frontiers | Frontiers in Science

TYPE Frontiers in Science Viewpoint
PUBLISHED 01 October 2024
DOI 10.3389/fsci.2024.1433766

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OPEN ACCESS

EDITED AND REVIEWED BY
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RECEIVED 16 May 2024
ACCEPTED 26 June 2024
PUBLISHED 01 October 2024

CITATION
Behera SK. Understanding the impact of climate change on extreme events. *Front Sci* (2024) 2:1433766. doi: 10.3389/fsci.2024.1433766

Understanding the impact of climate change on extreme events

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KEYWORDS

extreme events, ENSO, IOD, monsoon, teleconnection, climate change

A Viewpoint on the Frontiers in Science Lead Article
Emerging signals of climate change from the equator to the poles: new insights into a warming world

Key points

- Anthropogenic climate change is evident; however, projections vary across models due to uncertainties in factors such as greenhouse gas emissions and other influential variables, including climate sensitivity and feedback processes, leading to difficulty in predicting critical thresholds such as the 1.5°C and 2°C targets set by the Paris Agreement.
- Extreme events such as severe heatwaves are occurring more frequently around the globe, significantly impacting human health and ecosystems worldwide, which underscores the importance of better understanding the underlying processes that trigger these events and how they link to our changing climate.
- Understanding regional climate change and predicting the impact on regional phenomena, such as monsoons, atmospheric circulation patterns, and tropical cyclones, is critical for managing water resources, ensuring food security, and mitigating the effects of climate-related disasters.

Global warming and escalating extremes

From scorching heatwaves to persistent droughts, from heavy floods to coastal inundations, we are being confronted with a formidable set of challenges as a result of global warming. There is now indisputable evidence that human-induced climate change is underway. However, the trajectory of future climate change remains uncertain, with different climate models projecting varying degrees of warming. These projections, based on scenarios of future greenhouse gas (GHG) emissions and other influencing factors, are made through coordinated experiments, such as the Coupled Model Intercomparison

Project 5 (CMIP5) and CMIP6, and are used to inform the Intergovernmental Panel on Climate Change (IPCC) reports with a focus on global mean temperature targets for policy formulation.

Coordinated experiments, including those with fixed GHG concentrations and zero CO_2 emissions, provide insights into ongoing warming trends and the potential of reaching net zero emissions. However, despite uncertainties about projected global warming, understanding the current and future impacts of climate change is vital for crafting adaptation strategies and reducing GHG emissions. In this context, the article “Emerging signals of climate change from the equator to the poles: new insights on a warming world” by Collins et al. (1) is timely and offers a comprehensive overview of recent cutting-edge findings from models and observations on the impact of climate change on extreme weather. The study illuminates the interconnectivity of various climate systems and underscores the significance of grasping the regional implications of climate change. This article builds upon the aforementioned discussions by further examining the link between climate-related extremes and global warming in greater detail.

Worsening heatwaves

Heatwaves are extreme weather events that are becoming more frequent and severe as global temperatures rise. In many parts of the world, they have led to excessive human morbidity and mortality rates. Heatwaves have been responsible for over 166,000 fatalities between 1998 and 2017, and approximately 125 million people were exposed to extreme heat between 2000 and 2016 (2). Mortality due to such extremes is amplified when combined with changes in humidity [e.g., (3)]. Heatwaves also cause heat stress on livestock and vegetation, increasing the risk of forest dieback and crop loss and subsequently affecting food security. Therefore, it is crucial to have a better understanding of these extreme weather events and their responses to climate change.

Changes in atmospheric circulation patterns and regional effects, such as land surface changes, are often linked to the evolution of heatwaves. For example, summer heatwaves in the extratropics can occur under persistent anticyclones or blocking. Any changes in blocking would increase the chances of more intense and prolonged heatwaves. Climate change can alter such global atmospheric circulation patterns, teleconnections, and the position and intensity of subtropical high-pressure systems. For example, the changing teleconnection from a monsoon could significantly impact the way it influences the climate over Europe and parts of Asia through the monsoon teleconnection.

It is also important to consider diabatic heating in this context. Teleconnections from tropical climate variations, such as El Niño-Southern Oscillation (ENSO), ENSO Modoki, the Indian Ocean Dipole (IOD), and monsoons, play crucial roles in shaping the circulation patterns in high-latitude regions, including blocking highs that are responsible for heat and aridity in different parts of the world [e.g., (4)]. Collins et al. (1) discuss the influence of teleconnections between different climate system regions, particularly the impact of ENSO on midlatitude storms and storm tracks. It highlights the uncertainty and variability in the magnitude and direction of changes in ENSO impacts, underscoring the complexity and challenges in modelling and projecting these shifts. However, other factors, such as the higher mean temperature, could be more important for the observed increase in heatwave intensity. Additionally, future warming may weaken the dampening effect of soil moisture on summer temperatures, also contributing to more extreme heatwaves.

Desertification

Rising global temperatures can worsen aridity in subtropical deserts by increasing evaporation rates and water loss from soil and vegetation. More frequent and intense heatwaves will further stress ecosystems and water resources in the affected regions. For example, the CMIP6 simulations indicate that desert expansion will vary under different projected scenarios, such as Shared Socioeconomic Pathways (SSP) 2–4.5 and SSP5–8.5, and the most significant expansions are anticipated in Asia, Africa, and Australia, while parts of southern North Africa may experience a reduction in desert areas as their southern boundaries shift northward (5). Future projections of global warming also indicate a trend toward intensified dryness, in contrast to past climates in subtropical regions, where rich vegetation growth occurred due to sufficient precipitation during the warm Miocene and Pliocene epochs. This could be due to weaker atmospheric circulation resulting from altered ocean surface temperature patterns (6), which leads to reduced temperature gradients. In addition, changes in tropical climate variations and associated circulation patterns, particularly the Hadley circulation and tropical teleconnections from monsoons, may result in shifts in rainfall distribution and dry conditions, which in turn affect the boundaries and characteristics of subtropical deserts.

Changes in monsoon systems

The monsoon system, which brings seasonal changes in rainfall and winds, has a significant impact on many parts of the world. This is particularly true for the Indian summer monsoon system, which is well covered by Collins et al. (1). In addition to the changes in the monsoon season in India, monsoon seasons worldwide are exhibiting shifts in onset, withdrawal, and duration, resulting in increased erraticism. These are evidenced by the varying intensities of regional rainfall, with some areas experiencing heavier downpours that can result in flooding and landslides. Results from the CMIP6 model under the SSP2–4.5 scenario show monsoon rainfall over land in the Northern Hemisphere is likely to increase by about 2.8% per 1°C of global warming, while little change is expected in the Southern Hemisphere (7). Moreover, the Afro-Asian monsoon is predicted to become wetter, whereas the North American monsoon may become drier. In Eastern Africa, where rainfall patterns are bimodal, remote teleconnections from IOD and ENSO strongly influence the interannual variability of long and short rainfalls. Trends have indicated a tendency toward drier long rains and wetter short rains since the mid-1980s, impacting agriculture, public health, and ecosystems. Climate projections suggest that, by 2030–2040, short rains may surpass long rains in delivering rainfall (8). All these scenarios emphasize the need for sustained investment in adaptation and mitigation strategies and infrastructure developments.

Changes in tropical cyclones

Tropical cyclones play a crucial role in redistributing heat and moisture across the planet, maintaining the Earth's energy balance and supporting ocean mixing and nutrient cycling. However, they also pose significant dangers to coastal communities and economies due to their destructive winds, heavy rainfall, storm surges, and associated hazards such as flooding and landslides. Countries in tropical and subtropical regions, especially those with extensive coastlines such as those in the Caribbean, Southeast Asia, and the Indian Ocean region, are most affected by these storms. In the past decade, there has been an increase in the frequency of large-intensity tropical cyclones, commonly referred to as "super cyclones." According to a study by Pérez-Alarcón et al. (9), there could be an increase of 9.5–17% in tropical cyclone intensity by the end of the 21st century under different climate scenarios, with a projected 5–7% rise in maximum potential wind speed per degree of warming. However, future changes in tropical cyclones pose uncertainties regarding their intensity, frequency, regional variability, precipitation patterns, and interaction with climate modes. Although warmer ocean temperatures may indicate a general increase in cyclone intensity, the details of these changes, such as regional variations and precipitation distribution within cyclones, are still uncertain due to the complex interactions between atmospheric dynamics and climate forcing. This issue becomes even more complex due to the uncertainties in the developments of associated modes of climate variations, such as ENSO, ENSO Modoki, and IOD, which have been shown to influence the genesis, track, and intensity of tropical cyclones.

Conclusion

While the impact of GHG emissions on global temperatures is undeniable, the intricate relationship between this warming trend and the occurrence of extreme weather events remains a subject of ongoing investigation. Various factors, including feedback loops, complex ocean-atmosphere interactions, teleconnections, and regional disparities, contribute to the complexity of this relationship. Moreover, uncertainties persist regarding the frequency and intensity of key climate phenomena, such as ENSO, IOD, and monsoons, all of which significantly influence regional weather patterns, including the behavior of tropical cyclones. The interaction between these phenomena and atmospheric circulation systems such as the Walker and Hadley circulations, as well as oceanic meridional overturning, further complicates our ability to make precise predictions and projections. Given these uncertainties, it is imperative to approach climate projections with caution and to develop adaptive strategies capable of accommodating a range of potential outcomes in the face of evolving climate risks.

Statements

Author contributions

SB: Conceptualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author declared that he was an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

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