seismic surveys of sedimentary basins for mapping of oil and gas deposits by another year.
- Launched in fiscal year 2025, the programme aims to boost **energy security by identifying new reserves**.
- Under it, the government gives **incentives to state-run companies Oil and Natural Gas Corp. Ltd (ONGC) and Oil India Ltd** to carry out **'seismic data acquisition', processing, interpretation and mapping of oil and gas reserves**.

- It was launched in continuation of the **National Seismic Programme (NSP)** aiming at hydrocarbon resources in India's sedimentary basins.
- The goal is to assess the basins and highlight areas of hydrocarbon potential by conducting a **2D seismic survey in seven sedimentary basins**.
- These **basins** include Ganga-Punjab, Rajasthan, Saurashtra, Deccan Syncline, Cuddapah, Krishna-Godavari, and Chhattisgarh.

## National Deep Water Exploration Mission

- The Indian Prime Minister announced the **National Deep Water Exploration Mission** to boost offshore oil and gas discovery in deep waters, especially in the Andaman Sea and off the Andhra coast.
- The initiative, termed **"Samudra Manthan,"** aims for energy self-reliance by exploring high-potential areas, including those recently opened up in the Andaman-Nicobar basin.
- The mission will complement **India's Deep Ocean Mission** launched in 2021 by the Ministry of Earth Sciences (MoES) with an aim to **develop technologies for exploring** and sustainably utilizing the deep ocean's living and non-living wealth.
- Recently, nearly 1 million sq km of erstwhile **'No-Go' areas** along Andaman-Nicobar basin **have been opened up** for exploration and put up for bidding.
- Deep waters off the **Andhra coast and Andaman Sea** are considered high-potential exploration zones due to their **tectonic setting** and **proximity** to proven petroleum systems in Myanmar and North Sumatra, attracting global interest

## Delhi Artificial Rain Project

- The **Delhi Environment Department**, in collaboration with **IIT Kanpur**, plans to use **cloud seeding** to combat air pollution.
- **Cloud seeding** is a **weather modification technique** used to **induce or enhance rainfall** by dispersing certain chemicals into moisture-laden clouds.

- Delhi hopes to trigger **artificial rainfall** to wash out pollutants like **PM2.5 and PM10** by using a **modified Cessna 206-H aircraft**.
- The aircraft will disperse a mix of silver iodide, iodised salt, and rock salt into moisture-rich clouds—typically cumulus or nimbostratus—at altitudes ranging from **500 to 6,000 metres**.
- This process stimulates **raindrop formation**, allowing the rain to cleanse the polluted air below.
- Although **cloud seeding** has shown **mixed but measurable success** in other countries, it is being considered as a potential emergency measure to **improve Delhi's air quality**.

### Coalition for Disaster Resilient Infrastructure (CDRI)

- The 7th year of the International Conference on Disaster Resilient Infrastructure (ICDRI), organised by the **Coalition for Disaster Resilient Infrastructure (CDRI)**, was held recently in **Nice, France**.
- The theme of the conference: **'Shaping a Resilient Future for Coastal Regions.'**
- CDRI was launched by India at the **U.N. Climate Action Summit of 2019**.
- **Headquartered in New Delhi**, CDRI's Secretariat holds the status of an International Organization.
- CDRI's mission is, by **2050, to drive US\$10 trillion of new and existing infrastructure investments and services to be resilient** to natural hazards and climate change.
- This will be done through enhanced capacity, informed policy, planning, and management, thereby improving environmental quality, livelihoods, and overall well-being for more than 3 billion people worldwide.