TIMES evoke

EARTH'S CLOUD COMPUTING

The Indian monsoon is a time of magic. Suddenly, a sunny day turns dark as night. A wind whips into a frenzy and hitherto dignified-looking trees arch in a twisting, ecstatic dance. Then, with regal rumbling, the heavens open and you are soaked in the benediction of the skies. These rains are borne from Africa and the Indian Ocean, their journey proving nature abhors an imbalance — the searing summer heat of the Indian landmass causes winds to push oceanic clouds from the seas into the subcontinent. Between June to September, these moisture-laden clouds bestow India, UNESCO estimates, with over 75% of its total annual rainfall.

This is vital for 1.8 billion people living in the subcontinent. In India, the monsoon boosts key rivers and economic sectors — the World Bank estimates over 60% of Indian agriculture is rainfed — bolstering water, food, industrial and energy security. Even politicians, usually intricately conscious of rank and file, modestly acknowledge the monsoon to be India's true finance minister. Yet, this phenomenon reflects more than everyday economics for this is the result of nature's computing, adding Earth's orbit around the sun to jet streams, belts of tropospheric warmth, heat sinks in oceans and cumulonimbus clouds in the skies. Together, these create a friendly siege — the monsoon's airstream mounts the Western Ghats, recedes, then climbs again, each time pushing thicker clouds upwards. These finally cascade triumphantly into the plains, rain being the joy of this parade.

This monsoon is under threat now. Anthropogenic or human actions, from fossil fuel usage to pollution and deforestation, are emitting increasing carbon dioxide (CO_2) into Earth's atmosphere. The global warming from this is heating land and air faster, which means stormier monsoons. But alongside, the Indian Ocean is warming too, weakening rain. As Times Evoke's global experts emphasise, the monsoon — nature's wondrously balanced equation — faces an unpredictable future. Global warming wasn't caused by those who anxiously await these rains — yet, it bears the greatest consequences for them, a truth to be remembered in calls for climate justice. It is vital we know the science underpinning the magical monsoon now. Join Times Evoke in discovering the greatest cloud computing on Earth.

'Over millions of years, mountains, ice sheets and oceans shaped the Indian monsoon'

Steven Clemens *is associate professor of earth, environmental and planetary sciences at Brown University. Speaking to* ***Srijana Mitra Das*** *at* ***Times Evoke****, he discusses the factors that make the Indian monsoon:*

What is the core of your current research?

■ My work right now focuses on the East China Sea — it looks at the East Asian monsoon where we are seeking to reconstruct changes in the isotopic compo-sition of the rainfall and the runoff from river valleys into the East China Sea. This is similar to the work we've done in the Indian region, trying to differentiate changes in the isotopic comp-osition of rainfall from how much rain was occurring locally.

How do you study a transient phenomenon like the monsoon over the millions of years you survey — what sources and traces does this involve?

■ We mainly study sediments which accumulate on the sea floor — these integrate vast amounts of time. For example, the sedimentation rates we typically look for are in the order of 8 to 20 centimetres per thousand years. A given sample can integrate several hundred years of time. So, although the monsoon is a transient feature on the inter-annual and decadal timescale, we are looking at large-scale changes over long periods of time through these deep-sea sediments.

What are some natural factors which shape the Indian monsoon?

■ Many different aspects drive the monsoon which has inter-annual and multi-decadal changes and whose timescales range all the way to tectonic variability, associated with the growth and decay of mountain belts. At the inter-annual timescale, the El Nino Southern Oscillation (ENSO) Index is a big factor.

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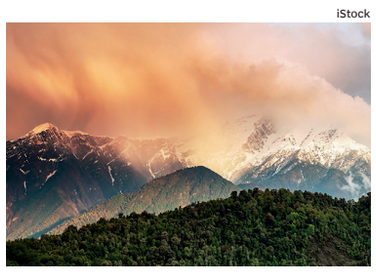

HOW IT PEAKS: The Himalayas and the Tibetan Plateau influence heat and rain

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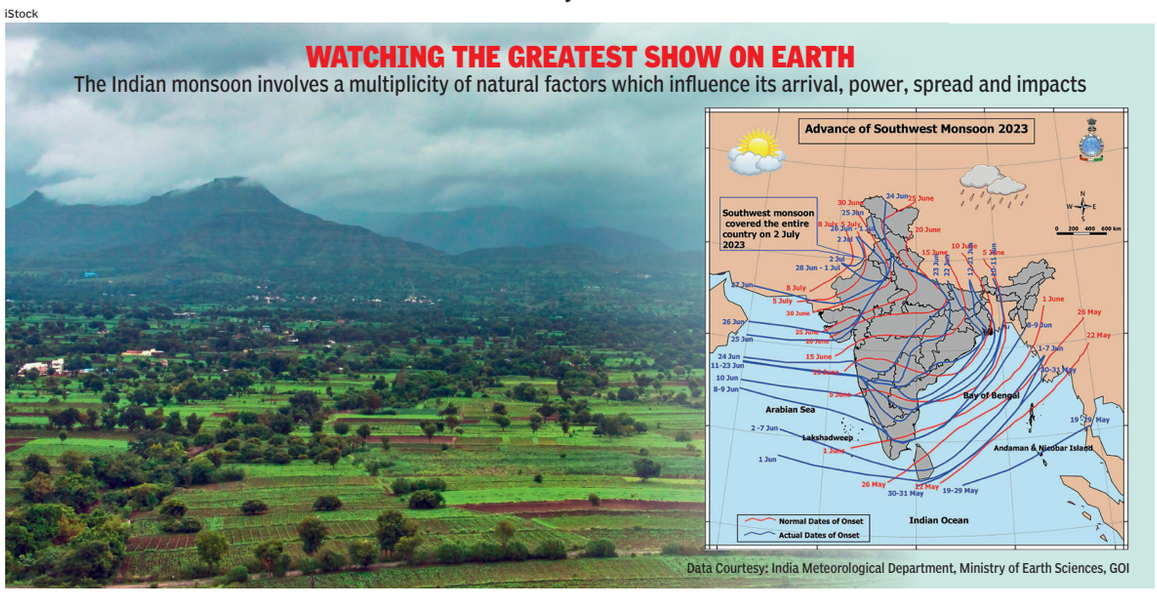


AS TIME POURS

In the multi-decadal timescale, changes in ocean temperatures influence evaporation from sea water. In the tectonic timescale, the rise of the Himalayan and Tibetan plateau are big players in the evolution of the Indian monsoon because they determine largely where the locus of heating is in summer, which drives low pressure over India and pulls in moisture from the ocean.

Among other factors, when Earth's ice volume is low and solar radiation is very high, the monsoon grows strong. So, there's also a linkage to high-latitude ice volume — when this is high, that tends to weaken the monsoon. When this is low, it tends to strengthen it. The combination of very strong solar radiation as a function of change in the orbital geometry of Earth around the sun and low ice volume are when you'll find very strong monsoons — this happened 1,25,000 years and 11,000 years ago.

Can you tell us about your recent research on how the monsoon responds to rising carbon dioxide (CO_2) concentrations?

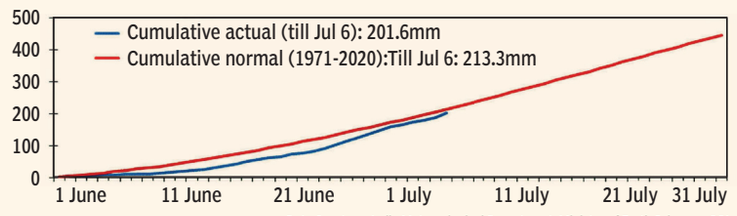
■ The modern monsoon in India has decreased in strength over the past many decades — this is largely attributed to aerosol forcing. But over the much longer term, like a 100-year-timescale, that factor is going to be in competition with CO_2 forcing because the latter is a global scale phenomenon. It causes a large-scale global increase in atmospheric temperature which drives more evaporation from ocean waters — hence, the winds falling from the oceans onto the continent during the summer monsoon will be carrying more moisture. So, there will be a competition between the monsoon-weakening aerosol forcing over India and this longer-term increase in global temperatures associated with CO_2 which will increase monsoon precipitation. At this point in time, most models predict the CO_2 increase factor will win out — the Indian monsoon will become stronger in terms of rainfall.

Does studying the monsoon's past help us learn more about its future, particularly in an era of climatic change?

■ Yes, absolutely. The IPCC models seeking to predict future changes in monsoons are fairly confident the impacts of the greenhouse gas forcing can be larger than the impacts of aerosols in the long run — so, part of our work involves going out to research to what extent the Indian monsoon is sensitive to this greenhouse gas forcing. A wonderful aspect to this search is that we know what the greenhouse gas forcing was over the last 8,00,000 years — we understand that as it's been recorded by ice cores. If we reconstruct the monsoon and statistically compare the runoff from the monsoon to the greenhouse gas forcing, we can derive those linkages quantitatively. That shows, for instance, how there were times when the greenhouse gas forcings were high — and these were followed by strong monsoons.

HOW IT STARTED & HOW IT'S GOING

Given its huge importance, IMD tracks Cumulative Rainfall (mm) across India

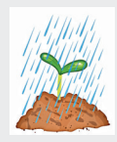


Data Courtesy: India Meteorological Department, Ministry of Earth Sciences, GOI

KNOW YOUR MEGHADUTA

● **The monsoon brought freshness to India's litterateurs** — perhaps the most iconic was **Kalidasa** who, in the 5th century, wrote of the rainy season as a 'king', whose splendour was mirrored in **elephant-like clouds and thunder evoking beating drums.** His words ring true many centuries later, with monsoon clouds that glow 'like blue lotus flower leaves' and **ketaki and kadamba groves,** spreading their fragrance when drenched in the rain

● The **2000-year-old Sangam poetry** also represented the Indian tradition of seeing **the monsoon as a fresh start** — a wonderful Sangam composition compares 'hearts earnest in love' to the pure melting of **red earth with rain.** In contrast, Western writers are more withdrawn — Shakespeare describes showers somewhat wearily in 'King Lear' as **'the rain, it raineth everyday',** a sight somewhat familiar in Britain



● While scientists see the **links between rain and ecosystems,** Western writers see rain as a one-way downpour. **George Bernard Shaw** wrote drily how 'the rain in Spain stays mainly in the plain' — but **Ruskin Bond** in India describes **the fragrance of a drenched Earth** rising up as if it were **'giving something beautiful back to the clouds'**

Research: Smithsonian Magazine, The Guardian, BBC, Yale School of Forestry, CNN, Encyclopaedia Britannica

Photos: iStock

SWINGING IN THE RAIN

● It's not just humans — many animals and birds are also **'pluviophiles'** or beings who love the rain. Some are considered harbingers of the monsoon itself — the **weaver bird,** famed for its **intricately constructed nests**, starts building as it senses the rains approach. By the time the downpours start, **the clever bird has its home ready** — male birds 'weave' these nests and add to their beguiling charms in the mating season

● **Amphibians, from bush frogs to gliding toads, love the monsoon** — and express their joy with songs in the rain. The **Indian bullfrog emerges from hibernation** in the rainy season **and sings to attract females.** The rare **purple frog** emerges from its burrows only during the monsoon to lay eggs — other less shy frogs enjoy the **lush microhabitat space** they get for breeding, without worrying about their skin drying out

● **Snails** cherish the rain because **high humidity helps them carry out key physiological activities** like feeding and reproduction. Snails are often seen moving over wet grasses, **making small holes in the ground** to lay their eggs which is difficult in hard, dry soils — of course, they still traverse **at their trademark pace**, understandable as they're literally carrying lock, stock and barrel

Research: Encyclopaedia Britannica, Wildlife SOS, National Geographic, IUCN

'A positive IOD can enable a normal Indian monsoon'

Indrani Roy *is a climate scientist at University College London (UCL). Speaking to* ***Times Evoke****, she discusses winds and waters in India's monsoon:*

I mainly research solar variability, atmosphere-ocean coupling, climate change, the monsoon and teleconnection. The Indian summer monsoon (ISM) is heavily influenced by the El Nino-Southern Oscillation (ENSO) phenomenon, generated by complex interactions between the atmosphere and oceans. One of Earth's most important modes of tropospheric variability, this influences the world through atmospheric teleconnection.

ENSO is the periodic variation of sea surface temperatures (SST) in east to central tropical Pacific which happens every two to three years. When the SST warms, we have a warm event ENSO phase. When it cools, it generates a cold event phase. The former is called El Nino and the latter La Nina. The monsoon from June to September is significantly impacted by the prevalent ENSO phase — warm ENSO phases generally yield less rain while cold ENSO phases bring more. Drought years in India often align with El Ninos while floods match La Ninas. The east-west Walker circulation of air flow, originating in the tropical Pacific, also plays a role in this teleconnection.

Interestingly, in 1999, a new mode in the Indian Ocean, termed the Indian Ocean Dipole (IOD), was discovered. This also has a strong influence on the Indian summer monsoon. The IOD Index is measured by differences in sea surface temperature anomaly between the western equatorial and south-eastern equatorial portions of the Indian Ocean. During a positive IOD phase, India receives more rain — a negative IOD phase usually offers less. Both ENSO and IOD exert an offsetting impact on India's summer monsoon — while El Nino tends to lower this, a positive IOD increases rainfall. This year, ENSO is in a positive phase, so less rain was anticipated — however, the IOD is positive too. If that doesn't change, normal rain can be expected.

There are different types of ENSOs, based on spatial patterns of sea surface temperature (SST) around the tropical Pacific. One is dominated by variability around the East Pacific and termed Canonical ENSO or EP type. Another is dominated by variability around the Central Pacific (CP), called Modoki or CP type. A third is a combination, termed Canonical-Modoki, all with different global and local influences.

The Indian summer monsoon (ISM)-ENSO teleconnection is strongly captured in Central North East (CNE) India. The ISM represents a large-scale source of heat around the CNE region and the Inter-Tropical Convergence Zone (ITCZ) — this separates the northern hemisphere from the southern hemisphere — passes through here. This is also the meeting point of the east-west Walker and north-south Hadley air circulation.

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HAPPY HARVESTS FOR ALL: Monsoon science is vital in climatic change for those relying on rain-fed farming

A joint initiative among various groups working on global circulation models coordinated experiments comprising the 5th phase of Coupled Model Inter-Comparison Project (CMIP5). I analysed the CMIP5 model output which captured the ISM-ENSO teleconnection — 80% of the models agree on the strength of the regional teleconnection around the CNE, suggesting the robustness of the ENSO teleconnection there. This is also present in models for future scenarios. Improved predictions can empower millions who rely on monsoon rains.

IN THE WINDS

Other factors can also shape the monsoon. In the last two decades of the 20th century, the ISM-ENSO teleconnection was disrupted. In my research, we found two powerful volcanic eruptions had taken place. The first was El Chichon in 1982, followed by Pinatubo in 1991. These occurred in phases of strong solar cycles and a domination of the Moduki ENSO. Researchers discussed a mechanism which could be triggered by explosive volcanos via a preferential alignment of the North Atlantic Oscillation (NAO) or fluctuations of atmospheric pressure over this ocean. Strong volcanos are often aligned with a positive NAO phase. Other features were also very distinct, including increases in Central Pacific warming, cooling in the North Atlantic and warming in the Eurasian sector. Both the NAO and Eurasian sector impact the N-S Hadley circulation. Thus, the strong teleconnection of the ISM and ENSO via the E-W Walker circulation was partly overtaken through a powerful N-S regional Hadley circulation — both the disruption and the subsequent recovery only emphasise the importance of the natural drivers of the Indian summer monsoon.

'Butterflies migrate with the rains, flying over mountains and against the winds'

Krushnamegh Kunte *is Associate Professor at the National Centre for Biological Sciences (NCBS), Tata Institute of Fundamental Research. He tells* ***Times Evoke*** *about the huge monsoon journeys of butterflies:*

It can be mindboggling to think of species as small as butterflies migrating over vast distances and in tough physical conditions — yet, come the monsoon and butterfly groups in India's Western Ghats do so. There are two distinct reasons why. One is a seasonal movement, fuelled by the monsoon. For a long time, this has been quite constant and fairly fierce, particularly in coastal areas. In the Western Ghats, butterflies are pushed out of the hills where it rains very heavily. They can't survive in such downpours, so they move east towards the plains, first to Mysore in the north, then further on to Krishnagiri and other locations which are relatively dryer even during the monsoon.

They migrate to escape torrential rain and because this happens on a fairly regular basis, their movements are regular too, with their journey's starting point and end destinations remaining quite similar across the years. The other kind of migration — this process is also termed 'dispersal' — happens because during the early monsoon, when the rains are light, many butterflies breed. They produce a large brood and the new larvae eat up all the larval host plants around. Then, as adults, they find they have no place to lay eggs. So, they need to move to another area where they can do so — this is a resource-based dispersal.

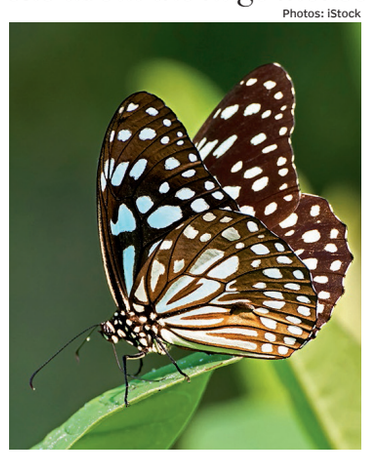
Butterflies can undertake such migration both in small numbers or in dispersals involving millions of them. Migration of the first kind, due to poor weather conditions, happens in large forms. The other strategy butterflies often use to deal with poor weather is to enter diapause which is a dormant state in which as pupae or caterpillars, they might remain frozen in development until clement weather returns. This is seen across the Himalayas, Europe and other cold places. It isn't common in the rainy wet areas of South India though where hibernation isn't required as the challenging weather conditions last for just about two months and undertaking brief movement is more favourable.

TO RICHER PASTURES: The delicate lemon emigrant travels to access new plants

WINGING IT

So, these small species embark on this vast migration, flying over high mountains, against the winds and across hostile habitat conditions to get to a place where they can either stay dormant — a state when they are not courting or breeding but fly around and feed — or go back and forth between the two locations, breeding in either place in alternative generations. This is what crows and tigers, the milkweed butterflies of the Western Ghats, do. Emigrant butterflies from dry areas embark on the earlier dispersal strategy, where they fly to a new area in order to access plants.

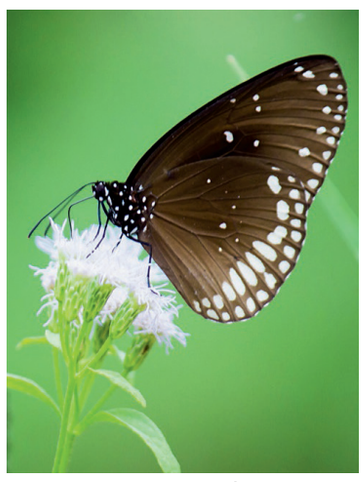
Photos: iStock



MONSOON JOURNEYING: The blue tiger butterfly undertakes a vast expedition

Formed under these two sets of conditions, these strategies are completely different — in the first one, there are steady movements across locations A and B because of weather conditions which are regular annual events. Here, butterflies migrate without being in a productive state. But butterflies which disperse due to resource conditions typically move with fully developed or developing eggs which are ready to be laid as soon as they find a new spot. Their flight morphology is therefore completely different from butterflies which fly in reproductive diapause — the latter's investment in flight muscles is very different. Both males and females here invest in a large thorax which fuels flight and not so much in reproductive tissue, unlike the other group which has well-developed reproductive tissue.

These contrasting migration and dispersal habits are shaped by different environmental conditions, annual predictability in these, resources in the locations butterflies can go to and whether they can breed there. So far, there has been a seasonal rhythm to such butterfly journeys. The impacts of climate change on such migration have not been documented yet — however, it is quite likely there will be effects caused by the growing unpredictability of weather events, the uncertainty around when exactly the monsoon will start and how much rain this will now bring. It is very probable that these conditions will affect butterfly migration and dispersal. Human activity overall is changing life for butterflies — the monarch in North America faces extensive habitat destruction, shrinking its population significantly. Whether climate change will add to that and alter the extraordinary expeditions undertaken by butterflies in India's monsoon must be studied.



ANYTHING BUT COMMON: The common Indian crow butterfly is quite an aviator

READERS WRITE

Dear Times Evoke,

TE's articles are eye-openers. The veil of growth on our eyes doesn't let us see how our activities are causing habitat destruction. Benton Taylor's insights on plants (2nd July) were very important. We must see Earth as a living entity.

— **Dikshita Jasrotia,** Delhi

I loved the beautiful article on Benton Taylor's research! Times Evoke takes a special place in my week's routine. All its articles are informative and heartening. It gives great knowledge about topics which don't appear in our daily sources of news. Congratulations, TE!

— **Neelamuthu T,** Bengaluru

TE outlining how plants devise ways to survive in climate change was amazing! I'm a teacher and we want children to be aware, so they can develop ways to mitigate environmental threats. TE helps marvellously!

— **Rosalynn Routray,** via email

I was thoroughly engrossed reading Benton Taylor! It's a matter of joy that a section like TE thrives in this era, focused entirely on nature, science and building public insights about the environment. TE's articles are informational, aesthetic and awakening. Thanks, TOI!

— **Debarati Mukherjee,** North 24 Parganas, West Bengal

Thanks for the excellent knowledge on plants and terrestrial ecosystems through Benton Taylor! It is such a pleasure reading about so many interesting aspects in nature in TE every week. TE's scientific information is very helpful for me being a Class 12 student and it also helps me significantly during debates in my school.

— **Sachin Singh,** Varanasi

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