Department of Meteorology

On the Structure and Variability of Indian Monsoon Depressions

Kieran Hunt | Andrew Turner | Pete Inness | David Parker | Richard Levine

Introduction

The Indian monsoon trough region usually experiences 3-6 synoptic scale depressions passing through it during an average summer. These disturbances are typically identified by their moderate winds (8.5-16.5 m s^{-1}) and characterised by widespread, heavy rainfall and associated flooding. They typically form over the Bay of Bengal and proceed northwestward, terminating over northwest India or Pakistan after a mean duration of 4.5 days.

Objective Feature Tracking

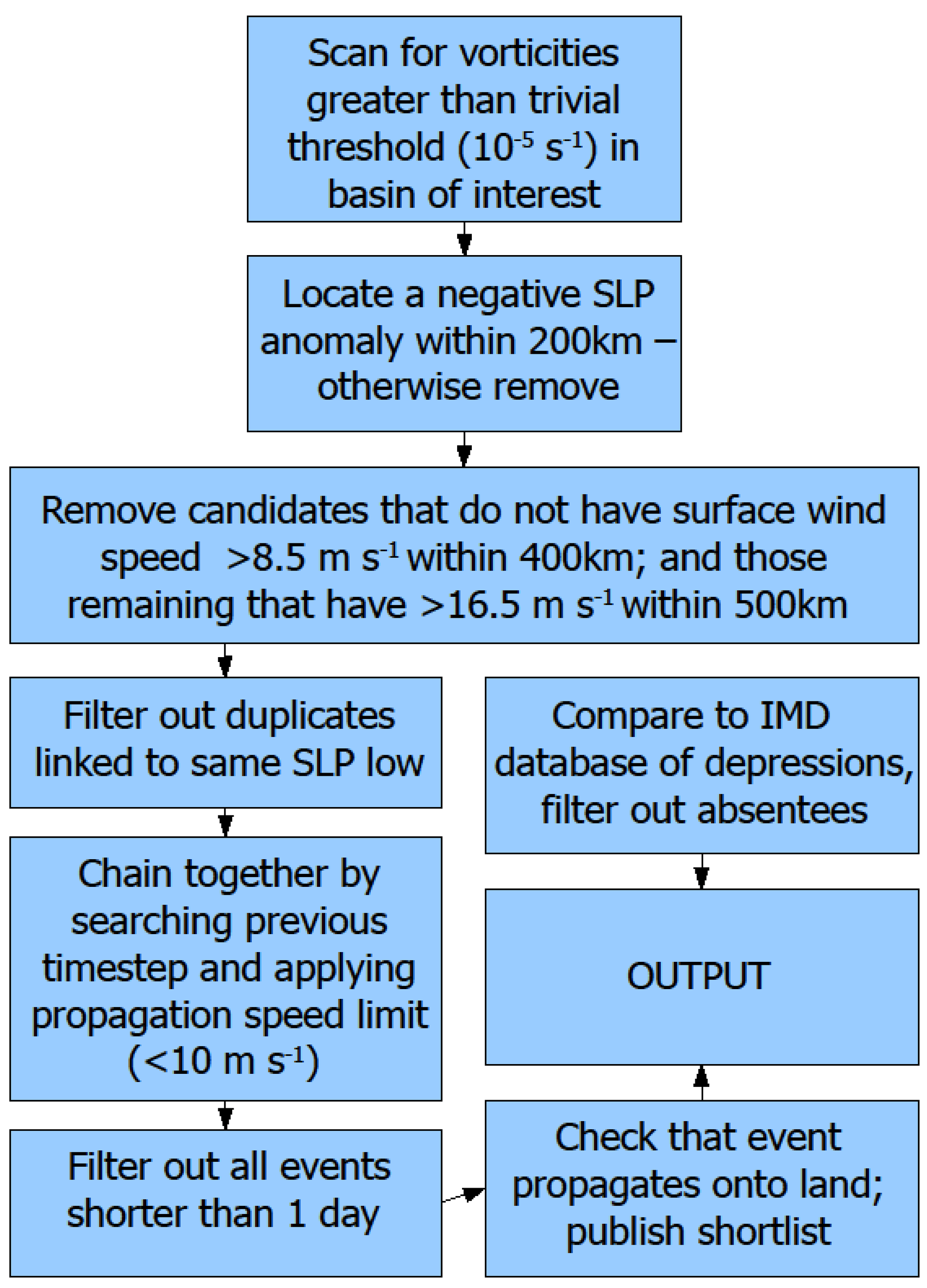

Fig. 1 A flowchart outlining the steps used in the objective feature-based tracking algorithm. The IMD database referred to here is published online by the India Meteorological Department at http://www.rmcchennaieatlas.tn.nic.in/ .

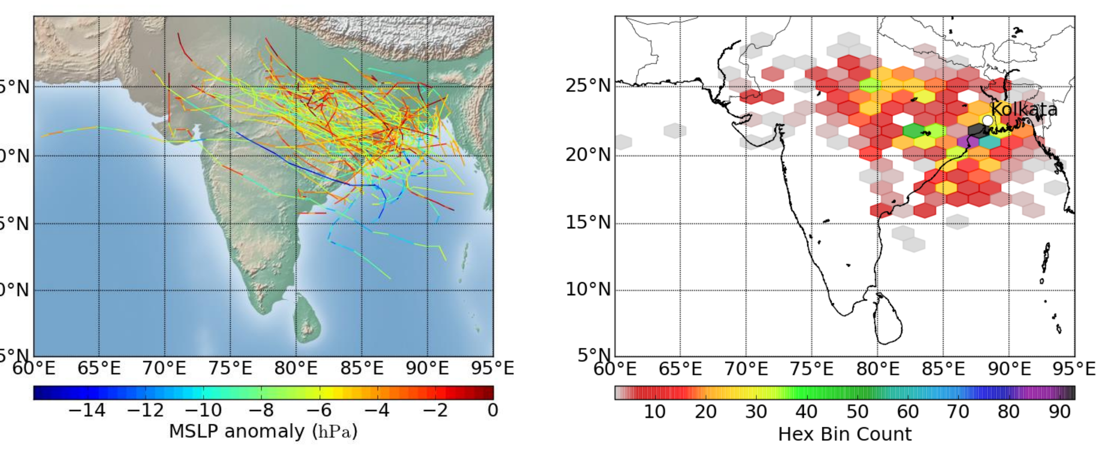

Fig. 2 Results of applying the tracking algorithm to reanalysis data over the period 1979-2013, where 104 depressions were identified. Left, all tracks are presented, coloured by surface pressure anomaly to a 21 day running mean; right, tracks are binned to show the spatial frequency distribution.

A novel objective feature-based tracking algorithm was developed to identify monsoon depressions using ERA-Interim reanalysis data. A synopsis of the algorithm is presented in Fig. 1 and expounded in *Hunt et al. (2015)*. Using this method, a total of 104 depressions were identified over the period 1979-2013, an overview of which is given in Fig. 2. These tracks were also compared to those presented in *Hurley and Boos (2015)* with which they were found to have a strong similarity.

References

- Hurley and Boos (2015). *QJRMS.* **141**(689) pp1049-1064
- Hunt et al. (2015). *Mon. Wea. Rev.* Submitted.
- Hunt and Parker (2015). *QJRMS.* Submitted.

Contact information

- Department of Meteorology, University of Reading, Whiteknights, RG6 6BB
- Email: k.hunt@pgr.reading.ac.uk

Composite Structure

The composite datasets are constructed by centralising each variable such that the depression centre lies at the origin of a lat/lon grid; these are then rotated such that the heading is 0 – making the direction of propagation of the composite due north. Using the tools outlined, we are now capable of probing the structure of monsoon depressions at an unprecedented level of detail. A composite three-dimensional view of some reanalysis fields from ERA-Interim is presented in Fig. 3, and a selection of vertical cross-sections are shown in Fig. 4.

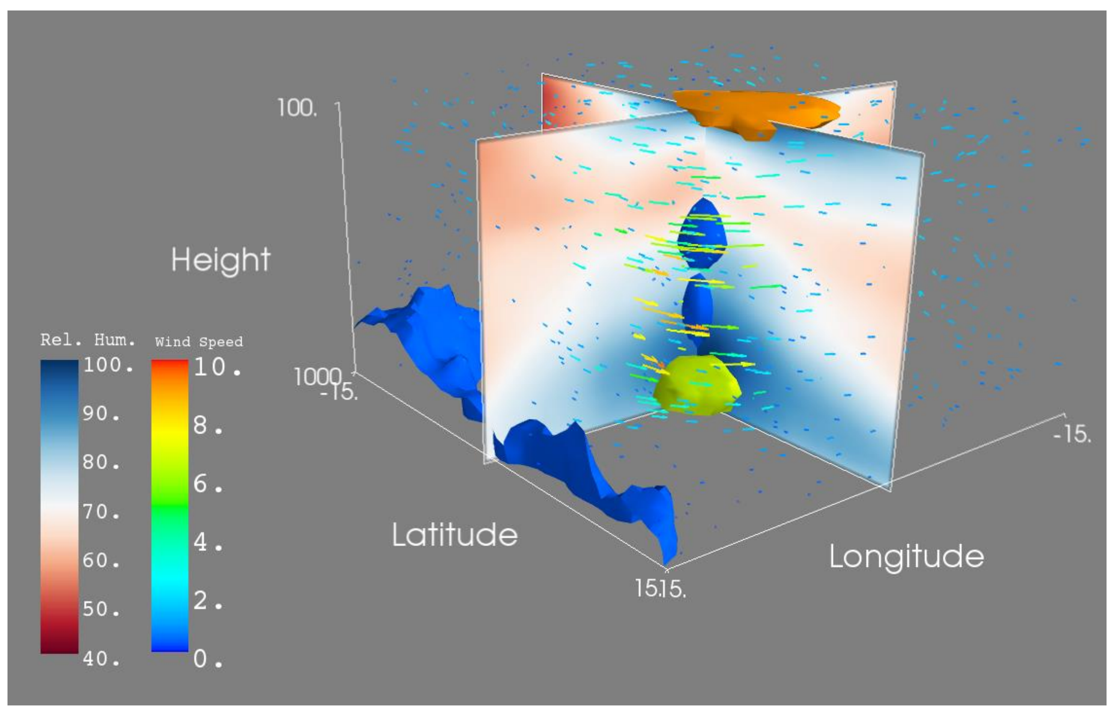

Fig. 3 Composite depression structure for some data fields. Wind (m s^{-1}) is represented by quivers; the $\pm 5 \times 10^{-6}$ s^{-1} divergence isosurfaces are coloured orange and yellow respectively; the 1 PVU (10^{-6} K m^{-2} kg^{-1} s^{-1}, not shown above 150hPa) isosurface is coloured blue; and the intersecting image planes show the structure of relative humidity (%).

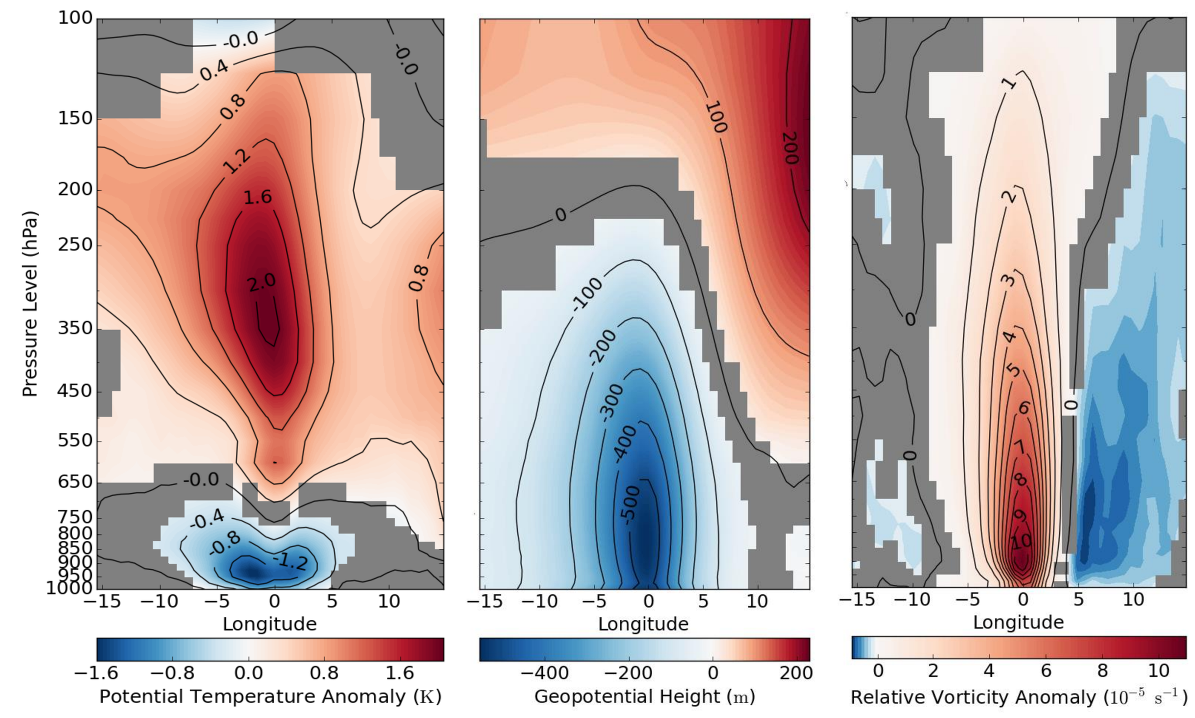

Fig. 4 Composite depression vertical cross sections for some data fields, shown as anomalies to the climatological boreal summer mean. Left: potential temperature (K); centre: geopotential height (m); right: relative vorticity (10^{-5} s^{-1}). Colours are greyed out where the composite does not differ from the climatology at the 95% confidence level.

Important composite structural features to note (some shown in Figs. 3 and 4) include:

- a bimodal potential vorticity core of magnitude ~1PVU;
- an asymmetry caused by the Himalayas a westward axial tilt;
- a narrow vortical core with annular winds reaching 10 m s^{-1};
- a cold anomaly (-1.5K) near the surface caused by cloud cover, but a warm anomaly aloft (+1.8K) caused by latent heating;
- thick low-level stratiform cloud with a resolved anvil;
- convergence, cloud cover, and precipitation maxima are all located several hundred kilometres southwest of the centre;
- a deep region of negative vorticity near the Himalayas due to friction and vortex squashing, this is key to the propagation mechanism outlined by *Hunt and Parker (2015)*;
- depressions can be clearly split into two types (neutral- and cold-core) by the nature of their lower tropospheric temperature anomaly.

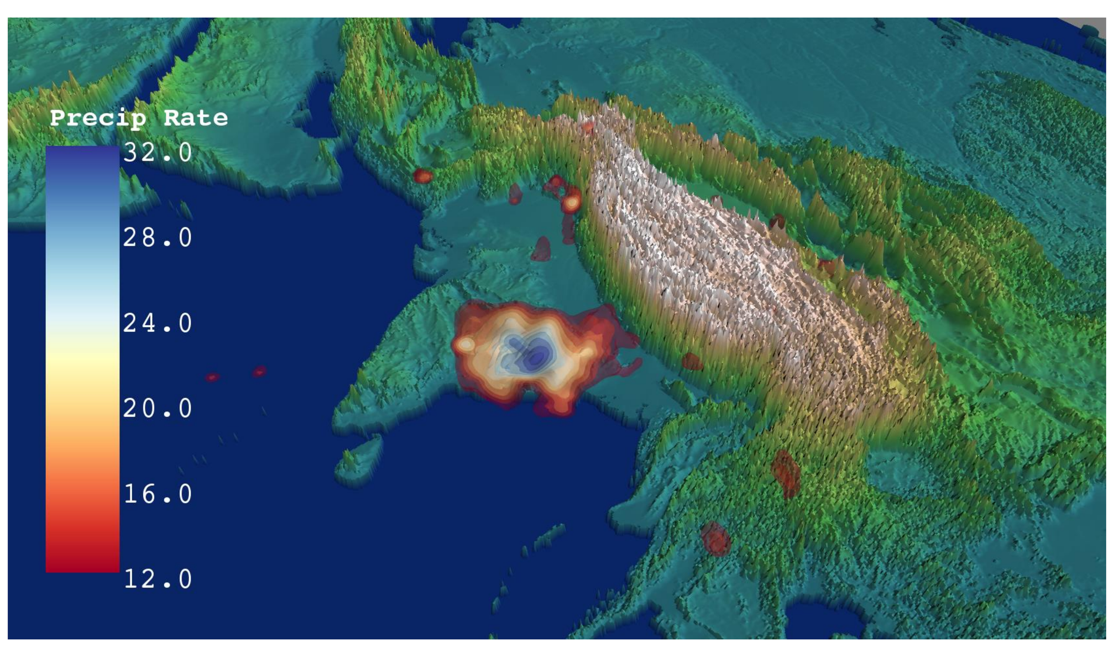

Fig. 5 Composite (unrotated) 3D precipitation rate (mm/day) for 34 depressions, derived from 1635 overpasses of TRMM PR data. Here, the composite depression is centred at 84°E 22°N. The data were smoothed with a 0.5° Gaussian kernel and thresholded at 12 mm/day.

Interannual, Intraseasonal and Diurnal Variability

We can further analyse depressions by assessing their variability and response to both large- and small-scale forcing. A simple way to do this is to select and compare contrasting subsets, as we have done in Figs. 6 and 7.

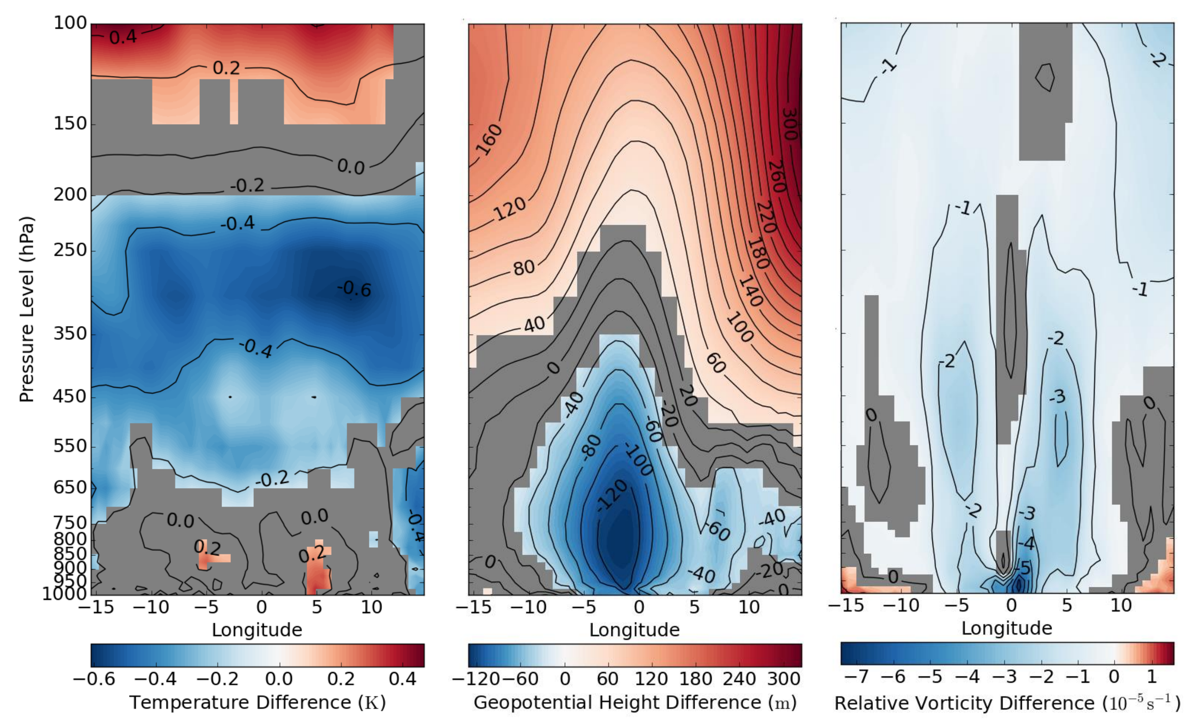

Fig. 6 Vertical structure of some composite subset differences. Left: temperature (K) for El Niño-minus-La Niña; centre: geopotential height (m) for active phase-minus-normal phase; right: relative vorticity (10^{-5} s) for land-minus-sea. Colours are greyed out where the difference is not significantly different from zero at the 95% confidence level.

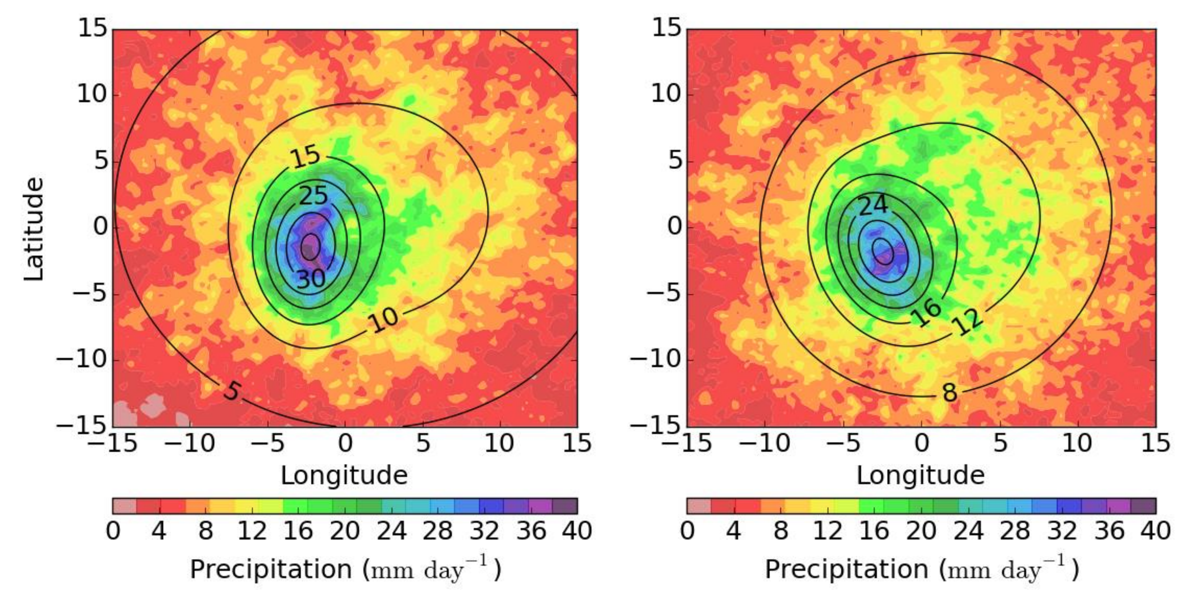

Fig. 7 Surface rainfall (mm/day, colours) composite subsets for night (left) and day (right); overlaid (lines) on each is the best fit pair of Gaussians. Data from TRMM 3B42v7.

Some key contrasts we can draw out (some shown in Figs. 6 and 7) from this are:

- El Niño depressions are cooler, drier, and generally less intense than those in La Niña years, with correspondingly lower rainfall;
- depressions occurring during the active phase of the monsoon (when compared to those that don't) are significantly more intense: they have stronger winds, lower pressure, steeper temperature gradient, more moisture, and more intense rainfall;
- during the day, depressions bring more widespread but less intense rainfall than at night – they also are warmer and drier throughout with reduced cloud cover;
- depressions on land (as opposed to those over ocean) are more constrained to the central axis, and more asymmetrical - they are also warmer and less intense near the surface with less rain;
- the phase of the Indian Ocean Dipole makes little, if any, significant difference, there is some evidence that a positive phase weakens the depressions and reduces the rainfall;
- neutral-core depressions are warmer throughout than those that are cold-core, they also have significantly heavier rainfall, wider extent (but thinner cloud and less moisture in the core), and faster vertical ascent in the core.

Key Points

- Novel tracking method used to catalogue Indian Monsoon depressions
- Reanalysis and satellite data used to develop the first truly thorough composite of these depressions
- The diagnostics of structure and variability presented create a firm basis for assessing depression representation and behaviour in NWP and high-resolution climate models