Research Review

The Holocene
1–22

DOI: 10.1177/09596836241254480
journals.sagepub.com/home/hol
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An assessment of the correlations and causations of palaeo-hydroclimatic variability in India's monsoon-dominated Central Himalaya

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Abstract

The Indian Central Himalaya Region (ICHR), the northern topographic front of the Indian summer monsoon (ISM), is an ideal location to study topography-climate interactions because two weather systems—the ISM and mid-latitude westerlies (MLW)—create distinct eco-climatic regimes from tundra (north) to tropical (south). The region's paleoclimatic studies show considerable climatic variations since the late Pleistocene. We evaluated 29 paleoclimatic records from the region and synthesized the results semi-quantitatively using the weighted palaeoclimate index (WApCI) to better understand the important climatic events and their driving mechanisms. According to the WApCI, the region has at least six enhanced monsoonal periods and eight drier spells during the past 34 ka. The cold-dry climatic events, such as the last glacial maxima (LGM), Younger Dryas (YD), 8.2 ka, and 4.2 ka, are associated with northern-hemisphere (NH) climate dynamics and propagated via MLWs. While, the warmer phases are dictated by the insolation-driven ISM dynamics. The WApCI's reconstructed rainfall anomaly aligns with paleoclimatic-model experiments for dynamically generated Paleoclimate Modeling Intercomparison Projects (PMIP3/PMIP4) rainfall for chosen time-slices (last-millenium, historical, mid-Holocene, and LGM). Finally, the Granger causality test determines the temporal relationship between the climatic drivers/forcing indices and primary meteorological parameters. The results showed that summer and post-monsoon precipitation is primarily influenced by total solar irradiation, winter precipitation is driven by a complex mix of variables, and pre-monsoon precipitation is driven by the Arctic oscillation. Based on the facts, we hypothesize that past climate variability demonstrates a complex interplay of local and hemisphere teleconnections in ICHR's climate dynamics.

Keywords

Granger causality test, Indian Central Himalaya Region, Indian summer monsoon, Mid-latitude westerlies, paleoclimatic data synthesis, weighted palaeoclimate index

Received 30 January 2024; revised manuscript accepted 22 April 2024

Introduction

The collision between the Indian and Asian continental plate boundaries, which was initiated in the central-eastern sector around 59 ± 1 million years ago, resulted in the formation of the extensive Himalayan-Tibetan mountain ranges (Hu et al., 2016). The subsequent sequence of tectonic events uplifted the Himalayas and Tibetan plateau, profoundly influencing (either started or intensified) Asian weather patterns and the evolution of the Asian monsoon system at around 7–8 Ma, when the mountain system reached half of their present-day elevations (Le Fort, 1975; Prell and Kutzbach, 1992; Wang et al., 2014). The Indian summer monsoon (ISM), a vital part of this system, provides crucial rainfall for southern and southeastern Asia, particularly supporting India's agriculture-based economy (Ali et al., 2018). This monsoon arises from seasonal wind reversals driven by solar radiation interacting differently with tropical land and ocean areas, creating a thermal low over the Indo-Tibetan region (Halley, 1686; Tada et al., 2016). The Himalayas play a crucial role in the development of the monsoon and also serve as a barrier at altitudes above approximately 5000 m. This barrier hinders the northward movement of precipitation from the ISM, resulting in reduced moisture for the higher and Trans-Himalayan regions of the eastern and central Himalayas (Bookhagen et al., 2005; Tada et al., 2016). The mid-latitude westerlies (MLW) have a significant presence in the northern and western parts of the region, gradually diminishing

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