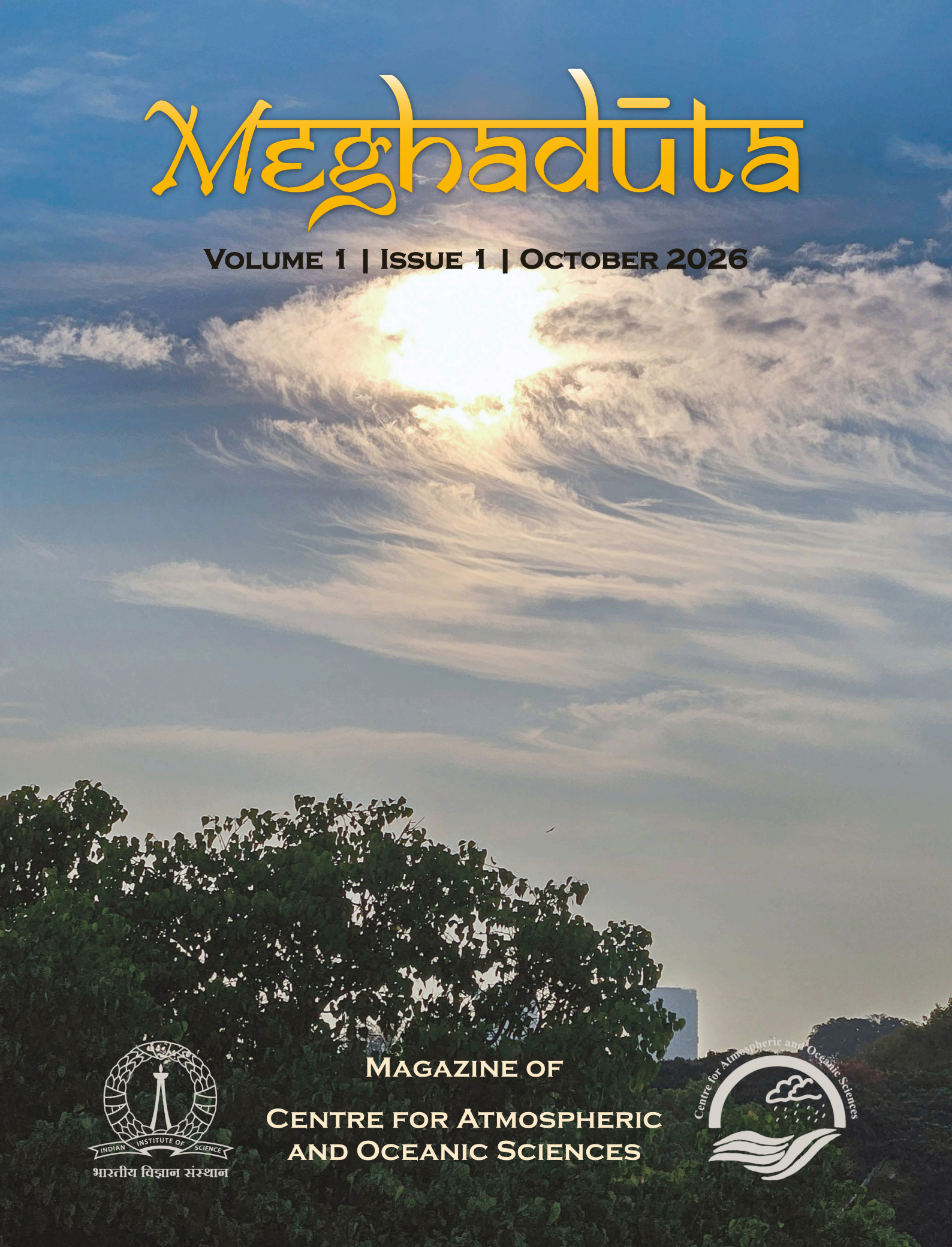
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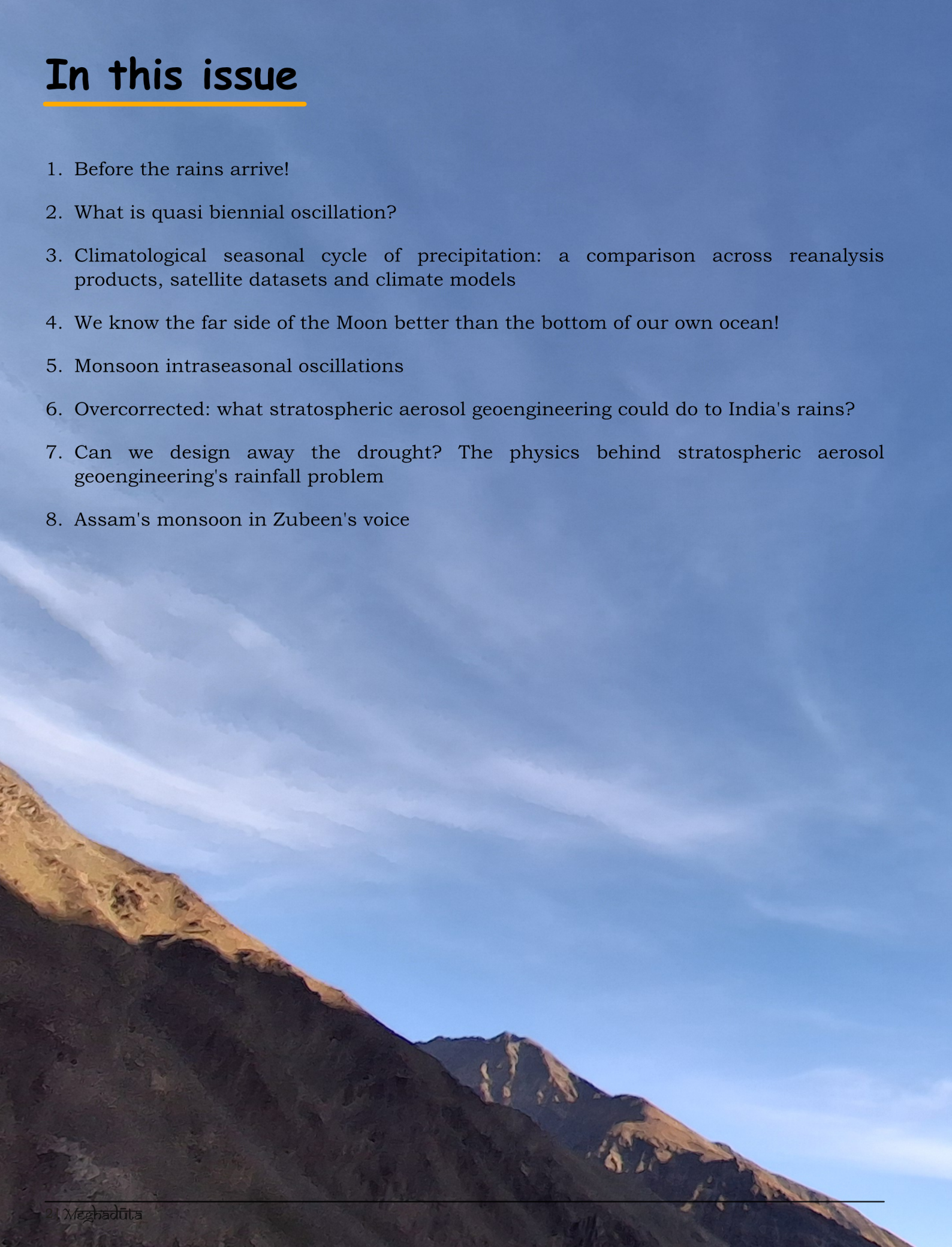
Indian Institute of Science

भारतीय विज्ञान संस्थान

Centre for Atmospheric and Oceanic Sciences

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Foreword

Established in 1982, the Centre for Atmospheric and Oceanic Sciences (CAOS) has grown over more than four decades into a leading centre for research and education in atmospheric and oceanic sciences. The year 2026 was particularly special for CAOS, as we celebrated our first Foundation Day on 23 September, bringing together faculty, students, staff, alumni, and well-wishers to reflect on the Centre's journey and look ahead to its future. It is a pleasure and a privilege to write this foreword for the inaugural issue of the CAOS magazine, launched on the occasion of our first Foundation Day, and to reflect, in a small way, on the remarkable journey of the Centre.

CAOS has always been a place where curiosity drives science. Over the years, the Centre has developed a strong tradition of research spanning atmospheric and ocean sciences, with a particular focus on monsoon processes, air–sea interactions, ocean observations and modelling, climate variability and change, and many other aspects of the ocean-atmosphere system. A distinctive strength of CAOS is its comprehensive and integrated approach, bringing together observations, experiments, numerical modelling, data analysis, and theoretical methods to address complex scientific questions. This breadth of approach has enabled the Centre to make significant contributions to our understanding of the atmosphere and ocean, particularly monsoons, while fostering a culture of interdisciplinary research and collaboration.

The strength of CAOS, however, lies not only in its scientific accomplishments but also in its people. The enthusiasm of our students, the creativity of our researchers, the commitment of our faculty, connections with the alumni, and the dedication of our staff collectively create the environment in which good science flourishes. The spirit of curiosity, collaboration, and collegiality that brings together the CAOS community is one of the Centre's greatest strengths.

The past few years have also been a period of change and new opportunities. Rapid advances in observations, high-resolution modelling, artificial intelligence, and computational science are opening new avenues for understanding the Earth system. The monsoon, with its complex interactions across the atmosphere, ocean, land, and cryosphere, remains a central scientific challenge, particularly in view of its variability, predictability, and response to a changing climate. Understanding changes in monsoon behaviour, including extremes, intraseasonal variability and long-term trends, and its response to the oceans has become increasingly important for both science and society. At the same time, climate change is presenting us with scientific questions of increasing complexity and societal importance. Addressing these challenges requires an integrated understanding of the atmosphere, ocean, cryosphere, and land surface, together with innovative approaches that bridge observations, theory, modelling, and data science. CAOS is well positioned to contribute to these efforts through its strong foundation in fundamental research and its culture of interdisciplinary collaboration.

I hope this magazine captures, at least in part, the energy, diversity, and spirit of CAOS. I congratulate everyone who has contributed to this inaugural issue and, more importantly, everyone who continues to contribute to the Centre's journey. I wish CAOS and its entire community continued success in the years ahead.

Prof. P. N. Vinayachandran
Chair, CAOS
23 September 2026

Before the Rains Arrive!

Gagan Hegde

Indian Summer Monsoon and IMD's forecast

One of the main sources of freshwater for the Indian subcontinent is the seasonal climatic phenomenon known as the monsoon. Since most of the rainfall occurs between June and September, this mausam is popularly known as the Indian Summer Monsoon (ISM).

Agriculture occupies an important place in the Indian economy because it supports rural incomes, contributes to food security, and provides employment and income to a large part of the population. The sector accounts for nearly 14% of GDP and exports and supports about half of the country's population as a principal source of income [4]. According to Census 2011, the total number of agricultural cultivators and agricultural labourers increased from 234 million in 2001 to 263 million in 2011 [4].

The performance of Indian agriculture has also shown considerable variation over time [2]. A major reason for this variability is its strong dependence on seasonal weather conditions and climatic phenomena, particularly rainfall associated with the ISM. Changes in the timing, distribution, and amount of rainfall can have important consequences for agricultural production and rural incomes.

Because agriculture is so closely tied to the weather, the ISM forecast is more than just a weather update. A good or bad monsoon can change expectations about crop production, rural incomes, and spending across large parts of the economy. These changes can also affect companies whose businesses depend on farmers, agricultural activity, and rural demand. The ISM forecast therefore provides an interesting way to study how information about seasonal climate risk is reflected in financial markets.

In this article, I wanted to see whether stock prices respond to the long-range forecasts provided by the India Meteorological Department (IMD) before the summer monsoon season. I am not an expert in economics, and I am still new to the stock market. This is simply a self-study motivated by curiosity: do agriculture-dependent companies respond systematically to expectations about the monsoon, and can an independent seasonal prediction made before the official IMD forecast provide useful information for making more calculated investment decisions as a student of the Earth system?

When does the stock market change?

The IMD releases its first long-range forecast for the ISM sometime during the first half of April. In 2026, this forecast was issued on 13 April [3]. The IMD predicted below-normal seasonal rainfall, with an expected rainfall of 92% of the Long Period Average (LPA) with a model error of ±5%, where the LPA is 870 mm. An updated forecast is released towards the end of May, when more information about the developing monsoon is available. On 29 May 2026, the forecast was revised further downward to 90% of LPA [3].

Farmers have to make decisions about sowing,

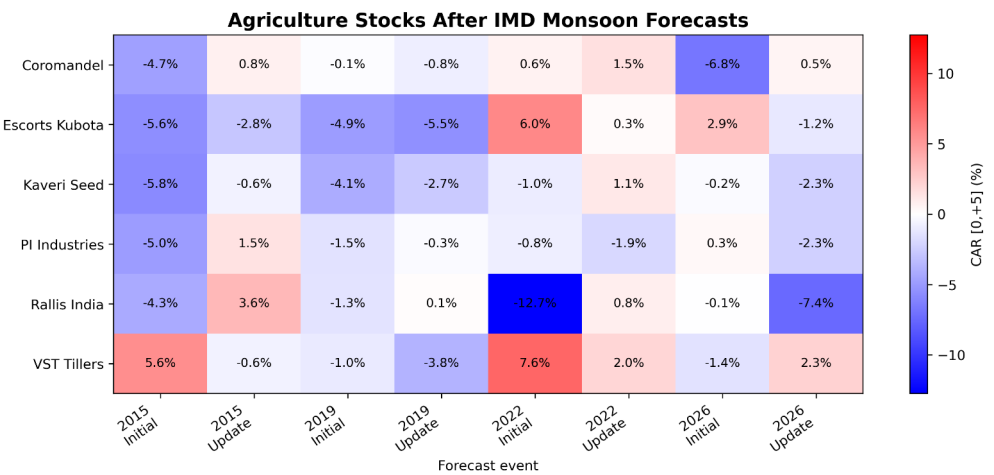


Figure 1. Post-forecast negative abnormal returns of selected agriculture linked companies relative to the NIFTY 50. Negative values indicate underperformance in the five trading days following the IMD forecast.

expenditure, and the amount of risk they are willing to take before the monsoon actually arrives. Expectations of a good season may encourage greater spending on seeds, fertilisers, pesticides, and agricultural machinery, whereas the prospect of a poor monsoon may lead farmers to conserve cash and reduce or delay such expenditure. Weather expectations can therefore influence demand across several agriculture dependent industries even before the first monsoon rains reach the fields. If these expectations affect future sales and earnings of agriculture dependent companies, some part of this change in outlook may also appear in their share prices.

With this link between the seasonal forecast and the stock market in mind, let us now look at how the market responds. Rather than examining the entire market, which contains many companies with little or no dependence on agriculture, I focus on a small subset of listed firms whose businesses are more directly exposed to agricultural activity and rural spending. Their response can then be compared with the broader NIFTY 50 index to separate movements in agriculture linked stocks from movements in the market as a whole.

Dependence on the seasonal forecast

I have considered a set of companies that represent different parts of the agricultural value [6]. This diversity is useful because the effect of the monsoon is unlikely to be identical across all agricultural businesses. The selected companies are: *(1) Rallis India* — crop protection and agricultural inputs; *(2) Kaveri Seed Company* — seeds; *(3) Coromandel International* — fertilisers, crop nutrients, and crop-protection products; *(4) PI Industries Ltd.* — agrochemicals and crop-protection products; *(5) Escorts Kubota Ltd.* — agricultural machinery, particularly tractors; and *(6) VST Tillers Tractors Ltd.* — tractors, power tillers, and other farm machinery.

A word of caution: these firms form only a small agriculture sensitive subset of the much larger Indian equity market. Their share prices are therefore not determined by the monsoon alone. Company earnings, input costs, global markets, government policy, and broader investor sentiment can all affect their prices. However, because a meaningful part of their business depends on agricultural activity, they still provide a useful sample for examining whether information contained in the ISM forecast is reflected in the stock market.

To account for movements in the wider market, I compare the return of each company with the return of the NIFTY 50 over the same period. In other words, I remove the movement of the market itself and look at what is left for the individual stock. These remaining returns are referred to as abnormal returns, and their sum over a chosen time window, let's say 5 days after forecast, is called the cumulative abnormal return (CAR) [5]. This allows me to ask a simple question: after the IMD announces its monsoon forecast, do agriculture dependent companies move differently from the market as a whole?

What does the data tell us?

I considered four years representing different combinations of the forecast and realised rainfall. The year 2026 was included as a deficient monsoon case, although the ongoing geopolitical situation means that the stock response to the monsoon may have been partly diluted by movements in global markets. The forecast and rainfall details are summarised in Table 1.

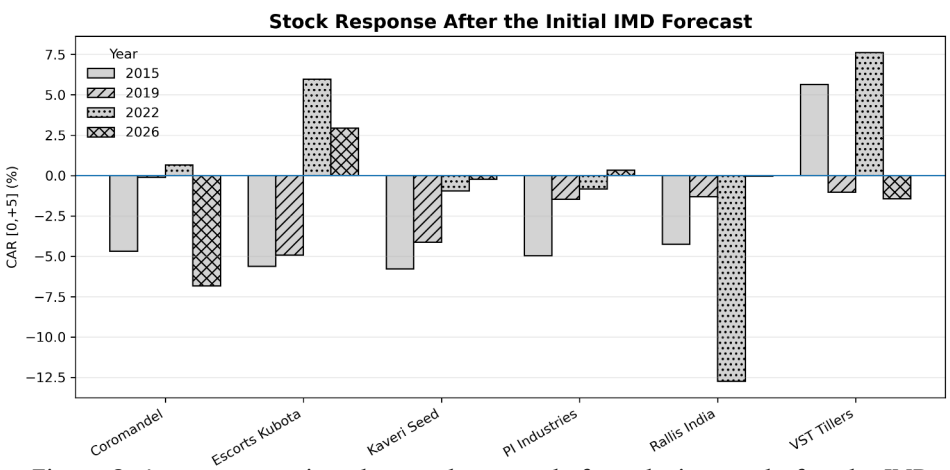


Figure 2. Average negative abnormal returns before, during, and after the IMD forecast announcements. The stronger negative response after weak forecasts suggests that downside monsoon risk is reflected more clearly in stock prices.

2015: The initial forecast was weak, the updated forecast became even more pessimistic, and the realised monsoon was also deficient. Agriculture linked stocks mostly showed negative abnormal returns after the initial forecast, suggesting that investors were pricing in less favourable conditions for agriculture.

2019: This was a particularly interesting season. The initial and updated forecasts were relatively weak, but the realised monsoon later turned out to be much stronger. Despite this, the selected stocks still showed negative abnormal returns after the forecast. This suggests that the market took a conservative view based on the forecast available at the time, rather than on the rainfall that was eventually observed.

2022: Both the updated forecast and the realised monsoon were favourable. The stock response was much less uniform, with only a modest positive reaction overall. This suggests that negative monsoon information may have a stronger effect on agriculture linked stocks than favourable information.

2026: The response to negative information was again clearer. The initial forecast was below normal and the updated forecast was revised further downward. Around the updated forecast, the selected agriculture linked stocks showed a more clearly negative abnormal return. However, as mentioned earlier, geopolitical developments and broader global market movements may also have played a role.

Table 1. IMD seasonal monsoon forecasts and the realised rainfall for selected years

Year	Initial Forecast	Updated Forecast	Actual Rainfall
2015	22 Apr: 93% of LPA	2 Jun: 88% of LPA	86% of LPA
2019	15 Apr: 96% of LPA	31 May: 96% of LPA	110% of LPA
2022	14 Apr: 99% of LPA	31 May: 103% of LPA	106.5% of LPA
2026	13 Apr: 92% of LPA	29 May: 90% of LPA	87% of LPA

The market data therefore seem to suggest an asymmetric response: weak or below normal forecasts appear to generate a clearer market reaction than above normal forecasts. This makes intuitive sense to me, since people often become more conservative during periods of uncertainty. In this case, that conservative response may mean lower investment and spending when the outlook for the monsoon is pessimistic. Interestingly, a similar asymmetry has been noted for realised monsoon outcomes, with deficient monsoon years having a stronger economic impact than excess rainfall years [2]. While that study considers realised rainfall and its effect on agriculture and GDP, the results here suggest that this asymmetry may already begin to appear at the forecast stage in financial markets.

The IMD forecast can be viewed as an important risk signal for agriculture sensitive companies. At the same time, company specific news, global markets, oil prices, and broader economic conditions can still influence stock prices. The monsoon signal should therefore not be interpreted as a standalone trading rule, but it may still be worth keeping in mind before investing around the monsoon season. Most importantly, any investment advantage would come from anticipating the IMD's forecast rather than reacting after it is published. In other words, ***The money is not in reading the forecast, it is in being right before everyone else reads it.***

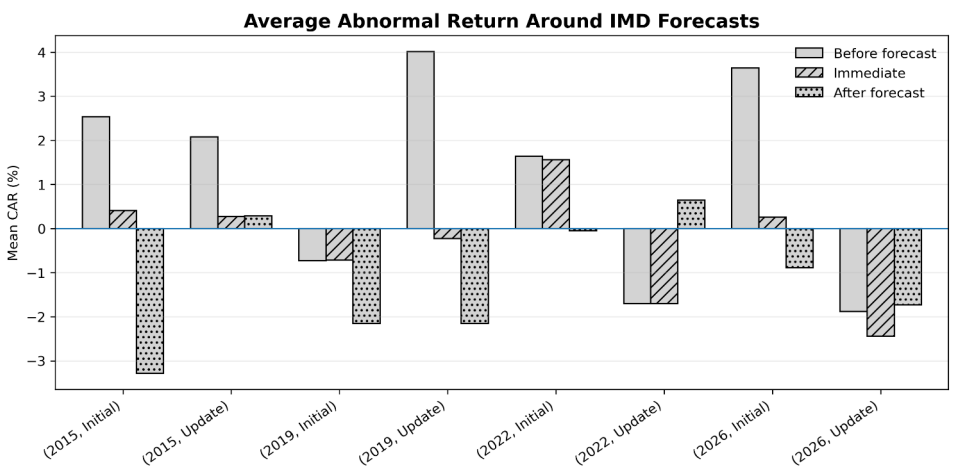


Figure 3. Five-day negative abnormal returns following the initial IMD forecast for selected agriculture-linked companies. The response is more consistently negative in years when the forecast pointed to weaker monsoon conditions.

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What is Quasi Biennial Oscillation?

Shubhrangshu Biswas

The Quasi Biennial Oscillation (QBO) is a quasi-periodic oscillation with a time period of 27-29 months in the equatorial stratosphere (15 to 50 km above the sea level). The alternate phases of easterly and westerly winds define the oscillation. The reversal of the wind begins from the middle stratosphere, and the wind propagates downward at an approximate speed of 1km/month before dissipating at the tropopause.

Key facts on QBO:

1. The speed of wind can reach values up to 30 m/s, with easterly winds being stronger than westerly winds.
2. The wind velocity at 30 hPa conventionally determines the QBO phase.
3. Large-scale equatorial oscillations like Kelvin, Gravity, and mixed Rossby-Gravity waves travel upward into the stratosphere and deposit momentum. This momentum can flip the phase of QBO.
4. In 1883, the eruption of Krakatoa (Indonesia) caused the debris to reach the stratosphere and circumscribe the atmosphere from east to west, driven by winds named Krakatoa easterlies.
5. In 1908, data balloons launched above Lake Victoria in Africa recorded westerly winds at the stratospheric levels.

Effects of QBO:

1. Stratospheric Ozone concentrations are affected by secondary circulations from QBO across latitudes.
2. Westerly (easterly) QBO induces a stronger, colder (weaker, warmer) polar vortex, affecting weather in the higher latitudes. A weaker polar vortex mainly causes unstable weather conditions.
3. QBO can interact with Madden-Julian Oscillation and El Niño Southern Oscillation to influence the tropical climate.
4. QBO can leverage intertropical convergence zones to modify precipitation patterns.

Climatological Seasonal Cycle of Precipitation: A Comparison Across Reanalysis Products, Satellite Datasets, and Climate Models

Sujatra Bhattacharyya

Precipitation over India from June to September is termed as the Indian Summer Monsoon Rainfall (ISMR), providing 75–80% of the total annual rainfall in the country. This is vital for agriculture, water resource management and power generation, which eventually connects to the economy [1]. For these practical purposes, the rainfall within the season is extremely important. Thus, accurate prediction of the sub-seasonal rainfall variations during the monsoon is crucial, but at the same time, it is a challenging task. Few studies have shown that the climatological seasonal cycle of ISMR intensity captured by coupled models is weaker in magnitude than that of the actual intensity, and also, it peaks in August instead of what is observed in July [2, 3]. In this study, I compare the climatological seasonal cycle of precipitation from different climate models, satellite-based products, and reanalysis datasets against the gridded precipitation observations from the India Meteorological Department (IMD) at 1° spatial resolution [4], focusing on the Indian land region. However, the IMD gridded dataset is not without uncertainties, as the interpolation of rain-gauge observations onto a regular spatial grid can introduce errors in the representation of rainfall, particularly in regions with sparse station coverage.

Precipitation Datasets

As mentioned above, IMD gridded rainfall (1°×1°) data is used for rainfall over India [4]. This is used as a reference for comparison.

Reanalysis-based

Daily total precipitation of the fifth-generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis [5] at 1° resolution (ERA5) and daily precipitation rate of the NCEP-NCAR reanalysis [6] from1997-2020 at 2.5° resolution (NCEP) are used.

Satellite-based

Daily data of the Global Precipitation Climatology Project (GPCP) gridded at 1° resolution [7] have been used in this study, which is based on a technique that combines satellite-based estimates, rain gauge analysis, and NWP model precipitation information [8]. Further, the Tropical Rainfall Measuring Mission (TRMM) 3B42 version 7 precipitation product, designed to combine precipitation measurements from various satellite systems and precipitation gauges [9] at a high resolution (approx. 25 km), is also used for this analysis.

Models

Daily precipitation data were obtained from the Community Earth System Model Version 2 (CESM2) [10], developed by the National Center for Atmospheric Research (NCAR), as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6). The dataset corresponds to the historical experiment (historical) and is identified by the ensemble member r1i1p1f1 [11]. For this analysis, I have used data from 1979–2014. It is important to note that the CESM2 historical simulation is driven by prescribed historical external forcings, such as greenhouse gas concentrations, aerosols, etc., rather than the actual sequence of atmospheric and oceanic conditions observed during each year. Consequently, the simulated year-to-year variations in precipitation may not correspond directly to those observed in reality.

The AI2 Climate Emulator version 2 (ACE2-ERA5) model is a deep-learning autoregressive global model trained on the fifth-generation ECMWF reanalysis (ERA5) with a Spherical Fourier Neural Operator architecture (SFNO, [12, 13]). The model was trained using ERA5 reanalysis data covering the period 1940–1995. For this study, the model was initialized on 1 January 2001 and integrated for 10 years using ERA5 forcings, corresponding to the

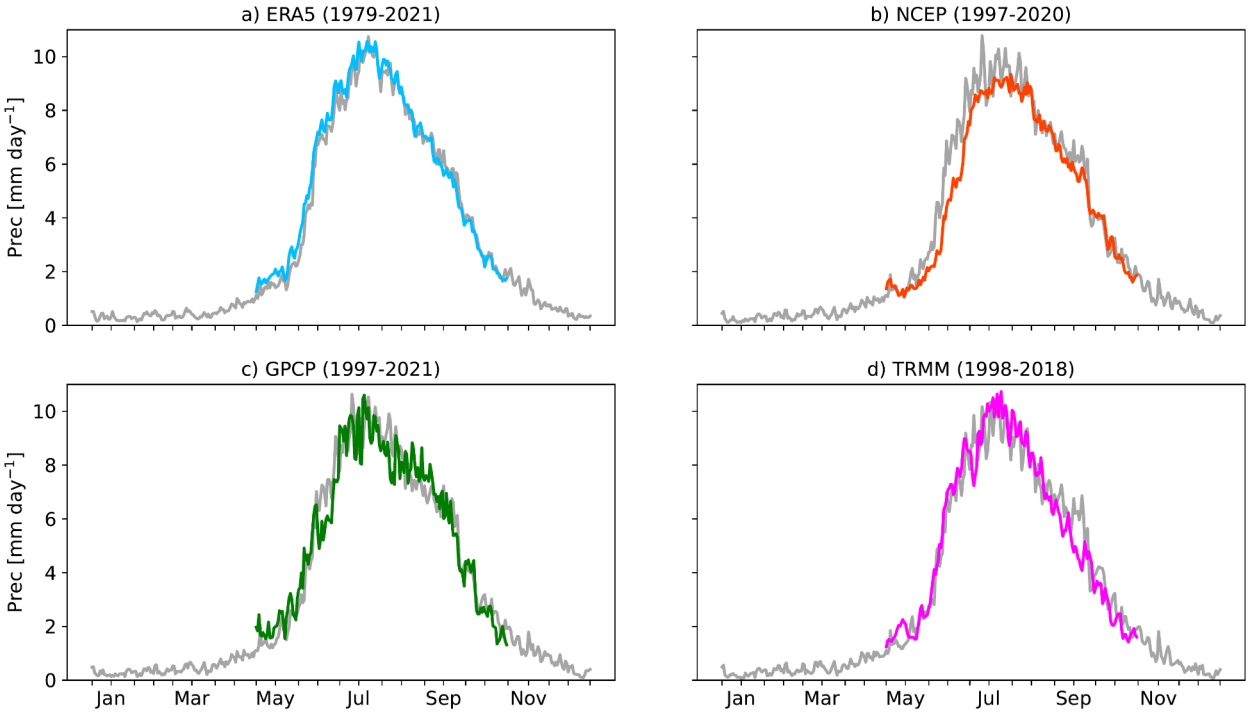


Figure 1: Climatological seasonal cycle of Precipitation over the Indian land using the IMD 1° gridded dataset (dark gray) compared with a) ERA5 (1979-2021), b) NCEP (1997-2020), c) GPCP (1997-2021) and d) TRMM (1998-2018). Here, the comparison is made from May 1 to October 31.

period 2001–2010. The resulting model simulations were used to investigate precipitation variability.

The second-generation Climate Forecast System (CFSv2), developed by the National Centers for Environmental Prediction (NCEP), is used for forecasting rainfall throughout the monsoon season [14]. CFSv2 is an atmosphere–land–ocean coupled dynamical forecast system with the Global Forecast System (GFS) model as its atmospheric component. CFSv2 employs a spectral triangular truncation of 126 waves (T126) horizontally (approx. 100 km). The model has 64 hybrid sigma-pressure levels. The ocean model in CFSv2 is the Geophysical Fluid Dynamics Laboratory Modular Ocean Model v4 (GFDL MOM4), and surface processes are represented by the NOAH land surface model. Please refer to the previous studies that have used this model [14–16]. Here, I have used 40 years of precipitation forecasts spanning from 1982–2021, based on 16th May initial conditions throughout the monsoon season.

All these reanalysis, satellite, and model-based precipitation products are masked over Indian land and are averaged over the region of 7.5°–28.5°N; 70.5°–90.5°E.

How close the reanalysis and satellite-based precipitation are to observations

ERA5 reanalysis precipitation captures the climatological seasonal cycle of IMD precipitation reasonably well, although it exhibits a slight overestimation from May to August. The agreement improves toward the end of the monsoon season with ERA5 capturing the IMD precipitation climatology more accurately during September and October (Figure 1a). In contrast, NCEP precipitation exhibits a substantial underestimation (Figure 1b), especially during the onset and the peak phases of the Indian monsoon (May, June, and July). Its performance improves somewhat towards the end of the season as compared to the onset phase, except for the period between the middle to late September.

GPCP precipitation also reproduces the IMD climatological seasonal cycle over Indian land reasonably well (Figure 1c). However, some discrepancies are evident during specific periods. It under estimates the observed precipitation climatology from mid to late June and again in August, while overestimating precipitation at the beginning of September. TRMM precipitation, on the other hand, does a nice job in capturing the onset phase of the monsoon (Figure 1d). However, during the peak phase, the climatological daily variations

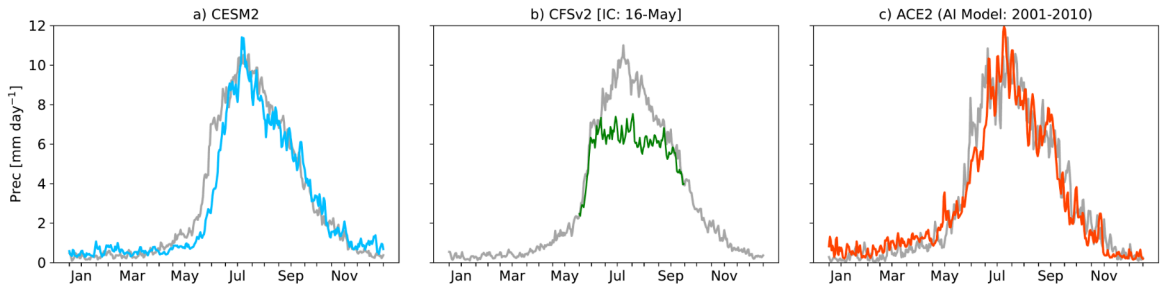


Figure 2: Climatological seasonal cycle of precipitation over the Indian land using the IMD 1° gridded dataset (Dark gray) compared with a) CESM2 Historical (1979–2014), b) CFSv2 (1982-2021), and c) ACE2 (2001-2010). Here, for the CFSv2 model, the comparison is made from May 1 to October 31.

are not well captured and finally, towards the end of the season, it tends to underestimate the observed precipitation.

How coupled GCM and AI model capture the observed seasonal cycle of precipitation

Each of the models used for this analysis shows a dry bias over the Indian land. In the case of CESM, a substantial amount of dry bias can be seen compared to the observations during the onset phase of the monsoon. However, although the dry bias exists, the model performs relatively better in simulating the post-onset climatological rainfall (Figure 2a). Surprisingly, the CFSv2 really doesn't show any peak monsoon rainfall. Although it captures the onset precipitation and end-of-season precipitation, the precipitation remains almost flat in between these two ends (Figure 2b). Past literature has shown a similar seasonal cycle pattern for T126, which improves as the resolution increases to T382 [17]. However, the same study showed that although the peak appears when high resolution is used, it remains substantially drier.

In the AI model ACE2, a dry bias is observed during the monsoon season; however, the precipitation was higher before the onset. Similar to the CESM, the model captures the peak and the end-of-season climatological precipitation relatively well compared to the onset-phase precipitation (Figure 2c).

Key Takeaways

Based on the comparison with IMD precipitation, ERA5 reproduces the climatological seasonal cycle of rainfall over India more accurately than NCEP. This is an important consideration for studies involving atmospheric moisture and dry static energy budgets, in which precipitation is a key component. Since consistency among the different budget terms is essential, it is preferable to use a single reanalysis dataset for their computation. Therefore, given its better representation of the observed rainfall climatology, ERA5 is a more suitable choice for studies requiring reliable estimates of these budgets.

Satellite-based precipitation products show reasonable agreement with IMD observations over Indian land. However, their spatial coverage makes them particularly useful for studies requiring precipitation estimates across the entire South Asian sector, including both land and ocean regions, where gauge based observations are limited. In this context, GPCP and TRMM precipitation products can provide valuable estimates of daily rainfall variability over the broader region, although their uncertainties and temporal coverage should be considered when selecting the appropriate dataset.

All the coupled climate models exhibit a dry bias in simulating Indian monsoon precipitation. Although CESM may reasonably reproduce the seasonal-mean precipitation over Indian land regions, its ability to capture the subseasonal evolution of rainfall may be limited. A similar limitation is evident in the ACE2 model. Likewise, forecasting systems such as CFSv2 struggle to accurately simulate precipitation during the peak monsoon months of July and August. To improve this, one possible way is to properly understand and hence represent the physical processes or modes that are directly associated with peak month rainfall

and its interannual variations.

In this study, I have compared the climatological seasonal cycle of precipitation from various reanalysis products, satellite-based datasets, and climate models against IMD observations. However, evaluating the climatological seasonal cycle alone is insufficient to assess how well these datasets capture observed rain fall variability. It is therefore important to further examine how accurately they represent the interannual variations in seasonal-mean and monthly precipitation relative to IMD observations.

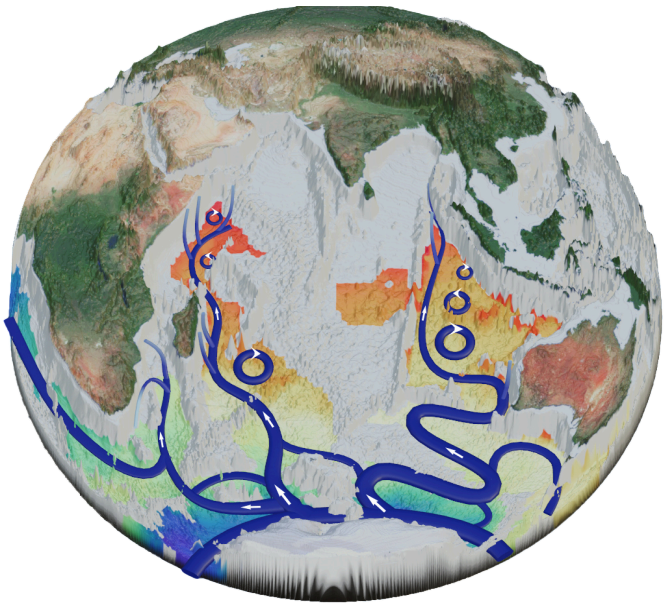
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We know the far side of the Moon better than the bottom of our own ocean!

Kaushik Mishra

You have probably heard the claim that we know more about the surface of the Moon than our own seabed. It turns out to be true, and the real numbers make the point far better than any slogan can. Orbiting spacecraft have mapped 98 percent of the Moon's surface down to 100-meter details, and almost as much of Mars at double that resolution. Earth's ocean floor is nowhere close. Modern high-resolution sonar has surveyed only about a quarter of it at comparable quality. For most of the rest, all we have is a rough estimate stitched together from satellite measurements of the sea surface, accurate to a few hundred meters at best.



Antarctic Bottom Water pathways as revealed from a high-resolution ocean simulation - Mishra et al 2026, GRL.

That gap gets stranger the deeper you look. More people have descended to Challenger Deep, the deepest point in the ocean, than have ever walked on the Moon. We have visited the extreme depths, but we have largely skipped mapping everything lying in between.

That unexplored middle turns out to be full of extraordinary life nobody has ever seen before. In roughly the last year alone, an international project called Ocean Census catalogued over 1,100 new marine species, marking a jump of over 50 percent on the usual annual discovery rate. The haul included a carnivorous sponge nicknamed the "death ball", found in the Southern Ocean; the first-ever footage of a live juvenile colossal squid in its deep natural habitat near the South Sandwich Islands; and a bubblegum coral on a seamount off Peru that turned out to have a skeleton made of chitin, a structural feature never recorded in that group before. Scientists hope to discover 100,000 more species before they are lost to a warming, more acidic ocean, quite possibly before humanity even realizes they existed.

The Indian Ocean is one of the least explored regions of this least-explored part of the world. Its first systematic deep-sea survey, examining the seamounts around the Seychelles, only began in 2019. A latest research from CAOS investigates on a different kind of invisible deep-sea phenomenon: the cold currents moving along the seafloor, carrying vast amounts of heat and carbon northward from Antarctica. The water and the life within it share this profound invisibility. We have built entire global climate theories on only a handful of direct physical observations. That uncertainty should make us uneasy. The deep ocean quietly regulates our climate and hides most of the planet's undiscovered life right off our own coastlines, yet we are still drawing its basic map for the first time. Every expedition, every moored instrument array, and every computer model run closes that gap a little bit. The ocean, unfortunately, is not waiting for us to catch up.

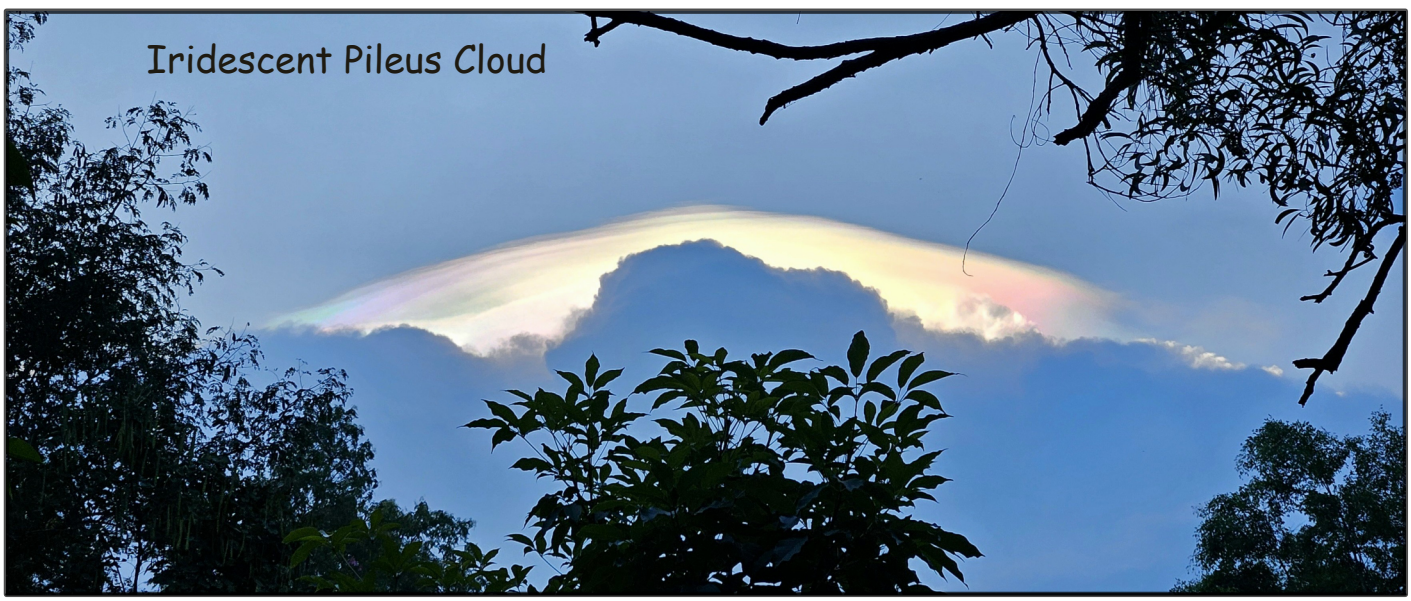
Monsoon Intraseasonal Oscillations

Parag Shende

Every year from June to September, our country is blessed with rain. Like clockwork, the rain starts around June (of course it starts at different times for different regions with Kerala getting it first), when the whole country gets relief from the scorching heat of summer. The monsoon season (as it is called owing to seasonal reversal of low-level winds) is the lifeline of our country – our agriculture depends on it; our economy is shaped by it. One also observes that during the season, there are alternating periods of heavy rain (lasting for several days) and days of clear weather. These are termed the active (rainy) and break (clear weather) phases of monsoon. This means that we don't get rain continuously throughout the season. This is driven by a phenomenon called Monsoon Intraseasonal Oscillations (MISO) -- intraseasonal because it happens within a season (less than 120 days) and oscillation owing to the alternating behavior (dry and active). It is also referred to as Boreal Summer Intraseasonal Oscillations (BSISO), northward propagation, etc.

MISO involves the movement of large band of clouds from equator just south of Indian landmass till the foothills of Himalaya. These clouds bring in moisture and rain over the whole country. This northward journey of MISO usually takes about 20 days. At the same time, we see a northward movement of clear weather conditions (no clouds, no moisture, and no rain) from the equator in a similar way. Hence, within a span of about 40 days, the whole cycle is complete and within a rainy season, we can see multiple such events. MISO is a large-scale phenomenon (occurring over 1000s of kilometer) and is unique to Indian ocean and western Pacific region.

MISO plays an important role in the initiation of monsoon over India, in modulating the active and break phase of monsoon and in the occurrence of extreme events like floods and droughts. It has been a source of constant study since its discovery in the early 1980s and further improving its understanding could lead to better prediction. In the past two decades, there has been a tremendous growth in the fidelity of weather prediction models, and we have improved the prediction of various atmospheric phenomena (including MISO). But there is a further need for improvement in the prediction of MISO so that the prediction accuracy is trustworthy and can be used by different sectors like agriculture to economists to the aviation industry.



Overcorrected: What Stratospheric Aerosol Geoengineering could do to India's Rains?

Shinu Sheela Wilson

Stratospheric aerosol geoengineering has the potential to offset greenhouse-gas-induced warming by reflecting incoming solar radiation. While global warming is projected to increase global mean precipitation and weaken tropical circulation, the extent to which stratospheric aerosol injection (SAI) may offset or modify these changes, and the underlying mechanisms, remain unclear. This study investigates projected changes in the Indian summer monsoon using simulations from the Community Earth System Model (CESM1) under a high-emission scenario (RCP8.5) and an SAI scenario from the Geoengineering Large Ensemble Project (GLENS), in which SO_2 is injected at multiple latitudes (15°N, 15°S, 30°N, and 30°S) in the lower stratosphere.

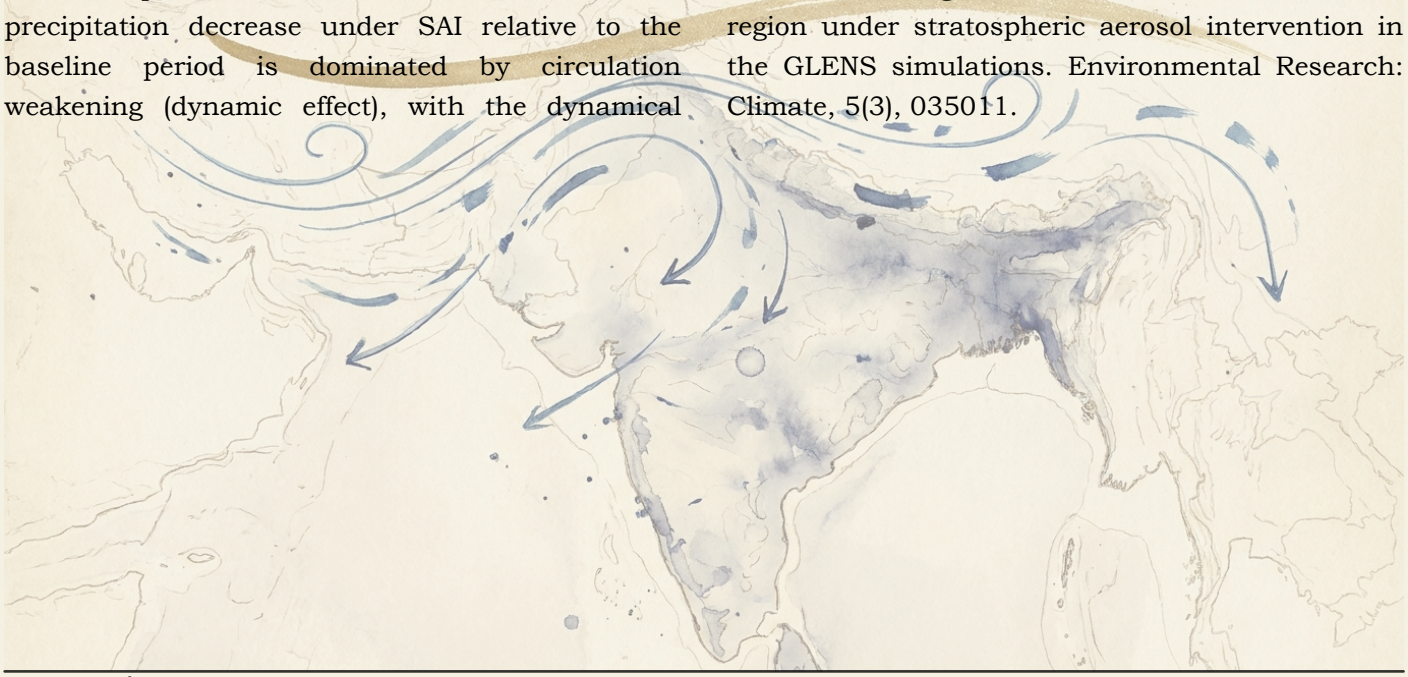
Indian summer monsoon precipitation increases by ~14% under RCP8.5 but decreases by ~10% under GLENS during 2071–2090 relative to 2011–2030, indicating precipitation overcompensation under SAI. Water vapor budget analysis reveals that the precipitation increase under RCP8.5 is primarily driven by enhanced atmospheric water vapor (thermodynamic effect), with only modest changes in atmospheric circulation. In contrast, the precipitation decrease under SAI relative to the baseline period is dominated by circulation weakening (dynamic effect), with the dynamical contribution being nearly four times larger than that under RCP8.5.

The weakening of the monsoon circulation under SAI is driven by a combination of aerosol-induced stratospheric heating, increased tropospheric static stability, and reduced low-level barotropic shear. These processes collectively weaken both the lower- and upper-level monsoon circulations. This dynamical weakening, characterized by anomalous subsidence and reduced water vapor convergence, leads to a decline in monsoon precipitation despite the near-restoration of surface temperature over the Indian region.

These results highlight that the monsoon response to SAI in GLENS (CESM1) is governed predominantly by circulation changes rather than the regional temperature changes. The study cautions that these findings are model-specific and strategy-dependent, emphasizing the need for multi-model and multi-scenario studies to assess the robustness of the results.

Reference

Wilson, S. S., & Bala, G. (2026). Precipitation and circulation changes in the Indian summer monsoon region under stratospheric aerosol intervention in the GLENS simulations. Environmental Research: Climate, 5(3), 035011.



Can we design away the drought? The physics behind Stratospheric Aerosol Geoengineering's rainfall problem

Anu Xavier

As the planet warms, stratospheric aerosol geoengineering (SAG) has been proposed as a possible way to temporarily limit greenhouse-gas-induced warming. Inspired partly by the cooling that follows major volcanic eruptions, SAG would introduce reflective aerosols into the stratosphere to reduce incoming solar radiation. But restoring global temperature does not necessarily restore rainfall.

In our recent review in Environmental Research Letters, Govindasamy Bala, Thejas Kallihosur and I examine why tropical precipitation can change under SAG even when global warming is offset. This is particularly important because tropical monsoons support more than two-thirds of the global population.

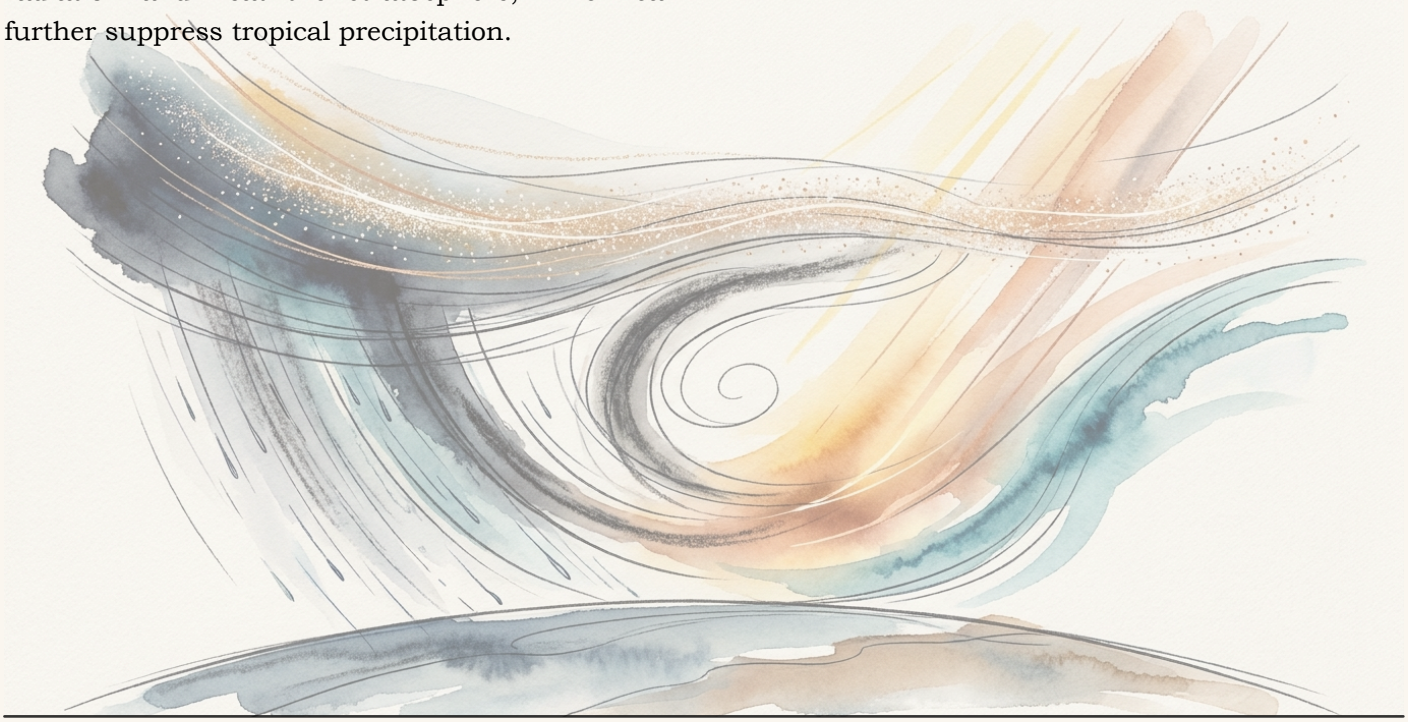
We identify two planetary energy constraints that provide a simple framework for understanding these changes. First, carbon dioxide and stratospheric aerosols affect the atmospheric energy budget differently. Their precipitation responses therefore do not simply offset each other when SAG offsets greenhouse warming. Sulfate aerosols also absorb radiation and heat the stratosphere, which can further suppress tropical precipitation.

Second, an unequal aerosol forcing between the Northern and Southern Hemispheres creates an energy imbalance. The atmosphere responds by transporting energy across the equator, shifting the Intertropical Convergence Zone (the tropical rain belt) and redistributing precipitation between hemispheres.

Together, these constraints show that where and how aerosols are introduced matters, not simply how much cooling they produce. Our review provides an energetic framework for evaluating SAG strategies while highlighting major uncertainties in regional rainfall responses and the need for further research before considering real-world implementation.

Reference

Xavier, A., Bala, G., & Kallihosur, T. (2026). Energetic constraints on tropical precipitation changes under stratospheric aerosol geoengineering: a topical review. Environmental Research Letters, 21(10), 103004. DOI: 10.1088/1748-9326/ae6714



Assam's Monsoon in Zubeen's Voice

Thanangka Chutia

When the first rain falls
upon the red earth of Assam,
the Brahmaputra grows restless,
and the green fields begin to breathe.

Somewhere, a cloud gathers
over distant hills,
and the wind carries
the fragrance of wet paddy,
of bamboo leaves,
of a village waiting for the rain.

Then Zubeen begins to sing.

And suddenly,
the rain is no longer rain.

It is a memory
returning through the window,
a name whispered
in the quiet of an evening,
a love that never quite left,
a longing carried
like a small boat
upon the Brahmaputra.

In Ejak Borokhune Muk,
the rain touches the heart
like an old forgotten hand.

In Topal Topal Borokhune ,
each drop seems to fall
with a story of its own,
a little tenderness,
a little loneliness,
a little Assam
hidden inside the sound.

And when Barasha Jetiya rises,
the monsoon becomes a lover,
arriving without warning,
filling the sky,
the river,
the fields,
and the spaces between two hearts.

This is the rain of Assam,
not merely water from the heavens,
but the music of wet earth,
the silver of overflowing rivers,
the mist upon the hills,
the fragrance of childhood,
the ache of distance.

And perhaps that is
what Zubeen knew better than most:

that Assam does not simply live
in its rivers and forests,
in its songs and stories,
in its fields beneath the rain.
Assam lives in the heart.

And whenever the monsoon comes,
whenever the Brahmaputra turns dark
beneath the clouds,
whenever rain begins to whisper
against a lonely window.

Zubeen's voice returns.

And for a moment,
the whole of Assam
seems to sing with him:
Barikhare Borokhunot Tumi Moi Ekeloge

Dedicated to Zubeen Garg (1972-2025)

Editorial Note

Every science needs data. Every discipline needs discourse. But every community also needs a voice. We give ours a name: Meghadūta. For those who know their Kalidasa, the Meghadūta is the cloud-messenger sent across mountains and monsoons carrying word from someone far away to someone waiting. It felt like the only fitting name for a magazine born out of a centre that spends its days reading clouds, currents, and the language of the sky and oceans. Because that is exactly what this magazine hopes to be: a messenger. A cloud that carries not rain, but ideas - from a researcher's desk to a curious reader's minds. It is meant to be a genuinely broad-spectrum publication carrying everything from the driest technical article to the lightest, funniest meme about a forecast that didn't quite hold up.

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Page 17 - Fog over Bengaluru by Chetan Bankar

Back Cover - CAOS Entrance


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