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Enhanced surface temperature over India during 1980–2020 and future projections: causal links of the drivers and trends

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The Earth's surface temperatures have increased significantly since the beginning of industrialisation. The substantial emissions of greenhouse gases have played a role in global warming and the ongoing climate change, with projections indicating continued trends. This study explores the long-term surface temperature trends in India from 1980 to 2020, utilizing surface, satellite, and reanalysis data. Causal discovery is employed to assess the impact of geophysical drivers on temperature changes. Southern India exhibits the highest mean surface temperatures, while the Himalayas experience the lowest, aligning with solar radiation patterns. The causal discovery analysis identifies the varying influence of atmospheric processes, aerosols, and specific humidity on surface temperature. Positive temperature trends are observed during the pre-monsoon (0.1–0.3 °C dec^{-1}) and post-monsoon (0.2–0.4 °C dec^{-1}) seasons in northwest, northeast, and north-central India. Northeast India demonstrates substantial annual (0.22 ± 0.14 °C dec^{-1}) and monsoon (0.24 ± 0.08 °C dec^{-1}) warming. Post-monsoon trends are positive across India, with the western Himalaya (0.2–0.5 °C dec^{-1}) and northeast India (0.1–0.4 °C dec^{-1}) experiencing the highest values. Projections based on the Coupled Model Intercomparison Project 6 (CMIP6) indicate potential temperature increases of 1.1–5.1 °C by 2100 under the Shared Socioeconomic Pathways (SSP5)–8.5 scenario. The escalating temperature trend in India raises concerns, emphasizing the necessity for adaptation and mitigation measures to counteract the adverse impacts of accelerated warming and regional climate change.