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Invited Article

India would warm by 3°C or higher by the end of this Century: How to cope with it?

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ABSTRACT

Climate change has emerged as one of the most crucial challenges of the twenty-first century, with far-reaching consequences for ecosystems, economies, and societies worldwide. In tropical countries such as India, the agricultural activities of working labour which involves higher levels of physical exertion had been badly affected by the summer time heat stress in recent years. For example, February 2025 was India's hottest in 125 years, with many states breaching 40°C. The unusual warming at several locations in India is expected to increase faster in coming decades and could become vulnerable to physiological acclimatization among the city dwellers as well as farmers in rural areas carrying out activities in outdoor and indoor work places. Other extreme weather events like floods and droughts are also becoming more frequent and intense, disrupting communities and the infrastructure they rely on. Worsening storms and floods have continued to inundate entire cities; crippling droughts parch farmland; and intensifying climate risks threaten water supplies. India seems to be on track for a 3°C rise in temperature or higher over the pre-industrial average by 2100. In addition to preventing further climate change through appropriate mitigation measures such as phasing out use of fossil fuels, and renewable energy and bioenergy generation, it is of fundamental interest to analyse the existing impacts and implement appropriate adaptation measures and strengthen our early warning systems. Managing water sustainably together with building more efficient irrigation systems and better drainage, restoration of forest ecosystems in degraded areas and improve land and forest management through nature-based solutions for increasing food production, seems fundamental to climate resilience in India. A clear and consistent Sector-Specific Policies and Regulations to support Nationally Determined Contribution (NDC) Implementation in India with a tailored intervention for high emission sectors is needed.

Keywords: Global Climate Change-Future Impacts in India, Adaptation & Mitigation, Floods and Droughts-Disasters & Extremes, Food Productivity & Livelihoods.

GLOBAL CLIMATE CHANGE: CURRENT STATUS & THE FUTURE RISKS

Global warming continues unabated, exactly as predicted correctly since the 1980s and millions of people are increasingly suffering the consequences. The global-average temperature for the northern hemisphere summer of June–August 2024 was the highest on record. The year 2024 was 0.72°C warmer than the 1991–2020 average, and 1.60°C warmer than the pre-industrial level, making it the first calendar year to exceed 1.5 above that level (WMO, 2025). The Copernicus Climate Change Service (2025) has reported the warmest January 2025 (Fig. 1a), with global mean surface – air temperatures 1.75°C above preindustrial levels continuing the record temperatures observed throughout the last two years (The year 2025 has recorded the third-highest September global surface temperature at 1.54°C since 1850; Fig. 1b). The past three years (2023-2025) have been the hottest on record since the industrial era and this is set to be the first period when the temperature rise taken as an average would surpass the level at which scientists believe irreversible changes to the planet will begin if sustained. The average global mean surface air temperature for the year 2024 was 1.55°C above pre-industrial temperatures. During 2024, 24% of the Earth's surface had a locally record warm annual average, including 32% of land areas and 21% of ocean areas (increasing heat is making more of the planet uninhabitable) (Rohde & Hausfather, 2025). The average sea surface temperature for November 2025 was 20.42°C, the fourth highest value on record for the month. The land areas recorded a staggering 2.3°C above pre-industrial levels

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on an average which coincidentally aligned with a number of major population centres (Fig. 2). About 3.3 billion people — 40% of Earth's population — experienced a locally record warm annual average in 2024 (partly boosted by a strong El Niño event). The last 10 years have included all 10 of the warmest years observed in the instrumental record (Berkley Earth, 2025).

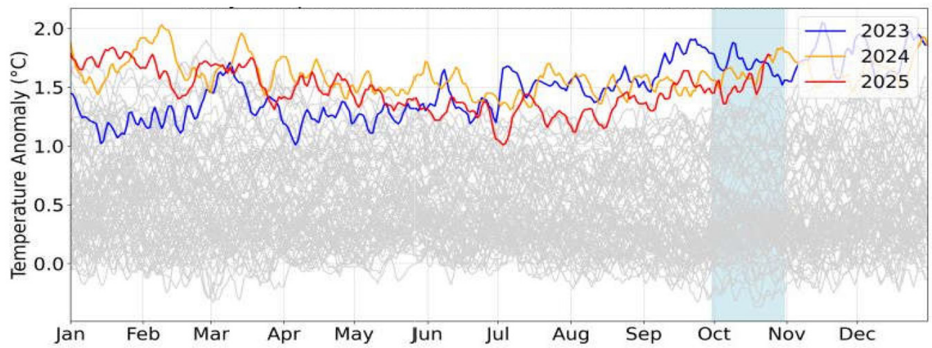

Fig. 1a: Global daily surface air temperature anomalies for different years until October 2025 (ERA5)

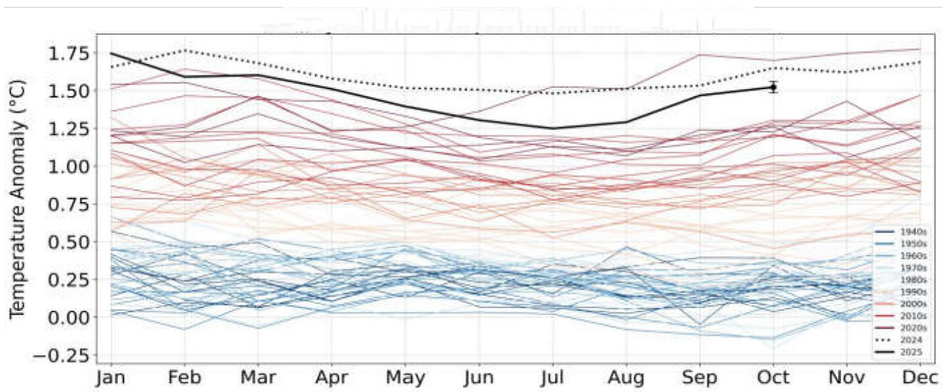

Fig. 1b: Monthly global mean surface air temperature anomalies, Jan 1850 to October 2025 (ERA5)

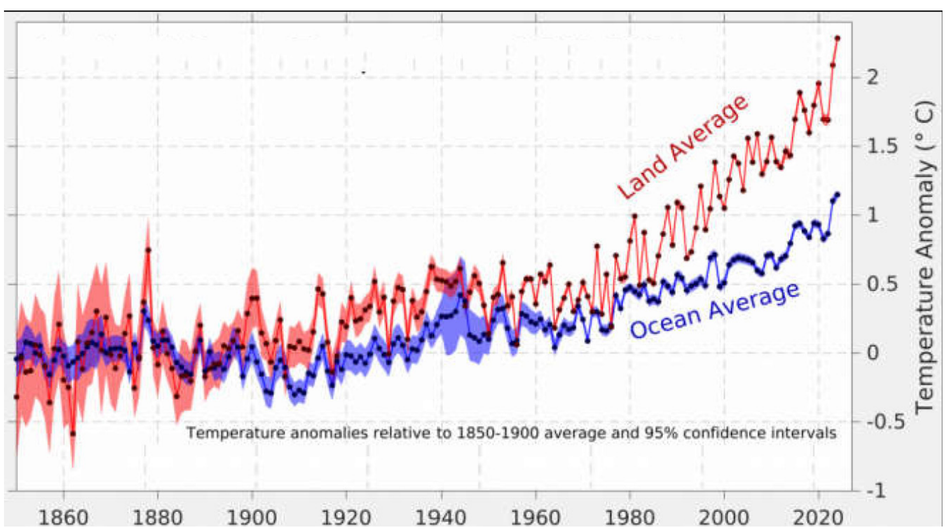

Fig. 2: Global mean land and ocean temperature anomalies with respect to 1850-1900 average (ERA5)

Global warming is primarily attributable to humans via greenhouse gas emissions (primarily Carbon Dioxide, Methane and Nitrous Oxide), which reached an all-time high in 2024, combined with a variety of other natural factors that contribute to natural short-term variability in the climate system (Fig. 3). The atmospheric concentrations of carbon dioxide and methane have reached record levels in 2024, at 422.1 ppm and 1897 ppb respectively (WMO, 2024). Through addressing these three greenhouse gases we stand a chance of staving off the most devastating effects of climate change. Methane, which is short-lived, is increasingly in the world's crosshairs because it is responsible for at least a third of current warming. It is also 80 times more potent than carbon dioxide in the first 20 years after its emission. Rising levels of atmospheric methane are directly at odds with the reductions needed to meet the Paris Agreement goals. Nitrous Oxide remains in the atmosphere for around 120 years, about a tenth as long as carbon dioxide and traps 270 times more heat per tonne than Carbon Dioxide. Measures to address nitrous oxide emissions would also tackle other air pollutants thus improving air quality. The increasing greenhouse gases in the atmosphere are driving the climate system into a never-before-seen state. Further, various carbon sinks, such as in the Arctic and the Amazon have weakened and have both become net emitters of greenhouse gases, and the failure of the land sink since 2023. World's fossil-fuel producers are on track to nearly quadruple the amount of extracted oil and gas from newly approved projects by the end of this decade, with the United States leading the way in a surge of activity. The failure to reduce emissions fast and the intention of petrostates and big oil companies to continue expanding production puts Earth on a path to 3°C of warming or more, given the political inertia and the inertia of the energy system.

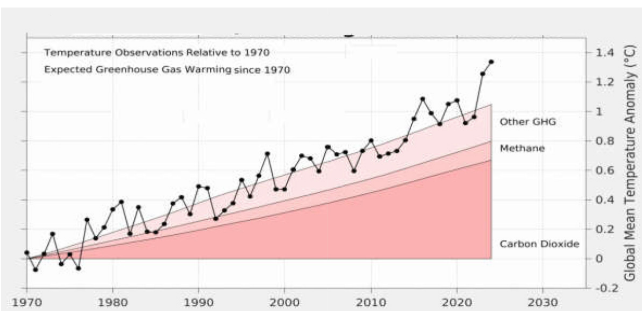

Fig. 3: Greenhouse gas warming vs. Temperature observations relative to 1970

Interestingly, 2024 was the wettest year for extreme precipitation as measured by maximum 1-day rainfall amounts. Record-breaking extremes mostly occurred within the tropical belt (Hohenegger and Stevens, 2022). The total amount of water in the atmosphere reached a record value in 2024, at 4.9% above the 1991–2020 average, markedly higher than in 2016 (3.4%) and 2023 (3.3%), the years with the second and third highest values (Fig. 4). The record high water vapour value for 2024 was influenced by a combination of increased surface evaporation from the ocean due to higher sea surface temperatures and the atmospheric water storage. Water vapour plays a crucial role in the climate system - it not only serves as an infrared green-house blanket wrapped around the Earth, but also acts like weather fuel because of its capability to release latent heat energy upon condensation. Unlike other greenhouse gases, such as carbon dioxide and methane, the concentration of water vapour is not directly influenced by human activities. However, as the atmosphere warms, it can hold more water vapour (about 7% more for each additional degree Celsius). In turn, the greater water vapour content further amplifies warming, a process known as '*temperature-water vapour feedback'*. Increased moisture in the atmosphere also heightens the potential for extreme rainfall events (Fowler *et al.,* 2021) and provides energy for more intense tropical storms as a weather phenomenon known as 'atmospheric rivers' characterised by strong horizontal water vapour transport typically associated with a low-level jet stream (over and above the tropical moistening under the strong influence of the El Niño-Southern Oscillation variability and Indian Ocean Dipole) can move the atmospheric water vapour inland which can lift and condense along orographic barriers and often cause severe thunderstorms and cloud bursts.

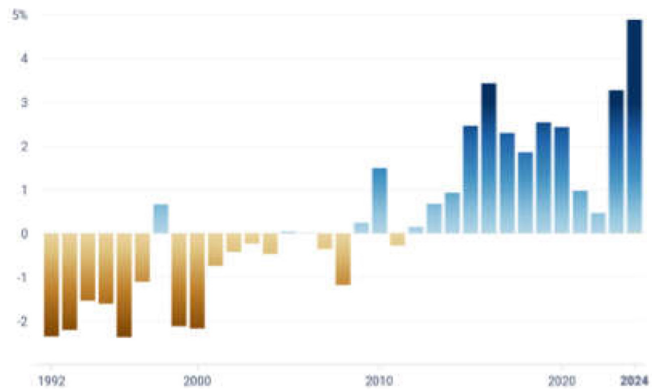

Fig. 4: Annual global mean total column water vapour anomalies for 60N to 60S inferred from ERA5 data (Reference period: 1991-2020).

The physical risks may be abrupt and difficult to predict, and they may also cascade in a domino fashion that is difficult to incorporate into climate models which also do not adequately account for the full range of reinforcing feedbacks. The past few years have seen an unprecedented number of climate-related disasters including extreme weather events across the world. Every fraction of a degree of warming above 1.5°C is expected to *increase the intensity and frequency of extreme weather events across the globe* (IPCC, 2023). The severity and frequency of extreme events such as heatwaves, heavy spells of rainfall, floods, droughts and storms, as well as record-breaking global temperatures, have already become unprecedented (Rahmstorf & Coumou, 2011; IPCC, 2018; WMO, 2023). For example, February 2025 was India's hottest in 125 years, with many States breaching 40°C as reports of heat-related deaths came in from Telangana, Gujarat, Punjab, and Odisha. During the year 2025, the monsoon rains during July - August have caused flooding and landslides that have swept away entire villages, killing thousands and leaving many residents trapped in the rubble and scores missing in Northen India where cloud bursts, flash floods, landslides and inundated cities have exposed the region's growing vulnerability to climate-related disasters. In China's Inner Mongolia province, 13 people have been killed in floods caused by climate change induced heavy rainfall and severe floods this year that are posing major challenges, including economic losses running into billions. Recent attribution studies suggest that, owing to global warming since 1850–1900, the median of the heatwaves during 2000–2009 became about 20 times more likely, and about 200 times more likely during 2010–2023 (Quilcaille *et al.,* 2025). Ongoing emissions and the loss of natural carbon sinks will drive further warming and more severe disruptive events globally (Fig. 5). There is a time lag between emissions and the warming that is experienced, meaning that unless emissions are reduced, more warming is in the pipeline. If unchecked they could become catastrophic, including loss of capacity to grow major staple crops under altered climate patterns, multi-meter sea level rise, and a further acceleration of global warming.

The Earth's energy imbalance — the difference between incoming energy from the sun and the amount of heat radiating from Earth back into space — has more than doubled since 2000 (Fig. 6), massively exceeding the increase predicted by climate models. In 2023, the imbalance reached 1.8 watts per square meter, which was twice what models estimated based on rising greenhouse gas emissions (Mauritsen *et al.,* 2025). Recent satellite observations reveal that the net energy flux in the North Atlantic and North Pacific Oceans (over an area of 10.7% of the earth's surface) have sharply increased to as much as +2.0 W/m^2 until June 2025 and are continuing to increase further since then (Fig. 7). Regardless of why Earth's Energy Imbalance (EEI) is growing so rapidly, the implications are alarming.

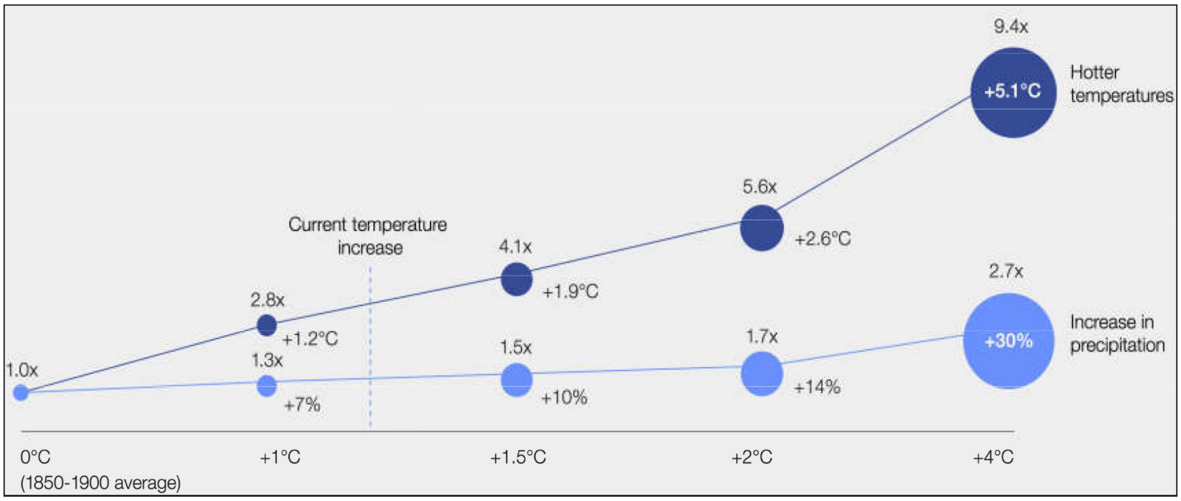

Fig. 5: Projected increase in frequency and intensity of heat waves and heavy rainfall under different warming scenarios**.**

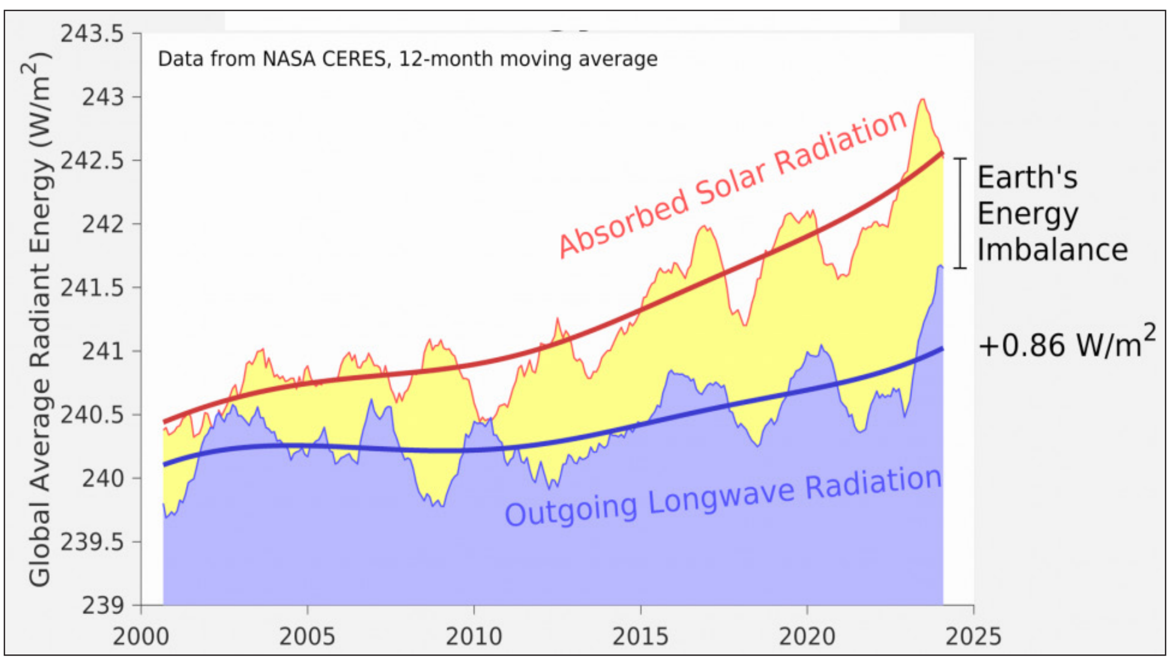

Fig. 6: Earth's energy imbalance in recent years

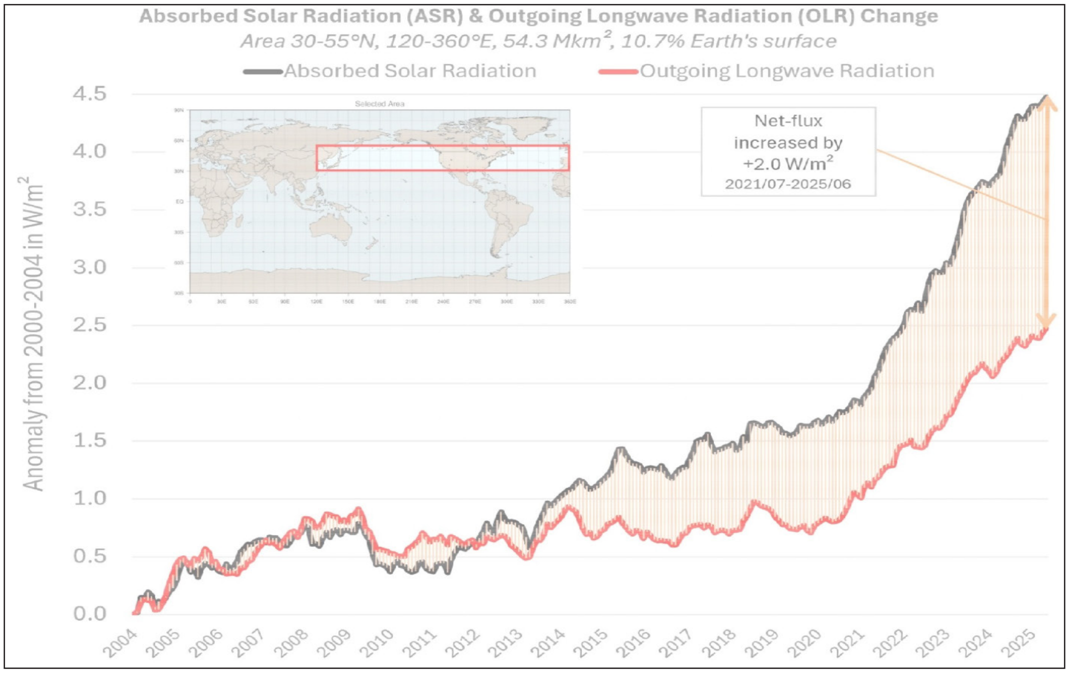

Fig. 7: Absorbed solar radiation and outgoing longwave radiation change over North Atlantic and Pacific Oceans in recent years

The larger the imbalance is, the faster climate change happens - If we have more imbalance, that means more energy accumulating, and temperatures rise faster. Earth is absorbing energy at an accelerating rate as depicted in Figs. 6 & 7 meaning thereby that the global warming has accelerated (Fig. 8) although this does not seem to be fully accounted for in our current climate models. A notable acceleration over the past 15 years has occurred compared to the rate of warming that characterized the post-1970 "modern warm period" when climate change began to notably take off alongside human emissions of CO_2 and other greenhouse gases (Hansen *et al.,* 2025). The rate of human-induced warming has increased from ~0.19°C post-1970 to 0.27°C over the past decade, roughly a 40% increase (Fig. 9). A much stronger (>95%) statistical significance of trend changes when we remove the effects of short-term variability – El Niño and La Niña events, volcanic eruptions, and changes in the solar cycle (Rahmstorf & Foster, 2025). The accelerated rate of warming is likely to continue to mid-century given the failure so far to reduce planet-warming greenhouse gas emissions. Perhaps the removal of sulphur from ship emissions (which was cooling the planet as a form of unintentional solar radiation management) is one of the leading factors to a greater and faster warming than is accounted for in the models.

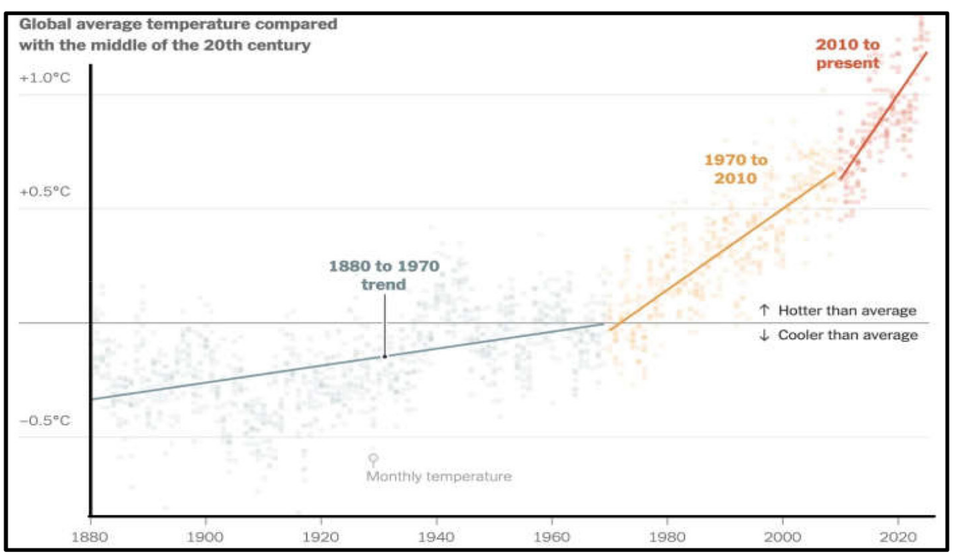

Fig. 8: Recent trends in rise in global mean temperature

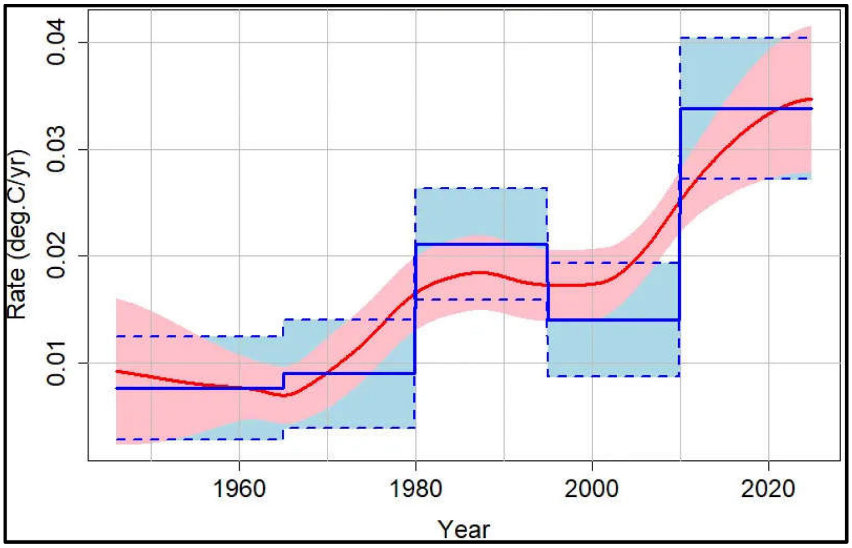

Fig. 9: Trend of global temperature after removing short term natural variability (e.g. El Niño and La Niña events, volcanic eruptions and changes in the solar cycle)

The ocean, being the largest heat reservoir on Earth, plays a crucial role in absorbing and storing the excess energy from the Sun. Numerous studies have shown that most of the heat in the Earth's energy budget due to the greenhouse effect is absorbed by the oceans (Fig. 10). Therefore, EEI should directly correspond with changes in ocean heat content (OHC). Ocean temperature data give some indication of Earth's energy imbalance. The abrupt new records of surface warming set in 2023 and 2024 and an unusually warm phase of oceanic variability, with unprecedented Sea Surface Temperature anomalies (average SSTs were 1.1°C above pre-industrial levels, a record with unprecedented ocean heat content) in multiple regions including Indian, Pacific and North Atlantic Oceans (Fig. 11). Oceans are an important climate regulator and carbon sink, and cooler waters can absorb greater amounts of heat from the atmosphere, helping to lower air temperatures. They also store 90% of the excess heat trapped by humanity's release of greenhouse gases (Li *et al.,* 2023). Records, however, suggest that, in 2024, both global sea surface temperature (SST) and upper 2000 m ocean heat content (OHC) reached unprecedented highs in the historical record (~16 ZJ higher than the 2023 value). The Indian Ocean, tropical Atlantic, Mediterranean Sea, North Atlantic, North Pacific, and Southern Ocean also experienced record-high OHC values in 2024 (Trenberth *et al.,* 2025). Cloud-heavy regions are also shrinking by about 1.5% per decade, reducing Earth's reflectivity and driving warming further. The exceptionally warm sea surface temperatures during 2023 - 2025 have heightened concerns about large-scale ocean and atmosphere interactions such as risks of more extreme events under climate change (Fig. 12). During the year 2025, global temperature remains near or above +1.5°C relative to 1880-1920, and, if the tropics remains ENSO-neutral, there is good chance that 2025 may even exceed the 2024 record high global temperature. It appears that the target of staying below 1.5°C threshold established by the Paris Agreement is unobtainable, and the long-term average will pass this milestone within the next five to ten years.

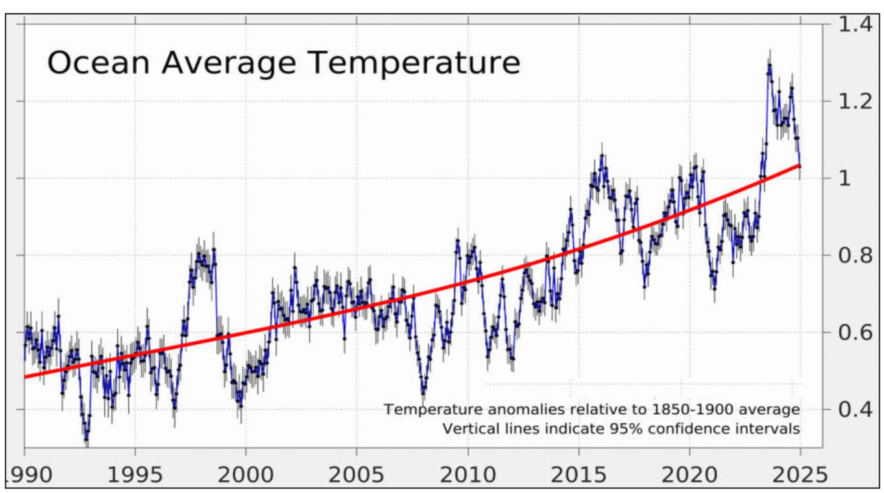

Fig. 10: Monthly time series of ocean average temperatures shifted sharply higher in the middle of 2023, peaked late in 2023 but persisted well-above the long-term trend in late in 2024.

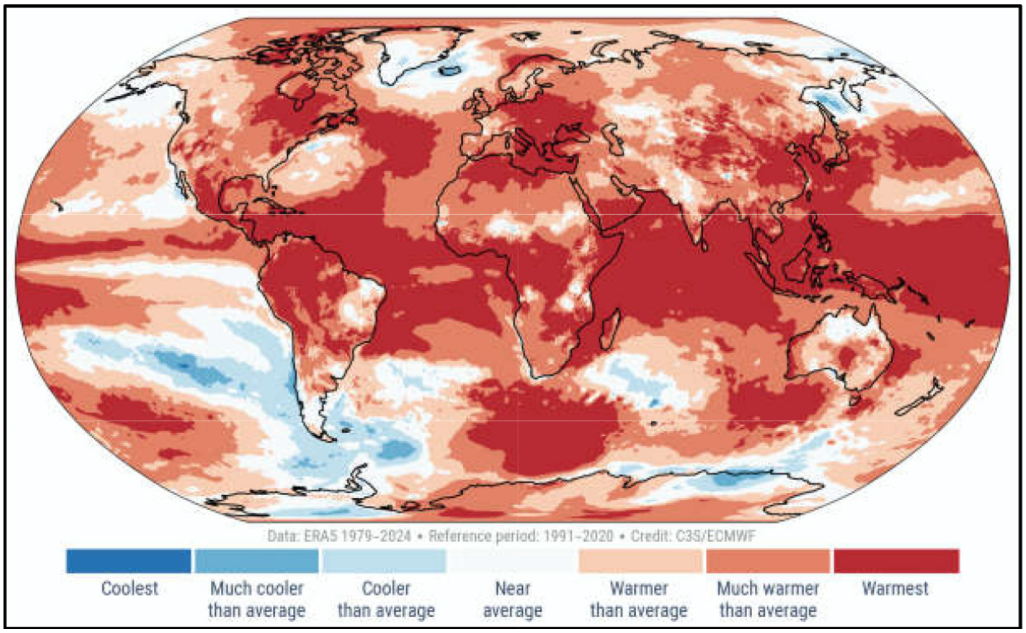

Fig. 11: Anomalies and extremes in spatial distribution of land & oceanic surface temperatures in 2024

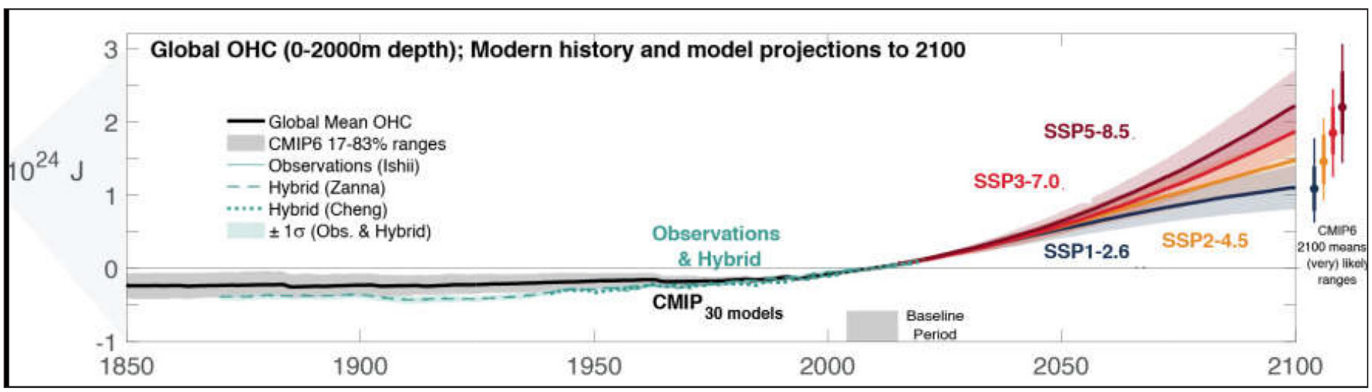

Fig. 12: The past, present and future of ocean heat content between surface and 2000m depth as observed and projected by CMIP6 Models

Ocean convection is known to have a tipping point, the northern convection regions are net-precipitation regions, so in the absence of deep mixing, freshwater tends to accumulate in the surface layer, increasingly inhibiting mixing that is otherwise forced by heat loss. This is another self-amplifying feedback which can shut down deep convection in the northern Atlantic. The Atlantic Meridional Overturning Circulation (AMOC) is the current that keeps Europe and the UK (weakest in 1600 years, Fig. 13) far warmer than their latitudes would indicate and it has massive implications for global weather and natural life. Changes in AMOC strongly impact northward ocean heat transport and the climate of the Atlantic mid- and high-latitudes, anthropogenic carbon and oxygen uptake by the ocean, sea level in the northern North Atlantic and the location of tropical rainfall belts. A new study warns that AMOC collapse is no longer low-likelihood and may occur in decades (Lenton *et al.,* 2025a). Studies have suggested that northward Atlantic heat transport at 26◦N decreases to 20%–40% of the current observed value beyond the year 2100 in CMIP6 models with high-emission (SSP5-8.5) scenario and sometimes also forced by an intermediate (SSP2-4.5) scenario (Rahmstorf, 2024). Avoiding the worst outcomes will require cutting GHG emissions at speed and scale. It also means preparing our built environment and infrastructure for unprecedented climate variability driven not just by AMOC but by multiple interacting climate risks. The impacts would be catastrophic as winters would plunge to –30°C in Scotland, with nearly half the year below freezing, and shorter, cooler summers with severe disruption to rainfall patterns, causing droughts and agricultural losses not only in Europe but also in tropical regions (Sybren Drijfhout *et al.,* 2025).

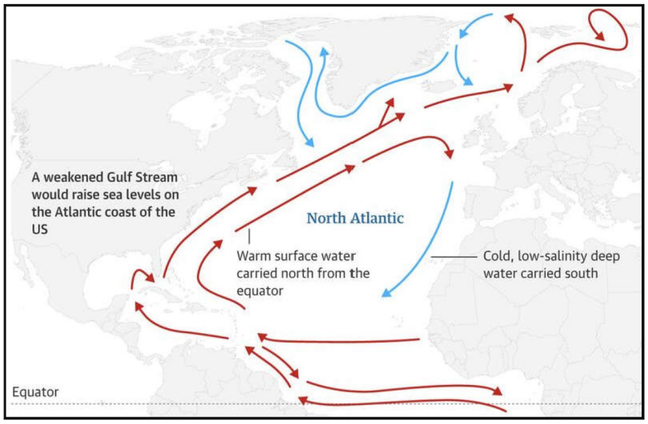

Fig. 13: Weakening trend of Atlantic meridional overturning circulation

The world seems to be on track for a 2.7-3.4°C rise in temperature or higher over the pre-industrial average by 2100, wreaking enormous damage to the global economy, natural ecosystems and human life, unless, the balancing the intake of energy on the Earth is achieved by removing GHGs, and also involves other techniques to reflect more energy away from the planet. Unfortunately, we have not transitioned off fossil fuels quickly enough, and we are not doing Carbon Dioxide Removal at a rate fast enough to counteract this completely in the short term. As a consequence, we are now at great risk that negative feedback loops accelerate in a catastrophic and cascading way, where things like reflective white ice melts due to the increased energy and heat in the system, which exposes more dark sea surface, which absorbs energy and warms the water in a runaway situation, which takes us to dangerous tipping points.

The current decade is crucial for aligning world emissions to a pathway compatible with the 1.5°C temperature change target set out in the Paris Agreement. To prevent the 2015 Paris Agreement's goals from being shattered – and to ensure that Earth system's tipping points are not breached – emissions must decrease by 9.0% annually from 2024 (triple the renew able energy capacity and double the rate of energy efficiency improvements by 2030) to keep warming below 1.5°C by 2030. However, G20 climate policies and pledges fall short of the 1.5°C pathway. The commonly used 'net zero' carbon budgets only give a 50/50 chance of limiting warming to well below 2°C (Fig. 14). Despite ambitious efforts to mitigate emissions, it is increasingly clear that the world's 1.5°C pathway is likely to result in global temperature overshoot (increasing climate impacts on natural and human systems and triggering potentially irreversible tipping points in the earth's climate system), and therefore negative emissions from both land-use sinks and the energy sector are required to limit the global temperature increase. This becomes more relevant now as, by exiting the Paris Agreement on 20th January 2025, United States, the world's biggest historic emitter, has joined Iran, Libya and Yemen as the only countries not committed to the global deal to keep global warming well-below 2°C by the end of the century. U.S. President D. Trump has also signed a bill temporarily halting offshore wind lease sales in federal waters and pausing the issuance of approvals, permits and loans for both onshore and offshore wind projects. Proposed coal-power capacity in India has also been on the rise, led by a record 38.4GW of coal-plant proposals in 2024 – driving up proposed coal capacity to over 92GW as of July 2025. Yet India also added more than 28GW of wind and solar power in 2025, a nearly 50% increase over the previous year. In the year 2025 so far, China and India have been "largely responsible for the surge in renewables", while the USA and Europe "have relied more heavily on fossil fuels. In these uncertain times for climate action and climate cooperation, attention to broader questions is necessary to deepen understanding and work toward a truly effective response to climate change.

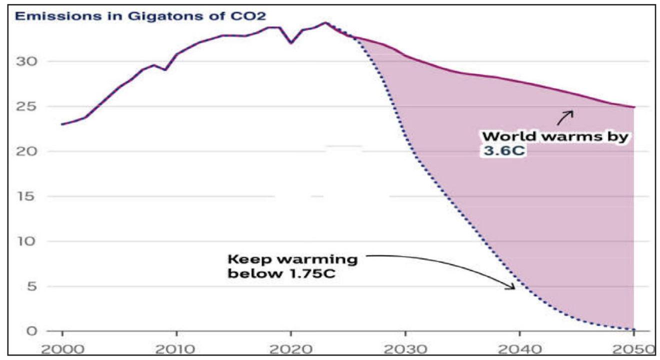

Fig. 14: Cut back on emissions will dictate how much the world would warm by 2050.

In practical terms, the world has reached 1.5°C of warming and the pace of warming is increasing. The global mass loss of glacier ice has increased significantly in the last 30 years and amounted to about 335 billion tons of lost ice per year since 2006 (Fig. 15; Zemp *et al.,* 2025). An accelerated rate of warming is likely to continue to mid-century and beyond given the failure so far to reduce the planet-warming greenhouse gas emissions. Global mean surface temperatures in 2025 and beyond will remain alarmingly high and calls for urgent, *collective action to mitigate emissions and adapt to changes to build a sustainable future*. Today, the climate risks faced by agriculture, energy, transport and manufacturing value chains are undeniable. Further, as extreme weather events become more frequent and severe, early warning systems are crucial to ensure resilience across value chains, reducing response times and resulting losses for local communities across developing world.

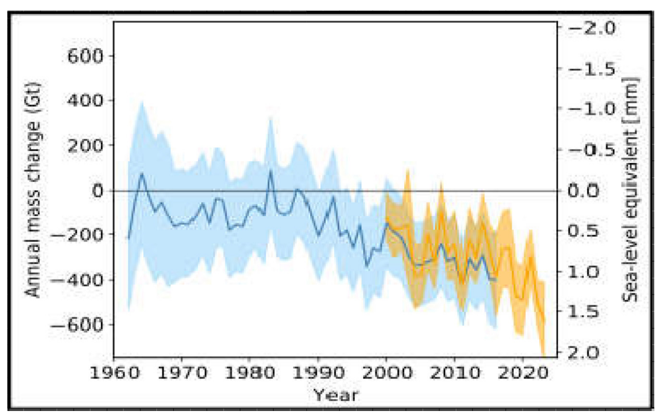

Fig. 15: Global glacier contributions to sea level rise from 1961-62 to 2022-23. Annual mass changes and global sea-level equivalents are shown with related error bars (indicated by shadings) corresponding to 95% confidence intervals. The ad hoc estimates (orange), based on the glaciological sample and calibrated with regional geodetic estimates are shown with adjusted and updated annual values (blue) from Zemp *et al.,* (2025).

Indian sub-continent : current status of climate change

Global mean warming was 1.57°C in 2024, and 2025 could be close to this threshold. In practical terms, the world has reached the lower end of the Paris target of 1.5-2°C of warming and an accelerated warming rate is likely to continue beyond mid-century. India's average temperature has risen by approximately 0.89°C during 2015–2024 relative to 1901–1930. The annual mean warming averaged across India during 1901-2024 is observed to be about ~0.67°C (warming both over land and Indian Ocean basin are close as seen in Fig. 16). The observed trends in spatial distribution of maximum temperatures (day-time) and minimum temperatures (night-time) over India are displayed in Fig. 17.

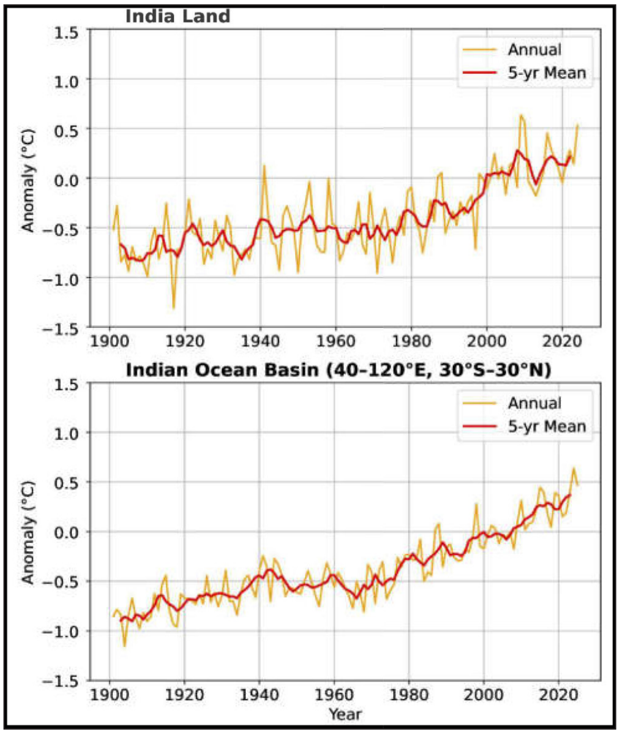

Fig. 16: Observed annual mean warming over and regions of India and surrounding Indian Ocean basin since 20th Century (Source: Dhara *et al.,* 2025)

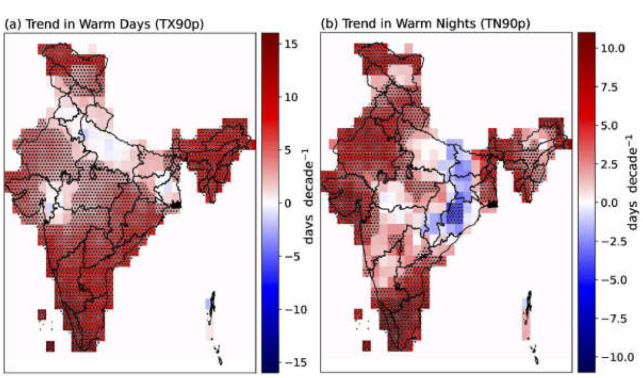

Fig. 17: Observed trends in spatial distribution of Maximum and minimum temperatures over India during 1901-2023 (Updated from Dhara *et al.,* 2025)

Given the current lack of willingness of human society to rapidly reduce greenhouse emissions, in India we are heading towards at least 3.4°C of warming and more by the end of this century (Fig. 18). Many events in the climate system are still beyond climate models' projections; that is, current models are not capturing all the risks. The small scale processes which govern global impacts are largely left out of climate models – *e.g.*, the impact of sea ice, aerosols, cloud feedback due to marine heatwaves, effects of dust emissions in circulation and precipitation, soil moisture gradients, vertical mixing of heat in the oceans to deeper depths, the effect of sub-seasonal intensifying gradients on circulation, impact of atmospheric circulation changes, and density gradients changes on circulations in the oceans and atmosphere, ocean fronts and low pressure systems on general circulation and blocking, *etc*. More precisely, they overlook or downplay the impacts of non-linear and difficult to predict processes such as the loss of ice sheet mass (in 2023 the rapid retreat of Antarctic sea-ice was astounding and five standard deviations beyond the mean), ocean heat drawdown (the rapid warming of the North Atlantic was greater than four standard deviations in 2023), rising sea levels (a one-meter sea level rise on both sides of the North Atlantic), upticks in extreme events, carbon stores losing integrity amount of carbon absorbed by the land sinks could collapse), and more. Climate change is significantly affecting the species population and ecological systems as well. In a 3°C hotter world, new extremes will occur — of unliveable heat and rainfall (AMOC collapse would result in the South Asian monsoons becoming highly variable), flooding and drought — beyond past human experience. With just 1.5°C global warming, many glaciers throughout the world as over Himalayas are already losing their ice-mass; eventually aggravating water scarcity on one hand and the sea level rise drowning coastal cities on the other hand. A committed sea level rise of few metres by the end of this century will be in the process of inundating coastal cities and deltas along India's coastline.

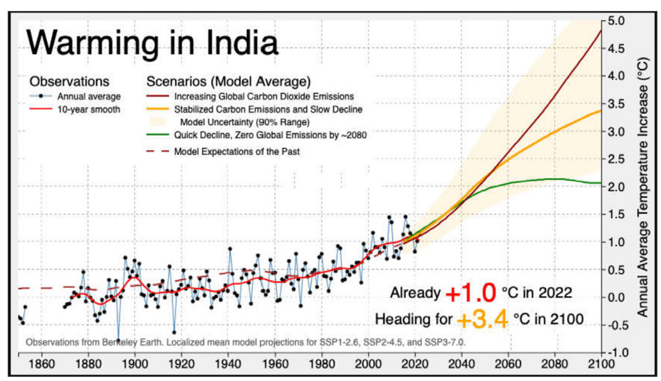

Fig. 18: Projected future warming over India under different SSP Scenarios (Source: Berkley Earth, 2025).

In the past few decades, India's climate vulnerabilities, as well as the economic losses experienced as a result of the weather extremes (minor changes in the average and variance caused by climate change has the potential to generate comparatively large variations in the probability of extreme events), have increased dramatically. Significant investments in disaster risk management are needed to safeguard human lives and infrastructure while minimizing economic disruption. This is particularly true of more cost-effective tools like early warning systems and making infrastructure more resilient. The challenges India will encounter by the end of this decade will perhaps be nothing less than an outcry for immediate and urgent climate actions for mankind's basic comfort zone (particularly to overcome potentially disastrous repercussions for our marginalized communities). Impacts on our food systems, infrastructures, finances, ecosystems will have devastating effects on the future generations (often seen as an unaffordable, incremental cost that competes with other national development priorities). The projected productivity and resilience gains by investing in modern agricultural practices and technology; installing treatment systems for agricultural waste and water, and improving climate-resilient rural infrastructure, such as building more efficient irrigation systems and better drainage and creating and rehabilitating wetlands through measures such as hillside terraces and tree planting are expected to increase food production and bioenergy generation, reducing soil erosion, improving local water quality, restoring forest ecosystems in degraded areas, sequestering planet-warming carbon as well as avoid other climate shocks thus facilitating job creation and productivity gains to healthier rural communities and environments. Today, India stands at a crossroad where if we not take a step towards quick and just transitions, the very survival of humanity will be jeopardized (Wani, 2023). The battle we face is not only about climate action but to achieve a just transition that will be inclusive of all sections of the society, so that building collective resilience and adaptation mechanisms at grass-root levels, and maintaining the ecological balance will be possible. India is, indeed, in the midst of a compound catastrophe due to worsening climate impacts.

What all may change in the climate challenged india

Heat Stress and Heat-related Mortality

Annual mean temperatures averaged across India rose by more than 0.67°C between 1901 and 2024 with statistically significant increases in heat waves at several locations. A heat wave is a prolonged period of unusually and excessively hot weather, which may also be accompanied by high humidity - definitions vary, in part because a heat wave is measured relative to the usual weather in the area and relative to normal temperatures for the season. A heat wave in India is declared when either there is an excess of 5°C over a normal daily historical maximum temperature (30-year average) of less than 40°C; or an excess of 4°C over a normal historical maximum temperature of more than 40°C. If the actual maximum temperature is above 45°C, a heat wave is declared irrespective of the normal historical maximum temperature. The increase in summer mean temperatures in India over this period corresponds to a 146% increase in the probability of heat-related mortality events of more than 100 people. In May 2010, Ahmedabad, India, faced a heat wave where the temperatures reached a high of 46.8°C with an apparent increase in mortality. On May 19, 2016, Phalodi in Rajasthan recorded the highest temperature of 51°C, which was also the third-highest temperature ever documented globally that year. In 2019, Churu - a deserted region in Rajasthan - recorded the hottest day of the year, with the mercury touching 50.8°C on June 2. This year, Rajasthan and Madhya Pradesh were also on alert for 'severe heat wave conditions', with both the states often recording warm days at the peak of summer. In 2022, Uttar Pradesh's Prayagraj broke its all-time record to become India's hottest city on April 27 as the city recorded a temperature of 45.9°C. In the year 2023, several locations in India experienced high temperatures, with some exceeding 45°C. Mungeshpur and Najafgarh, both in Delhi, recorded 48.3°C and 48.1°C respectively, while Narnaul reached 47°C. Other locations like Faridkot, Akola, Yavatmal, Sagar, and Guna also saw temperatures above 46°C. India recorded the year 2024 as warmest as is evident from deviations from normal of average annual mean temperature (the warmest of the five years as listed in Fig. 19). The highest temperature recorded in India during 2010-2024 was 52.9°C in Delhi's Mungeshpur area on May 29, 2024. The year 2024 reported the most intense and the highest number of heatwaves in the past 15 years (Over 37 cities recorded temperatures exceeding 45°C). Buxar in Bihar recorded 47.2°C, the highest in the country on Thursday, which was 8.9 degrees above the normal maximum temperature for the season. The year 2025 is no exception. February 2025 was India's hottest in 125 years, with many states breaching 40°C. Reports of heat-related deaths came in from Telangana, Gujarat, Punjab, and Odisha. Temperatures in India have again climbed to "dangerous levels" in April 2025. Delhi has recorded temperatures above 40°C "at least three times this month". Sri Ganganagar in West Rajasthan reported a maximum temperature of 49.4°C on 13th June 2025. This is the season's highest maximum temperature reported by any station for the year 2025 over India (*based on author's own extraction of analysis of open source district-wise maximum temperature data set available from IMD website open source*). Such unusually high temperatures during hot summer season result in the dangerous exposure of heat stress and becomes vulnerable to physiological acclimatization among the workers carrying out activities in outdoor and indoor work places without thermal neutralities (Perkins-Kirkpatrick & Lewis, 2020; Ebi *et al.,* 2021; Vecellio *et al.,* 2023).

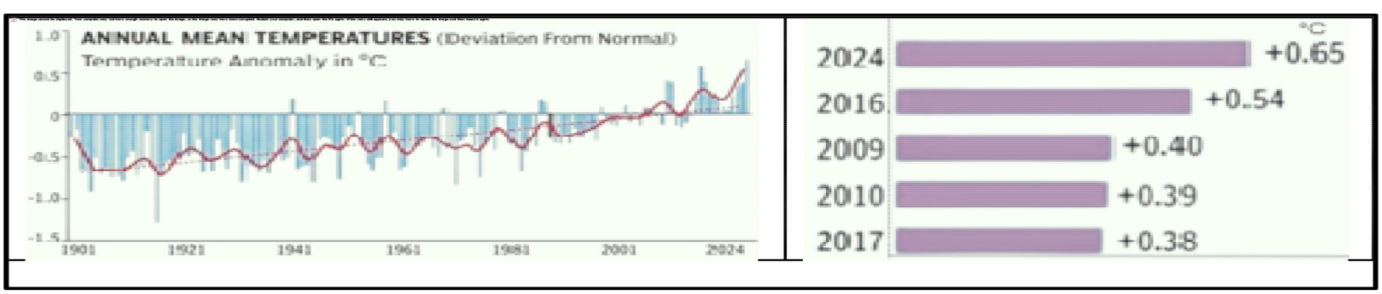

Fig. 19: Deviations from normal in annual mean surface temperature and the five warmest years in India (*Sources:* IMD (2025) *Annual Climate Summary for 2024 published by IMD in Jan 2025 and other press releases published in Jan to March 2024*)

Extreme heat is no longer a distant threat. Over the past few years, it has claimed lives, destroyed crops, disrupted governance, and pushed India's systems to the brink. In 2022, intense heatwaves devastated wheat crops, prompting an export ban. A year later, over 600 people suffered heatstroke at a state award ceremony in Khargar; 12 died. And in 2024, at least 33 people, including election officials, died from suspected heatstroke during the Lok Sabha elections. Yet, despite these rising impacts, extreme heat continues to be treated as a seasonal, static, and short-term risk. In reality, heat is complex, pervasive, and deeply unequal in how it impacts different communities and sectors. As India is more vulnerable to the heat extremes such as heat waves, heat stress due to its projected annual spatial warming in India will be between 2.8° and 5.5°C by the end of this century, with higher projections over northern, central, and western India. The rising temperatures are testing human limits and, by 2050, "India will be among the first places where temperatures will cross survivability limits" with exacerbated disparities in income, gender difficulties, and socio-cultural factors among its large population. A single day of an India-wide heatwave can lead to an estimated 3,400 excess deaths nationally, while a single five-day heatwave could lead to approximately 30,000 excess deaths, distributed across rural and urban districts. Heat waves in a sizable part of India are likely to become more intense, more frequent, and longer lasting in the second half of this century. With India's urban population projected to reach 600 million by 2036, the challenge of ensuring a thermally comfortable living environment is urgent and central to safeguarding health and well-being of its population (Balasubramanian, 2023; Behrer *et al.,* 2023; Mishra *et al.,* 2025). The priority action should include practical solutions to sustainable cooling, green urban planning, early warning systems, and passive cooling solutions like tree planting etc. While mitigating further global warming can reduce heat mortality, mass mortality events remain plausible at near-future temperatures despite current adaptations to heat. Preparedness for hospital overcrowding and health system surge capacity should therefore be benchmarked to a plausible extreme scenario rather than an average projection.

Changes in Spatial and Temporal Rainfall Variability and Associated Hazards

The Indian monsoon is one of the most prominent parts of the world's monsoon systems, which blows from the northeast during cooler months and reverses direction to blow from the southwest during the warmest months of the year. This process brings significant rainfall to the region from June to September, the principal rainy season. Nearly 75% of the country's annual rainfall is received during the southwest monsoon season with a large inter-annual variability in its onset and withdrawal dates as well as spatial variability in its distribution over different parts of the country. Based on data from 1971-2020, all-India normal annual rainfall is 1160.1 mm. On average, about 868.6 mm of rainfall is received over the country between June and September during the monsoon season (Fig. 20). Although, there is inter-annual variability (largely attributed to predictable mode of El Niño- Southern Oscillation, equatorial Indian Ocean Oscillation in Indian Ocean Dipole mode, Atlantic Meridional Oscillation and Pacific Decadal Oscillation), the total precipitation during the Indian summer monsoon has remained largely stable over the period 1901-2023 (Fig. 21). However, a weakening link between monsoon rainfall and El Niño observed in recent years has led to south-eastward movement of the walker circulation anomalies which has enhanced the inter-annual variability in seasonal rainfall.

Throughout the season, the Indian Summer Monsoon (ISM) is characterized by strong circulation at 850 hPa southwesterlies and 200 hPa upper-level easterly jet. Southward displacement of the Asian jet is observed to have a substantial impact on ISM rainfall (JJAS) primarily in northern and central India. Weak Tropical Easterly Jet changes the low-level ISM circulation, resulting in changes in active - break cycle (Monsoon Intra-Seasonal Oscillations - MISOs cause the fluctuations on two broad scales of 10–20 and 30–60 days) and thus leading to intra-seasonal variability in rainfall over India. The Indian Ocean, also the warmest among the world's oceans and part of the Indo-Pacific warm pool (SST > 28°C), plays a pivotal role in maintaining deep atmospheric convection and tropical circulation. The Indian Ocean is also the birthplace of critical climate phenomena like the Madden-Julian oscillation (an intermittent wave of enhanced tropical convection that transits west to east through the entire tropics in 30 to 60 days) and monsoon intra-seasonal oscillations, which impact rainfall and tropical cyclones on shorter timescales.

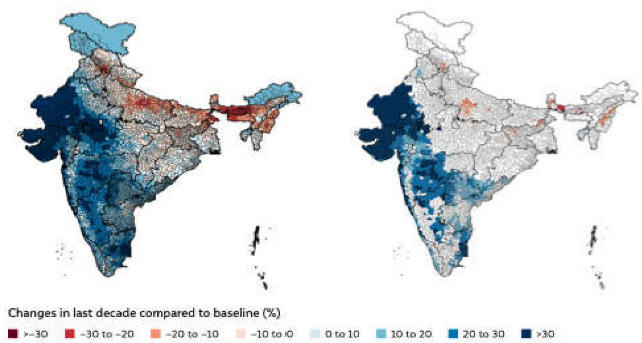

Fig. 20: Trend of monsoon rainfall in India - a) Changes in JJAS rainfall in last decade (2012-2022) compared to the baseline (1982-2011); b) Stastically significant trends in JJAS rainfall over 40 years time series at 95% confidence level

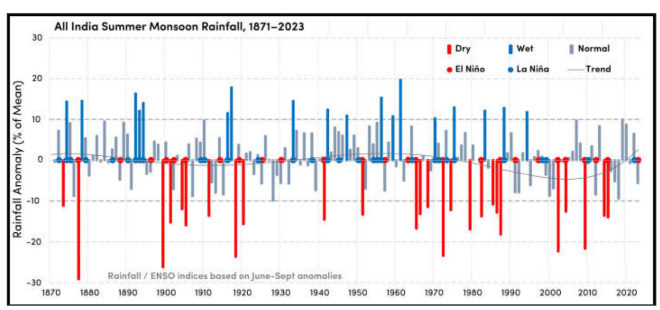

Fig. 21: All-India averaged JJAS rainfall shows a slightly increasing but insignificant trend @3 mm/year for the period from 1871 to 2023.

Mean southwest monsoon rainfall has declined by 0.5-1.5 mm day^{-1} every decade over the Indo-Gangetic plains and northeast

India during 1951–2024. Extreme precipitation events have also intensified, with coastal Gujarat experiencing about 0.15 additional extreme events every decade during 1951–2024 (Fig. 22).

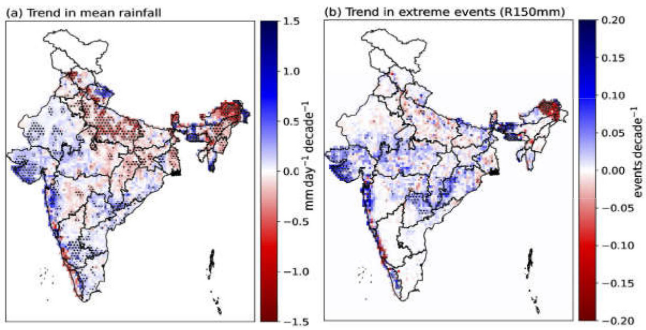

Fig. 22: Observed trend in monsoon rainfall over India & trends in extreme rainfall events during 1951-2024.

The enhanced greenhouse gas emissions may alter the monsoon circulation and in turn, lead to changes in rainfall patterns and intensities. The warmer Indian Ocean, which accentuates the land-ocean contrast and thus increase the amount of atmospheric moisture carried to India during summer months. During the recent decade, there has been a significant decrease in light and moderate rainfall events, while heavy and very heavy rainfall events have increased in frequency (Fig. 23) (Pandya *et al.,* 2022). Interannual variability is expected to become stronger in the Pacific and Indian Oceans and weaker in the Atlantic along with changes of the hydrological cycle due to enhanced radiative forced surface warming. Indian summer monsoon rainfall is projected to increase and the wet season to lengthen despite a slowdown of atmospheric circulation (Ma *et al.,* 2020). Strong variations among spatial variability in monsoon rainfall are likely to emerge, depending on surface conditions such as orography and coastline and other ocean–atmosphere interaction processes.

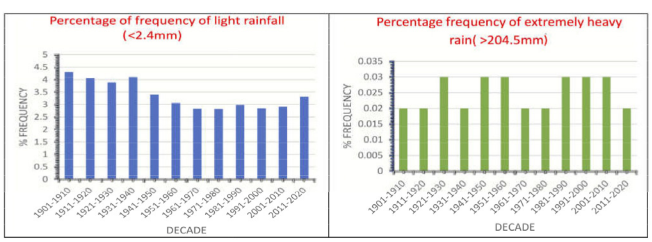

Fig. 23: Percentage frequency of decadal light and very heavy rainfall events during monsoon season in India during 1901-2020.

The regional climate in the tropics is strongly influenced by the Inter Tropical Convergence Zone (ITCZ is the region of trade-wind convergence and ensuing upward motion in an unstable tropical atmosphere, leading to high cloudiness and precipitation), also known as the monsoon trough over the Indian subcontinent. Understanding the physical processes that determine the ITCZ's location, strength, and width, and how it responds to radiative forcing and natural variability, is crucial. The expansion of greenhouse gases and aerosol forcing in the Northern Hemisphere, along with stratospheric ozone depletion in the Southern Hemisphere, has led to a poleward shift of the subtropical edges of Earth's Hadley circulation during summer and monsoon seasons (Hastenrath, 2012). Recent Indian Ocean warming (warmed rapidly and notably at a faster rate than the other tropical ocean basins in the latter half of the twentieth century) has also been linked to anomalies in the lower and upper troposphere, driven by increased latent heat uplift due to ocean convection (Praturi & Stevens, 2025). This warming intensifies convection over the ocean while leading to subsidence over land, reducing convection over the subcontinent and causing a drying trend. Another significant factor contributing to decreased rainfall since the mid-20th century is the narrowing of the ITCZ, related to changes in upper tropospheric relative humidity, cloud-radiative feedbacks, and the associated belt of ascending motion and rainfall over India. This narrowing is associated with various factors, including moisture diffusion, cloud-radiative and water vapor-radiative effects, and the skewness of vertical velocity distribution. The poleward shift of the Hadley circulation is a robust response to a warming climate in global climate models. Historical observations indicate that regional Hadley circulation, driven by the North Atlantic Oscillation in the northern hemisphere and the Indian Ocean Dipole in the southern hemisphere, may influence Indian monsoon behaviour in coming decades. In the Northern Hemisphere, the direct radiative effects of CO_2 enhance the land-sea temperature contrast, shifting the circulation poleward. Also, the SST warming in tropical oceans reduces the land-sea temperature contrast and shifts the circulation equatorward. This shift is evidenced in re-analysed ERA5 data from the past five to six decades, showing a contraction of the Hadley circulation by about 0.5^{o} latitude per decade. These Hadley and Walker circulation anomalies, particularly over Central India, are also observed in CMIP6 simulations where tropical circulation weakens by about 10- 15% with the lifting of the tropopause height over the 21st century. The specific pattern of SST warming in tropical oceans and coupled atmosphere-ocean variability is crucial for understanding how the NH JJA Hadley cell edge contracts over the 21st century. It's worth noting that a northward shift of the monsoon trough over India during the summer monsoon season during the past few years have led to more erratic short spells of very intense rainfall across Rajasthan, Delhi, Punjab, Haryana, Jammu & Kashmir, Uttarakhand, Himachal Pradesh, Uttar Pradesh and Bihar. A northward shift in monsoon trough is also found to strengthen a secondary tough off the west coast of India in June - July - August which results in heavy to very heavy rainfall spells along Kerala coast, Maharashtra, Goa, Karnataka (along Sahyadri mountains) and Gujarat coastal regions.

There have been multiple devastating floods in different regions of India in past decades due to incessant monsoon rainfall, cloudbursts, changes in the land use pattern (key factor for urban floods), and GLOFs due to melting of glaciers. The Mumbai flood in 2005, Bihar floods in 2007 and 2008, Assam flood in 2012, Uttarakhand floods in 2013 and 2021, Jammu & Kashmir floods in 2014, Chennai flood in 2015 and, most recently, the Kerala floods in 2018 and 2024 can be identified as the most severe ones. With a death toll of over 6,000, the 2013 floods in Uttarakhand were one of India's worst ever natural disasters. This flood resulted in over 6,000 deaths in Kedar Nath valley and surrounding areas. The flash floods, triggered by heavy rainfall combined with melting of the Chorabari Glacier, caused a breach of the Chorabari glacial lake and claimed a large number of lives and causing widespread destruction. Again, GLOF disaster struck Joshimath of Chamoli District on 7 February 2021 (occurred in an area about 60 km northeast of where the flash flood occurred in 2013), when a massive flash flood ravaged through the valleys of the Rishi Ganga, Dhauliganga and Alakhnanda rivers. More than 70 people were confirmed dead and another 134 people reported missing. The flood swept away the unfinished Tapovan Vishnugad Hydropower Project and inflicted substantial damage on the Rishi Ganga Hydropower Project. A "torrent of mud" has killed more than a dozen people in the northern Himalayan state of Uttarakhand and destroyed the entire village of Dharali on 5th August 2025. "Multiple cloudbursts" together with GLOF in the Himalayan region also hit the high-altitude districts of Uttarkashi, and Jammu & Kashmir triggering flash floods. The cloudburst risks are "projected to increase with climate change" since the number of glaciers in the Indian Himalayas are "receding at an alarming rate due to global warming". Extreme rainfall events are projected to rise in intensity throughout the 21st century in the entire Himalayan-Tibetan Plateau region, particularly durin g the summer monsoon.

In South India, incessant heavy rains for over 24 hours on 30th July 2024 in the Wayanad region (bordering the Nilambur forests and the Chaliyar river) of Kerala (this disaster was one of the deadliest in Kerala's history) led to flash floods in the Chooralmala area – a place where deadly consecutive landslides washed out two villages, devastated a total of 600 hectare of land and claimed over 400 fatalities. When the ocean is warmer, cyclones have more fuel and evaporation increases, loading the atmosphere with moisture that can fall as intense rain once a storm develops. Even weak cyclones (in terms of wind speed) can therefore hold exceptional amounts of rain. In November 2025, two cyclones namely *Ditwah* and *Senyar* formed in North Indian Ocean unusually close to land and travelled along the coastline for an extended period and communities in Sri Lanka, Indonesia and Thailand were inundated as they unleashed days of relentless rain. Millions were affected, more than 1,500 people lost their lives, hundreds are still missing, and damages ran into multiple millions of US dollars. This meant they stayed over warm waters (the eastern Indian Ocean was more than 1°C above normal (Fig. 24), with large areas long enough to continuously draw moisture), but remained close enough to land to dump that moisture as intense rainfall in extremely short bursts almost immediately. In the days before the cyclones formed (20–24 November), the oceans were even warmer than usual, creating conditions that could have fuelled and intensified the rainfall.

In India, since independence, substantial progress has been achieved in flood disaster preparedness, recovery, and management activities. The flood risk in India has also been exacerbated by exposure growth and urbanization in riverine floodplains. The interaction of the cross-equatorial flow with the upper-tropospheric penetrated trough through the Indian landmass increases the moist static energy, which results in heavy rainfall along the west coast of India (rapid urbanization in several cities here has led to the expansion of human settlements in flood-prone areas where pervasive slums with disproportionate flood exposure present a major challenge to inclusive urban planning and flood management), and causes a shift of monsoon westward. Climatic condition of key metropolitan cities in India have also undergone significant changes over time due to localized anthropogenic activities such as urbanization, industrialization, pollution, rapid population growth etc. which alter land surface characteristics, increase heat absorption, and reduce evapotranspiration, contributing to the urban heat island (UHI) effect. These localised effects also result in short spells of heavy rainfall leading to urban floods (requiring upgraded drainage management systems and emphasizing the urgent need for climate-resilient urban planning) while increasing the length of dry spells at the outskirts causing water crisis (Murugan and Santoshkumar, 2025). With the unprecedented growth of civil construction activities in flood-prone regions in India with each passing year, there is an urgent need to review the developmental activities and to strive to make them more resilient for the future by considering robust strategies. The currently available climate models often do not capture these links due to inconsistencies in representing regional teleconnection features (a stochastic climate signal is essential for accurate flood prediction assessment). However, *such a notable northward shift of monsoon trough and associated cloud bursts can complicate the distribution of future monsoon rainfall over major river basins in north-central India.*

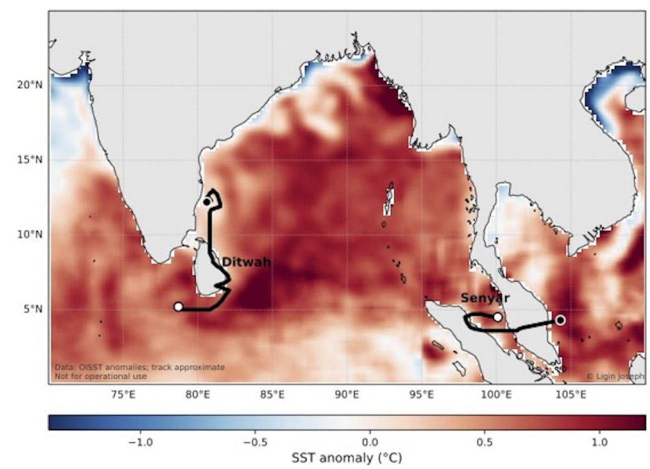

Fig. 24: Sea Surface Temperature Anomaly & Track of Cyclones in North Indian Ocean in November 2025

The physical explanation for the increase in the precipitation extremes with temperature is typically offered by the Clausius–Clapeyron (C-C) scaling. However, the majority (more than 80%) of extreme precipitation events occur during the monsoon season, which indicates that the negative relationship between surface air temperature and precipitation extremes is largely driven by precipitation-temperature coupling in the monsoon season. It is well known that the tropical regions are known to exhibit changes in precipitation extremes that do not correspond to C-C scaling. In India, thermodynamic components (*e.g*., changes in the atmospheric moisture content) have a minimal influence on changes in the characteristics of precipitation extremes since the intensification of extreme precipitation over the South Asian land mass emerges from dynamic rather than thermodynamic changes. Moreover, during summer, moisture availability, and not the moisture holding capacity, plays a dominant role in the changing characteristics of precipitation extremes. Extreme precipitation and flooding events are projected to further intensify in the future under a warmer climate. Climate change continues to be perceived as the gravest threat to humanity and, "*climate action failure*", "*extreme weather*" and "*biodiversity loss*" rank as the three most potentially severe risks and as strong aggravators of "livelihood crises" in India during the next decades. The physical impacts of future climate change-related events (heat waves, floods, droughts, wildfires, deforestation and air / water pollution), the fast-and-yet-slow elements of climate change (extreme weather events and chronic exposure) would bedevil our national capacity to absorb projected losses. In India, more than 22.5 million hectares of degraded land has been restored in the past decade through various measures such as afforestation, reforestation, agroforestry, integrating advanced technologies in forest monitoring, supporting the G20's trillion-tree pledge and more. Nature-based strategies, supported by aligned policies, strong targets, local action, and regulatory clarity, are key to India's holistic response to ecosystem restoration, forest cover and land use goals.

Climate Change along India's Coasts and Associated Hazards

Climate risk has also spread to our oceans which have historically been buffering communities from the worst impacts of climate change. The tropical Indian Ocean has warmed at 0.12°C per decade since 1950 and is projected to warm at 0.17°C per decade through 2100 under SSP2-4.5 emission pathway as projected by CMIP6 model ensembles. Marine heatwave days have risen about 20 days per year historically (1970–2000) and are projected to increase to nearly 200 days per year by mid-century. Coastal regions are unique because of their position at the interface of the atmosphere, lithosphere, and hydrosphere. Across India's coast, the important marine ecosystems include wetlands, mangroves, tidal mudflats, lagoons, beaches, marshes, and coral reefs. More specifically, within the peninsular region of India, there are 25 Marine Protected Areas (MPAs), 97 significant estuaries, 34 major lagoons, 5,790 km^2 of coral reefs, and mangroves spread over 4975 km^2. The impacts of climate variability and change and extreme events on these systems are affecting India's coastal community and strategically important infrastructures. Sustainable fishing and other aspects of the blue economy are being compromised by the accelerating climate impacts on the oceans. These include marine oxygen depletion, marine heatwaves (in the past few decades), accelerating ocean acidification, and other extreme conditions. The unravelling associated with cascading effects is becoming even more pronounced for our coastal communities. The solution requires increasing attention on the role of resilience in blue carbon ecosystem and fortifying individuals and communities in the face of grave loss of lives, livelihoods and system function along India's coastline.

India's more than 7500 km long coastline spreading over nine states and five union territories (+1208 island territories) of flat coastal terrain, shallow continental shelf, high population density, geographical location, and varied physiological features are extremely vulnerable to cyclones and their associated hazards. Thirteen coastal states and Union Territories (UTs) in the country, encompassing 96 coastal districts, including 72 touching the coast and 24 not touching the coast, are affected by tropical storms. These synoptic scale systems, including low-pressure areas and cyclonic disturbances (depressions and cyclones) that form over the northern Indian Ocean and particularly over the Bay of Bengal during the southwest monsoon season, contribute significantly to the southwest monsoon rainfall over India. A decreasing trend has been observed in the total number of cyclonic disturbances (cyclonic storms and depressions put together) during the period 1951 – 2023. However, the frequency of more intense cyclonic storms hitting India's coastline have increased in recent decades (Bhatia *et al.,* 2019), particularly In the Arabian Sea where maximum pre-monsoon cyclone intensity has increased by 40% over 1981–2020. Sea levels in the north Indian Ocean have risen at 3.36 mm $year^{-1}$ (1993–2021), with extreme sea level events increasing 2–3 fold. Sea level projections are generally based on scenarios of plausible global emissions trajectories out to 2100. Historical one-in-hundred-year extreme sea level events along the Arabian Sea coastline are projected to become annual occurrences by mid-century under SSP2-4.5 emission pathway. By end of the century, a SSP2-4.5 emission trajectory would commit the sea level to rise by 0.64 m (0.39–1.14 m) and perhaps slightly closer to 1 meter along the Indian Coastline (Nauels *et al.,* 2025).

The current climate models overlook or downplay the impacts of non-linear and difficult to predict processes such as the loss of ice sheet mass, ocean heat drawdown, rising sea levels, upticks in extreme events, carbon stores losing integrity, and much more. For example, models have been unable to reproduce the frequency and intensity of persistent summer weather extremes of recent years. In 2023, the rapid warming of the North Atlantic was beyond model expectations (greater than four standard deviations). Likewise, in 2023 the rapid retreat of Antarctic sea ice was astounding and five standard deviations beyond the mean. Permafrost is thawing much more quickly than models have predicted, with unknown consequences for greenhouse gas release. These climate risks are existential and emerging faster than forecast. Their non-linear and cascading nature make them difficult to predict, so particular attention must be paid to the plausible worst-case scenarios, because that is where the greatest possible damage lies.

Future emissions are a primary determinant of the warming path over the medium to longer term; but so are other factors including accelerated sea ice loss decreasing Earth's reflectivity, and accelerating emissions from carbon stores. India has demonstrated strong climate leadership under the Paris Agreement and is on track to meet its existing Nationally Determined Contribution (NDC) for 2030. However, in absolute terms, India has not yet started to decarbonise because lower emissions from electricity use are being offset by growth in other areas of energy use. So, for the time being at least, we are not experiencing an energy transition: we are adding energy from renewable sources to the growing amount of energy derived from fossil fuels. What we need is *clear and consistent Sector-Specific Policies and Regulations to support NDC Implementation with* a tailored intervention for high emission sectors.

Implications for future global warming in india & how to cope with it?

Whilst rainfall is projected to increase in the tropical zone under future warming scenarios, it will be too hot to live or for crops to survive here. At 3°C of warming, water availability is also projected to decline sharply in the, affecting about millions of people, and agriculture may become non-viable in critical areas. In a 3°C warmer climate, the Ganges-Brahmaputra basin will face the largest water gap increase (11.8 km^3/yr) compared to baseline conditions, followed by the Indus (8.4 km^3/yr), and Godavari (2.6 km^3/yr) basins. Moreover, in India, a 3°C hotter atmosphere would result in new extremes — of rainfall and unliveable heat, flooding and drought — beyond past human experience. And a committed sea level rise of at least a few metres will be in the process of inundating our coastal cities and deltas. We urgently need to enhance our efforts on the collection and integration of socioeconomic data, high-resolution digital elevation models (DEM), consideration of local characteristics such as topography and beach slope variations, range of flood parameters, hybrid approach by combining deterministic and probabilistic models, use of both trend extrapolation and scenario prediction techniques, comprehending interactions between storm surges and wave setup, thorough vulnerability assessment with a more balanced emphasis on physical, functional, socioeconomic, and geomorphological factors.

Climate change impacts have direct consequences for water security. Despite having approximately 18% of the world's population, India has only approximately 4% of the world's freshwater resources. According to the Central Water Commission, the annual average per capita water availability in India between 2021 and 2031 is assessed to be between 1486 cubic meters and 1367 cubic meters per person, respectively. Increasing water use efficiency is an affirmation of India's commitment to the Environment by optimizing the use of limited water resources and minimizing wastage. India's national water supply is forecast to fall 50% below demand as early as 2030. By mid-century, water flows into the key rivers of South Asia could be reduced by the loss of more than one-half, and perhaps much more, from the Himalayan ice sheet. In the coming decades, the impact of climate change threatens to make floods and droughts more frequent and intense, and so there is a need for adequate adaptation measures to ensure water security, power generation, drought mitigation, and flood control.

The Hindu Kush Himalayas (HKH) are a 3,500-square-kilometer stretch of mountains which contain the largest reserve of freshwater outside the polar regions. Its glaciers feed 10 large Asian rivers, including the Ganges, Mekong, and Yangtze. The Himalayan glacier systems are an important ecosystem within the Indian sub-continent. Water supply from snow and glacier melt affects the livelihood of large Himalayan Mountain communities. The Himalayan Mountain range supplies water to major Indian rivers, including the Ganga and the Brahmaputra. Air over HKH has warmed at a rate of 0.28 ^{o}C each decade from 1951 to 2024 and at the even higher rate of 0.5^{o}C per decade at elevations higher than 4,000 meters, could warm by 2.6^{o}C–4.6^{o}C by 2100. As a consequence, the loss in mass of glaciers has declined by as much as a quarter over the last four decades and the rate is accelerating. Accelerated glacier melting is driving the expansion and formation of these lakes, significantly increasing the frequency and magnitude of Glacial Lake Outburst Floods (GLOFs), which pose severe and escalating risks to downstream communities, infrastructure, and ecosystems. This may also potentially increase the number of glacial lakes and expand the size of existing ones. This may potentially increase the number of glacial lakes and expand the size of existing ones. Climate change (rising temperatures and extremely heavy rainfall) has played a key role in the "catastrophic" floods and landslides in the Himalayan states of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Assam and Sikkim in recent years with accelerated glacier melting is driving the expansion and formation of these lakes, significantly increasing the frequency and magnitude of Glacial Lake Outburst Floods (GLOFs), which pose severe and escalating risks to downstream communities, infrastructure, and ecosystems. This may also potentially increase the number of glacial lakes and expand the size of existing ones. The Indian Himalayan Region (IHR) is facing critical challenges while coping with the adverse effects of climate change. Climate change is most likely to accelerate the retreat of glaciers. We require enhanced monitoring networks, validated risk assessments, robust and sustainable EWS implementation, effective inter-agency coordination, community preparedness, and targeted research to fill critical knowledge gaps for effective disaster risk reduction in this dynamic, high-mountain environment.

The Tibetan Plateau a critical indicator of climate change, with significant temperature and precipitation increases observed over recent decades, which contributes to a rising risk of floods. From 1961 to 2010, there have been 30 floods in the Tibetan Plateau (TP) each year, and the flood frequency has increased by 10-fold every ten years on average. These floods in the TP were mainly caused by heavy rainfall or the outburst of glacial lakes. When combined with climate and land use changes, the flood susceptibility in the TP is projected to increase by as much as 15% by the end of this century and primarily concentrated in densely populated areas located in the eastern and southern parts largely due to increase in mean annual precipitation.

The summer monsoon winds seem to have crossed the Himalayas into Tibet for the first time in July 2025. Intense monsoon rains and cloud bursts, as a consequence, overwhelmed the Tibetan Plateau, leading to flash floods. A flash flood occurred on the Nepal-China border in early July 2025, triggered by a Tibetan glacial lake drainage (and the monsoon winds crossing the Himalayas into Tibet). The heavy rainfall in Tibet is suspected to have triggered the flood the Bhotekoshi River and leading to the destruction of the Miteri Bridge. Satellite pictures also show monsoon winds cutting across the Himalayas into Tibet (normally monsoon cloud do not rise above 2000 meters). This year, monsoon winds over India were so intense that even the cold deserts of Ladakh, Himachal, Uttarakhand and Tibet received above normal rainfall (On August 24-25, 2025, in Zanskar region, more than 100 mm rainfall and half a foot of snowfall were recorded). The unprecedented event of the Indian monsoon crossing the Himalayas into the Tibetan plateau is a signal that points to the fact that "*the era of a stable monsoon climate in India is over*" due to multiple concurrent circulation anomalies.

Western Disturbances usually come across North India during winter, bringing snowfall that nourished Himalayan glaciers. However, in 2025 monsoon season, as many as 14 western disturbances were reported in North India resulting in heavy rainfall, also supported by the rapid drainage of glacial lakes, which led to flash floods and infrastructural damage such as bridges and roads in downstream areas of Nepal and India disrupting transportation and supply lines. If this becomes a regular occurrence, it could further exacerbate future flood risks in these rugged mountain areas.

The Kashmir valley in the northwest Himalayas faces unprecedented climate change with erratic rainfall patterns and frequent extreme weather events in the form of hailstorms. The Himalayas are warming faster than the global average, which affects agriculture by altering crop cycles and soil moisture. It has also led to an increase in pest attacks and diseases. Climate change also influences the food chain by damaging the ecology that sustains it. These factors make food systems more fragile and vulnerable to future shocks in sensitive areas. The spatial distribution of severe thunderstorms and hailstorm events indicates the highest occurrences in the north zone, followed by the south and central zones. Severe hailstorms occur predominantly from March to November, varying across the three zones, and a distinct clustering of peak incidences is observed from April to June. During the year 2022, the highest number of severe hailstorm events totalling about 13 were recorded, resulting in an estimated 15–30% reduction in annual apple yield. The most significant impact and cumulative damage occurred in the north zone in Hilly mountainous regions, accounting for ~ 30% of the total regional loss, followed by the south zone (26%) and central zone (15%), respectively. A broader and potentially more severe impacts of climate change could continue to threaten the horticultural economy in the Kashmir Valley.

Indian farmers especially the small and marginal farmers have traditionally always grappled with the effects of climate variability and extreme events. Farmers cultivating climate-sensitive crops such as tomatoes are also witnessing rising losses due to perishability and high input costs. In Madhya Pradesh, farmers reported dumping their tomato crop by the roadside when prices weren't profitable enough to justify transport and sorting, reflecting the vulnerability of perishable crops to weather and market shocks. Small and marginal farmers, who comprise over 85% of India's agricultural community, are most affected. With poor access to irrigation, credit, and insurance, they lack the resources to adapt to climate shocks, leading to food insecurity, debt, and distress migration. Coastal lands are also threatened by rising sea levels, which can lead to the intrusion of saltwater, reducing the amount of arable land.

With a net sown area of approximately 140 million ha, which has remained the same in recent years, food grain production in 2021-22 rose to 315.72 million tonnes in India. Rising temperatures, erratic monsoons, extended dry spells, and unseasonal rains directly lower crop yields by inducing heat stress, disrupting flowering and pollination, and damaging grains at maturity. Crops such as wheat, rice, and maize—cornerstones of India's food system—are especially vulnerable. Climate variability and change is also disrupting precipitation and evapotranspiration patterns further aggravating water scarcity. The increasing demand for water, driven by population growth and urbanization, pollution, expanded irrigated agriculture and greater industrial use, also exacerbates water scarcity. Moreover, these yield losses are compounded by soil degradation and water stress. Years of intensive monoculture and chemical fertiliser use, encouraged by the Green Revolution, have depleted micronutrients and organic matter in soil. In addition, studies have indicated that increased carbon dioxide levels are decreasing the concentrations of protein, iron, and zinc in crops such as rice, maize, and wheat. India is the world's second largest producer of rice, accounting for 21% of global production.

Reduced or erratic precipitation also lowers yields by increasing drought stress. Extended dry spells in rainfed regions, which account for about half of India's agriculture, result in widespread crop failures. India's rice production is strongly dependent on the Asian Summer monsoon, during which the vast majority of rice is grown, particularly in the Indo-Gangetic Plains. Some of the key agricultural states in India have been the most affected by such events. Rice production failure is a major threat to food security and supply chain resilience across India. The majority of rice in India is grown in the summer kharif (June to October) season when most regions receive 80% of their annual rainfall. Timing of monsoon onset is crucial as well, with delays often linked to lower yields. Dates of rice growth stages vary by region but typically planting occurs in June/July (nursery planting followed by transplanting into main field 12– 14 days later), vegetative growth in July to September, flowering in September–October and harvesting in October–November. Most kharif rice irrigation in India relies on traditional flood irrigation, supplied by canal systems and groundwater pumping. Understanding causes of rice production failures is critical for policymakers due to their severe effects on farmers, societies, economies, and global supply chains.

According to projections, a 2.5 to 4.9°C increase in temperature across the country could decrease the wheat yield by 41–52% and rice yield by 32–40%. Temperatures equal to or higher than 30–34°C at the time of flowering may inhibit pollen production and grain setting, giving unstable yields from year-to-year; lethal limits beyond which the plant dies are in the range of 45–47°C. Higher minimum temperatures pose risks by reducing spikelet fertility and sink strength in developing grains, leading to lower grain weight and quality. The probability of crossing such thresholds in a given year becomes increasingly significant with global temperature rise of more than 2°C, and in the worst cases reach somewhere in the region of 25% (for maize) and 75% (for rice) respectively with temperature rise of around 4°C.

Heatwaves and floods have particularly caused major damage to crop production, and crop harvesting activities in India in recent years, particularly so in the Indo-Gangetic Plain (IGP) which is home to over 900 million residents and is among the most densely populated and agriculturally active regions in the world. Irrigation coverage is also a significant determinant of failure events here. Districts under more temperature and water extremes during the growing season and with less than 5% irrigated rice area can have highest failure probability, while areas with more than 18% irrigation may lead to a nominal reduction in rice productivity. This suggests irrigation buffers against drought and heat stress. Recent studies suggest that most considerable reductions may occur in southern states like Karnataka, Tamil Nadu, Andhra Pradesh, and Telangana, with some areas seeing up to 20% reduction in failure risk. Over-reliance on groundwater for agriculture in some states is leading to depletion, with many bore wells expected to dry up in the next decade. In coastal areas of Odisha and West Bengal, farmers are leaving agriculture due to increasing salinity and loss of arable land, contributing to growing populations of internal migrants who face new vulnerabilities. Targeted adaptation strategies such as earlier transplanting or adopting shorter-duration rice varieties may help reduce exposure to temperature and water stress could help mitigate rice production failures to some extent. However, an average one-fifth or more decline in crop yields projected in a 3°C scenario is likely along with a decline in the nutritional content of crops, catastrophic decline in insect populations, desertification, monsoon failure and chronic water shortages, and conditions too hot for human summer habitation in significant food-growing regions.

The development of agricultural production and productivity is key to rural development in India as agriculture retains 45.6% of the total workforce (NITI Aayog, 2022). As well as affecting food production, the extreme weather in agricultural states impacts employment and the economy, with agriculture the primary source of livelihood for approximately 58% of the population, and agriculture and allied sectors contributing about 18% of gross value added (GVA). To counter this, India has been taking regularly proactive steps for managing climatic risks to farmers and deliberating on innovative approaches to adopting climate resilient farming and food security for sustainable livelihood since the Green Revolution. In recent years, weather advisories for farmers are providing real-time information to farmers, helping them adjust sowing times and manage pests effectively (Singh *et al.,* 2023). Regenerative practices like natural composting, agroforestry, and reduced tillage help increase carbon storage in the soil, reduce erosion, and improve moisture retention. The Indian Council of Agricultural Research (ICAR) has developed thousands of climate-resilient crop varieties designed to withstand weather extremes. Techniques like drip and sprinkler irrigation are also being adopted to conserve water, especially in regions with erratic rainfall. Rainwater harvesting helps to conserve water for drier periods. India is projected to experience significant increase in water gaps under warming scenarios. In a 1.5°C warmer climate, India will have an additional 11.1 km^3/yr water gap. Government agencies are promoting organic farming as a climate adaptation solution. However, a lack of resources acts as a barrier to the adoption of organic farming by small to marginal farmers. The systemic exclusion of certain caste and gender groups, combined with limited financial buffers, makes adaptation almost impossible without targeted support. Regenerative practices like natural composting, agroforestry, and reduced tillage help increase carbon storage in the soil, reduce erosion, and improve moisture retention. With a responsibility to feed over 8 billion people, agriculture is also the second-largest source of greenhouse gases. Agriculture is the second highest GHG emitting sector, behind electricity production, plus it uses about 20% of the produced electricity. A central government initiative launched to promote solar energy in agriculture has facilitated use of solar power for climate resilient sustainable agricultural practices.

With almost 75% of land surface and 66% of oceans being significantly altered by humans, more than 1 million plant and animal species face extinction within the next few decades, and 14 of 18 categories of ecosystem services, mostly regulating services and non-material contributions, have already declined. Forests are important ecosystems in India which provides various ecosystem goods and services. Forests are also regions of biodiversity hotspots. With only 2.4% of world's land area, India accounts for 11% of recorded species of bio-diversity, including threatened and at-risk flora and fauna of the world. India is one of the few countries where forest and tree cover has continued to increase over the years, qualifying the country's forests as net sink. The total forest and tree cover of the country in 2023 stands at 8,27,356.95 km^2 which is 25.17% of the geographical area of the country. The total Forest Cover has an area of 7,15,342.61 km^2 (21.76%) whereas the tree cover has an area of 1,12,014.34 km^2 (3.41%).

India's current NDC for 2030 includes a target to create an additional carbon sink of 2.5–3.0 billion tonnes of CO_{2eq} by 2030 (baseline: 2005) and has already achieved 2.3 billion tonnes. The updated National Biodiversity Strategy and Action Plan align with the Kunming-Montreal Framework, setting 23 biodiversity targets to halt biodiversity loss by 2030 and live in harmony with nature by 2050. Under the United Nations Convention to Combat Desertification (UNCCD) and voluntary Bonn Challenge, India has a target of restoring 26 million hectares of degraded land. Already more than 22.5 million hectares of degraded land has been restored through various measures such as afforestation, reforestation, agroforestry, integrating advanced technologies in forest monitoring, supporting the G20's trillion-tree pledge and more. India's forest strategies, backed by community participation, are central to climate resilience. It is also recognized that climate change adaptation must build resilience, strengthened through healthy ecosystem services that rely on well-functioning river basins of India.

Rising sea levels have significant social implications, including displacement, loss of livelihoods, and increased vulnerability to coastal storms. Coastal communities, particularly those with disadvantaged populations, are disproportionately at risk. Addressing the challenges posed by rising sea levels requires a combination of mitigation and adaptation measures. Studies suggest that a (local) sea level rise of 0.5 m can result in a 10-fold amplification of the entire flood risk distribution at most tide gauges and a 100-fold amplification at more than half (Yan Li *et al*., 2025). To assess the adverse impacts of coastal flooding and inundation, the collection and integration of socioeconomic data, high-resolution digital elevation models (DEM), consideration of local characteristics such as topography and beach slope variations are vital in addition to a hybrid approach by combining deterministic and probabilistic models, use of both trend extrapolation and scenario prediction techniques, and comprehending interactions between storm surges and wave setup is needed for decision-making and climate adaptation planning. Building seawalls and other coastal defense structures can help protect coastal communities from flooding and erosion while healthy coastal ecosystems, such as mangroves and wetlands help buffer the impacts of sea level rise. We should strive for enhancing data integration and collecting, applying hybrid modelling approaches, extending the range of flood parameters, and taking local conditions into account thorough vulnerability assessment with a more balanced emphasis on physical, functional, socioeconomic, and geomorphological factors.

As the impacts of climate change intensify, the urgency to scale up adaptation has never been greater. India needs to look for solutions that protect lives, safeguard livelihoods and economies, and strengthen resilience in the face of accelerating risks. We need to implement priorities identified in its National Adaptation Programmes of Action (NAPAs), National Adaptation Plans (NAPs), NDCs and related national strategies. Adaptation measures, such as strengthening early warning systems or making infrastructure more resilient, not only avoid potential losses, but also a wide range of economic, social and environmental benefits that are generated even when disasters don't occur. For example, cost-effective tools like early warning system deliver high returns — nearly 36% on average — by safeguarding lives and infrastructure while minimizing economic disruption. Similarly, adaptation returns in the agriculture and forestry sector average over 29%, largely driven by developmental gains like higher yields and productivity, as well as environmental benefits. Thus, adaptation projects often have benefits evenly distributed across "triple dividend of resilience" framework to capture three key categories of returns on adaptation investments: avoided losses, induced economic development, and additional social and environmental benefits.

Developing a process for monitoring, reporting and acting on the risks that leverages the resilience principles provide clear, concise, timely and realistic information to policymakers could help to accelerate risk-informed policy decisions and avoid catastrophic impacts that are likely on current trajectories (Rogers, *et al*., 2023). India would need to build resilience to worsening and inevitable climate impacts through accelerating decarbonisation by reducing emissions to zero as quickly as possible, by identifying and leveraging positive socio-economic tipping cascades. Our climate goals must be defined from a risk perspective as excluding risks due to uncertainty breaches the precautionary principles.

With a growing economy and rising energy demand, India has been taking bold steps to improve energy efficiency and reduce reliance on imports. Decarbonization of high energy-using sectors is essential for tackling climate change (*e.g.*, agriculture is the second-largest source of greenhouse gases). Intervention strategies targeting demand-side mitigation with distinct emphases focussing on reducing or changing activity, improving technological efficiency and electrifying energy end use can reduce emissions by 51–85% in buildings (encompassing residential and service-sector buildings) and 37–91% in transport (encompassing aviation, navigation and land transport) by 2050 relative to a current policies scenario (ranges indicate model variability).

A decade ago in the year 2015, the world rallied around the Paris Agreement on climate change and the goal of holding global temperature rise to 1.5°C (sustained temperature anomaly over a period of at least 20 years). Since then, the "1.5°C goal" has become a critical benchmark against which policies are set for climate action on emission reduction and progress is measured through evaluating the ambition of countries' national climate commitments known as nationally determined contributions (NDCs). The year 2024 was the first full year on record in which the global average temperature was more than 1.5°C above pre-industrial levels, with an estimated anomaly of 1.55°C. This continued an alarming pattern in which the 10 warmest years on record have all occurred since 2015. Meeting the Paris Agreement to limit global warming to 1.5°C requires global anthropogenic net greenhouse gas emissions to decline rapidly to zero (Fig. 25), meaning a radical acceleration of actions on low-carbon transitions in a range of sectors to achieve a maximum rate of decarbonisation, as the global economy is decarbonising at least five times too slowly (Lenton *et al.,* 2025b).

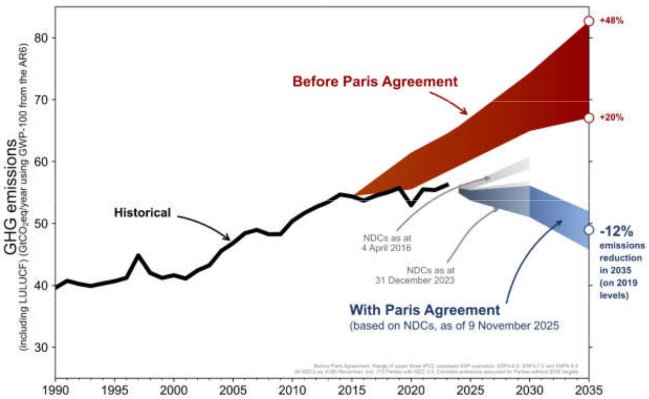

Fig. 25: Historical greenhouse gas emissions and future pathways based on commitments made by Parties to UNFCCC as reflected in their NDCs.

While scaling up essential clean power generation infrastructure, including solar, wind and hydropower, India needs to explore a more diversified mix of energy technologies, including non-emitting, dispatchable power generation. Over the next 10 – 15 years, a new wave of small modular nuclear reactors – alongside existing assets – may be capable of delivering on this need for more energy diversity. India has to expand nuclear capacity rapidly in spite of the most critical domestic challenges such as public opinion while judiciously addressing technology selection, infrastructure readiness, policy and regulatory gaps and geopolitical considerations.

Breaching 1.5°C also increases the risk of crossing tipping points — critical thresholds beyond which parts of Earth may undergo abrupt, self- perpetuating and potentially irreversible changes. Tipping points, where low-carbon transitions become self-propelling, could be key to achieving the necessary acceleration. We deem these normatively 'positive', because they can limit considerable, inequitable harms from global warming and help achieve sustainability. The challenge now is to credibly identify potential positive tipping points, and the actions that can bring them forward, whilst avoiding wishful thinking about their existence, or oversimplification of their nature, drivers, and impacts.

Future outlook

The United Nations Environment Programme (UNEP) annual "emissions gap" report released in 2025 has warned that global mean temperature rise could be heading for 2.8°C this century, if only current policies are fulfilled. The rise could be limited to 2.5°C, if unconditional national pledges are met in full – or to 2.3°C, if pledges conditional on financial support are put into action. Further, speaking at the World Leaders' Summit which kicked off in Belém, Brazil, ahead of the official opening of COP30, UN secretary-general António Guterres described failing to remain below 1.5^{o}C as a "moral failure and deadly negligence" and added that "Every fraction of a degree means more hunger, displacement and loss – especially for those least responsible".

The 30th annual UN climate summit (COP30) took place during Nov. 10-Nov. 21, 2025 in Belém, Brazil. COP stands for "the Conference of the Parties". It is the annual United Nations conference dedicated to climate change. This crucial event is being organized under the UN Framework Convention on Climate Change (UNFCCC) since 1995. COP represents the world's most significant annual climate gathering of nations who are parties to the Paris Agreement to discuss their next steps to combat climate change and work towards establishing legally binding agreements to support climate action. It's a major moment for the world's leaders to demonstrate progress on past pledges and put forward new plans that benefit people, nature and the climate. A landmark moment was at COP21 in 2015, where the Paris Agreement was signed. This agreement set the ambitious goal of limiting global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. The UNFCCC secretariat plays a vital role in facilitating these intergovernmental negotiations. COP is a powerful forum where commitments are made, progress is assessed, and, hopefully, ambitions are raised. It reminds us that global challenges require global solutions.

In COP30, more than 200 governments, banks, businesses, and communities joined forces to outline workable solutions for mobilizing climate finance. An action plan was also agreed to enable better evaluation of global progress to implement ecosystem-based adaptation and enhance the resilience of ecosystems, cultural heritage, biodiversity and on the Baku Adaptation Roadmap to accelerate adaptation action After two weeks of negotiations and hectic discussions, climate talks concluded with countries agreeing on a goal to "triple" adaptation finance by 2035 and efforts to "strengthen" action plans thus helping developing countries meet their climate goals. This brings tremendous benefits for the global economy – generating jobs, protecting communities, and driving innovation. Thanks to all the policies enacted and advances in clean energy over the last decade, we're currently heading towards a world that's 2.8^{o}C warmer. And if all of the countries' Nationally Determined Contributions are implemented (that will shape the future of climate action), the warming will be around 2.4^{o}C. It was also noted in COP30 that there could not be a uniform phase-out plan for everyone, and that countries should be free to decide on their own pathways for eliminating fossil fuels in their national interest.

Climate adaptation remains vastly underfunded, especially in developing countries. New research offers practical solutions to ramp up investments in resilience. As part of the COP30 Action Agenda, Brazil announced a suite of efforts to accelerate climate action across all levels of government, from local to regional to national. Recent estimates of the amount of carbon dioxide (CO_2) the world can emit (from the start of 2026) to have a 50% likelihood of staying below each temperature level of 1.5^{o}, 1.7^{o} and 2.0^{o}C relative to pre-industrial temperatures are depicted in Fig. 26.

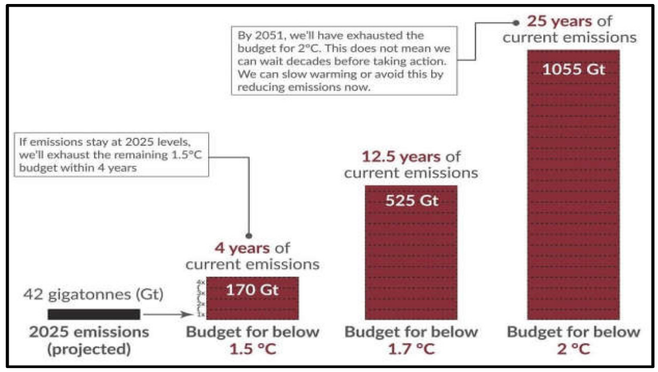

Fig. 26: How much more CO_2 can we emit while staying below 1.5^{o}C, 1.7^{o}C and 2.0^{o}C?

The fossil-fuel electricity generation has flatlined for the first time outside a recession, with soaring solar and wind more than meeting rising electricity demand. At COP30, South Korea (which operates the world's seventh-largest fleet of coal plants) committed to closing all 40 plants by 2040 and build no new unabated plants. This makes South Korea the second Asian nation, after Singapore, to join the Powering Past Coal Alliance, launched in 2017 at COP23 in Germany. The global fossil fuel emissions will hit a record high in 2025, even as a surge in energy sharply slows the growth of overall emissions. The world's fossil-fuel use is on track to peak before 2030 – despite a surge in political support for coal, oil and gas. But the world remains dangerously off-track: current policies put Earth on a 2.8°C warming trajectory, far above the Paris Agreement's 1.5°C goal.

The final deal "*fell short on the global transition away from oil, gas and coal*", as Brazil announced that it would bring forward voluntary roadmaps to phase out fossil fuels and deforestation, before the next COP. It was a "*frustrating end*" for more than 80 countries who wanted a roadmap away from fossil fuels to be part of the formal COP agreement. The agreement completely left out a fossil fuel exit roadmap, which the European Union, some Latin American countries and small island nations had been pushing hard for and the roadmap on fossil fuel phase-out did not find a place in the final outcome due to stiff opposition from petrostates and some other major economies.

There is no hope of maintaining the 1.5^{o}C goal without ending dependency on fossil fuels. The latest World Energy Outlook from the International Energy Agency projects a 344% rise in the global use of solar from 2024 to 2035 under "stated policies". However, without rapid implementation of the goal towards net-zero, even an emissions peak will only slow - not stop - global warming. Both near-term and net-zero targets play vital roles in the global climate response. Near-term targets remain a required stepping stone to net-zero, providing accountability and momentum in the critical years ahead, while net-zero targets offer a clear end goal. Together, these targets establish a comprehensive and credible approach to emissions reduction — one that balances urgency and accountability with long-term vision. There are feasible pathways that address the root fossil fuel causes of global warming, and halt the current global insanity that would lock in thousands of years of human suffering and species loss. All involve phaseout of fossil fuel use: first of coal (2040s), then gas (2050s), then oil (2060s). These steps would bring us to net zero greenhouse gas emissions in the 2060's. After that, feasible methods of carbon dioxide removal (CDR) can bring down temperatures to as low as 1.2°C – lower than today's temperatures.

As the chances of limiting global warming to 1.5°C dwindle, there is now increasing focus on the prospects for "overshooting" the Paris Agreement target (If warming temporarily exceeds the threshold before falling back below it by the end of the century, this is referred to as "overshoot") and then bringing temperatures back down by removing CO_2 from the atmosphere. Non-Annex I countries now constitute nearly two-thirds of global emissions and are likely to be a far higher proportion of emission's growth. So, to limit climate change, these emissions must be priority target. Of course, quicker action by Annex I countries must complement this, perhaps alongside negative emissions, and by providing much more serious help to some non-Annex I countries to accelerate solutions for a just and effective energy transition.

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