Diagnostics and real-time extended range prediction of cold waves over India

R. Mandal[1], S. Joseph[1], A. K. Sahai[1], A. Dey[1], R. Phani[1], D. R. Pattanaik[2], M. Kaur[1], N. Karmakar[1]

[1] Indian Institute of Tropical Meteorology Pune, [2] India Meteorological Department

1. Background

- Our climate and its extremes are changing, according to the IPCC's sixth Assessment Report[1].
- Cold wave (CW) is one of the extreme temperature events. In India, CWs occur during the boreal winter month, November to February (NDJF) and over most of the stations from north, northwest, east and central parts[2,3].
- In 23 of the last 38 years (1980-2018), the human death toll in India due to cold waves was higher than that due to heat waves[4].
- These extreme events should be predicted by developing a skillful prediction system/strategy, which not only satisfies the public's desire to be better prepared but also helps emergency managers, regional planners, and policymakers.
- This study proposes an objective criterion using the actual, departure from normal and the percentile values of the daily gridded minimum temperature (Tmin) data for the monitoring of the CW events over the Indian region and also checks its usefulness in a multi-model ensemble (MME) extended range prediction system (ERPS)[5].

2. Datasets

- Daily gridded (1°×1°) IMD observed minimum (Tmin) temperature dataset (1951-2022) has been used for the proposed CW-criterion[6].
- The daily gridded (2.5°×2.5°) NCEP Reanalysis dataset has been used for the composite analysis[7]. The NOAA High-Resolution Sea Surface Temperature (SST) dataset is used for the composite analysis of SST[8].
- The model hindcast/forecast data (1°×1°) are derived from an MME prediction system that has been built in-house at IITM, Pune and is currently operationally run by IMD on every Wednesday.
- It includes the GFSv2 and CFSv2 at two different resolutions (T382 and T126), separately. It has a total of sixteen ensemble members.
- Hindcast is available from 2003 onwards.

3. Methodology

CW criteria by IMD

i. CW will be considered when Tmin of a station is 10°C or less for Plains and 0°C or less for Hilly regions and when the negative departure from normal is 4.5°C to 6.4°C

OR,

ii. When the actual Tmin is ≤ 4°C (only for Plain stations)

OR,

iii. When the departure from normal is -4.5°C or less (for the coastal stations where the minimum temperature is 15°C or less)

New Proposed Criterion for gridded data

i. If the Tmin of a particular day is ≤ climatological 5th percentile (calculated from daily values during NDJF) and ≤ 10°C and also its departure from normal is < -3.5°C

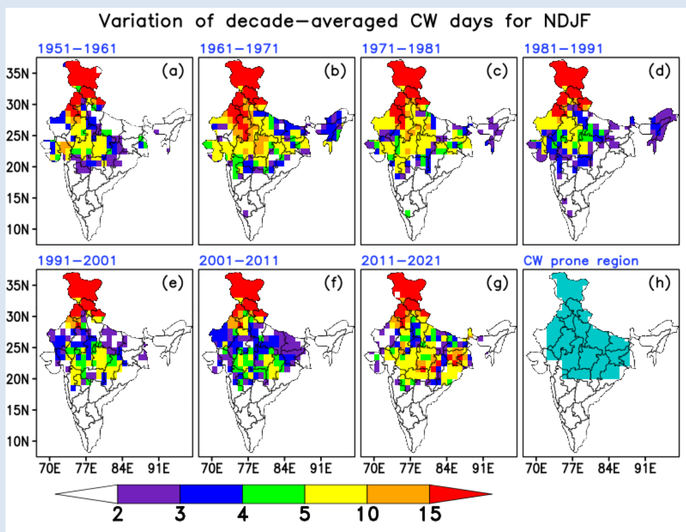
OR,

ii. Simply when the actual Tmin is ≤ 4°C then, it will be a CW day.

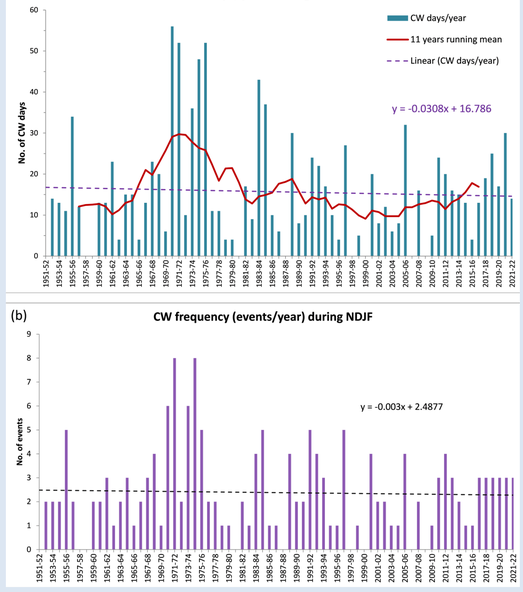
Identification CW spells over the CW-prone region

The CW events over the CW-prone area during 1951-2022 have been identified when the area-averaged standardized (by its own standard deviation) Tmin anomalies are less than -1.0 for 4 consecutive days during NDJF.

4. Results



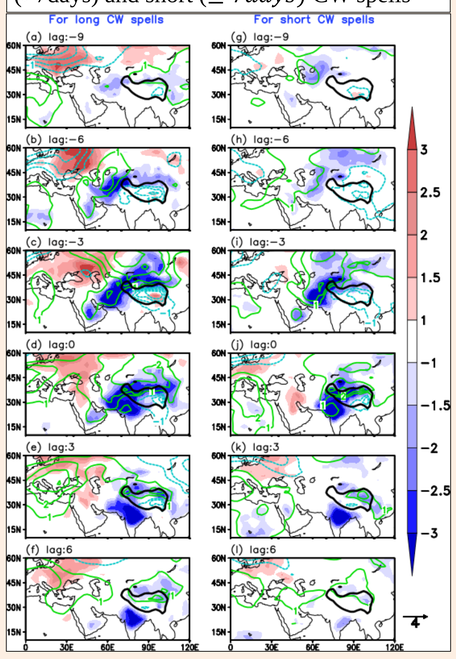
CW prone regions are above the 20°N and are mostly observed towards the north-west and central parts of the country. In recent decades, CW days are more over the central and eastern parts.



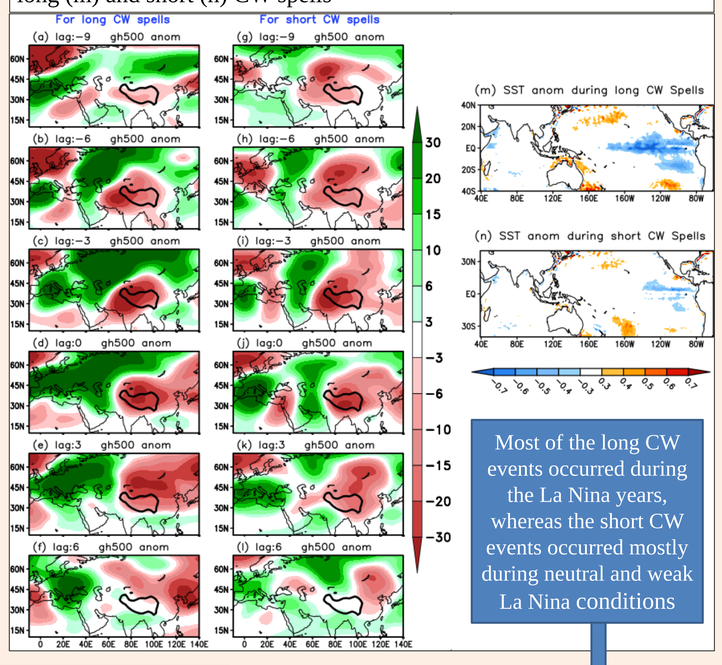
Trend lines for CW days/events not significant

4. Results

Lag composites of Tmin (shade; ℃) and mslp (contour; hPa) anomalies for long (>7days) and short (≤ 7$days$) CW spells



Lag composites of 500 hPa geopotential height (in m) anomalies for long (a-f) and short (g-l) CW spells. Composites of SST anomalies for long (m) and short (n) CW spells

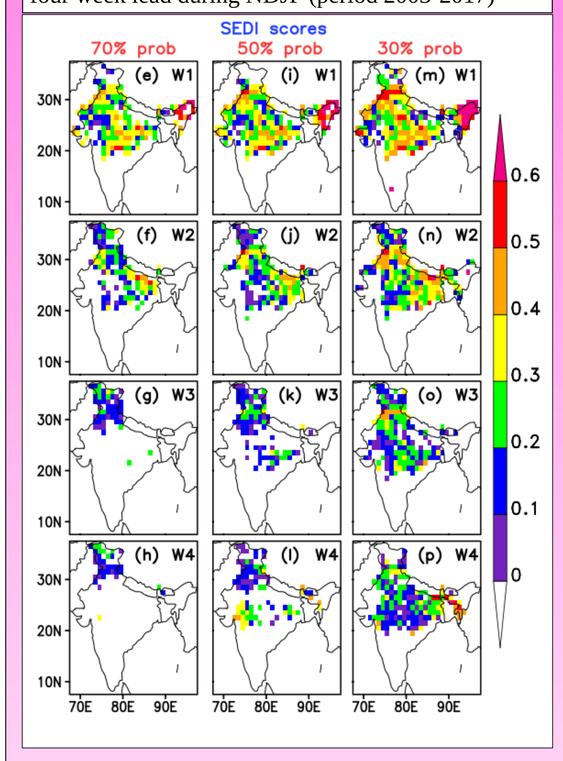


Most of the long CW events occurred during the La Nina years, whereas the short CW events occurred mostly during neutral and weak La Nina conditions

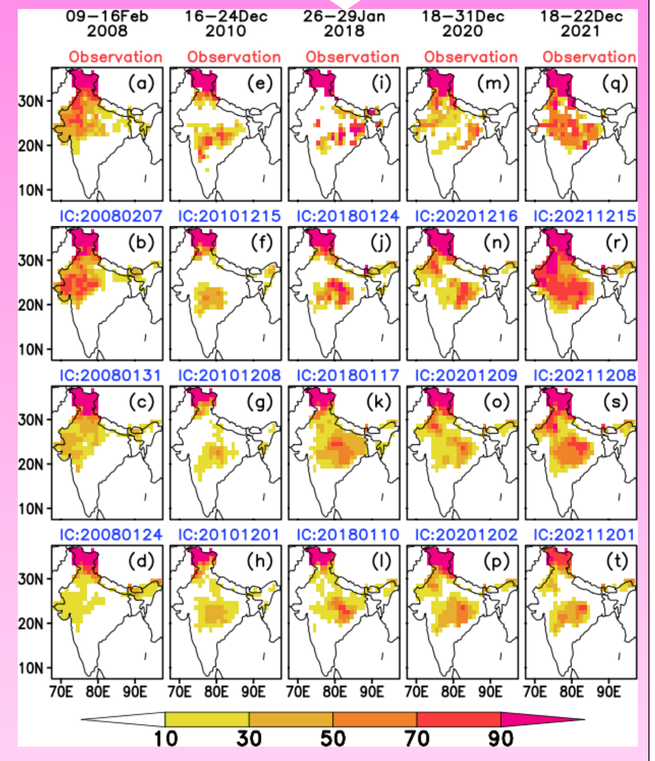
The longer persistence of low level anticyclonic pattern (high mslp anomalies) and slower movement towards the Indian subcontinent is associated with the CW events having longer duration.
The blocking of high-pressure cells persisting for longer time might cause a southern shift of the atmospheric tunnel of high-speed westerly winds, resulting in an outbreak of severe cold weather over north India's hills and plains. The frigid winds might last for a week or longer.

ENSO phase	No. of years	No. of long CW events (% of events)	No. of short CW events (% of events)
Neutral	11	5 (17.8)	24 (40)
El Nino	14	6 (21.4)	14 (23.3)
La Nina	15	17 (60.7)	22 (36.7)

Symmetric Extremal Dependence Index (SEDI)[9] values are shown different fixed CW probabilities for four week lead during NDJF (period 2003-2017)



Verification of the ERP for different events: Probabilities of occurrence of CW



- ERPS has a good skill with 70% probability up to week-2, with 50% probability up to week-3 (reduced spatially) and with 30% probability of occurrence up to week-4 leads, though the SEDI values decrease in the longer leads.
- It has a great potential to predict the upcoming CW events (using the newly developed CW creation) from the 2-3 weeks lead time, though with relatively less confidence at the far ICs.

5. Summary

- This study is a first-of-its-kind attempt to define an objective criterion using the thresholds of actual, departure from normal and the percentile values of the daily gridded observed Tmin data.
- A CW-prone region has been identified. During recent times, more CW days are observed across the central and parts of eastern India.
- The CW events have been identified based on the standardized area-averaged Tmin anomaly time series from 1951 to 2022 and during NDJF. Even during the recent warming period, the no. of CW days are not affected significantly.
- Strong La Nina situation favours long CW events (> 7 days), while the neutral and weak La Nina conditions favour short CW events (≤ 7 days). The long events are linked with the blocking high to the north-west of Indian longitude with a very slow movement of the westerly trough to the east, whereas short CW events are not as strongly associated with the blocking high.
- A promising skill has been found with a 70% chance of CW occurrences in the week-1 lead, a 50% probability in the week-2 lead, and a respectable skill over a few parts of central India in the week-3 and week-4 leads. This criterion will be implemented for the real-time monitoring and prediction of CWs over India in due course.

6. Acknowledgements

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Presenting Author: Raju Mandal

Email: raju.cat@tropmet.res.in

7. References

1. IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.
2. Nair SA, Pai DS, Rajeevan M (2016) Climatology and trend of cold waves over India during 1971-2010. Mausam 67:651–658. https://doi.org/10.54302/mausam.v67i3.1384
3. Ratnam J V., Behera SK, Annamalai H, et al (2016) ENSO's far reaching connection to Indian cold waves. Sci Rep 6:1–12. https://doi.org/10.1038/srep37657
4. Gupta, A.K., Chopde, S., Nair, S.S., Singh, S., and Bindal, S. (2021). Mapping Climatic and Biological Disasters in India: Study of Spatial & Temporal Patterns and Lessons for Strengthening Resilience. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH India. [Pages 160]
5. Abhilash S, Sahai AK, Borah N, et al (2015) Improved spread-error relationship and probabilistic prediction from the CFS-based grand ensemble prediction system. J Appl Meteorol Climatol 54:1569–1578. https://doi.org/10.1175/JAMC-D-14-0200.1
6. Srivastava AK, Rajeevan M, Kshirsagar SR (2009) Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region. Atmos Sci Lett 10:249–254. https://doi.org/10.1002/asl.232
7. Kalnay E, Kanamitsu M, Kistler R, et al (1996) The NCEP/NCAR 40-Year Reanalysis Project. Bull Am Meteorol Soc 77:437–471. https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2
8. Reynolds RW, Smith TM, Liu C, et al (2007) Daily High-Resolution-Blended Analyses for Sea Surface Temperature. J Clim 20:5473–5496. https://doi.org/10.1175/2007JCLI1824.1
9. Ferro CAT, Stephenson DB (2011) Extremal dependence indices: Improved Verification measures for deterministic forecasts of rare binary events. Weather Forecast 26:699–713. https://doi.org/10.1175/WAF-D-10-05030.1