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The Influence Of Multiyear La Niña On Rainfall Anomalies In South Bengal: A Review

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Abstract

South Bengal, encompassing the lower Gangetic plains and the Sundarbans delta, exhibits significant rainfall variability that profoundly affects its agriculture, ecology, and economy. This review synthesizes current understanding of how multiyear La Niña events influence monsoon rainfall patterns in this region. The literature indicates that La Niña's impact on South Asian rainfall is not uniform across consecutive La Niña years. During the first year of a multiyear event, rainfall anomalies over much of South Asia tend to be negative, with the notable exception of Bangladesh and the Sundarbans region of South Bengal, where positive anomalies occur due to localized moisture convergence. In the second year, widespread positive rainfall anomalies emerge across the South Asian monsoon region, driven by enhanced moisture transport from the Bay of Bengal via an anomalous cyclonic circulation and upper-level divergence. These findings have important implications for water resource management, agricultural planning, and disaster preparedness in South Bengal, particularly in the context of climate change and projected increases in multiyear La Niña frequency.

Key word: La Niña, South Bengal, monsoon rainfall, multiyear events, Bay of Bengal, climate teleconnections

1. INTRODUCTION

South Bengal, comprising the southern districts of West Bengal including the Sundarbans, is one of India's most climatically sensitive regions. The area's agricultural productivity, freshwater availability, and ecosystem health depend critically on the spatiotemporal distribution of monsoon rainfall. Interannual climate variability, particularly phenomena originating in the Pacific Ocean such as the El Niño-Southern Oscillation (ENSO), exerts a dominant influence on this rainfall regime.

La Niña—the cold phase of ENSO characterized by anomalously cool sea surface temperatures (SSTs) in the central and eastern equatorial Pacific—typically enhances the Indian summer monsoon. However, the relationship is more nuanced than a simple strengthening effect. Recent research has revealed that multiyear La Niña events, in which the phenomenon persists for two or more consecutive years, produce complex and evolving rainfall anomalies across South Asia.

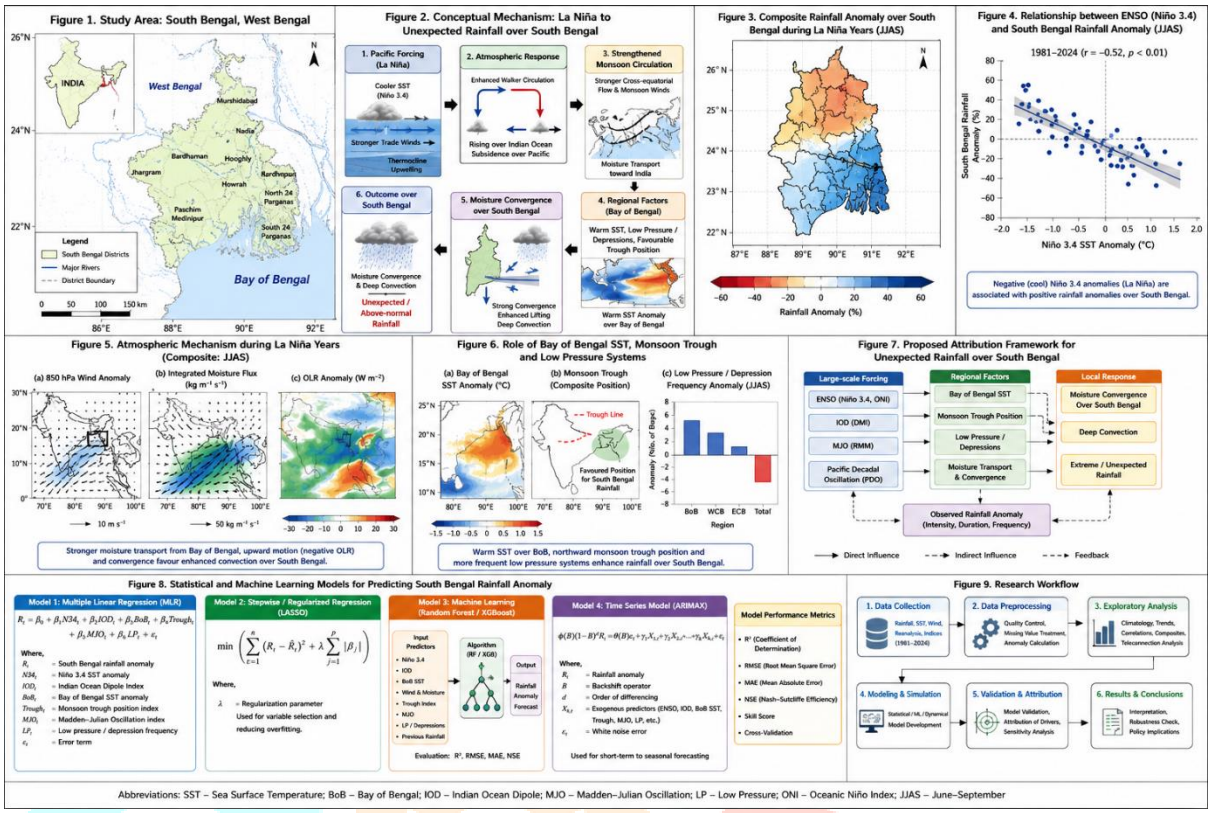

Fig.1: Study area map

This review examines the mechanisms through which multiyear La Niña events influence rainfall patterns in South Bengal. We synthesize findings from observational studies, reanalysis datasets, and climate model simulations to provide a comprehensive understanding of how these remote Pacific Ocean conditions translate into local rainfall outcomes. Particular attention is paid to the differing impacts between the first and second years of multiyear La Niña events, the role of the Bay of Bengal in modulating these effects, and the implications for regional climate resilience.

2. THE ENSO-MONSOON TELECONNECTION

The physical basis for ENSO's influence on the Indian summer monsoon lies in the modulation of the Walker circulation. During La Niña, enhanced convection over the maritime continent and the western Pacific, driven by warmer waters in that region, strengthens the ascending branch of the circulation over Southeast Asia. This, in turn, promotes moisture convergence and rainfall over the Indian subcontinent through atmospheric teleconnections.

However, this simplified framework belies considerable complexity. The ENSO-monsoon relationship is nonlinear, time-dependent, and influenced by other climatic modes such as the Indian Ocean Dipole and the Atlantic Niño. Furthermore, the specific response of regional rainfall—particularly over climatically sensitive areas like South Bengal—depends on local factors including land-sea temperature gradients, moisture transport pathways, and orographic effects.

3. MULTIYEAR LA NIÑA EVENTS: MECHANISMS AND CHARACTERISTICS

Multiyear La Niña events have become a focus of intense research interest, particularly as their occurrence frequency appears to be increasing. Observational records indicate that multiyear La Niña tends to follow strong El Niño events in the preceding year. The mechanism involves atmospheric conditions set in motion during the strong El Niño's decay phase.

Easterly wind anomalies along the northern off-equatorial Pacific during the decay phase act to discharge ocean heat content via anomalous northward Ekman transport. The resulting negative ocean heat content anomaly is sufficiently large that it cannot be fully restored by a single La Niña year, thereby setting the

stage for a second consecutive La Niña year. This persistence has significant implications for monsoon rainfall teleconnections, as the oceanic and atmospheric boundary conditions evolve between the first and second years.

4. LA NIÑA IMPACTS ON SOUTH ASIAN RAINFALL

4.1. First-Year La Niña Effects

Composite analyses of multiyear La Niña events provide a detailed picture of their rainfall impacts. During the first summer, La Niña-related SST cooling is most pronounced in the central and eastern equatorial Pacific. An Atlantic Niño-like pattern is also evident, which contributes to the remote influence on South Asian rainfall.

The rainfall response across South Asia during the first year is spatially heterogeneous. Negative rainfall anomalies are apparent over most of the South Asian region, contrary to the typical expectation of La Niña enhancing the monsoon. However, a critical regional exception exists: Bangladesh and the Sundarbans—the eastern and southern parts of the Bengal basin—experience positive rainfall anomalies.

This anomalous pattern is attributed to localized moisture convergence supported by low-level circulation features to the north of Bangladesh and over central India. The convergence creates conditions favourable for enhanced convection in this specific region, even as other parts of South Asia experience suppressed rainfall.

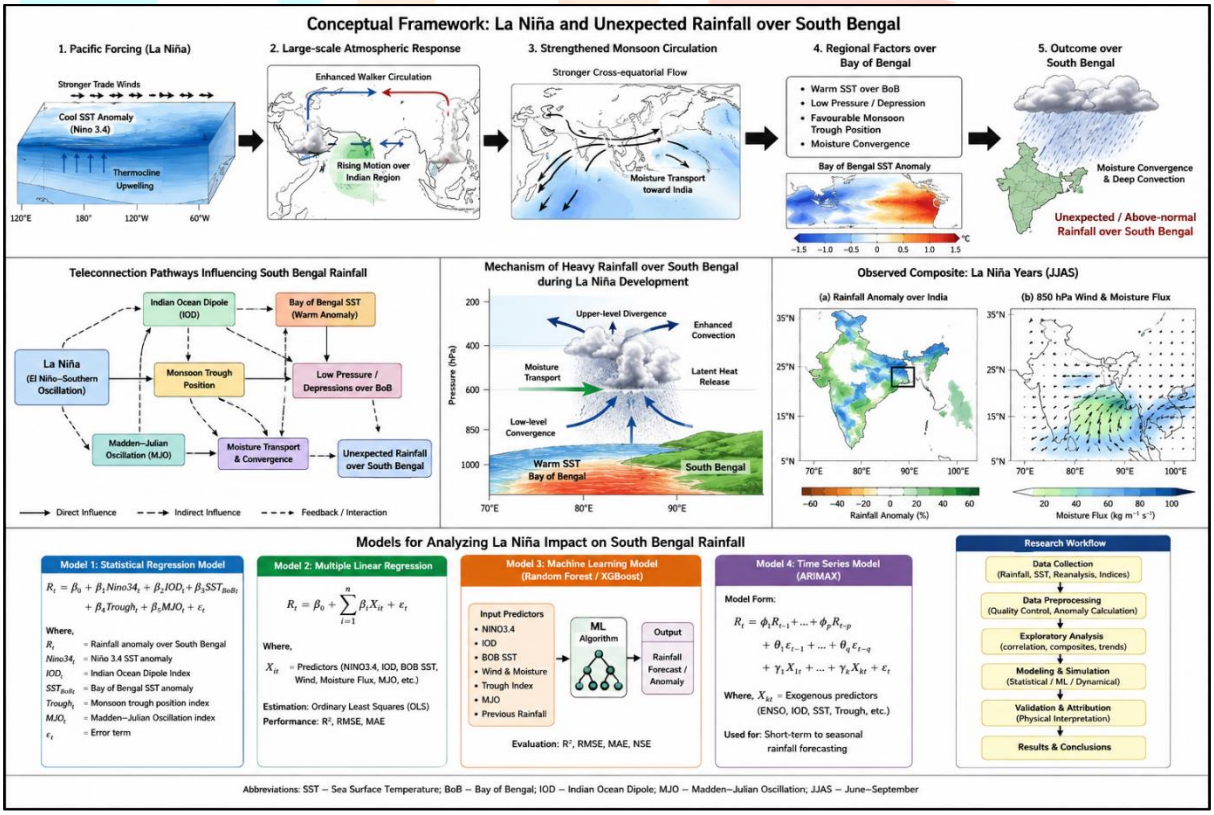

Fig.2: Showing

- La Niña/Pacific forcing
- Walker circulation and monsoon response
- Bay of Bengal SST and moisture transport
- Monsoon trough and low-pressure systems
- Moisture convergence over South Bengal
- Proposed mechanism for unexpected rainfall
- Statistical regression model

- Multiple linear regression
- Machine-learning model
- ARIMAX time-series model
- Complete research workflow

4.2. Second-Year La Niña Effects

The second year of a multiyear La Niña event presents a different picture. During this phase, the anomalous SST cooling shifts toward the south and south-central Pacific Ocean. The Atlantic Niño signature observed in the first year is largely absent in the second year.

Most significantly, positive rainfall anomalies become widespread across the South Asian monsoon region during the second year. This shift is driven by two principal mechanisms:

Enhanced Moisture Transport: An anomalous low-level cyclonic circulation develops over the central Bay of Bengal, which acts to enhance moisture transport into the Indian subcontinent. This circulation pattern funnels moisture-laden air toward the region, providing the necessary thermodynamic conditions for enhanced precipitation.

Strengthened Upper-Level Dynamics: An anomalous upper-level divergence extends from the southeast Indian Ocean toward the Indian subcontinent. This upper-level feature, a response to the second-year La Niña forcing, is notably weak in the first year. The combination of low-level moisture convergence and upper-level divergence creates a vertical structure highly favourable for convective activity and enhanced rainfall.

These findings suggest that the local circulation changes over the Bay of Bengal, in concert with remote La Niña forcing, are responsible for the distinct rainfall patterns observed between the two years.

5. SPECIFIC IMPLICATIONS FOR SOUTH BENGAL

South Bengal's location, at the interface of the Gangetic plain and the Bay of Bengal, makes it uniquely susceptible to the circulation changes associated with multiyear La Niña events. The following specific implications emerge from the literature:

Flood Risk: During the first La Niña year, while much of South Asia experiences drought-like conditions, the South Bengal region (particularly the Sundarbans and adjacent districts) receives above-normal rainfall. This localized enhancement, combined with the region's low-lying topography and tidal influences, elevates flood risk. During the second year, the widespread positive anomalies further amplify this risk across the entire region.

Agricultural Impacts: The cropping calendar in South Bengal, dominated by kharif (monsoon) rice cultivation, is highly sensitive to rainfall timing and intensity. The contrast between negative anomalies elsewhere in South Asia and positive anomalies in South Bengal during the first La Niña year creates a distinctive risk profile that requires localized agricultural planning rather than region-wide strategies.

Ecosystem Stress: The Sundarbans mangrove ecosystem, a UNESCO World Heritage site, depends on a delicate balance of freshwater influx from rainfall and upstream river flow. Enhanced rainfall during La Niña years, particularly if sustained across multiple years, can alter salinity gradients and affect mangrove health and the fisheries that depend on this ecosystem.

Interaction with Climate Change: Long-term precipitation reconstructions indicate that the late twentieth century witnessed unprecedented increases in precipitation relative to the past 438 years. Whether this trend reflects enhanced La Niña impacts under climate change remains an open question. However, projections

of increased multiyear La Niña frequency suggest that the rainfall anomalies described in this review may become more common in the coming decades.

6. MODEL REPRESENTATION AND UNCERTAINTIES

Climate models are essential tools for understanding and projecting La Niña impacts. However, significant uncertainties remain. Studies examining CMIP5 model performance in simulating multiyear La Niña teleconnections have found that while some models successfully reproduce South Asian rainfall and circulation anomalies during the second La Niña year, most fail to do so for the first year.

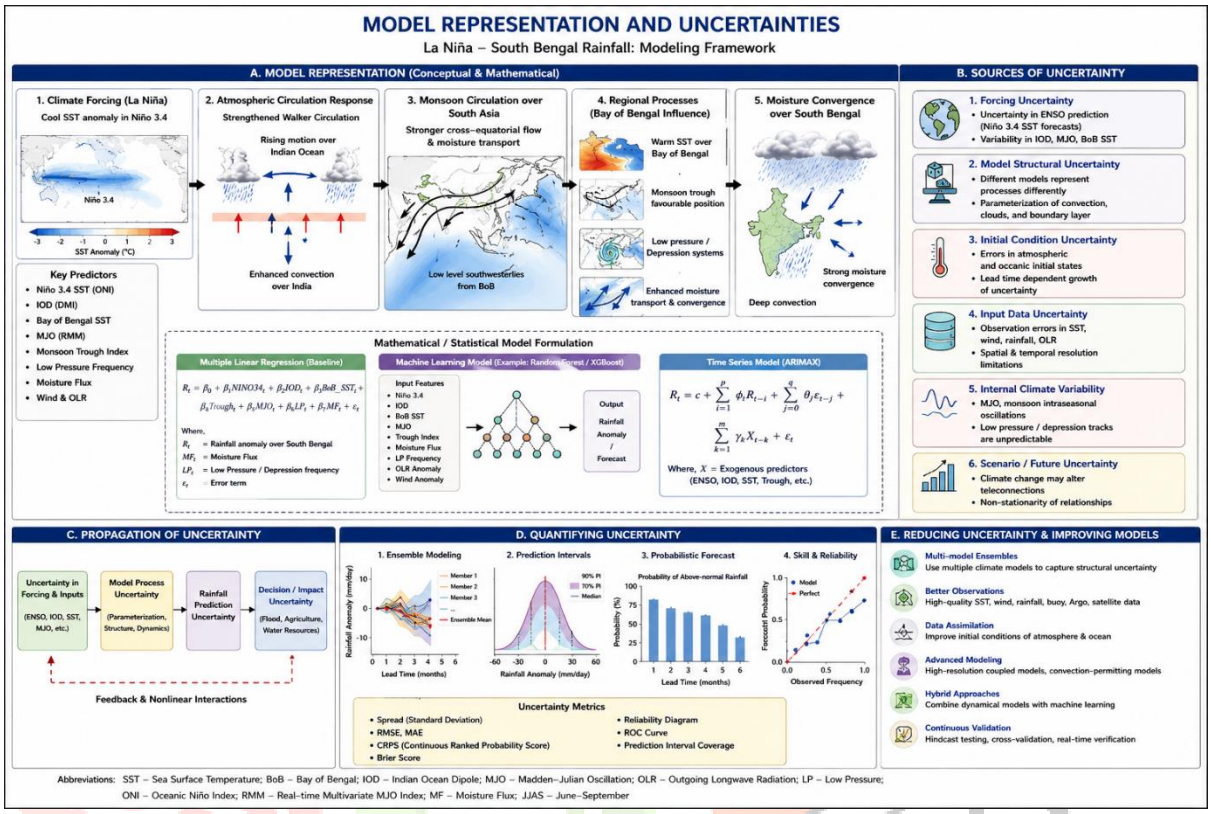

Fig.3: Model representation and uncertainties

Several factors are thought to contribute to this model weakness:

1. **Inadequate representation of the Atlantic Niño influence**: The Atlantic Niño-like pattern observed in the first year is difficult for many models to simulate realistically, given the limited resolution and physical parameterizations.

2. **Local circulation biases**: Models often struggle with the accurate representation of Bay of Bengal circulation features, particularly the low-level cyclonic circulation that drives moisture convergence in the second year.

3. **Ocean-atmosphere coupling delays**: The temporal evolution of SST anomalies and their atmospheric response may be misrepresented in some coupled models.

These limitations underscore the need for continued model development and the use of multi-model ensembles to assess the robustness of projected changes.

7. CONCLUSION AND FUTURE DIRECTIONS

The influence of multiyear La Niña events on South Bengal rainfall is characterized by a dynamic, two-year evolution of impacts. The first year brings localized positive anomalies to Bangladesh and the Sundarbans, while the second year delivers widespread positive anomalies across the entire South Asian monsoon region. These patterns are driven by evolving Pacific SST anomalies, changing influences from the Atlantic, and shifting circulation features over the Bay of Bengal.

For the South Bengal region, these findings have immediate practical relevance for:

- **Disaster preparedness**: Early warning systems should account for the differing impacts between first and second La Niña years.

- **Water resource management**: Reservoir operations and irrigation planning must anticipate the spatial heterogeneity of rainfall anomalies.

- **Agricultural adaptation**: Cropping strategies may need to be differentiated according to whether the region is experiencing the first or second year of a multiyear event.

Future research should focus on several priority areas. First, the role of the Indian Ocean Dipole in modulating the La Niña teleconnection to South Bengal requires further investigation. Second, high-resolution downscaling studies are needed to better resolve local-scale rainfall variability. Third, projected changes in multiyear La Niña frequency under different emission scenarios should be assessed using the latest CMIP6 models. Finally, the specific impacts on the Sundarbans ecosystem and the livelihoods dependent upon it warrant dedicated study.

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