

Mesoscale Convection and Moisture Dynamics during Western Disturbance Extreme Precipitation Events over India

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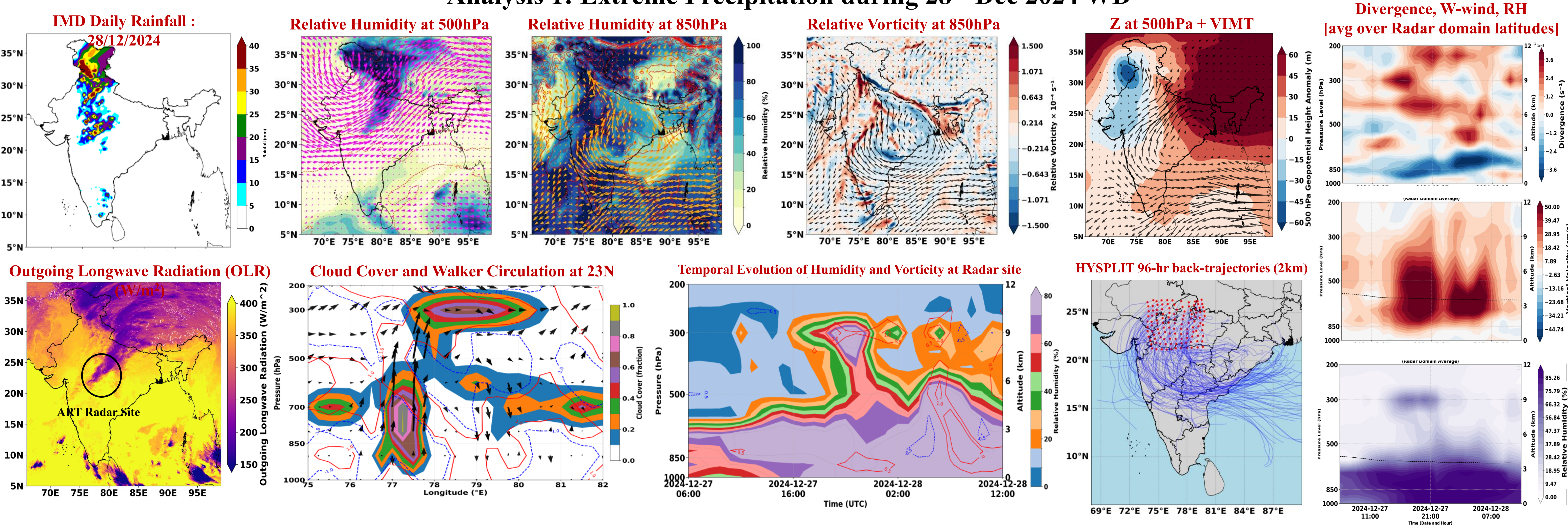


Abstract: Western Disturbances (WDs) are the dominant winter weather systems over northern India, driving extreme rainfall and modulating fog over the Indo-Gangetic Plains (IGP). This study combines C-band dual-polarisation radar, ERA5 reanalysis, satellite and trajectory analysis to examine a WD that produced extreme rainfall as far south as Central India. A cold-core frontal trough with strong low-level convergence and Bay of Bengal moisture supported narrow convective bands embedded in widespread stratiform rain, deep echo tops and mixed-phase microphysics. Over the IGP, WD warm fronts weaken inversions and dissipate fog, while cold-front passage restores stability and allows fog to re-establish.

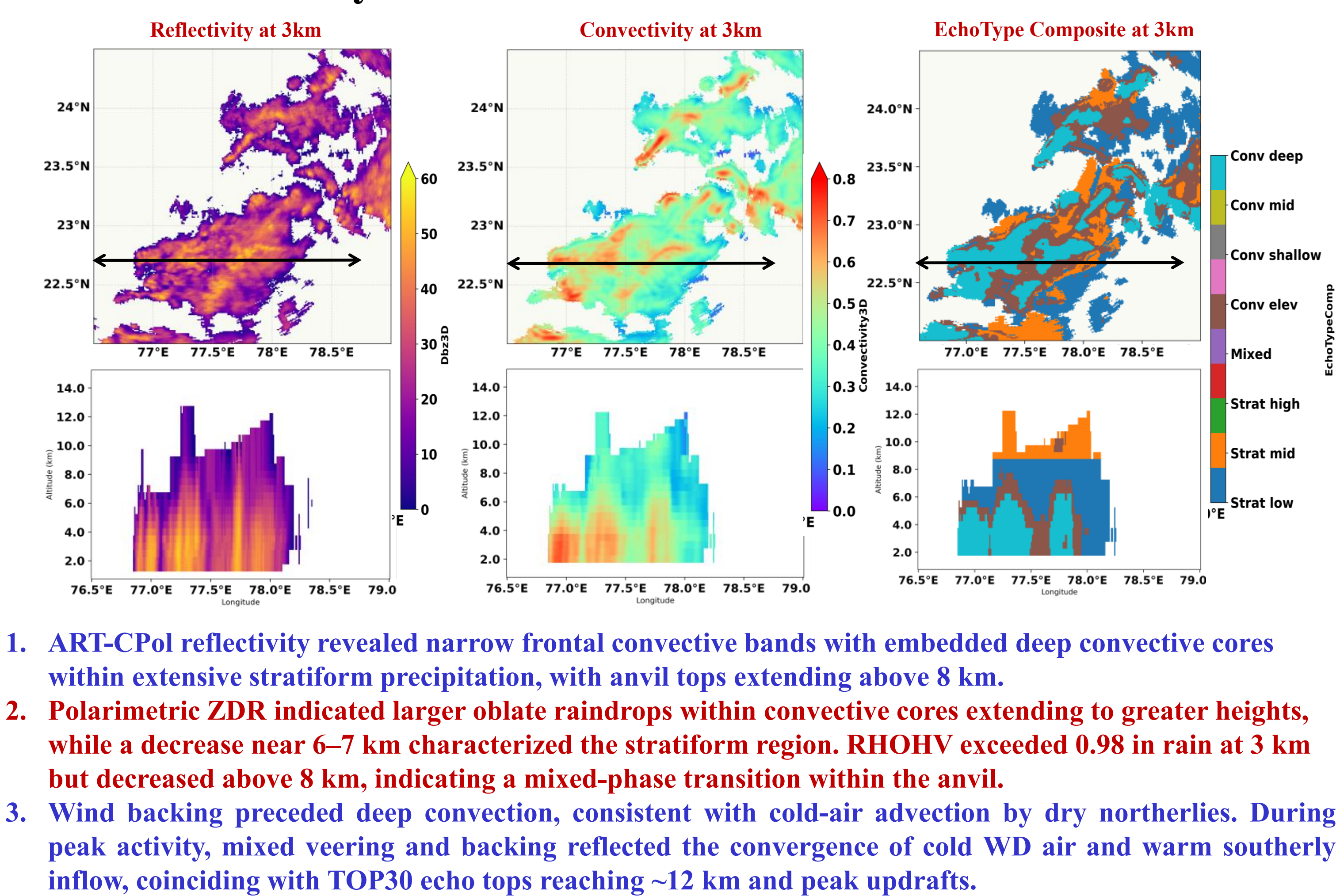
Introduction: WDs are eastward-moving, cold-core systems embedded in the STJ, bringing vital winter rain and snow to northern India. Interacting with tropical moisture, they can trigger extreme rainfall and floods. Their mesoscale structure, including frontal convection and cloud microphysics, remains poorly documented because high-resolution observations are sparse. Radar, combined with reanalysis and satellite data, offers a way forward. WD fronts also reshape boundary layer conditions and inversion strength over the Indo-Gangetic Plains, influencing winter fog and aviation.

Data and Methods: Radar observations come from the ART C-band polarimetric radar (6-minute, 1 km). IMD gridded rainfall (daily, 0.25°) and merged infrared and INSAT-3DR satellite data (half-hourly, 4-8 km) supplement these. ERA5 reanalysis (hourly, 0.25°) and HYSPLIT trajectories give synoptic context. Fog was derived from INSAT-3DR.

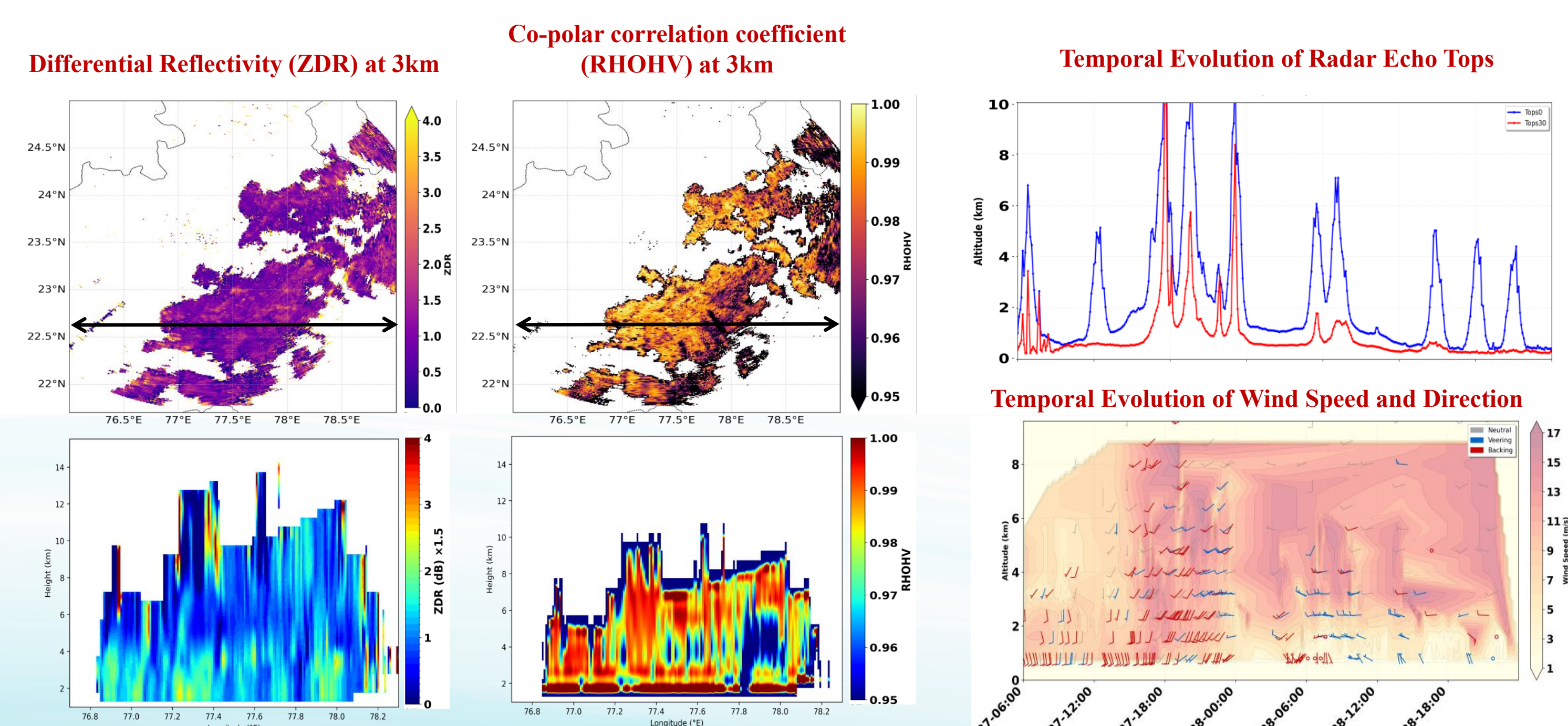
Analysis 1: Extreme Precipitation during 28th Dec 2024 WD



Analysis 2: Radar observations over ART-CI



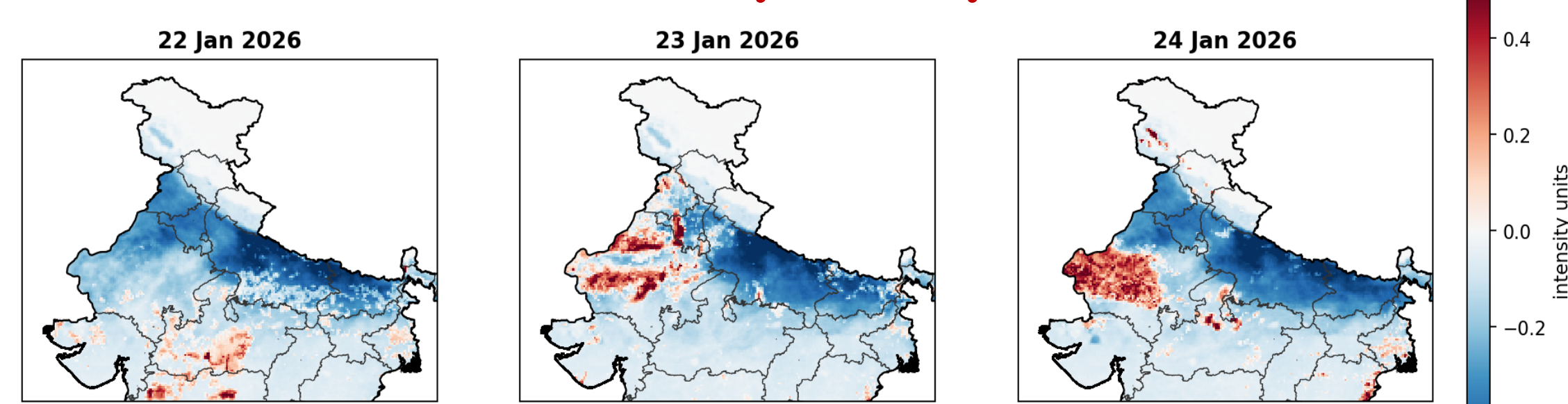
- ART-CPol reflectivity revealed narrow frontal convective bands with embedded deep convective cores within extensive stratiform precipitation, with anvil tops extending above 8 km.
- Polarimetric ZDR indicated larger oblate raindrops within convective cores extending to greater heights, while a decrease near 6–7 km characterized the stratiform region. RHOHV exceeded 0.98 in rain at 3 km but decreased above 8 km, indicating a mixed-phase transition within the anvil.
- Wind backing preceded deep convection, consistent with cold-air advection by dry northerlies. During peak activity, mixed veering and backing reflected the convergence of cold WD air and warm southerly inflow, coinciding with TOP30 echo tops reaching ~12 km and peak updrafts.



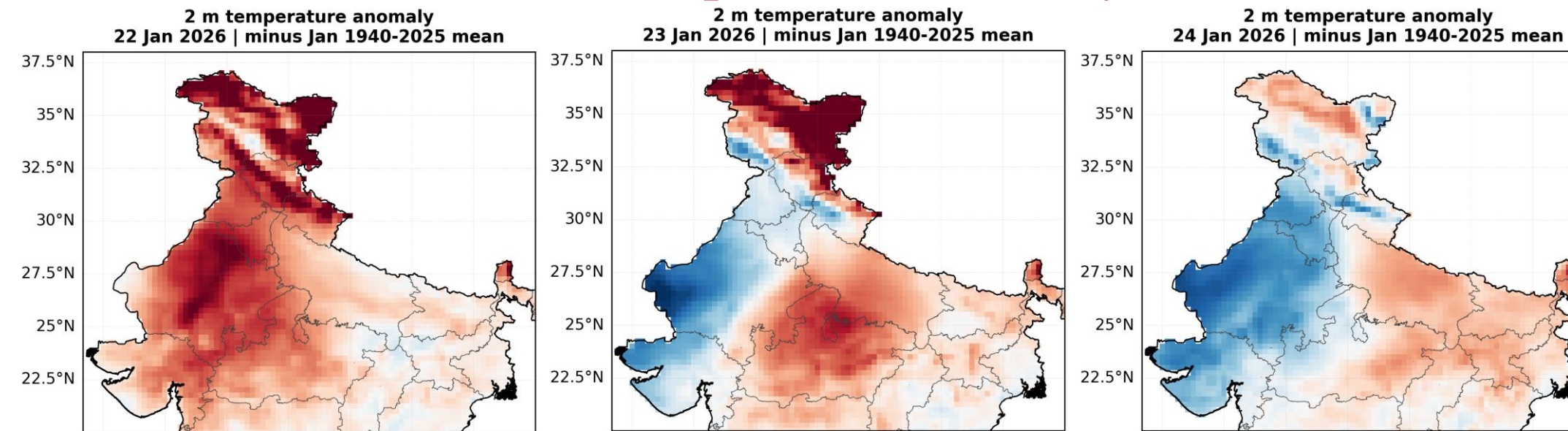
- A cold-core, comma-shaped WD trough at 500 hPa with high RH curving southeast across the Himalayas, IGP and Central India. At 850 hPa, dual frontal vorticity bands formed where warm, moist southerlies met cold north-westerlies, with a pronounced updraft.
- VIMT and HYSPLIT back trajectories show Bay of Bengal as the dominant moisture source, channelled inland by an anticyclone over eastern India. RH Hovmöller shows a lower-tropospheric cold dry-air intrusion followed by rapid mid-to-upper RH rise, a cold-frontal ascent signature.

Analysis 3: Frontal Dynamics over Indp-Gangetic Plains and influence on Winter Fog

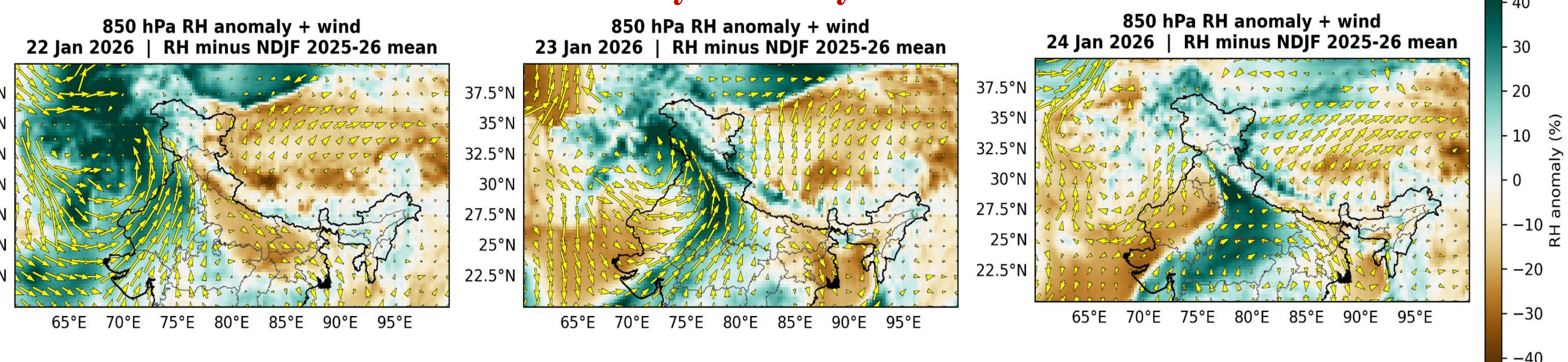
FOG Intensity Anomaly



2m Temperature Anomaly



850 hPa Relative Humidity Anomaly + Winds at 850 hPa



- Western Disturbance warm fronts weakened nocturnal inversions and disrupted stable boundary layers, causing fog dissipation across the IGP.
- Cold-front passage restored stability and inversions, enabling fog re-establishment.

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References: Dixon, M., & Romatschke, U. (2022). Echo Classification from Convectivity (ECCO) algorithm (Software). NCAR/UCAR, <https://doi.org/10.5065/D6MK6B1Q>. Hunt, K. M. R., Baudouin, J.-P., Turner, A. G., Dimri, A. P., et al. (2025). Western disturbances and climate variability: A review of recent developments. Weather and Climate Dynamics, 6(1), 43–112. <https://doi.org/10.5194/wcd-6-43-2025>