STUDY OF HEAT WAVES OVER INDIA

Abstract

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (AR6) highlights alarming climate projections for the Indian subcontinent, including a more variable monsoon, extreme rainfall, floods, droughts, heatwaves, and intensified tropical cyclones. India, highly vulnerable to climate events, faces yearly challenges impacting lives, infrastructure, agriculture, and the economy. Heatwaves, exacerbated by climate change, pose a significant threat, causing numerous deaths and economic losses. The AR6 findings reinforce the link between global warming levels and the intensification of extreme events, including heatwaves.

This study addresses the pressing concerns outlined in the AR6 regarding the escalating impacts of climate change on the Indian subcontinent. With a focus on heat waves, this study underscores the urgency of enhancing scientific understanding to inform effective adaptation planning and action. Numerous studies have documented the increasing frequency and duration of heat waves in different parts of India. The observed trends reveal a substantial impact on human health, agriculture, and overall mortality. Understanding the characteristics of heat waves is crucial for informed policy responses. India's current response involves Heat Action Plans that have been formulated by local and regional governments, but their effectiveness requires accurate heat wave forecasts. This thesis is focused on addressing the questions of how heat waves change in the future. This is investigated with the help of simulations of +1.5°C and +2°C warmer worlds designed to address the question of future changes in extreme weather. The mechanism of how the heat waves over Northwest India are triggered by atmospheric blocking events over North Atlantic through teleconnection is investigated for its robustness in future warmer worlds. In order to inform adaptation to climate change, risk-

based event attribution on a recent heat wave that occurred over India and Pakistan is carried out and, emphasizing the need for reliable forecasts, the forecast skill of state-of-art numerical weather prediction models for that heat event are analysed .

This study begins by analyzing past, present, and future heat wave conditions using operational definitions of heat events, such as "hot day," "heatwave," and "severe heatwave," employed by the India Meteorological Department. This allows for a meaningful comparison of future and past conditions and provides valuable insights for decision-makers. The methodology involves the identification of heat events of different categories in observations and bias corrected model output. The findings of this study reveal decreasing hot day duration but increasing heat wave duration in certain regions of India between 1951–2015. Future climates at +1.5°C and +2.0°C indicate a rise in frequency and duration of heat events, with shorter events 2-10 times more probable and longer duration events increasing by 10-30 times. The increased likelihood of heat waves in June and July poses additional risk due to higher moisture levels. A few recent heat waves that resulted in high mortality are taken as case studies to examine their characteristics in the two future climates. It is shown that the duration and area affected by the heat waves will most likely increase.

Next, this thesis investigates the influence of atmospheric blocking patterns and Rossby Waves on the heat events, particularly heat waves over Northwest India. Rossby Waves, exhibiting meridional expansion attributed to Arctic amplification, are linked to slower propagation and heat wave development. IPCC AR6 highlights robust trends in blocking frequency, showing increases in specific regions and seasons. A quasi-stationary Rossby Wave pattern, characterized by anomalous cyclonic and anticyclonic flow, plays a crucial role in heat wave dynamics. This study explores teleconnections between atmospheric blocking over the North Atlantic and heatwaves in Northwest India, adopting a methodology to assess potential changes in teleconnections under future climate scenarios (+1.5°C and +2°C). The results suggest that specific Rossby wave patterns, such as those with wavenumbers 5 and 7, can induce simultaneous heat extremes in distinct regions. The findings highlight that atmospheric blocking events over the North Atlantic teleconnect with heat waves in Northwest India, with a 3-day lag, persisting in +1.5°C and +2°C future climates. Granger Causality tests confirm the continued influence of North Atlantic blocking on higher daily maximum temperature anomalies over Northwest India in warmer climates. The analysis of Rossby wave numbers (4-11) highlights that Rossby Waves 7 and 9 trigger anomalous blocking over North Atlantic, leading to increased heat events over Northwest India, and their higher frequency in earlier in the season (March and April) and more frequent and earlier heat events over Northwest India.

Next, well established event attribution techniques were employed to understand the contribution of human-induced global warming to a specific heat event - the 2022 heat wave over South Asia. Despite La Niña conditions contributing to a slightly lower global temperature, 2022 marked the fifth warmest year on record globally. The study delves into the unprecedented and prolonged heat wave experienced in North India and Southern Pakistan from March to May 2022, with significant impacts on public health and agriculture (specifically the wheat crop), glacial lake outbursts, and forest fires. This study finds that the 2022 event (March-April observed daily maximum temperature) had a return period of ~1-in-100 years and that human-caused climate change made this heat wave about 1°C hotter and 30 times more likely in the current, 2022 climate, as compared to the 1.2°C cooler, pre-industrial climate.

Finally, this thesis also conducts a comprehensive analysis of the prediction skills of several state-of-the-art numerical weather prediction models for the 2022 heat wave. The results show that the multi-model mean gives better forecast skills on prediction of heat waves during March-April 2022.

Overall, the findings discussed in the thesis warn of heat waves that will occur earlier in the season in the future and last longer over a larger area. This is an insight for the government's preparedness measures, including Heat Action Plans, early warning systems, and healthcare strategies in India, offering a tangible basis for decision-makers and emphasizing the significance of actionable climate science in the face of evolving climate challenges.