Structure and dynamics of a case-study monsoon depression in high-resolution numerical simulations using the Met Office Unified Model

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Introduction

Indian monsoon depressions are synoptic-scale cyclonic vortices which usually form over the Bay of Bengal and propagate north-westwards over the Indian subcontinent.

In this study, high-resolution model simulations are used to understand the structure and dynamics of a case study monsoon depression (1-10 July 2016) and its interaction with mid-tropospheric dry air intrusions.

Model description and observational data

Model details:

- Nested suite limited-area model (LAM) simulations using the Met Office Unified Model were performed for the period 1-10 July 2016 at 1.5 km, 4.4 km and 17 km horizontal resolutions for the Indian region.
- The 4.4 km LAM has a vertical resolution of 80 levels with a 38.5 km lid and the 17 km has a vertical resolution of 70 levels with an 80 km lid.
- The LAM is nested within the global model at N768 resolution. The lateral boundary conditions for the LAMs are provided by the global model every 24 hours.
- 1.5 and 4.4 km models have explicit convection and 17 km has parameterised convection.

Reanalysis and observational data:

- Relative vorticity, equivalent potential temperature, rainfall and winds from the ERA5 Reanalysis dataset (C3S, 2017)

Depression Track

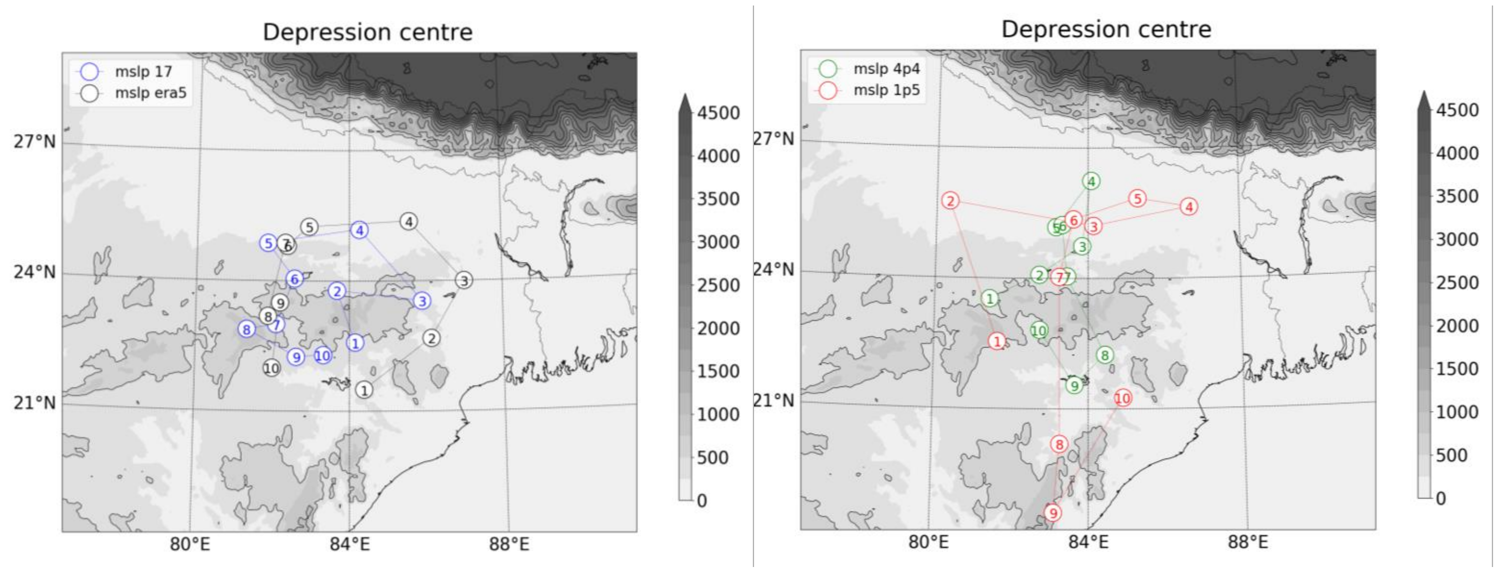

Figure 1. Track of the depression from ERA5 and the three simulations with different spatial resolutions. The depression centre is detected as the point of MSLP minima (masking points where surface pressure < 925 hPa) in a rectangular region around the vorticity maximum. Shadings represent orography in m.

- The 17 km model simulates the track closer to the ERA5 depression track (Fig. 1)
- The higher resolution simulations show slightly different tracks as the tracking algorithm captures the added details of intense convection and the associated MSLP minima.

Cross sections along the storm paths

- Now we compare the vertical structure of some dynamic and thermodynamic parameters along a north-south cross-section that passes through the depression rain bands to see how well the models simulate the storms compared to the ERA5 re-analysis.

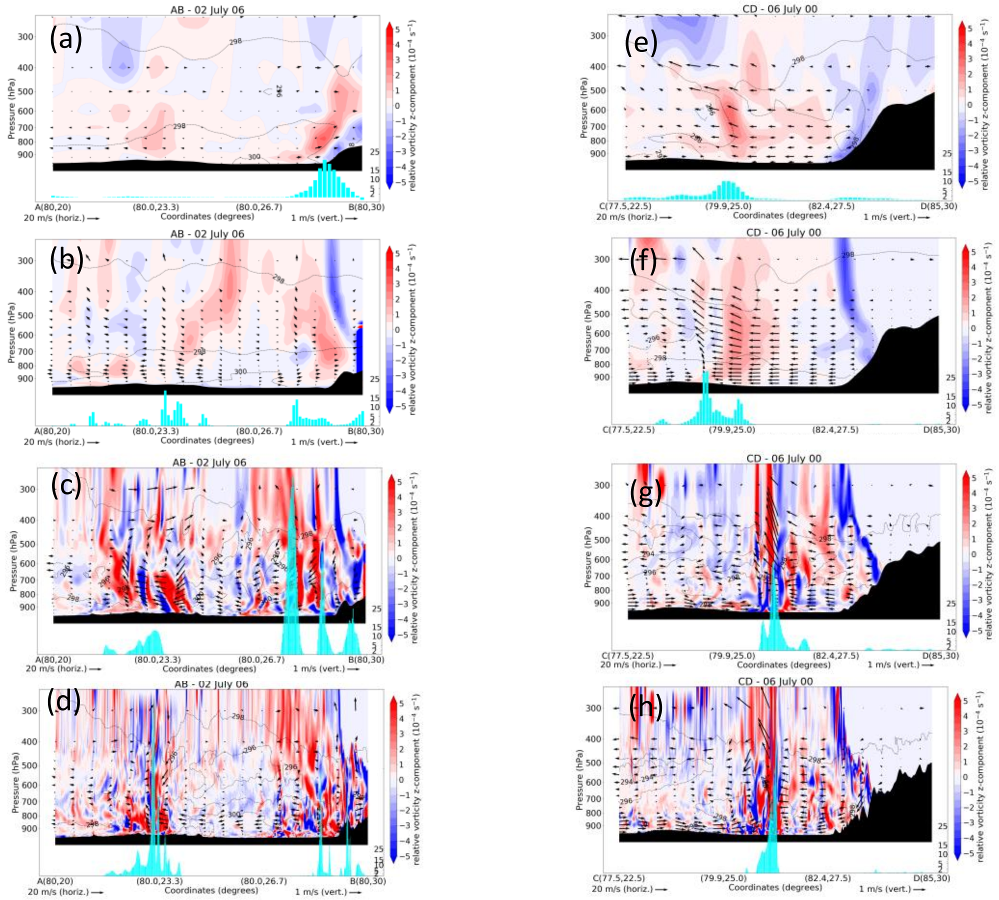

Figure 2. Relative vorticity (shaded), equivalent potential temperature (contours), wind vectors and rainfall (blue bars) along cross sections that passes through the depression (marked on Fig. 3) from (a,e) ERA5, (b,f) 17 km, (c,g) 4.4 km and (d,h) 1.5 km models. Black shadings represent orography.

- Cross-sections across the depression during a day with intense MCS (Fig. 2, first column) and well-defined depression (Fig.2, second column) show that the location of rainfall, higher relative vorticity, etc. in the simulations are similar to that from ERA5 on both days.
- Hence, the results from the 1.5 km model will be shown in the rest of the analysis as the highest resolution model captures the structure of the depression in more details.

Two phases of the depression

- The spatial pattern of rainfall during the depression period identifies two phases of the depression (Fig 3):
  - ➢ An early phase with intense mesoscale convective systems.
  - ➢ A later phase with a well-defined depression structure and rainfall convergence line.

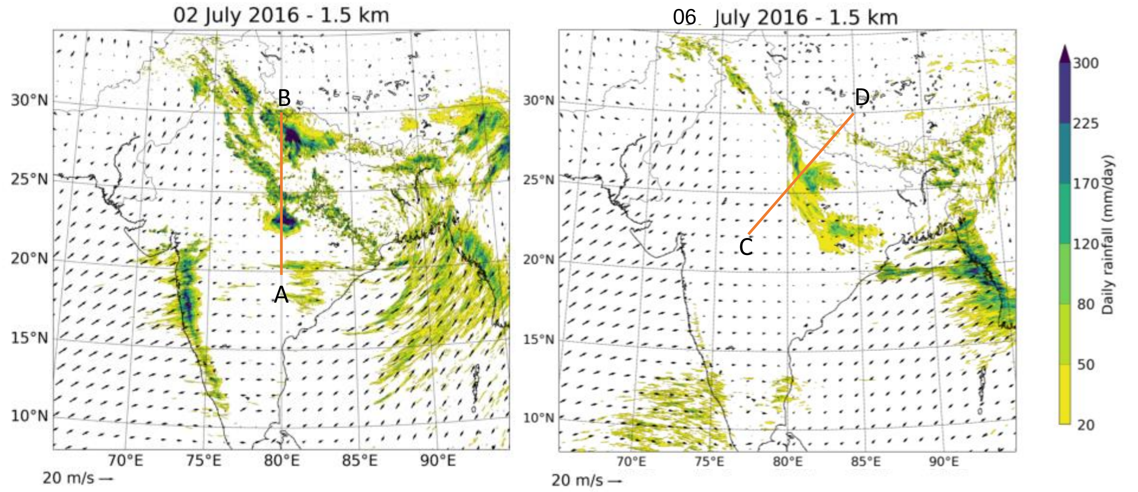

Figure 3. Daily mean rainfall (mm/day) and 10 m wind vectors (m/s) for 2 and 6 July 2016 from LAM with 1.5 km resolution. The orange lines on each panel represent the cross-sections AB and CD on Fig. 2 for 2 and 6 July.

Interaction of monsoon depression and dry-air intrusion

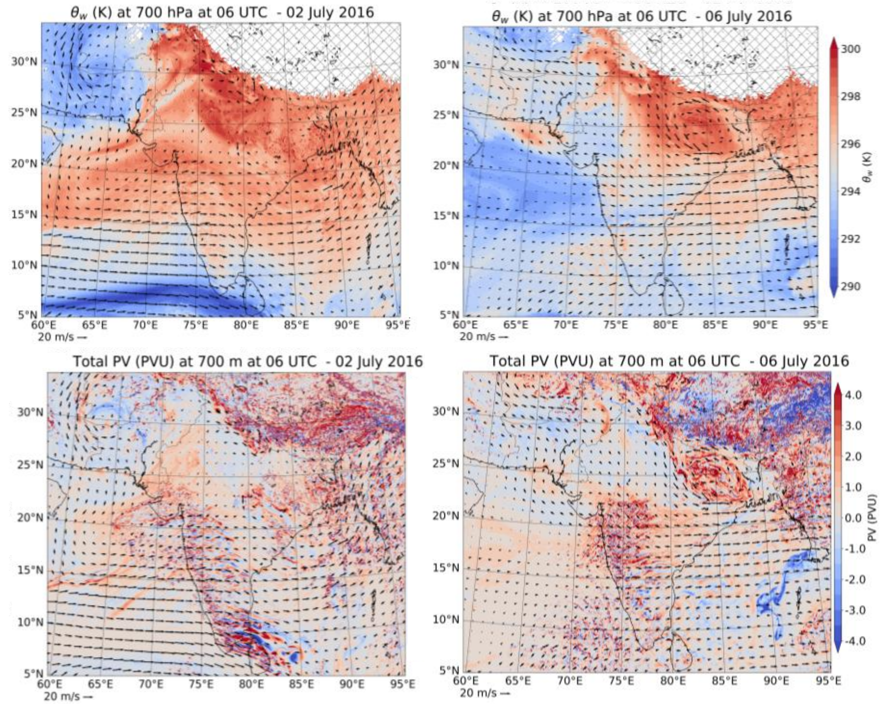

Figure 4. (Top row) Wet bulb potential temperature (^{o}C) and (bottom row) Total PV (PVU) at 700 hPa and wind vectors for 2 and 6 July 2016 from LAM with 1.5 km spatial resolution.

- Dry air intrusion at 700 hPa represented by the lower values of θ_e is prominent on 6 July.
- Dry- air intrusions carry lower PV air into the depression (Fletcher et al., 2019).
- Convergence and convection occur at the western boundary of the depression where it interacts with the dry-air intrusion.

Evolution of thermodynamic parameters in a system-following framework

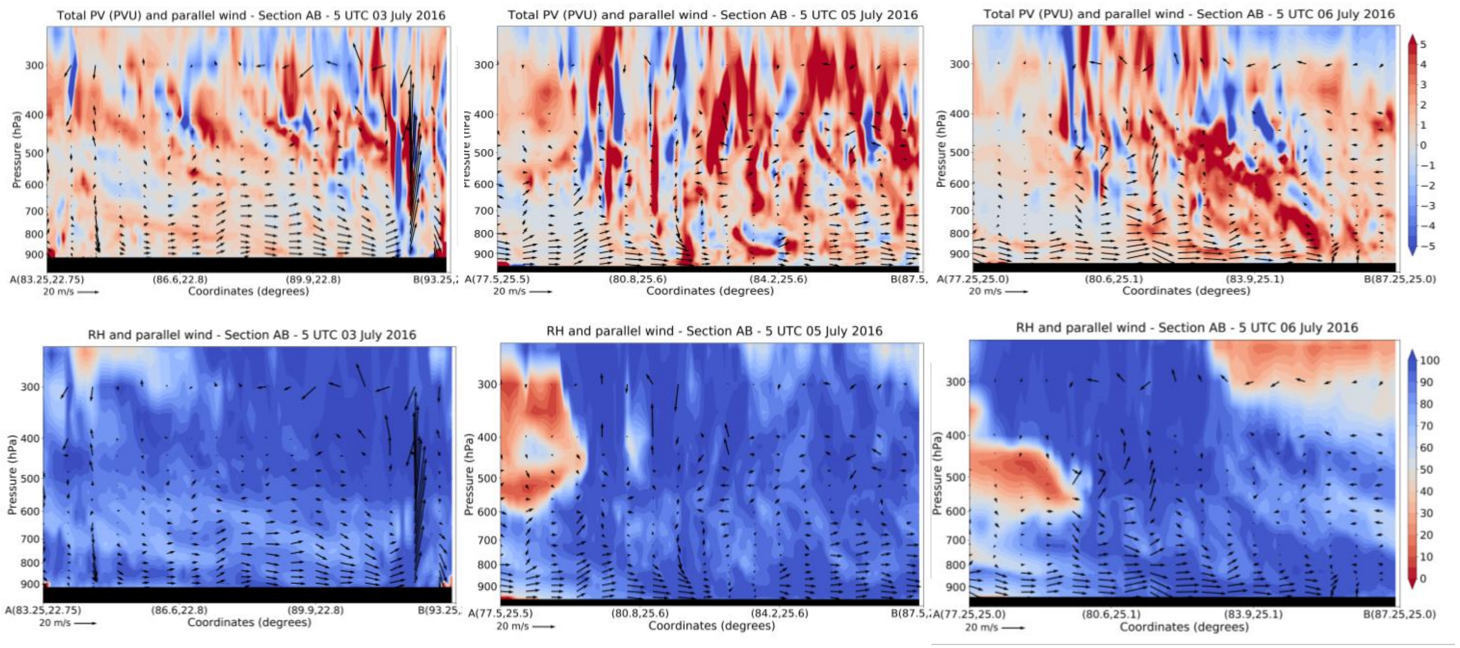

Figure 5. Zonal cross-sections across the center of the depression of (top row) total PV (PVU) and (bottom row) relative humidity and wind vectors for 3rd , 5th and 6th July 2016 from the LAM with 1.5 km spatial resolution.

- Zonal cross-sections are made on a system-following framework where the central longitude of the cross section on each day corresponds to the center of the depression on that day.
- On 3rd July 2016, we can see some wave patterns at higher levels and high relative humidity in the entire troposphere.
- On 5th July, when the depression is well-defined, we can see the vorticity structures extending throughout the troposphere, with relatively more positive PV towards the east of the depression and negative PV values towards the west.
- On 6th July, we can see strong westerlies at lower levels carrying the dry air with negative PV from the mid troposphere into the lower levels of the depression, disrupting the vertical structure of the PV at lower levels of the depression.

Conclusions

- Even though the tracking algorithm captures the depression track in the 17 km simulation closer to ERA5, the storm locations are similar at different model resolutions.
- The convection permitting simulations captures the detailed structure of the depression and convective plumes.
- Two different patterns of rainfall during the evolution of the depression: MCSs leading to widespread rainfall in the beginning followed by a well-defined convergence line with most of the inland precipitation on the southwestern quadrant of the MD.
- The second phase is associated with the intrusion of dry air into the depression from the western side of the depression that carries low PV air into the depression .

References

- C3S (2017) ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), *date of access*. https://cds.climate.copernicus.eu/cdsapp#!/home
- Fletcher, J. K., Parker, D. J., Hunt, K. M., Vishwanathan, G., & Govindankutty, M. (2018). The interaction of Indian monsoon depressions with northwesterly midlevel dry intrusions. Monthly Weather Review, 146(3), 679-693.