# Assessing Future Heat Wave Patterns in India: Insights from a High-Resolution Regional Climate Model

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## Abstract

This research investigates the impact of climate change on heat wave patterns in India from the late 20th century (1986-2005) to the mid-21st century (2041-2060). Utilizing 20-km resolution regional climate model simulations, we estimate the projected changes in the timing, duration, and frequency of 1 to 5-day heat wave events. We utilize two heat wave indices, HI14 and HI15, where a heat wave is defined as the daily highest heat index surpassing 90°F for HI14 and 105°F for HI15. Results indicate a projected future shift towards earlier onset, and later demise of heat waves, implying an expansion of the season of their occurrence. In addition, the frequency of heat waves is expected to increase in the future. This study highlights the pressing need for adaptation in India, as increasingly severe and prolonged heat waves threaten agriculture, water resources, and public health. Policymakers can use these insights to mitigate climate change impacts on vulnerable areas.

## Data and Methodology

### Data Used

- We utilized a 20-km resolution regional climate model (RCM) simulation driven by the CMIP5 CCSM4 model, specifically tailored for India by Jayasankar et al. (2023), to estimate hourly heat index values over 20 years, encompassing the late 20th century (1986-2005) and mid-21st century (2041-2060) periods. The simulation for the mid-21st century is based on the RCP 8.5.

### Methodology

- The heat index at each hour is defined using $I_{\mathrm{NWS}}$;

$$I_{\mathrm{NWS}} = \begin{aligned} &-42.379 + 2.04901523\,\mathrm{T} + 10.14333127\,\mathrm{R} \\ &- 0.22475541\,\mathrm{TR} - 0.00683783\,\mathrm{T2} \\ &- 0.05481717\,\mathrm{R2} + 0.00122874\,\mathrm{T2R} \\ &+ 0.00085282\,\mathrm{T2R2} - 0.00000199\,\mathrm{T2R2} \end{aligned}$$

Where $I_{\mathrm{NWS}}$, $T$, and $R$ represent heat index in °F, temperature in °F, and relative humidity in %, respectively (Beasley et al. 2023)

- When R < 13%, calculation is adjusted accordingly:

$$I^{*}_{\mathrm{NWS}} = I_{\mathrm{NWS}} - B$$

- Where: $B = \frac{(13-R)}{4}\sqrt{\frac{17-|T-95|}{17}}$

- If R > 85% and 80 < T < 87: $B = \frac{(R-85)}{10} \times \frac{(87-T)}{5}$

- The HI14 (HI15) heat index is defined as grid points where hourly $I_{\mathrm{NWS}}$ > 90°F ($I_{\mathrm{NWS}}$ > 150°F)

## Results

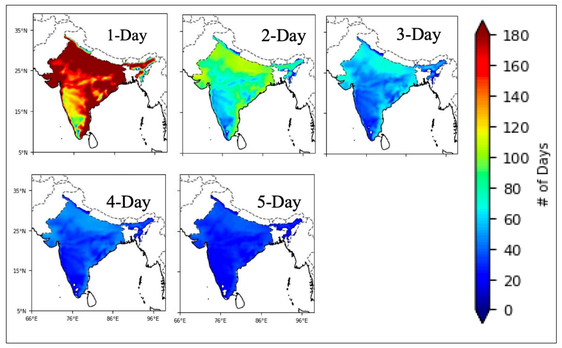


**Figure 1:** The 20-year (1986-2005) climatology of number (in days) of 1-day to 5-day HI14 heat wave events.

- Historical simulations indicate that the frequency of occurrence of 1 to 5-day HI14 heat wave events is higher in the northern parts and coastal regions of India

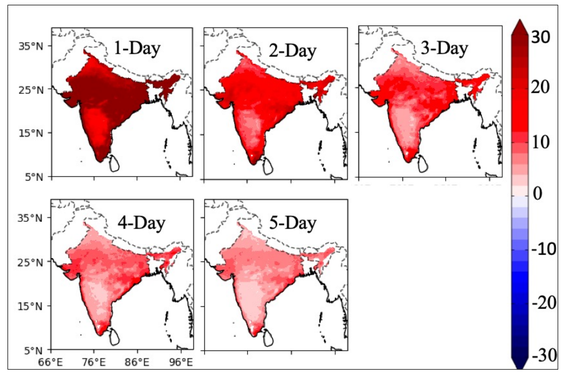


**Figure 2:** The 20-year climatological projected change in the number of 1-day to 5-day HI14 heat wave events (mid-21st century [2041-2060] minus 20th century [1986-2005]) under RCP 8.5 scenario.

- 1-day to 5-day HI14 heat wave events show a consistent projected future increase throughout India

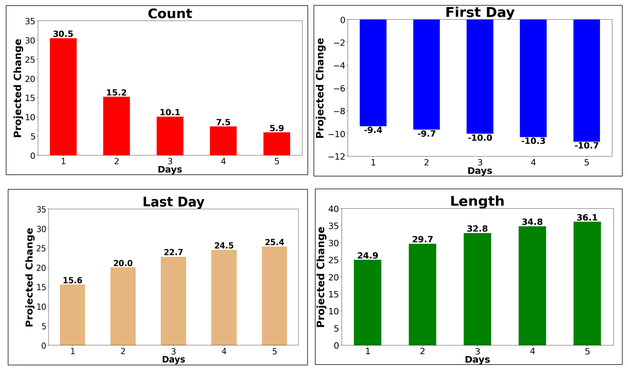


**Figure 3:** The 20-year climatological projected changes in the number, first and last day, and length between the first and last day of occurrences of 1-day to 5-day HI14 heat wave events.

- 1-day to 5-day HI14 heatwave events show a projected future shift towards earlier onset (9.4 to 10.7 days), and later demise (25.4 to 15.6 days) of heat waves, implying an expansion of the season of their occurrence (36.1 to 24.9 days)
- The frequency of 1-day to 5-day HI14 heat wave events is expected to increase in the future (30.5 to 5.9 days)

## Results

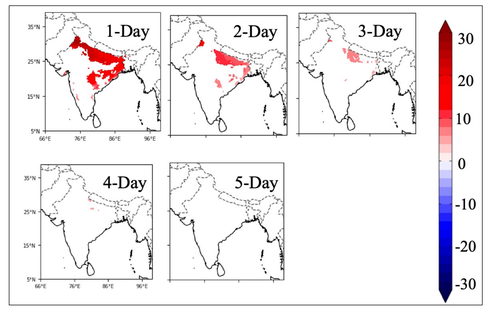


**Figure 4:** The 20-year climatological projected change in the number of 1-day to 5-day HI15 heat wave events (mid-21st century [2041-2060] minus 20th century [1986-2005]).

- 1-day to 5-day HI15 heat wave events show a projected increase over India, but the number of grid points is much less than HI14 due to the high threshold (> 105°F)

## Conclusion

- The projected future changes indicate a shift towards an earlier onset and later demise of heat waves, implying an expansion of their occurrence season
- It is expected that the frequency of HI14 and HI15 heat wave events will increase in the future
- The largest projected changes are expected to occur over North, Northeast, and Northwest parts of India, as well as coastal regions

## Future Considerations

- Estimating quantification at the district level is valuable for planning and mitigating the impacts in vulnerable areas
- This study spans 20 years and extends the model integration period to provide more robust estimates
- Estimating the projected changes of heatwave events by examining different emission pathways

## References

- Jayasankar, C.B., Misra, V., Karmakar, N. (2023). A Comparative Study Between Regional Atmospheric Model Simulations Coupled and Uncoupled to a Regional Ocean Model of the Indian Summer Monsoon. *Earth and Space Science*, https://doi.org/10.1029/2022EA002733.
- Beasley, P., Misra, V., Jayasankar, C. B., & Bhardwaj, A. (2023). Heat waves in Florida and their future from high-resolution regional climate model integrations. *International Journal of Climatology*, *43*(16), 7532–7548. https://doi.org/10.1002/joc.8278