**MAINS iMPACT 2026** **10-05-2026**

## ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC)

### SYLLABUS:

GS 1 > Geography > Oceanography

### REFERENCE NEWS:

- Scientists are increasingly concerned about the weakening of the Atlantic Meridional Overturning Circulation (AMOC), one of Earth's most important ocean current systems. A recent **2026 Science Advances study titled "Observational constraints project a ~50% AMOC weakening by 2100"** estimated that the AMOC could weaken by around **51 ± 8% by 2100**, with upper estimates close to **59%**.

### MORE ON NEWS:

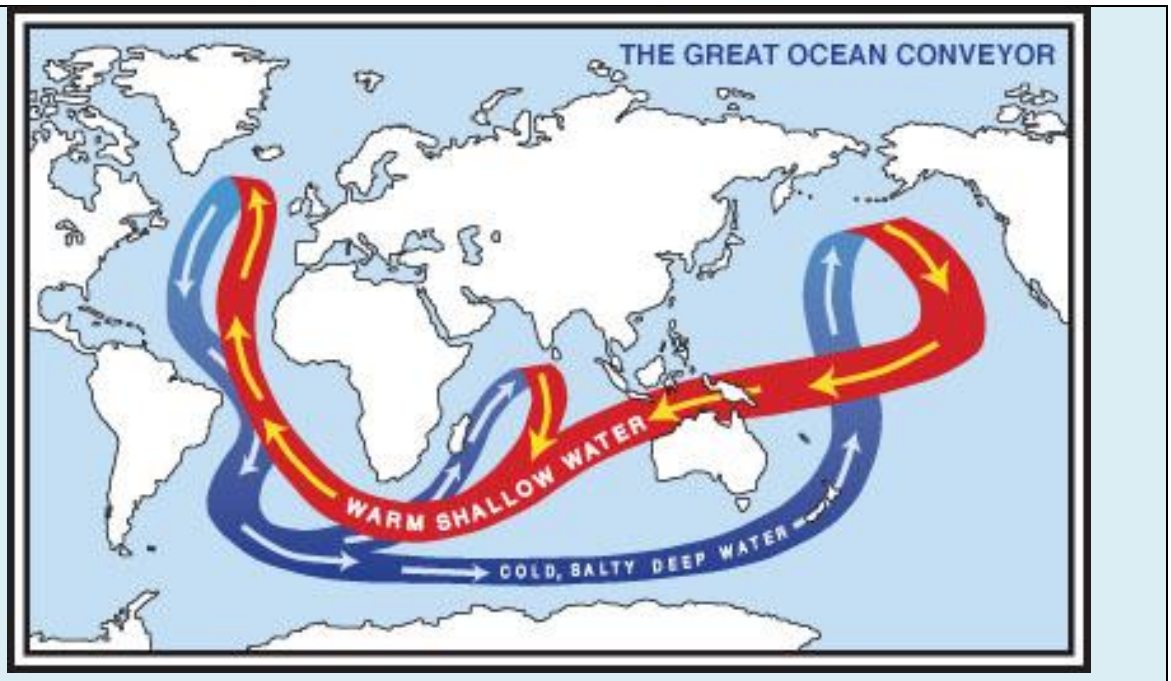
- Such a slowdown could fundamentally alter **global climate systems**, affecting **temperature patterns, rainfall distribution, sea levels and extreme weather events** across multiple continents.
- The issue is especially **important for India** because the **Indian summer monsoon**, the backbone of Indian agriculture, food security, rural livelihoods, and water availability, is **strongly influenced by global heat distribution and ocean-atmosphere interactions.**

### WHAT IS AMOC?

- The Atlantic Meridional Overturning Circulation (AMOC) is **the Atlantic branch of the ocean conveyor belt or Thermohaline circulation (THC),** and distributes heat and nutrients throughout the world's ocean basins.

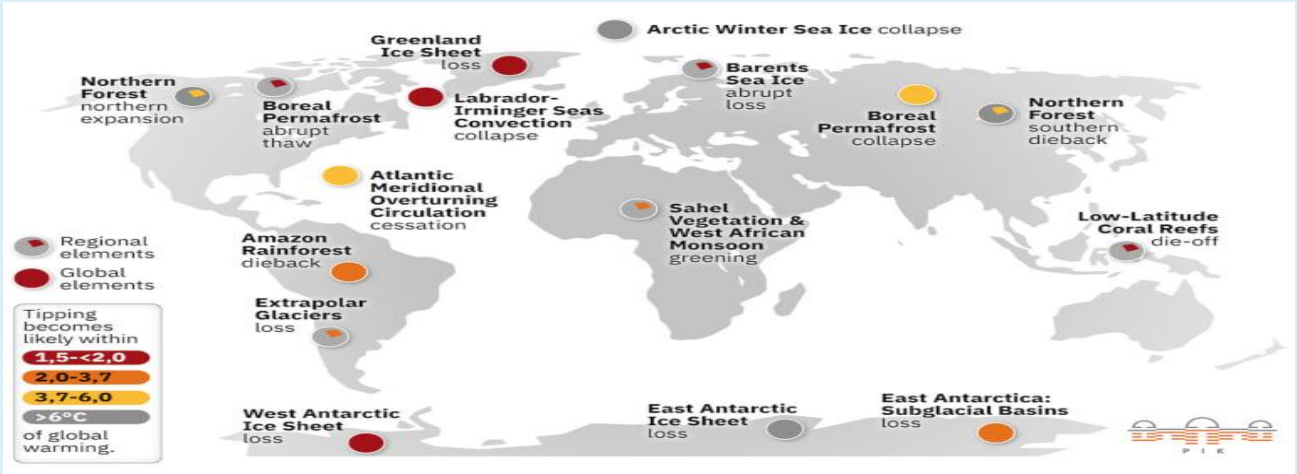
### THERMOHALINE CIRCULATION:

- Thermohaline circulation describes **the movement of ocean currents due to differences in temperature and salinity** in different regions of water.
- Temperature and salinity change the density of water, resulting in the water to move accordingly.
- **Cold water is usually denser than warm water** (4°C is where water is densest). **Water with a high salinity is also denser** than less saline water.
- Deep ocean currents are driven by differences in the water density, which is **controlled by temperature (thermo) and salinity (haline), hence the name "thermohaline circulation".** This process is **also sometimes to referred to as the "ocean's conveyor belt system".**
- Any major change to ocean circulation could have damaging effects on the water cycle and weather patterns




- A 2024 study by researchers from the University of Copenhagen, Denmark, published in Nature Communications, indicates that the Atlantic **Meridional Overturning Circulation (AMOC) is at risk of collapsing within the period from 2025 to 2095** due to the effects of human-caused emissions.
- The findings suggest that, given the current trajectory of emissions, the **likelihood of this event occurring in the 2050s is high**, with the scientists expressing 95 percent confidence in their prediction.If this prediction deems true, AMOC may be the **first of the 16 climate tipping elements to be breached.**

**Tipping elements** are large-scale systems that **influence the planet's climate and ecology**, which are undergoing changes due to warming and accumulation of greenhouse gases in the atmosphere from anthropogenic emissions. **If these elements cross certain thresholds** due to rise in temperature, **changes in them will become irreversible.**




**MECHANISM OF AMOC:**

- AMOC transports **warm salty surface waters from the tropics to the northern regions.**
- The waters then **cool down, increase in density and sink** in the North Atlantic Ocean, in a phenomenon called **downwelling or overturning.**

- Cold, fresh water from the melting ice of the Arctic is added to the cooler ocean that moves towards the equator. This cycle, therefore, acts like a **heat conveyor belt**, **warming the northern latitudes and cooling the southern latitudes.**
- The warm, **salty water of the Gulf Stream**, as part of the AMOC, **travels northward** from the Gulf of Mexico, along the eastern coastlines of the United States and Canada, and across the North Atlantic. This water warms the atmosphere above it, **contributing to warmer air temperatures in Northern Europe**. As the water cools, it **becomes denser and sinks in the North Atlantic**, driving the deep-water component of the circulation.

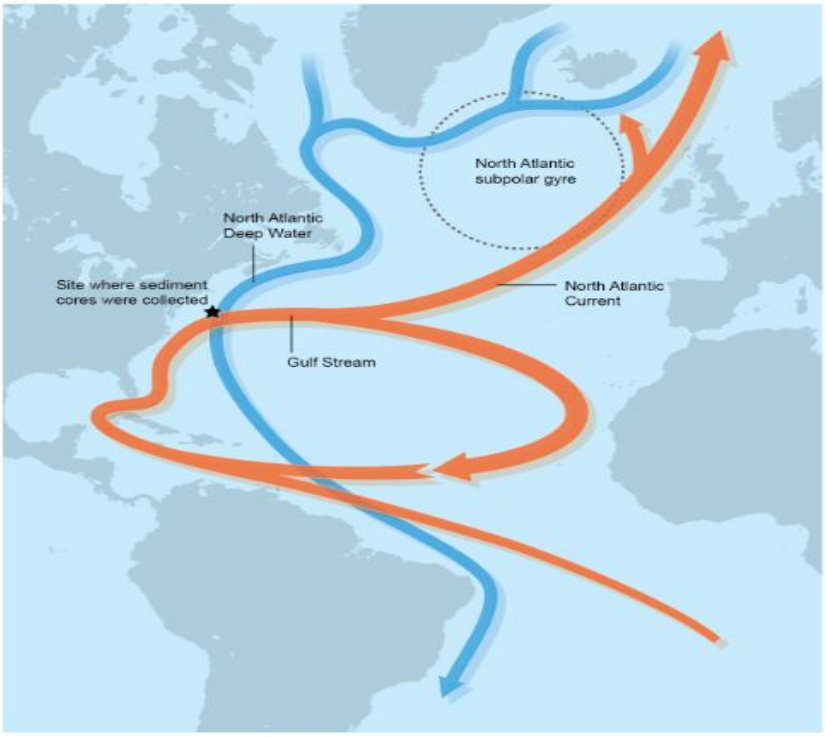


Fig. Outline of the North Atlantic part of the AMOC.

**SIGNIFICANCE OF AMOC:**

- **Climate Regulation**: The AMOC helps to regulate the climate of the North Atlantic and Europe. By transporting warm water northwards, it contributes to **milder winter temperatures in Western Europe** than would otherwise be expected at those latitudes.
- **Heat Exchange**: The AMOC is a key mechanism for the **global redistribution of heat.** It transports heat from the equator towards the poles and cold water from the poles back to the equator, helping to moderate global temperatures.
- **Carbon Dioxide Sequestration**: The AMOC plays a role in the global carbon cycle. Deep water formation in the North Atlantic is a process where surface water becomes dense enough to sink, which helps **sequester carbon dioxide from the atmosphere into the deep ocean.**
- **Influence on Weather Patterns**: The AMOC influences weather patterns across the North Atlantic and beyond. Changes in the strength or direction of the AMOC can **impact hurricane activity, rainfall patterns, and even droughts** in various parts of the world.
- **Potential for Abrupt Climate Change**: There is concern among scientists that significant alterations to the AMOC, such as a slowdown or shutdown, could lead to **abrupt changes in the climate system**. Historical evidence suggests that past changes in the AMOC have been linked to rapid climate shifts.
- **Impact on Marine Ecosystems**: The flow of the AMOC affects marine ecosystems by influencing **water temperature, salinity, and nutrient distribution** across the Atlantic. This can impact fish populations, coral reefs, and the broader biodiversity of the Atlantic Ocean.

- **Link with El Niño:** A weaker AMOC can disturb Pacific Ocean temperature balance and make **El Niño events more extreme or unpredictable**. This is important because El Niño often weakens the Indian monsoon.
- **Importance for Indian Monsoon:** AMOC weakening can **shift the tropical rain belt** southward, reducing moisture transport towards the Indian subcontinent and weakening summer monsoon circulation.

**CAUSES OF SLOWDOWN OF AMOC:**

- **Warming of cold North Atlantic deep water**:
  - Warming of cold North Atlantic deep water mass **due to global warming** has **adversely affected the vertical mixing** of water and thereby the AMOC.
- **Freshwater influx :**
  - The **freshwater from the melting of Greenland's ice sheet reduces the salinity and density of the water**.
  - As a result the **water is unable to sink as it used to** and weakens the AMOC flow.
- **Gulf Stream:**
  - Studies show that the **Gulf Stream,** a part of the Atlantic Meridional Overturning Circulation (AMOC) system, **has weakened substantially in the past decades**.
- **Higher rainfall and Arctic warming**:
  - Recent studies also point to **increased freshwater from rainfall** and Arctic warming as additional factors weakening North Atlantic sinking zones

**PROBABLE IMPACTS OF THE SLOWDOWN OR COLLAPSE OF AMOC:**

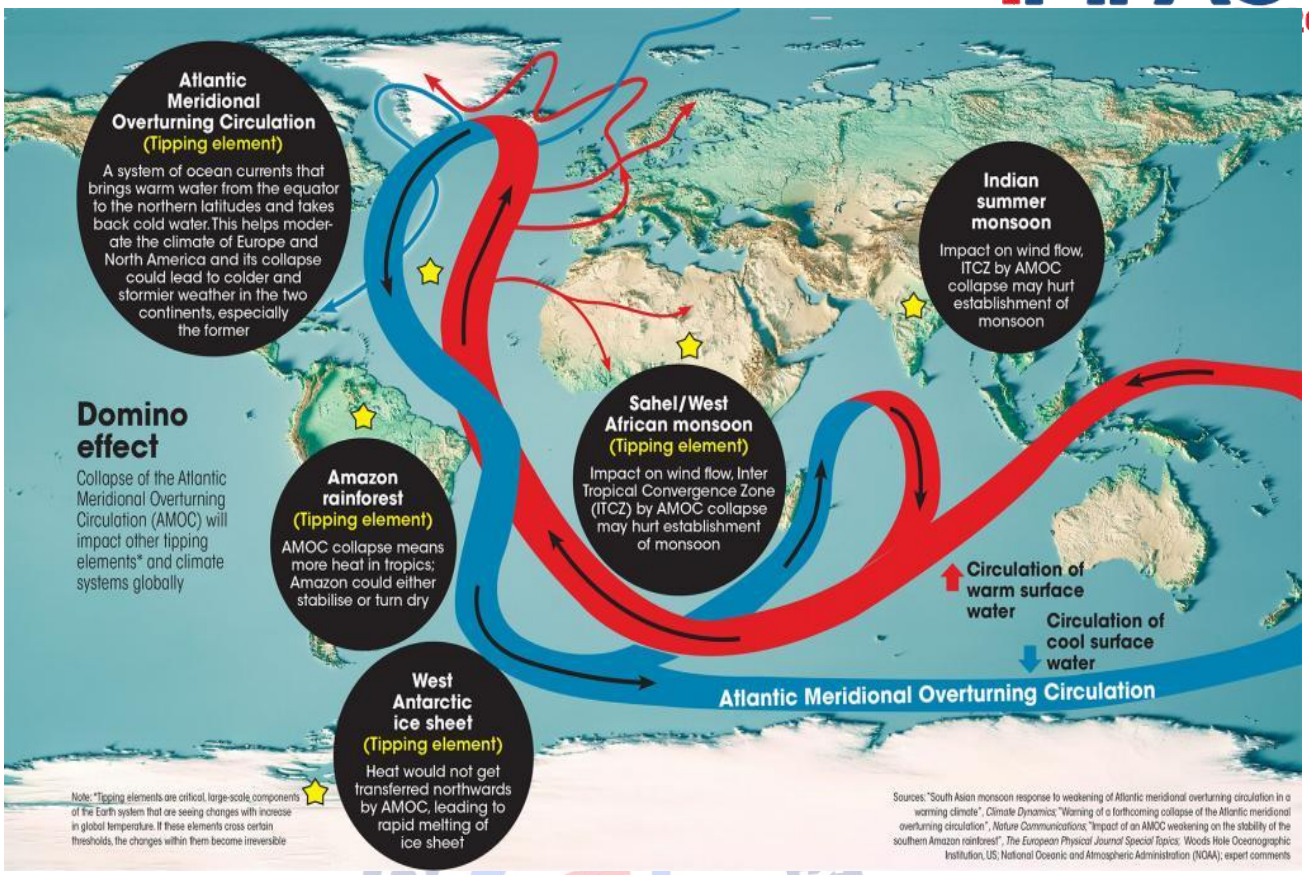
**Impact on Local Climate of Europe and North America:**

The AMOC's role in moderating the climate of Europe and North America is significant. A slowdown or collapse would likely lead to:

- **Decreased Temperature and Rainfall**: Europe could experience cooler temperatures and reduced rainfall, affecting agriculture, water supply, and general climate comfort.
- **Increase in Sea Ice**: The Greenland-Iceland-Norwegian seas could see an increase in sea ice coverage, altering marine habitats and possibly affecting shipping routes.
- **Increased Winter Storms**: Europe may face more frequent and intense winter storms, leading to increased damage and climate-related challenges.
- **Stronger Hurricanes in the US**: The shift in temperature gradients could lead to more intense hurricanes impacting the eastern coast of the United State
- **Sea-level rise along North America:** AMOC weakening can cause sharp **regional sea-level rise** along the North American Atlantic coast due to redistribution of ocean water. Some reports warn of extreme regional rise under collapse scenarios.

**Indirect Impacts:**

- **Shrinking of the West Antarctic Ice Sheet**: The redistribution of heat could accelerate ice melt in the Antarctic, contributing to sea-level rise.
- **Migration of the ITCZ and Tropical Rain Belt**: Shifts in these critical climate zones could alter rainfall patterns, affecting agriculture and water resources in the tropics and subtropics.




- **Warming of the Southern Ocean**: This could further contribute to Antarctic ice melt and global sea-level rise.
- **Disruption of Hemispherical Heat Transfer**: Affecting atmospheric pressure cells, wind patterns, and long-term climate processes, potentially altering weather patterns globally.

**Ecological and Broader Climate Impacts:**

- **Amazon Rainforest:** The collapse of the AMOC could lead to less rainfall over the Amazon, making it drought-prone and potentially **transforming it into a savannah-like ecosystem.** This would have profound effects on global biodiversity, carbon storage, and local climates.
- **Monsoon Systems:** The stability of monsoon systems in South Asia and West Africa could be compromised, impacting water availability and agriculture in regions that are home to billions of people. For example, the weakening of the summer monsoon circulation over the Indian region could alter agricultural productivity and water resource management in South Asia.
- **Global Climate Feedback Loops:** The AMOC's collapse could trigger or exacerbate **other climate tipping points**, leading to **cascading effects** across various ecosystems and climate systems.]

**PROBABLE IMPACT ON INDIA:**

- **Weakening of Indian Summer Monsoon:** AMOC slowdown can shift the tropical rain belt southward, reducing the strength of moisture-bearing monsoon winds reaching India.
- **Shorter Wet Season:** India may experience a shorter monsoon season, affecting sowing cycles, crop planning and kharif agriculture.
- **Longer Dry Spells:** A weaker AMOC may increase intra-seasonal breaks in monsoon rainfall, leading to longer dry periods during the rainy season.
- **Threat to Food Security:** Since Indian agriculture is heavily dependent on monsoon rainfall, erratic rainfall can reduce crop yields and affect rural livelihoods.
- **Water Security Stress:** Weak monsoon rainfall can reduce river flows, reservoir recharge and groundwater replenishment, increasing drinking water and irrigation stress.

- **El Niño Link:** AMOC weakening may make El Niño events more unpredictable or intense, further increasing the risk of deficient monsoon rainfall over India.
- **Extreme Rainfall Risk:** The impact may not be only drought. Erratic circulation can also produce sudden heavy rainfall events, causing floods, landslides and crop damage
- **Economic Impact:** Monsoon instability can affect agriculture, food inflation, hydropower generation, rural demand and overall economic stability.

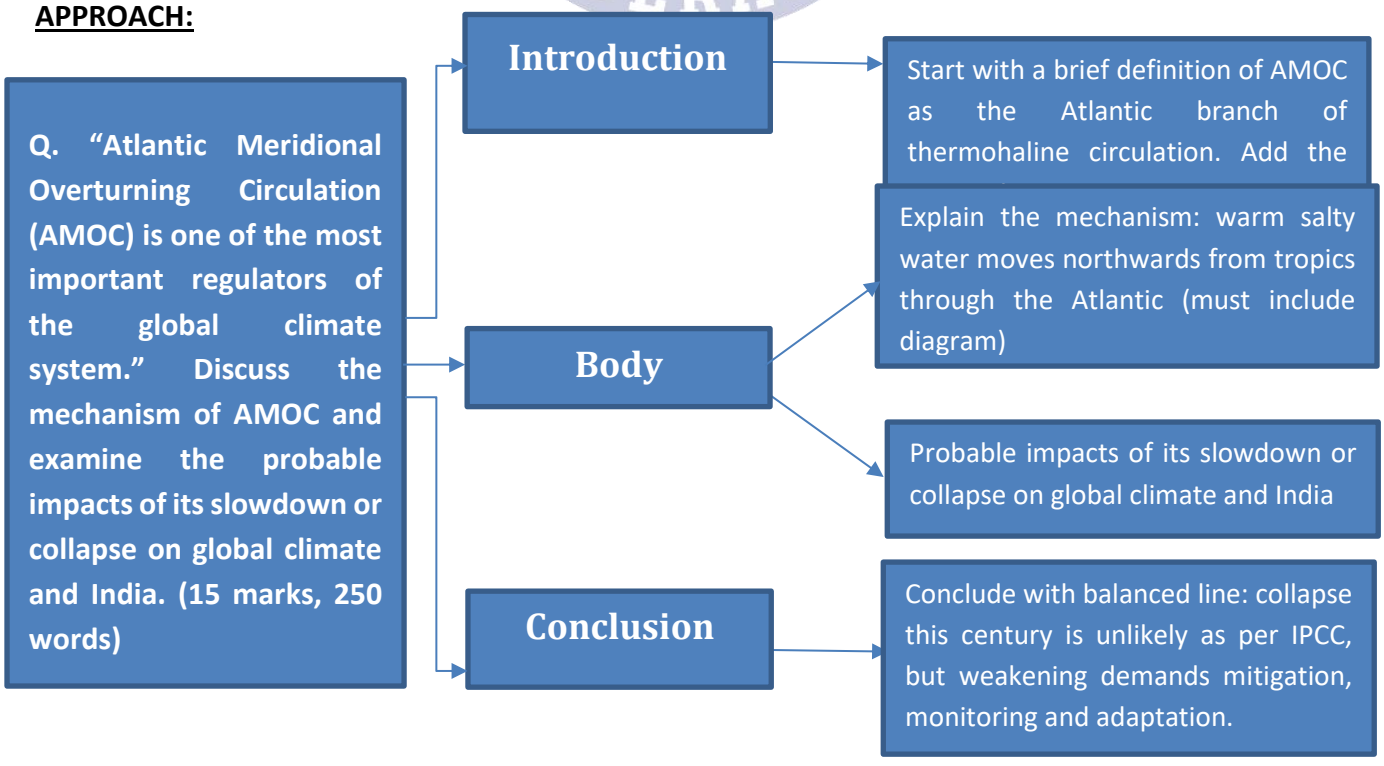
**CONCLUSION:**

- The AMOC is a critical climate-regulating system whose weakening can disturb global heat transfer, rainfall belts, sea levels and extreme weather patterns. Recent studies warning of nearly **51 ± 8% weakening by 2100** show that its stability can no longer be treated as a distant concern.
- For India, the risk is especially serious because AMOC slowdown may weaken the Indian summer monsoon, increase dry spells, disturb El Niño behaviour and threaten agriculture, water security and food security
- Although the IPCC assesses a complete AMOC collapse this century as unlikely, the emerging evidence highlights the need for stronger climate mitigation, improved ocean monitoring and better adaptation planning for monsoon-dependent countries like India.

**PRACTICE QUESTION:**

**Q. "Atlantic Meridional Overturning Circulation (AMOC) is one of the most important regulators of the global climate system." Discuss the mechanism of AMOC and examine the probable impacts of its slowdown or collapse on global climate and India. (15 marks, 250 words)**

**APPROACH:**




**MODEL ANSWER:**

The Atlantic Meridional Overturning Circulation (AMOC) is the Atlantic branch of the global thermohaline circulation, driven by differences in ocean temperature and salinity. It transports warm, salty surface water northwards and cold deep water southwards, acting as a global heat conveyor belt. A recent **2026 Science Advances study** estimated that AMOC may weaken by around **51 ± 8% by 2100**, with upper estimates close to **59%**.

**Mechanism of AMOC:**

AMOC begins when warm, salty surface **waters from the tropics move northwards** through the Atlantic. This includes the **Gulf Stream system**, which carries heat towards the North Atlantic and helps moderate Europe's climate.

As this water reaches higher latitudes near Greenland and the North Atlantic, **it cools down.** Cooling increases its density, and because it is salty, it **becomes heavy enough to sink**. This sinking process is called **downwelling or overturning**.

The cold, dense water then **flows southwards as a deep ocean current**. Eventually, it rises again in other ocean basins, warms up and continues the cycle. Thus, AMOC is driven by the combined effect of **temperature, salinity and density differences**.

**Global warming weakens this mechanism** because melting Greenland ice and Arctic ice add freshwater into the North Atlantic. Freshwater reduces salinity and density, making the water less capable of sinking. This slows the entire overturning circulation.

*<Include diagram provided in the article>*

**Probable Impacts on Global Climate:**

1. **Reduced Heat Transfer:** A slowdown would reduce northward heat transport, causing cooler conditions, reduced rainfall and harsher winters in parts of Europe.
2. **Expansion of Sea Ice:** The Greenland-Iceland-Norwegian seas may see increased sea-ice formation, affecting marine habitats, fisheries and shipping routes.
3. **Regional Sea-Level Rise:** North America may face increased sea-level rise along the Atlantic coast due to redistribution of ocean water under weaker circulation.
4. **Intensification of Storms:** Changes in Atlantic temperature gradients may intensify winter storms in Europe and strengthen hurricanes affecting the eastern United States.
5. **Shift in Tropical Rain Belt:** AMOC weakening can disturb hemispheric heat transfer and shift the Intertropical Convergence Zone and tropical rain belt southward, affecting rainfall in Africa, South America and Asia.
6. **Southern Ocean Warming:** A weaker AMOC may trap more heat in the Southern Hemisphere, warming the Southern Ocean and accelerating Antarctic ice melt.
7. **Ecosystem Disruption:** Changes in ocean temperature, salinity and nutrient distribution can affect plankton productivity, fish populations, coral systems and marine biodiversity.
8. **Tipping Point Risk:** AMOC slowdown may trigger other climate feedbacks such as ice-sheet melt, Amazon dieback and monsoon instability.

**Probable Impacts on India:**

1. **Weakening of Indian Monsoon:** India's summer monsoon depends on global heat distribution. A weaker AMOC can shift the tropical rain belt southward, weakening monsoon circulation.
2. **Reduced Moisture Transport:** Moisture-bearing winds from the Arabian Sea may weaken, reducing rainfall over the Indian subcontinent.
3. **Shorter Wet Season:** India may experience a shorter monsoon season, disturbing sowing cycles and kharif agriculture.
4. **Longer Dry Spells:** Intra-seasonal breaks in monsoon rainfall may increase, producing longer dry spells during the rainy season.
5. **Food Security Risk:** Erratic rainfall can reduce crop yields, affect rural livelihoods and increase food inflation.
6. **Water Security Stress:** Weak monsoon rainfall can reduce river flows, groundwater recharge and reservoir storage.
7. **El Niño Link:**AMOC weakening may make El Niño events more intense or unpredictable, further increasing the risk of deficient rainfall over India.
8. **Extreme Rainfall Risk:** The impact may not be only drought. Erratic circulation may also cause sudden heavy rainfall, floods, landslides and crop damage.

AMOC is a **critical regulator of global climate, rainfall belts, sea levels and ocean ecosystems**. Although the IPCC considers a complete collapse this century unlikely, recent evidence shows that AMOC weakening is a serious climate risk. For monsoon-dependent countries like India, it demands **stronger climate mitigation, ocean monitoring and adaptation planning.**