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Vertical structure of Western Disturbances in the subtropical jetstream and mechanisms associated with extreme rainfall in South Asia

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Western disturbances (WDs) are upper-level synoptic-scale systems embedded in the subtropical westerly jet stream (STWJ), often associated with extreme rainfall events in north India and Pakistan during boreal winter.
Here, we use an objective feature-tracking algorithm on reanalysis data to develop a 37-year, 3000-event catalogue of systems. Events from this database are then interrogated using system-centred compositing, revealing for the first time the development and structure of dynamical and thermodynamic fields therein. Key results include: (i) a strong northwestward tilt with height, (ii) pronounced ascent ahead of the centre, co-located with the highest precipitation rates, (iii) a warm-over-cold, dry-over-moist structure, and (iv) a strong dependence of cloud structure and vertical wind speed on local orographic features. k-means clustering is then used to separate the database into different WD classifications based on dynamical features and precipitation footprint, from which we show firstly that heavier rainfall is strongly coupled with winds aloft, and secondly that there are several mechanisms responsible for generating precipitation in WDs.
The nature of these Pakistani/north Indian extreme precipitation events (EPEs) is then explored in further detail. It is shown that during the winter, about a third of the total rainfall in this region is delivered by western disturbances, and that winter EPEs are commonly associated with an extensive upper-level Rossby wave train. In contrast, summer EPEs are typically generated by tropical low-pressure systems embedded in the Indian monsoon. A detailed Lagrangian method is then used to explore possible sources of moisture for EPEs, and suggests that in winter, the moisture is mostly drawn from the Arabian Sea, whereas during the summer, it comes from along the African coast and the Indian monsoon trough region.
Finally, we track WDs in CMIP5 climate models. Using the historical runs, we show that that their frequencies are typically over-estimated, and that both frequency and intensity are strongly dependent on model resolution. Using the future climate scenario runs, we show that WD frequency is projected to decrease over the coming century, by as much as 10/year/century in the RCP8.5 scenario. These changes are explained in the context of trends in upper-tropospheric fields, where we show in particular the importance of meridional temperature gradient.