



DAILY EDITORIAL ANALYSIS

TOPIC

MONSOON PREDICTABILITY IN INDIA

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Monsoon Predictability in India

Context

- Rapid advances in AI, high-performance computing and climate science are opening new possibilities for predicting India's monsoon, even as climate change makes extreme rainfall increasingly difficult to anticipate.

About Monsoon Predictability in India

- The **Indian Summer Monsoon** is a highly complex climate system. Its behaviour is influenced by the **land–sea thermal contrast, sea-surface temperatures** in the Indian and Pacific Oceans, **Himalayan topography, atmospheric circulation, greenhouse gases and aerosols**.
- Monsoon predictability also depends on the time horizon.
 - ♦ **3–10 day forecasts** are crucial for farmers for sowing, irrigation and harvesting decisions.
 - ♦ **Sub-seasonal forecasts** help anticipate active and break phases of the monsoon.
 - ♦ **Decadal and long-term projections** are needed for infrastructure such as reservoirs, drainage systems and irrigation networks.
- A major difficulty is the difference in **scale between atmospheric models and actual rainfall processes**.
- **Convective clouds** responsible for much monsoon rainfall can be only a few kilometres across, whereas global climate models generally operate at much coarser spatial resolutions.
- Processes such as **cloud formation, turbulence and aerosol–cloud interactions** therefore have to be represented approximately.

Key Parameters Related to Monsoon Predictability

- **Land–Sea Thermal Contrast:** The differential heating of the Indian landmass and surrounding oceans drives the seasonal monsoon circulation.
- **Oceanic Conditions:** Sea-surface temperatures in the **Indian Ocean and Pacific Ocean**, including ENSO-related variability, influence monsoon circulation and rainfall.
- **Himalayan Topography:** The Himalayas act as a major barrier to atmospheric circulation and play an important role in shaping the South Asian monsoon.
- **Aerosols:** Aerosols from industrial activity, biomass burning and other sources can alter radiation and cloud microphysics. Their net influence on monsoon rainfall remains an important area of scientific uncertainty.
- **Atmospheric Moisture and Convection:** Rainfall depends strongly on moisture availability, atmospheric instability and the organisation of convective systems.
 - ♦ These small-scale processes are particularly difficult to simulate.

Need for Monsoon Predictability

- Improved prediction has direct consequences for **food, water and disaster security**.
- **For farmers**, reliable short-range forecasts can improve decisions regarding sowing, fertiliser application and irrigation.
- **For governments**, better predictions support reservoir management, flood preparedness and drought response.
- **Long-term projections** are equally important for urban drainage, bridges, reservoirs and other infrastructure constructed today may remain operational for several decades.
- Their design therefore needs to account for the possibility of more intense rainfall under a warmer climate.

Current Technologies and Measures

- **Numerical Weather Prediction:** The **India Meteorological Department (IMD)** combines observations with numerical weather prediction systems and other forecasting techniques.

- ♦ Satellite observations, weather radars, rain gauges and ocean observations improve the quality of initial atmospheric information.
- **AI and Machine Learning:** AI-based weather models are emerging as a promising complement to conventional numerical models.
 - ♦ They can learn atmospheric patterns from large historical datasets and, in some applications, generate forecasts much faster than traditional computational approaches.
 - ♦ Their potential applications include **rainfall forecasting, heat-wave prediction and subseasonal monsoon forecasting**.
 - ♦ However, AI models learn primarily from historical data, **creating difficulties** when predicting climatic conditions that have no close historical analogue.
- **High-Performance Computing:** India is expanding its computational capabilities through initiatives such as the **IndiaAI Mission** and high-performance computing infrastructure developed with institutions such as **C-DAC**.
 - ♦ The **growing availability of GPUs** is particularly relevant because the same hardware can support both AI models and newer climate-modelling approaches.
- **Hybrid Models:** The most promising long-term approach is likely to combine **physics-based climate models with AI/ML techniques**.
 - ♦ AI can help represent computationally difficult processes, while physical models provide the scientific framework required for projections beyond the historical climate.

Related Issues and Concerns

- **Model Bias:** Climate models have historically faced difficulties in accurately reproducing the spatial distribution of Indian monsoon rainfall, including biases over land and surrounding oceans.
- **Aerosol–Cloud Uncertainty:** The interaction between tiny aerosol particles, cloud droplets and rainfall involves processes occurring across vastly different spatial and temporal scales. These remain difficult to resolve directly.
- **Extreme Events:** The most severe heat waves and rainfall events are relatively rare in historical datasets. It limits the ability of purely data-driven AI systems to learn such events.
- **Future Climate Is Not the Past:** A warmer atmosphere can hold more moisture, increasing the potential for intense precipitation.
 - ♦ Research indicates that extreme rainfall can intensify substantially under global warming.
 - ♦ However, the **exact location, magnitude and timing of future changes in Indian monsoon rainfall remain uncertain**.
- **Onset and Active–Break Cycles:** Considerable uncertainty persists regarding future changes in monsoon onset, withdrawal and the frequency or duration of active and break phases.

Way Forward: For Long-Term Monsoon Predictability

- India needs a **‘predict better and build flexibly’** approach.
 - ♦ **Strengthen observations** through more rain gauges, **Doppler weather radars**, satellites and ocean buoys.
 - ♦ **Integrate** IMD, universities, research institutions and private-sector innovators.
 - ♦ Develop **high-resolution regional climate models** capable of better representing India's diverse geography.
 - ♦ Combine **AI with physics-based models** rather than treating them as competing alternatives.
 - ♦ Improve understanding of **aerosol–cloud–precipitation interactions**.
 - ♦ Produce **district-level climate-risk information** for planners and engineers.
 - ♦ Strengthen the last-mile delivery of forecasts through farmer advisories, mobile applications and early-warning systems.

- ♦ Adopt **adaptive infrastructure planning** so that drainage, reservoirs and flood-management systems can be upgraded as scientific projections improve.

Conclusion

- India's monsoon challenge is not simply about predicting whether it will rain. It is about knowing **when, where and how intensely it may rain, and how changes as the climate warms.**
- **AI and high-performance computing** can substantially improve short- and medium-range forecasting, but they cannot eliminate the uncertainties of long-term climate change.
 - ♦ Physics-based models, better observations and AI will therefore need to work together.
- **For the farmer**, the priority is a more useful forecast for the coming days. **For the engineer**, the priority is infrastructure that remains safe despite an uncertain future.
 - ♦ **India's climate resilience will depend on addressing both needs simultaneously.**

Daily Mains Practice Question

[Q] Discuss the major factors governing monsoon predictability in India. Examine the limitations of existing forecasting systems and suggest measures to improve short-term as well as long-term monsoon prediction.

Source: HT

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