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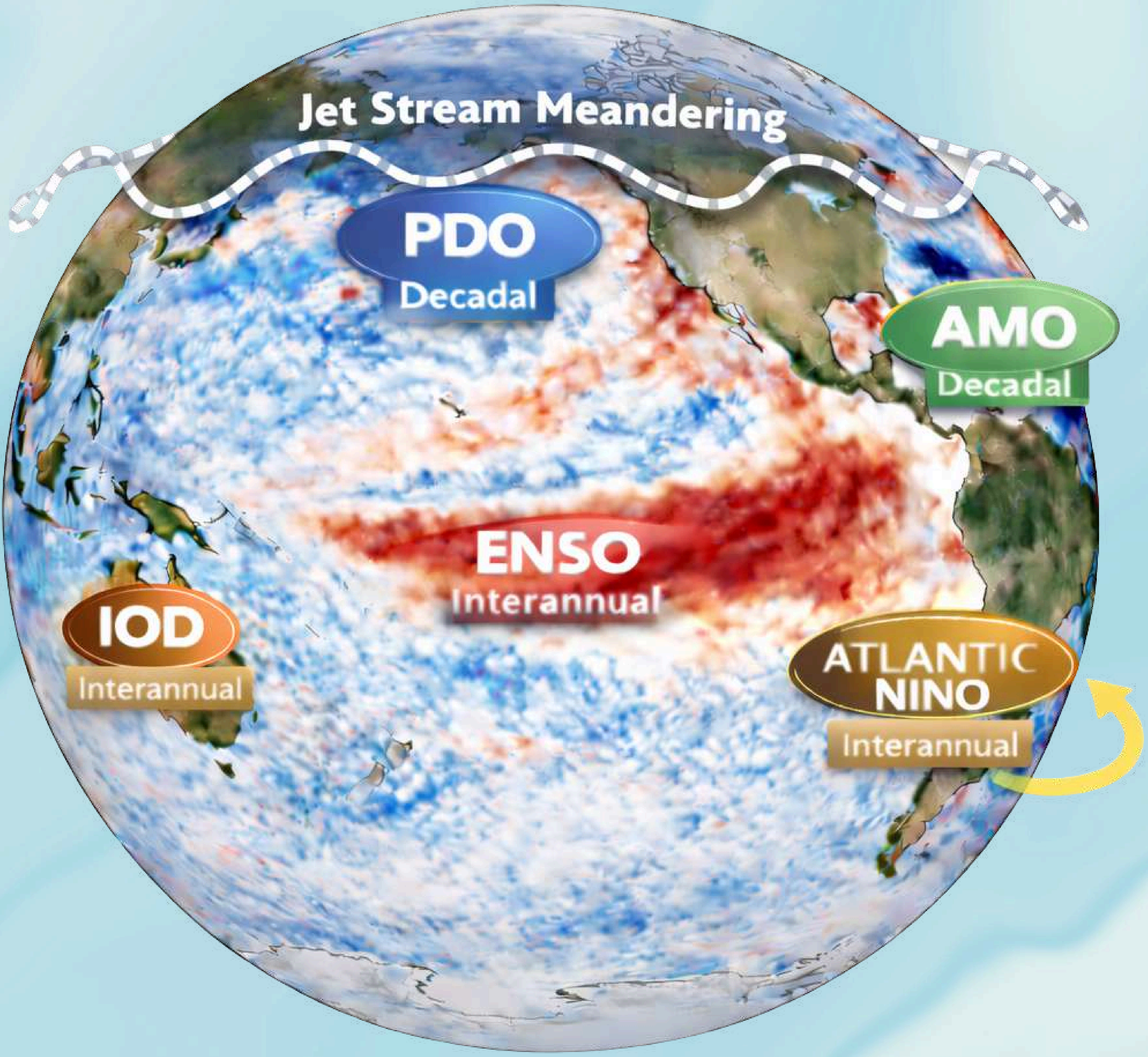

Global climate modes–ENSO, IOD, PDO, IPO, AMO, and Atlantic Niño– shape weather and ocean patterns across the tropics and beyond. Their interactions ripple through rainfall, temperature, and monsoon variability, reminding us how deeply interconnected our planet's systems are.

Ocean Digest

Volume 13, Issue 1, January 2026

From the Editors' Desk

As the calendar turns to a new year, the ocean and atmosphere remind us that transitions are never merely dates on paper—they are pulses of nature, rhythms that shape our lives. The first quarter of 2026 has already unfolded with striking contrasts: an unusually snowy winter across vast stretches of the northern hemisphere, including parts of India, now giving way to the gentle bloom of spring. Rising temperatures are not just a seasonal delight; they are the subtle prelude to the grand orchestration of the monsoon. The land–ocean temperature and pressure gradients, quietly building, set the stage for circulation patterns that sustain billions.

This issue captures that very pulse through the keen eyes of a young meteorologist. In our student article, readers will find an investigation into the long-term trends of this monsoon precursor- a study that bridges weather's immediacy with climate's enduring memory. It is a reminder that the curiosity of students often illuminates pathways for the future, and their voices deserve to be heard alongside seasoned scholarship.

Equally compelling is the invited article by an eminent paleo-biologist from the Birbal Sahni Institute of Paleosciences, Lucknow. With meticulous detail, the author takes us into the treasure trove of sediment deposits in the Andaman and Nicobar Islands. These deposits, rich in marine microfossils, are not just remnants of ancient seas; they are storytellers of epochs. From the Neogene Period, spanning 23.03 to 2.58 million years ago, to the late Holocene, they reveal monsoonal variations, sea-level fluctuations, and the chemical signatures of past oceans. In their silent layers lies a vivid chronicle of how the ocean has shaped—and been shaped by—the climate system.

Beyond research, this issue also celebrates community. The Ocean Society of India (OSI) announcements highlight one of our most cherished traditions: honoring the work of young oceanographers through recognition of their PhD theses and postgraduate dissertations. These acknowledgments are more than ceremonial; they are affirmations that the future of ocean science rests in capable hands. Alongside, we recount the spirited celebration of World Meteorological Day, a reminder that the ocean and atmosphere are inseparable partners in sustaining life on Earth.

Together, these contributions—student insights, scholarly explorations, and community celebrations—form the tapestry of this issue. They remind us that the ocean is not a distant entity but a living system intertwined with our climate, culture, and collective future.

As we step into the rest of 2026, Ocean Digest extends an open invitation to the ocean community: researchers, educators, policymakers, and citizens alike. Let us come forward, share knowledge, and act with resolve. The endeavor to maintain a sustainable ocean environment is not the responsibility of a few—it is the calling of all. By safeguarding our seas, we safeguard our planet.

May this issue inspire dialogue, collaboration, and above all, commitment. The ocean awaits our stewardship; let us answer with unity and purpose.

The Editorial Team

Cover page:

Climate modes exert a profound influence on the global climate system across multiple spatial and temporal scales. Among these, the El Niño–Southern Oscillation (ENSO) is the dominant mode of climate variability on interannual timescales. ENSO significantly modulates atmospheric circulation, sea surface temperatures, and precipitation patterns worldwide. It is well established that global mean surface temperatures tend to increase during El Niño events, while La Niña phases often produce cooling effects.

ENSO also plays a crucial role in driving rainfall variability and temperature extremes across diverse regions, including the tropics, subtropics, and extratropics. However, ENSO does not operate in isolation; it often co-occurs and interacts with other major climate modes such as the Indian Ocean Dipole (IOD), Pacific Decadal Oscillation (PDO), Interdecadal Pacific Oscillation (IPO), and Atlantic Niño. These interactions can amplify or dampen climate anomalies, leading to complex and sometimes nonlinear impacts.

While ENSO operates on interannual timescales, modes such as PDO, IPO, and the Atlantic Multidecadal Oscillation (AMO) evolve on decadal to multidecadal timescales and act as modulators of regional climate variability. Over India, these modes exert a substantial influence on the Indian Summer Monsoon. Typically, El Niño events are associated with suppressed monsoon rainfall. However, when El Niño co-occurs with a positive IOD event, the adverse impact on monsoon rainfall can be mitigated, often resulting in near-normal precipitation.

Similarly, the combined influence of strong El Niño events and certain phases of the PDO can alter large-scale circulation patterns, including shifts in the subtropical westerly jet streams, thereby affecting monsoon dynamics and rainfall distribution. These examples highlight the critical role of interactions among multiple climate modes in shaping regional climate variability.

Overall, the combined effects of interannual and decadal climate modes are not limited to India but extend across tropical, subtropical, and extratropical regions, underscoring the importance of understanding their coupled behavior for improved climate prediction and risk assessment.

Figure credit: Jasti S. Chowdary, Shreyasi Upadhyay and team, CVP group, IITM, Pune.

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Invited Article

Sedimentary rocks of Andaman and Nicobar Islands: A treasure trove for the signatures of past climatic events

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Abstract

The sediments deposited in the Andaman and Nicobar Islands of northeastern Indian Ocean archives rich, well-preserved and diverse marine microfossils that are unique for the determination of age and also for the reconstruction of past climate, specifically during the Neogene Period (23.03 to 2.58 Ma) and the late Holocene (4.2 kyr BP to Present). These microfossils recorded from the outcrops on different islands and recovered from deep-sea sediment cores provide valuable information regarding monsoonal variations, sea level fluctuations, sea surface temperatures, ocean acidification, and interactions of tectonic and climate. At present a tropical, humid climate, influenced by southwest and northeast monsoons prevails in this region. Climate reconstruction of the past few millenia is primarily based on proxy records retrieved from the isotopic studies of corals, speleothems as well as sediment cores. To understand the history of the Indian Summer Monsoon (ISM) and sea-level changes in this region these studies provide valuable insights.

Introduction

The Andaman and Nicobar Islands, a Union Territory of India comprises of about more than 800 islands and islets and out of these only 27 percent of the islands are inhabited. Many of these islands are restricted owing to the settlement of rare and primitive tribal population. The white sandy beaches and crystal-clear turquoise waters can be considered as the paradise for the tourists, however, in only in very few islands the tourism is developed and further development is on the way.

From geological point of view, the islandic arc of Andaman and Nicobar is more than 5000 km long, tectonically active, submerged mountain chain that extends from Myanmar in the north to Indonesia in the south. It is an ideal example of a major active accretionary prism and volcanic arc system that was formed by the subduction of the Indian Plate under the Asian Plate. These islands are flanked by Bay of Bengal in the west and Andaman Sea in the east that belongs to northeast Indian Ocean. A stretch of 5000 km long linear underwater mountain range known as Ninety East Ridge (NER) stretching north-south direction, almost parallel to the 90th meridian east, is located in the Indian Ocean extending from the Bay of Bengal down to the Southeast Indian Ridge. The formation of NER took place between 83 and 43 million years ago by the northward movement of the Indian-Australian plate over the Kerguelen hotspot.

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Historically Netaji Subhas Chandra Bose hoisted the flag of Indian Tricolour i.e., flag of Provisional Government of Free India or Azad Hind on December 29, 1943 at the Gymkhana Ground in Port Blair (recently renamed as Srivijayapuram), the capital city of the Indian Union Territory of Andaman and Nicobar Islands.

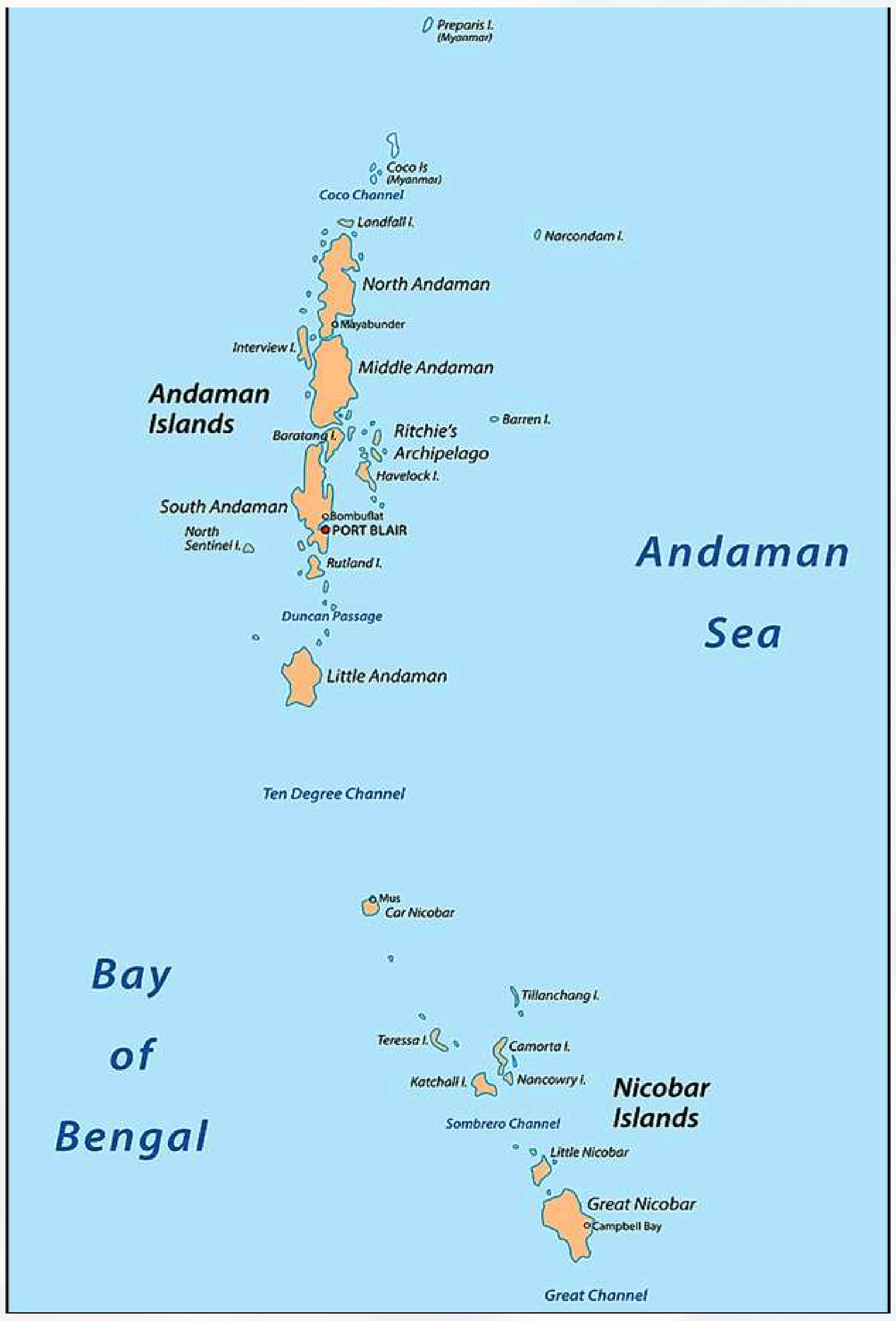

Fig. 1. Map of Andaman and Nicobar Islands (Source: World Atlas; https://www.worldatlas.com/islands/andaman-and-nicobar-islands)

This was marked as the first hoisting of Indian tricolour on Indian soil liberated from British rule, though, almost more than three years later India became independent. In fact, during World War II the Britishers evacuated these Islands owing to advancement of Japanese Forces and the Japanese ruled these islands during 1942 to 1945. Ultimately with the birth of independent India on 15th August 1947, the Andaman and Nicobar Islands were merged with the main stream India.

The Southwest Monsoon first hits the Andaman and Nicobar Islands in India. Around the third or fourth week of May the monsoon arrives in these islands, before it reaches mainland of India. In fact, the economy of India is dependent on agriculture and from this point of view active monsoon is essential. The onset of monsoon and its intensification in the peninsular region of India can be forecasted on the basis of monsoonal circulation in the Andaman and Nicobar Islands.

Present biodiversity

Exciting biological discoveries from the Andaman Islands reveal new and endemic species. Most likely plenty of secrets are still to be discovered. The marine invertebrate fauna is represented by more than 1200 species of fish, 350 species of echinoderms, 1000 species of molluscs, diverse foraminifers etc. The significant vertebrates are dugongs, dolphins, whales, salt water crocodiles, sea turtles, sea snakes, etc. The fringing coral reefs on the eastern coast and barrier type on the western coast harbour 179 species of corals belonging to 61 genera, though; coral bleaching is a threat in the Andaman Sea (Sarkar and Ghosh, 2013).

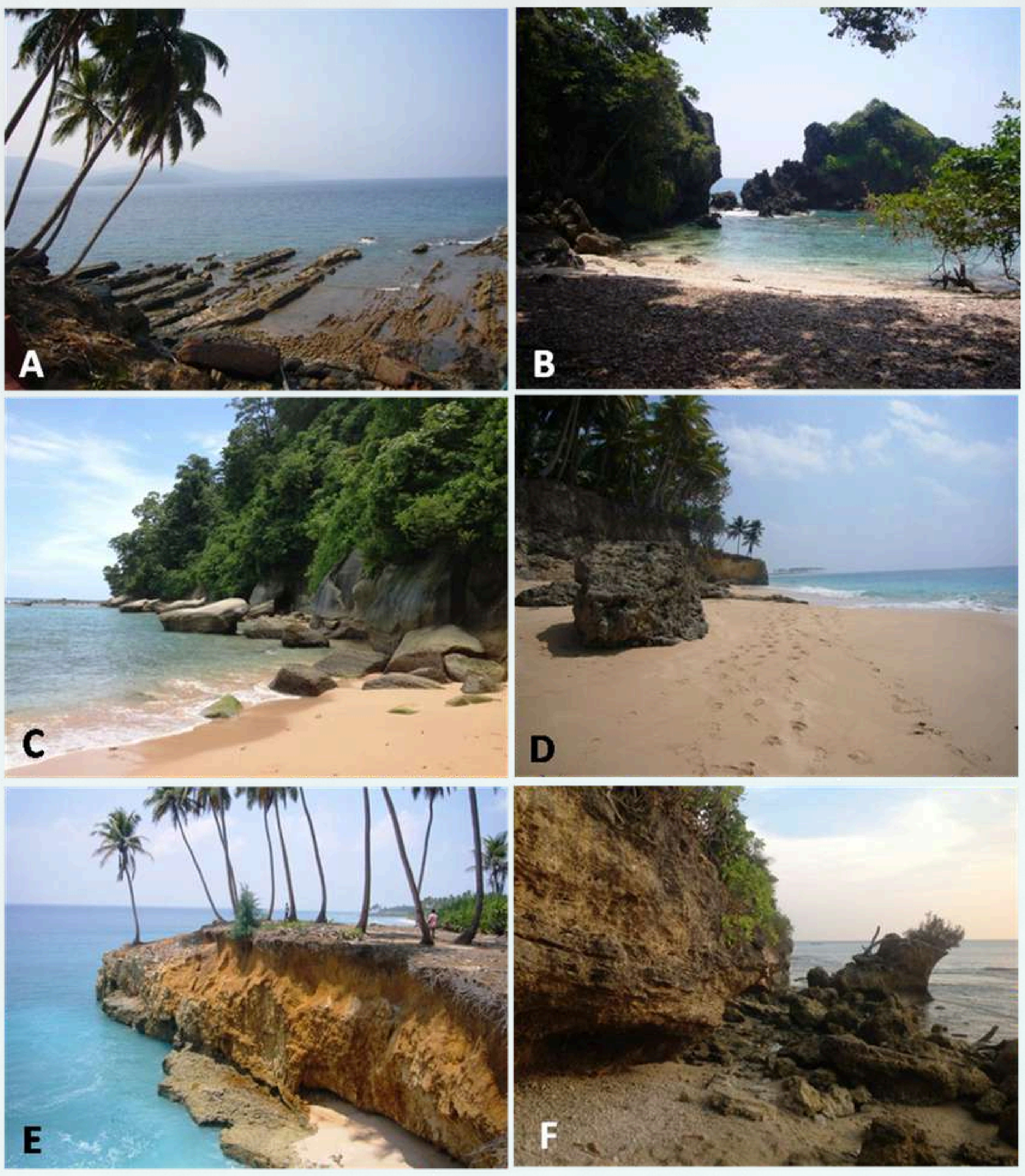

Fig. 2. A. Flysch sediments exposed on Port Blair; B. Middle Miocene sediments on Little Andaman (Hut Bay) Island, C. Late Miocene outcrop on Neil Island, D-E. Pliocene sediments exposed on Car Nicobar Island, F. Plio-Pleistocene outcrop on Neil Island. (Image credit: author).

Apart from corals, the benthic marine flora is also very much diversified and is preponderant with calcareous marine algae belonging to coralline red algae and variety of green algae alongside sea grasses. In addition, the plankton community is also diverse in this region as these are dominated both by phytoplankton and zooplankton. Basically, from the ecological and environmental point of view the coral reefs and coralline algae function as essential marine carbon sinks and are designated as carbonate factories. Specifically, removing CO_2 from the atmosphere and oceans for photosynthesis and for the construction of calcium carbonate ($CaCO_3$) skeletons the coralline algae play an important role in carbon sequestration along with corals. These altogether contribute to oceanic carbon cycling, though ocean acidification may be considered as a threat and as a negative aspect in this regard. Amongst the phytoplankton, diatoms may be considered as the prime producers in the ocean and at the base of marine food chain produce a significant portion (25-40%) of the Earth's oxygen. Diatoms, the most significant primary producers in oceanic realms, serve as a vital food source for aquatic organisms that are incapable of performing photosynthesis.

Brief geological background

The rocks preserved in different islands archive various signatures of the climate of the past several million years. The major stumbling block for the age determination of most of these rock units are dearth of suitable radiometric dates owing to absence of suitable radioactive elements. Though there are very few records of ash layers in some rock units and those can be absolutely dated by tephrochronology.

One of the significant geological formations in the Andaman and Nicobar Islands is Andaman Flysch that has been assigned an age of around 30 to 20 million years ago. It has been revealed that the source of the Andaman Flysch sediments is linked to erosion from nascent Himalayas and the arc of Myanmar. The sediments are characterised by inter-bedded turbidites referable to "deep-sea fan" deposit and based on radiometric dating an Oligocene (around 30 to 20 million years old) age (Fig. 2 A) has been assigned (Bandopadhyay, 2012).

The younger sediments deposited overlying the Andaman Flysch is known as Archipelago Group. The rocks of Archipelago Group are well exposed in a cluster of islands in the Andaman Group known as Ritchie's Archipelago (Fig. 1) alongside some other islands of Nicobar Group (Fig. 1) ranging in age from approximately 18 million years ago to 2.5 million years ago. These rocks have been dated solely based on index or marker microfossils namely fossilized phytoplankton and zooplankton archived in the sediments (Chakraborty et al., 2023; Ghosh et al., 2025 and the references therein). These microfossils encompassing a wide array of biotic proxies namely calcareous nannofossils, planktic foraminifers, diatoms, radiolarians, silicoflagellates are not only significant for age determination of the sediments but also for decoding the past environment. In this context, during the last one-decade number of contributions have been made from the outcrops on different islands on Andaman and Nicobar using these microfossils (Chakraborty and Ghosh, 2016; Chakraborty et al., 2019, 2021a, 2021b, 2023; Dey et al., 2021; 2022; Saxena et al., 2021; 2022, Ghosh et al., 2025). Significant contributions on the same aspect also have been made by Roy et al. (2022, 2023, 2025a, 2025b) from the deep-sea sediment cores from the offshore of Andaman and Nicobar Basin. The scientific community throughout the globe is focussing on climate change owing to accelerated impact of temperature rise since Industrial Revolution. The rise in global temperature is the cause of extreme weather condition, rise of sea-level, and break down of ecological balance. Based on instrumental data we can access the climate records for the last few centuries but for estimation of climate of the geological past, the microfossils preserved in the rock record and geochemical features are excellent tools to interpret the climate of past million years. There is published evidence that the Miocene Epoch (23.03 to 5.33 million years ago) can be considered as “Future of the Past”. The Miocene sediments are well exposed on different islands e.g., Havelock (renamed as Swaraj Dweep), Neil (renamed as Shaheed Dweep), Little Andaman or Hut Bay (Fig. 2 B-C) of Andaman Group and in some other islands. The younger sediments of Pliocene Epoch (5.33 to 2.58 million years ago) are well exposed on Car Nicobar Island of the Nicobar Group (Fig. 2 D-E) alongside other islands of both Andaman Group (Fig. 2 F) and Nicobar Group. Most of these sediments have been dated based on microfossils and based on these microfossils the past extreme climatic conditions, sea level fluctuations and intensification of South Asian Monsoon have been interpreted (Chakraborty et al., 2023; Ghosh et al., 2025 and the references therein).

Climate record of the past few millenia

Studies on the variability of Indian Summer Monsoon (ISM) during the last several millennia have been documented based on stable oxygen isotope record using speleothem carbonate from Baratang cave on Baratang Island, South Andaman. Lascar et al. (2013) analyzed two stalagmites from Baratang cave for their temporal variations in $\delta^{18}O$ and reconstructed the variability of ISM during the last ~4 kyr. Precise radiocarbon ages were determined for the stalagmites. They interpreted that there was a significant reduction (about 33% less than the present) in monsoon during 1800-2000 cal yr BP, 1500 and 400-800 cal yr BP. The monsoon was strongest (around 8 % higher than the present) during 800-1200 cal yr BP i.e., in the Medieval Warm Period. During the transition to the Little Ice Age relatively arid conditions prevailed. An increased trend of monsoon was recorded after 1.8 ka BP, however, there is no significant change in monsoonal activity during the recent ~400 yrs. Further study on stable oxygen isotope record of Indian summer monsoon (ISM) variability using speleothem carbonate from Baratang Island was conducted by Jaglan et al. (2020). Their study on the last millennium (10^{th} to 19^{th} century CE) includes some major climatic events namely, Medieval Climate Anomaly (MCA), the Little Ice Age (LIA) and the Current Warm Period (CWP). Their generated datasets also suggests that monsoonal activity was strong during MCA and declined during LIA and relatively weaker ISM during 16^{th} to 19^{th} century CE. Accordingly, Jaglan et al. (2020) interpreted that the weak ISM during 16^{th} to 19^{th} century CE is correlatable to severe droughts and famines in the Indian subcontinent as a result of deficient monsoonal rainfall.

Monsoon-driven environmental changes have been studied by Rixen et al. (2011) using coral growth rates and isotopic signatures (e.g., $\delta^{18}O$ and $\delta^{13}C$). The coral sample Porites sampled from the reef of southern Port Blair revealed impact on coral growth due to seasonal monsoon winds that drive upwelling and nutrient mobilization. Their results indicate that in defining the nutrient availability and water quality for the coral reef ecosystems in the Andaman Sea the Indian Ocean Dipole (IOD) and monsoonal circulation play a pivotal role. They also interpreted that a connection may exist between the variation of monsoon and North Atlantic oscillation patterns that influence the nutrient availability and growth of coral. High-resolution radiocarbon record between 2007 and 2014 on the stony coral Porites was evaluated by Raj et al. (2022). Based on their study they opined that a positive correlation exists between the seasonal radiocarbon changes and the stable oxygen isotope values of the coral. Seasonal changes in the mixed layer depth and sea surface temperature between the monsoon and non-monsoon periods have been observed by Raj et al. (2022). Their study also suggests that the recent radiocarbon values of the Andaman Sea surface water are higher in comparison to the contemporary atmospheric radiocarbon values.

Fousiya et al. (2022) examined the potential of the precipitation isotopic records for the study of the monsoon process. For the estimation of the monsoon withdrawal date, they used a novel water-isotope technique at Port Blair, South Andaman.Their study provides perception for interpreting paleo-monsoon records from isotopic proxies and the potential of the proxies e.g., corals for the reconstruction of past monsoonal variability.

Concluding remarks

The present climatic condition of Andaman and Nicobar Islands is characterized by tropical, warm and humid climate with almost devoid of winter. From the perusal of the foregoing account, it is evident that the Andaman and Nicobar Islands not only archives the past biodiversity and past climate in the rock record of past several million years but also the isotopic records may be useful for the estimation of rainfall during the past few Millenia and that in turn can provide an insight for the prediction of future climatic scenario in this part of the world. So, this region of Indian Territory possesses ample potentiality for the climate research.

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Snow bloom - Oregon.
Picture credit: P. Saranya

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Student Article

A Persistent Weakening of the South Asian Monsoon Pressure Gradient (1940–2025)

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Abstract

The land–sea pressure gradient (LSPG) is a key driver of the South Asian monsoon circulation. This study examines its long-term evolution using ERA5 mean sea level pressure data for the period 1940–2025. Area-weighted averages were computed over representative land (15–30°N, 70–90°E) and ocean (5°S–5°N, 60–90°E) domains. Both absolute and anomaly-based JJAS (June–September) gradients were analysed to distinguish mean-state behaviour from variability. The absolute gradient exhibits a stable mean magnitude of ~7.17 hPa with moderate interannual variability (~0.54 hPa). In contrast, the anomaly-based gradient has a near-zero mean by construction but a standard deviation of ~0.54 hPa, indicating that the residual variability is small compared to the mean state but dynamically important. The anomaly time series reveals a statistically significant declining trend of −0.132 hPa per decade, supported by bootstrap confidence intervals. These results indicate a gradual weakening of the surface pressure contrast. However, the JJAS surface pressure gradient alone does not sustain the monsoon circulation, highlighting the dominant role of tropospheric temperature gradients. Additionally, correlation analysis demonstrates that relationships inferred from raw data can be misleading, reinforcing that correlation not necessarily imply causation.

Introduction

The South Asian monsoon is a complex coupled system driven by large-scale thermodynamic and dynamical processes. One of the classical mechanisms underlying monsoon circulation is the land–sea thermal contrast, which manifests at the surface as a pressure gradient between the Indian subcontinent and the surrounding oceans (Webster et al., 1998).
During boreal summer, enhanced heating over land reduces surface pressure relative to the ocean, establishing a pressure gradient that drives cross-equatorial flow and monsoon winds. However, recent studies have suggested that this gradient may be weakening over time (e.g., Gangane et al., 2024) , raising questions about its long-term evolution and its role in sustaining the monsoon.

A key challenge in analysing the LSPG lies in separating the strong seasonal cycle from long-term variability. The seasonal signal dominates the raw pressure gradient, making it necessary to analyse anomaly-based time series to detect meaningful trends.

This study aims to:

1. Quantify the long-term evolution of the LSPG using ERA5 reanalysis data
2. Compare absolute and anomaly-based JJAS LSP gradients
3. Assess the statistical significance and robustness of observed trends
4. Interpret the physical implications of the results in the context of monsoon dynamics.

Data and Methodology

Monthly mean sea level pressure data were obtained from the ERA5 reanalysis (Hersbach et al., 2020) for the period 1940–2025. Two spatial domains were defined to represent the large-scale land–sea contrast relevant to the South Asian monsoon:

Land region: 15–30°N, 70–90°E
Ocean region: 5°S–5°N, 60–90°E

Mean pressure over the ocean and land is denoted as P_{ocean} and P_{land} respectively.

Area-weighted averages were computed using cosine latitude weighting to account for variations in grid-cell area.

The land–sea pressure gradient (LSPG) was defined as:

$$LSPG = P_{ocean} - P_{land}$$

Two forms of the gradient were analysed:

· Absolute JJAS gradient, representing the mean monsoon pressure contrast

· Anomaly-based gradient, obtained by removing the monthly climatology to isolate variability and long-term trends

JJAS seasonal means were computed annually. Linear trends were estimated using least-squares regression. Statistical robustness was assessed using bootstrap resampling with 1000 realizations.

Results

Full Time Series Characteristics

The raw LSPG time series exhibits a strong seasonal cycle (see Fig. 1), reflecting the annual heating contrast between land and ocean. This seasonal signal dominates the variability, with amplitudes ranging from approximately −5 hPa to +10 hPa.

After removing the seasonal cycle, the anomaly time series reveals interannual variability with no dominant periodicity, but clear long-term structure as illustrated by the orange line in Fig. 1.

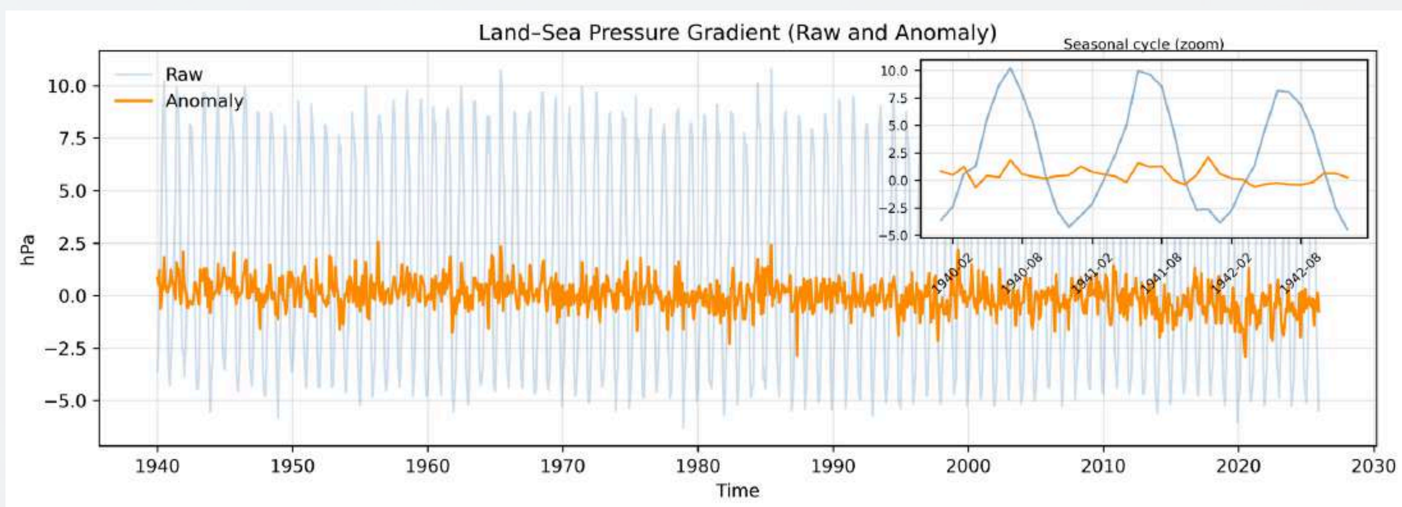

Fig. 1: Land–Sea Pressure Gradient (Raw and Anomaly) Time series of the land–sea pressure gradient (LSPG) showing the raw monthly values (light blue) and the anomaly after removal of the seasonal cycle (orange). The raw series is dominated by a strong seasonal cycle, while the anomaly highlights interannual variability and long-term changes. The inset highlights the seasonal cycle.

Absolute JJAS Gradient

The absolute JJAS LSPG has a mean value of approximately 7.17 hPa, with a standard deviation of 0.54 hPa.

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This magnitude is consistent with previous studies (e.g., Webster et al., 1998; Gangane et al., 2024) and reflects the strong pressure contrast associated with the monsoon system.

The linear trend in the absolute gradient is:

$y = -0.013x + 33.4 \quad (p \approx 0.0)$

indicating a highly significant progressive weakening of the pressure contrast over the observed time period as shown in Fig. 2.

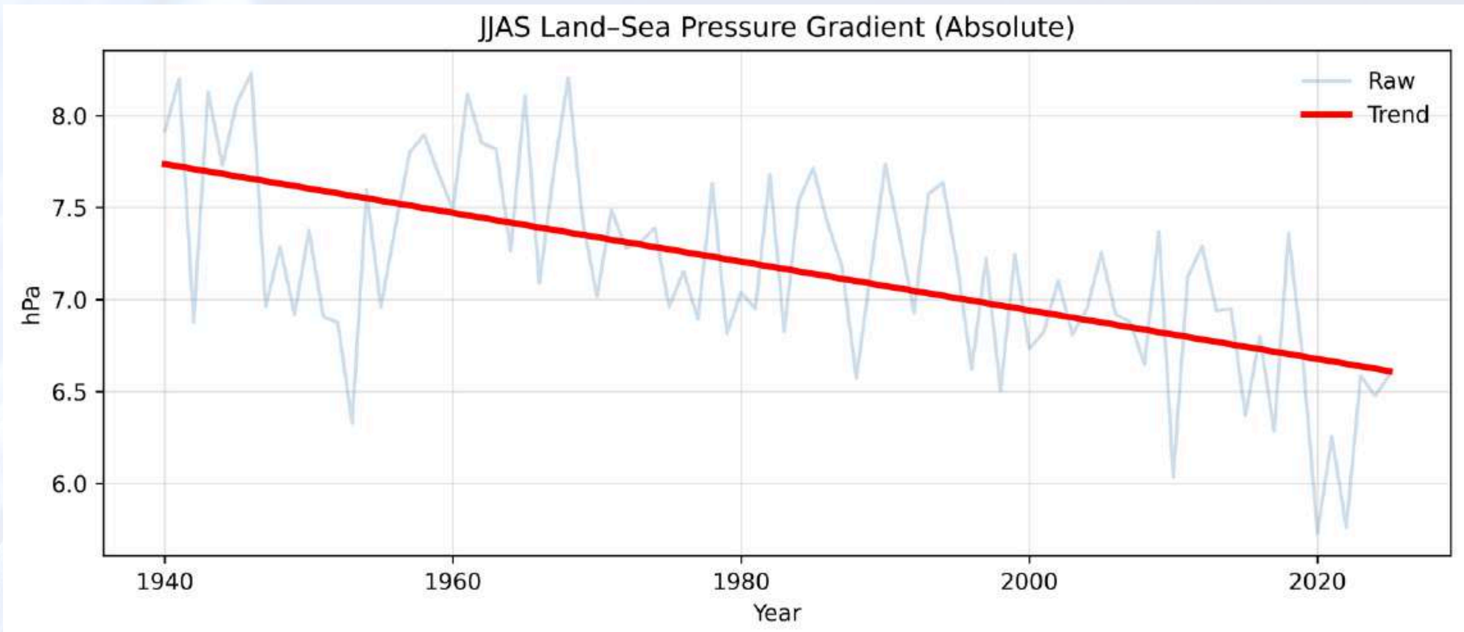

Fig. 2: JJAS Land–Sea Pressure Gradient (Absolute) JJAS land–sea pressure gradient (absolute). The raw data are shown in light blue, and the fitted linear trend is shown in red.

Anomaly-Based Gradient and Trend

After removing the seasonal cycle, the anomaly-based gradient isolates interannual variability and long-term changes in the system. The JJAS anomaly time series exhibits a statistically significant declining trend of −0.132 hPa per decade as shown in Fig. 3.

Interestingly, the trend derived from the absolute JJAS gradient (−0.013 hPa per year, equivalent to −0.13 hPa per decade) is nearly identical to that obtained from the anomaly-based analysis. This agreement is noteworthy, as trends in absolute and anomaly time series typically differ due to the influence of seasonal cycle variability.

The similarity of the trends suggests that the observed weakening of the land–sea pressure gradient is not primarily driven by changes in seasonality, but rather reflects a robust long-term shift in the mean state of the system. This consistency strengthens the confidence in the detected trend and indicates that the weakening is a physically meaningful signal rather than an artifact of seasonal variations.

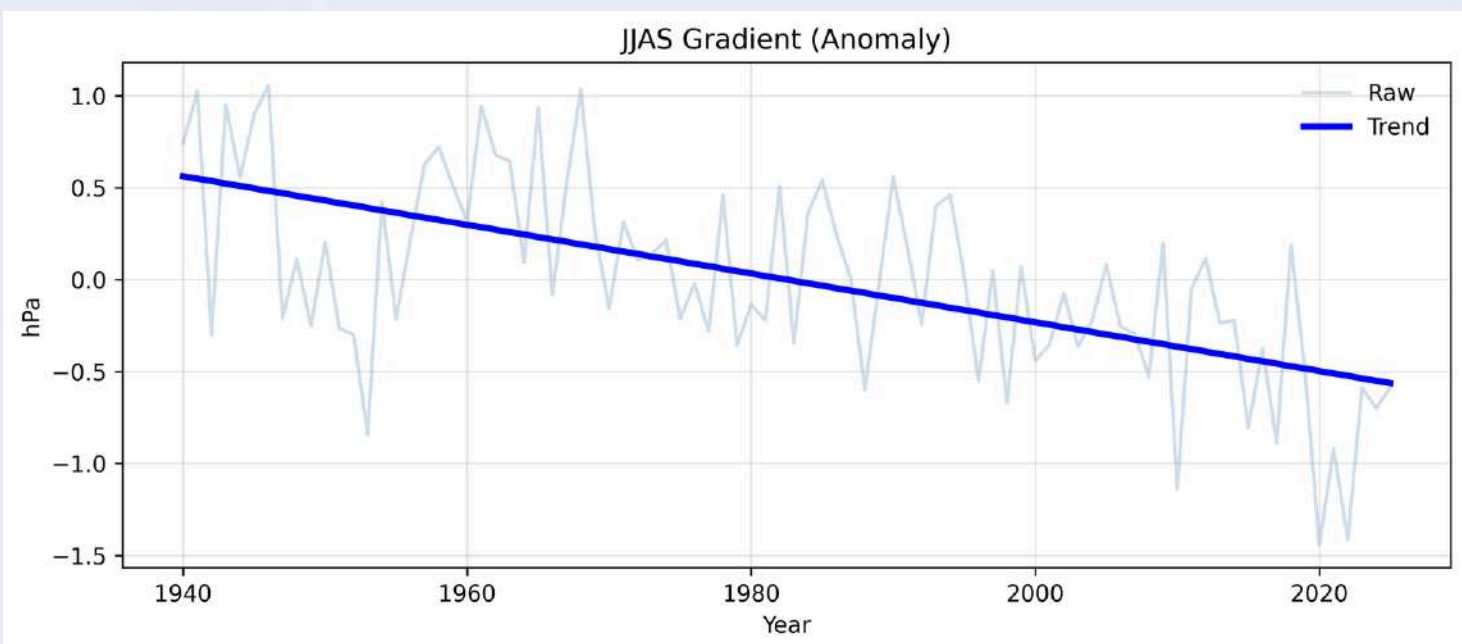

Fig. 3: JJAS Gradient (Anomaly): JJAS anomaly-based LSPG showing interannual variability and declining trend.

Bootstrap analysis helps mitigate sample size limitations and autocorrelation by generating an empirical distribution of slope estimates through resampling (Kiran Kumari et al. 2026). Fig. 4 presents the distribution obtained from 1000 bootstrap replicates, yielding a 95% confidence interval of −0.171 to −0.093 hPa per decade. Because zero lies outside this interval, the observed trend is statistically significant and robust.

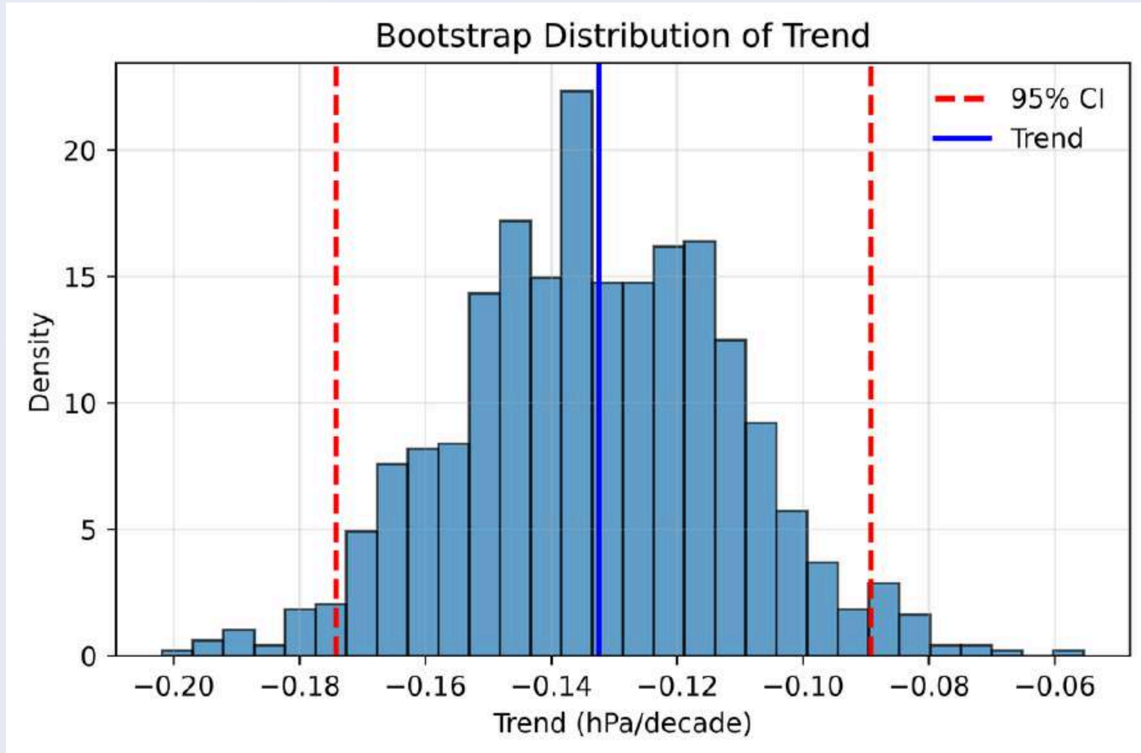

Fig. 4: Bootstrap Distribution of Trend: Histogram of bootstrap trend estimates with confidence intervals. The x-axis shows the trend (units/decade), and the y-axis shows frequency. Vertical red dashed lines indicate the confidence interval boundaries.

Multi-decadal Variability

The 30-year running mean highlights a clear multi-decadal decline in the anomaly-based gradient, indicating a persistent weakening of the land–sea pressure contrast over the study period. While the raw anomaly time series exhibits noticeable interannual variability, the smoothed series effectively suppresses short-term fluctuations and reveals a coherent long-term downward trend.

The standard deviation of the anomaly-based JJAS gradient is approximately 0.54 hPa, which represents the typical magnitude of year-to-year variability. In comparison, the total change in the gradient over the analysis period exceeds ~1 hPa, indicating that the long-term signal is substantially larger than individual interannual fluctuations as shown in Fig. 5.

This difference in scale explains why the long-term decline remains clearly detectable despite the presence of variability. In other words, while interannual variations introduce short-term fluctuations, they are not large enough to mask the persistent multi-decadal weakening. The consistency of the downward trend in the smoothed (30-year mean) series further confirms that the observed change is not driven by episodic variability but represents a sustained shift in the mean state of the system.

CO_2–LSPG Relationship: A Cautionary Example

To further demonstrate the effect of seasonal variability on a climate variables, we consider the atmospheric CO_2 cycle and the land–sea pressure gradient (LSPG). On an annual timescale, these two parameters exhibit strong co-variation, as illustrated in the inset of Fig. 1, although the CO_2 cycle is not explicitly plotted to avoid clutter. When the long-term records of LSPG and CO_2 are correlated, the raw time series yields a strong negative correlation ($r = -0.55$) as shown in Fig. 6. However, after detrending, the correlation coefficient drops to 0.14, which is statistically insignificant. This outcome is expected, since the annual CO_2 cycle is primarily controlled by vegetation dynamics rather than the land–sea pressure gradient.

The apparent correlation therefore arises from shared long-term trends rather than a direct physical coupling.

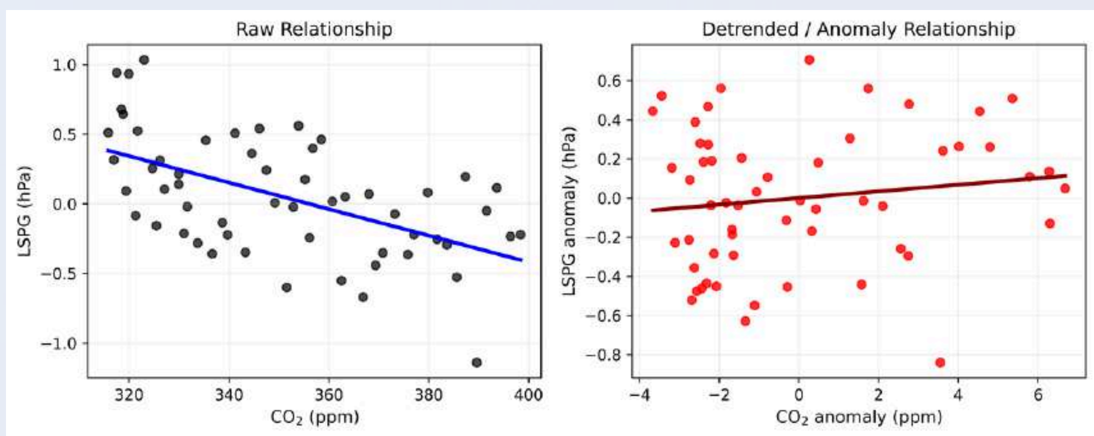

Fig. 6: CO_2–LSPG Relationships Scatter plots comparing CO_2 and LSPG data. Left: raw relationship (black points with blue regression line). Right: detrended/anomaly relationship (red points with red regression line).

Discussion and Summary

The results indicate a statistically significant weakening of the land–sea pressure gradient (LSPG) over the South Asian region during the period 1940–2025. This weakening is primarily associated with a relatively faster increase in mean sea level pressure over the Indian landmass compared to the adjacent ocean, leading to a gradual reduction in the surface pressure contrast. The JJAS LSPG retains a robust mean magnitude of approximately 7.17 hPa, while its interannual variability remains moderate (~0.54 hPa). The anomaly-based analysis reveals a significant declining trend of −0.132 hPa per decade, supported by bootstrap confidence intervals. Notably, the close agreement between trends derived from absolute and anomaly-based time series suggests that the observed weakening reflects a genuine long-term shift in the mean state rather than changes in the seasonal cycle, consistent with recent findings (Gangane et al., 2024).

The multi-decadal behaviour further supports this interpretation. Although the anomaly time series exhibits noticeable interannual variability, the magnitude of this variability is substantially smaller than the cumulative long-term change, allowing the downward trend to remain clearly detectable. The 30-year running mean effectively filters out short-term fluctuations and highlights a persistent decline, indicating that the weakening is not driven by episodic variability but represents a sustained structural change in the system.

Despite this clear long-term weakening, the dynamical role of the LSPG in the monsoon system requires careful interpretation. While the surface pressure gradient is central to the classical understanding of monsoon dynamics (Webster et al., 1998), its influence varies across different phases of the monsoon lifecycle. The monsoon circulation is primarily initiated during the pre-monsoon (MAM) season, when strong land heating establishes a pronounced land–sea thermal contrast that drives cross-equatorial flow. During the JJAS season, however, increased cloud cover, latent heat release, and rainfall lead to a relative cooling of the land surface, which weakens the surface pressure gradient. This implies that the JJAS LSPG alone cannot sustain the monsoon circulation over its full duration. Instead, the maintenance of the monsoon is governed by the tropospheric temperature gradient, which provides the necessary large-scale pressure gradients in the upper troposphere (Goswami et al., 2006; Xavier, Marzin and Goswami, 2007).

An additional methodological insight emerges from the correlation analysis with atmospheric CO_2. While the raw time series exhibit a relatively strong correlation, this relationship weakens substantially and becomes statistically insignificant after removing long-term trends. This contrast demonstrates that apparent correlations in climatic time series may arise from shared trends rather than direct physical coupling, emphasizing that correlation does not necessarily imply causation, particularly in non-stationary datasets.

Overall, the findings provide a consistent picture of a gradually weakening surface pressure contrast over the South Asian region. However, this weakening should not be interpreted as a direct weakening of the monsoon system itself. Rather, it reflects changes in one component of a complex coupled system, where the large-scale monsoon circulation is sustained by processes beyond the surface pressure gradient alone.

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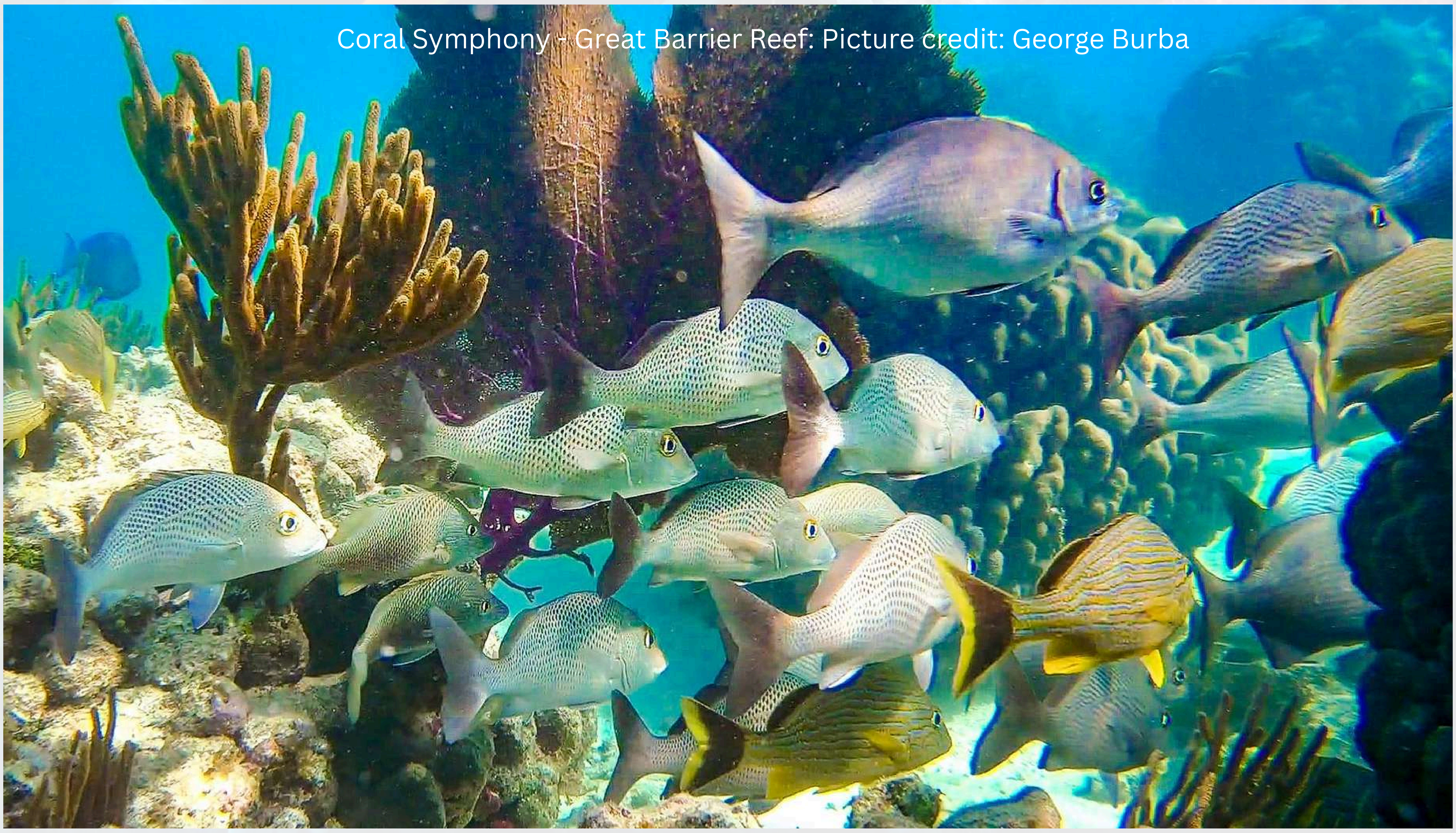


Coral Symphony - Great Barrier Reef: Picture credit: George Burba

Announcements

Ocean Society of India – Biennial PhD Theses Awards in Ocean Science & Technology

The Ocean Society of India (OSI) invites applications for its **Biennial PhD Theses Awards**, recognizing outstanding doctoral research in ocean science and technology. Each award carries a citation and ₹10,000, to be presented at OSICON 27, IITM Pune.

Themes of the Award

Prof. Vallam Sundar Award in Ocean Engineering
Topics: Ocean structures, coastal engineering, hydrodynamics, renewable energy, ports, harbours, underwater and environmental engineering.

Dr. N. P. Kurian Award in Physical Oceanography
Topics: Circulation, currents, water masses, waves, tides, sea level, climate variability, regional and coastal oceanography.

Prof. A. D. Rao Award in Oceans and Atmosphere
Topics: Monsoon, climate change, air pollution, cyclones, wind energy, storm surges, internal waves, acoustic propagation.

Dr. Rabindranath Sengupta Award in Chemical Oceanography
Topics: Biogeochemistry, nutrient and trace metals, elemental cycles, marine pollution, boundary exchanges, extraction of bioactive substances.

Dr. H. N. Siddiquie Award in Geological Oceanography
Topics: Coastal/offshore geology, marine minerals, sediments, micropaleontology, seafloor volcanism, tectonics, geophysics, seismic studies.

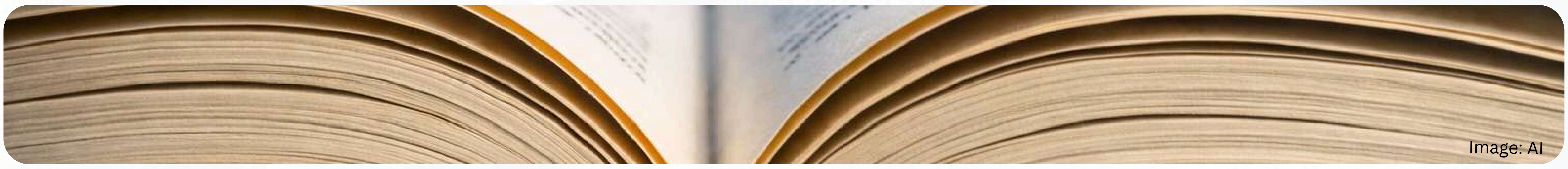
Dr. (Mrs.) N. I. Joseph & Prof. K.V. Jayachandran Award in Biological Oceanography
Topics: Productivity, ecology, deep-sea biology, food webs, fisheries, estuarine biology, genetics, climate change impacts.

Dr. Shanta Achuthankutty & Dr. P.A. Lokabharathi Award in Marine Microbiology & Biotechnology
Topics: Taxonomy, ecology, microbial functions, pollution, resistance, bioproducts, vaccines, probiotics, aquaculture applications.

Eligibility
PhD holders from Indian universities/institutes are eligible. Age limit: 40 years (relaxation of 3 years for women).

The application as per the prescribed format* along with a soft copy of PhD thesis and required documents may be submitted as a single PDF file on or before 31st May 2026 to Dr. M. Baba (Email: dr.mbaba@gmail.com), Chairperson with copies to Dr. Anas Abdulaziz (Email: anasabdulaziz@gmail.com) and Dr. C. Revichandran (Email: revichandran@gmail.com), Co-Conveners of the Experts Committee.

*available on the OSI Website: https://www.oceansociety.in/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Best Dissertation Awards for PG Students in Ocean Science and Technology

The Ocean Society of India invites nominations from Heads of Departments of Universities and Colleges conducting PG courses in any disciplines related to Ocean Science and Technology for the award "Best dissertation in Ocean Science and Technology in India" for the calendar year 2025. One award each will be given to the PG students in the following themes:

1. **Physical Oceanography**
2. **Oceans and Atmosphere**
3. **Chemical Oceanography**
4. **Marine Geophysics and Geological Oceanography**
5. **Biological Oceanography**
6. **Ocean Engineering and Technology**
7. **Marine Microbiology / Biotechnology.**

The nominations of those students who completed their course in the academic year 2024- 2025 and submitted dissertations in the calendar year 2025 will only be considered for the current award. Nomination subject to a maximum of two from each Department shall be in the following format:

The application in the prescribed format*, along with a soft copy of the dissertation, may be submitted on or before 31st May 2026 to Dr. K Jossia Joseph (Email:osipgaward2026@gmail.com), convener of the Award Committee. The selected students, one from each theme, will receive a cash award and a citation at a subsequent OSI function. * available on the OSI website https://www.oceansociety.in

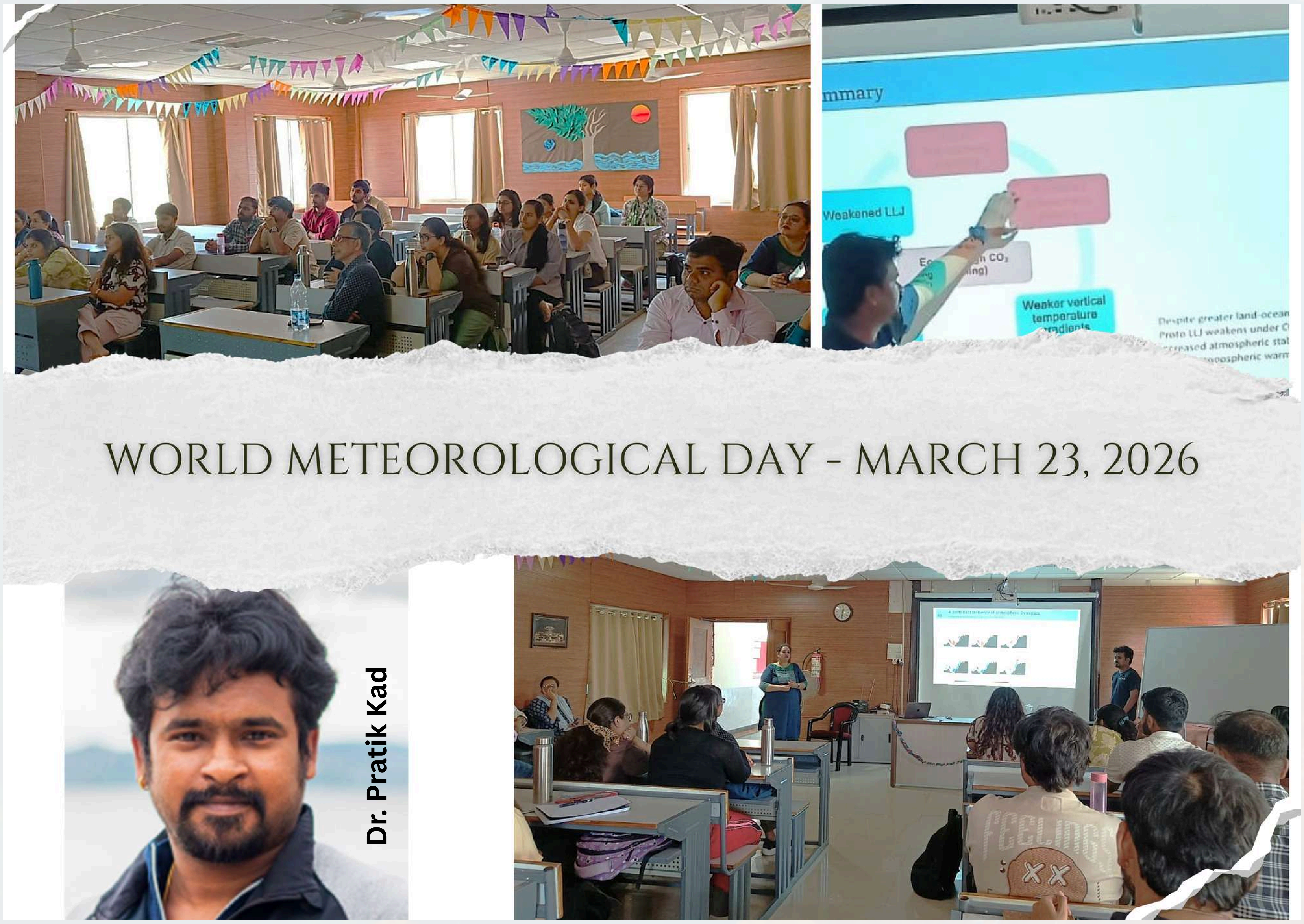
WMO Day Celebration – OSI Pune Chapter

World Meteorological Day is celebrated annually on March 23. It's a global event organized by the World Meteorological Organization (WMO) to raise awareness about meteorology and its applications, highlight the importance of weather, climate, and water sciences.
The Ocean Society of India- Pune Chapter commemorated World Meteorological Day with a special program at the Department of Atmospheric and Space Sciences (DASS), Savitribai Phule Pune University. The event highlighted the significance of mountain meteorology and past climate studies in advancing scientific understanding and public awareness.

Dr. Pratik Kad, an alumnus of DASS, currently affiliated with the Bjerknes Centre for Climate Research, Bergen, Norway, delivered two engaging talks:

- Reduction of the Proto Low-Level Jet During the Eocene Hothouse Climate
- Dynamics of Recent Monsoon Variability in the Eastern Himalayas

His lectures offered valuable insights into both ancient climate dynamics, evolution of monsoon circulation and contemporary monsoon variability, underscoring the importance of integrating paleoclimate perspectives with present-day atmospheric research. The program brought together faculty, researchers, and students, reinforcing OSI's mission to foster dialogue and outreach in ocean and atmospheric sciences.



We'd love to hear from you! Please feel free to send your comments, criticism, feedback, and contributions to: osioceandigest@gmail.com.