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

Arathy Menon[1], Ambrogio Volonté[2], Andrew Turner[2], Kieran Hunt[2]
[1]UK Met Office, [2]NCAS, University of Reading
arathy.menon@metoffice.gov.uk

Introduction

Indian monsoon depressions (MD) are synoptic-scale cyclonic vortices which usually form over the Bay of Bengal and propagate north westwards over the Indian subcontinent. They bring large portion of widespread and heavy rains to central and northern India.

Despite their importance, key questions on the mechanisms driving the generation and development of MD are still open. Here we inspect the structure and dynamics of a MD case study (1-10 July 2016) using a high-resolution simulation (1.5 km horizontal resolution) performed for the INCOMPASS project.

Objectives

In this study, we try to understand the detailed evolution of a depression and its interactions with surrounding air masses by using a high-resolution model simulation of an MD case study of July 2016. We use our model data to understand some of the drivers of this MD evolution. We analyze in detail the effect of mesoscale convective systems (MCSs) in the intensification of MD and the interactions between dry air intrusions at different levels and the MD.

Data & Methodology

Model data: Nested suite limited-area model (LAM) simulation using the Met Office Unified Model was performed for the period 1-10 July 2016 at 1.5 km horizontal resolution for the Indian region. The LAM is convection permitting and has a vertical resolution of 80 levels with a 38.5 km lid. The LAM is nested within the global model at N768 resolution. The lateral boundary conditions for the LAM is provided by the global model every 24 hours and the sea surface temperature is updated daily using the Operational Sea Surface Temperature and Sea Ice analysis. The LAM is allowed to run freely within the driving global model.

Lagrangian trajectory analysis: Lagrangian trajectories are computed using a software adapted from the LAGRANTO Lagrangian analysis tool (Sprenger and Wernli, 2015). LAGRANTO uses an iterative Euler scheme with an iteration step equal to 1/12 of the time spacing of the input data, i.e. 5 minutes for the hourly data used in this work. Backward and forward trajectories are computed using the instantaneous three-dimensional wind field to calculate the positions of the selected air parcels and local values of the relevant physical quantities are traced onto those trajectories.

Results & Discussion

Synoptic conditions during the MD

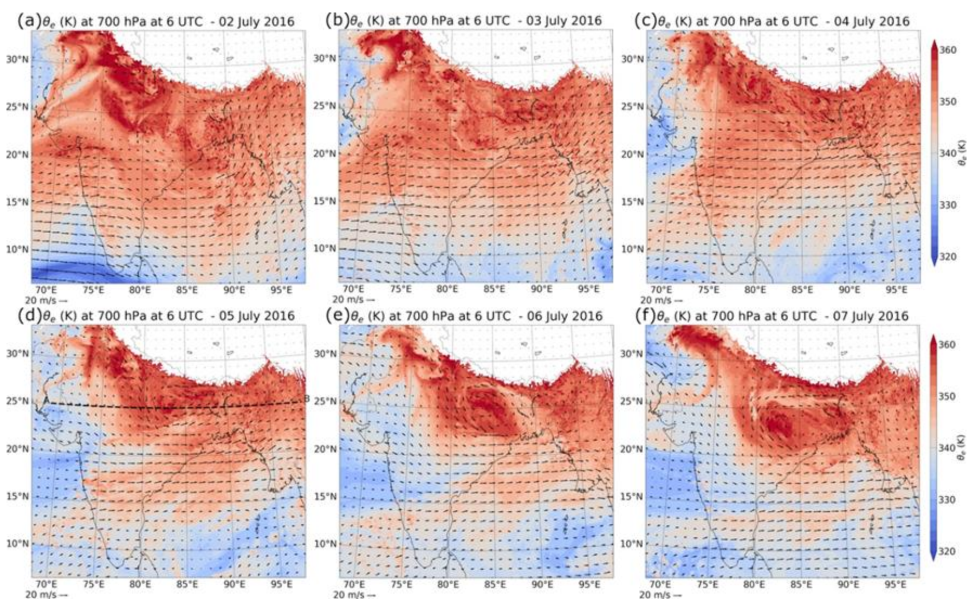

Fig 1. 700 hPa equivalent potential temperature (theta-e) and 10-m winds (m s-1) at 6 UTC during the evolution of MD

Low values of theta-e represent dry-air intrusion. Dry-intrusion is approaching the MD from 5th July onwards.

Dynamical processes influencing MD evolution

1. Interaction of mesoscale convective systems (MCS) with MD

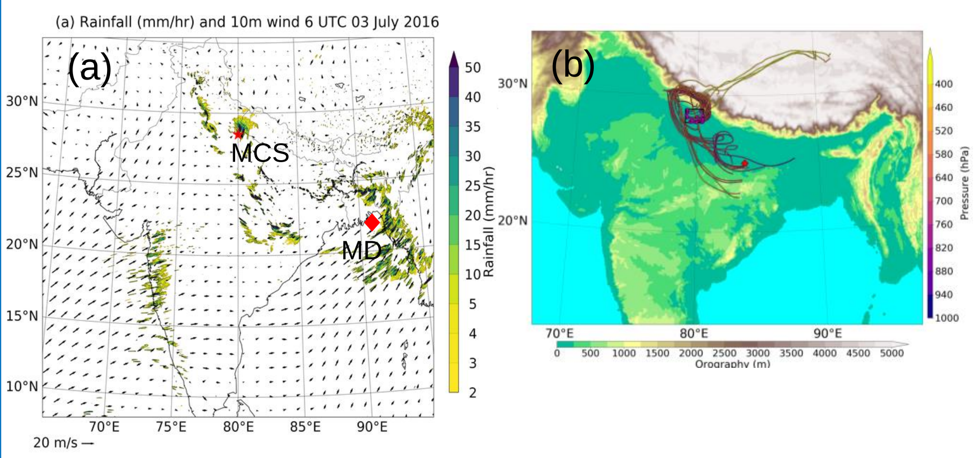

Fig 2. (a) Rainfall (mm h^{-1}) and 10m winds (b) 48-hour forward trajectory starting on 3 July at 6UTC (starting domain is the location of MCS in a)

During the initial stages of evolution of MD, mesoscale convective systems (MCS) are present towards the west of the MD. High theta-e low-level air from the MCS is feeding into the depression

2. Interaction of dry-air intrusions with MD

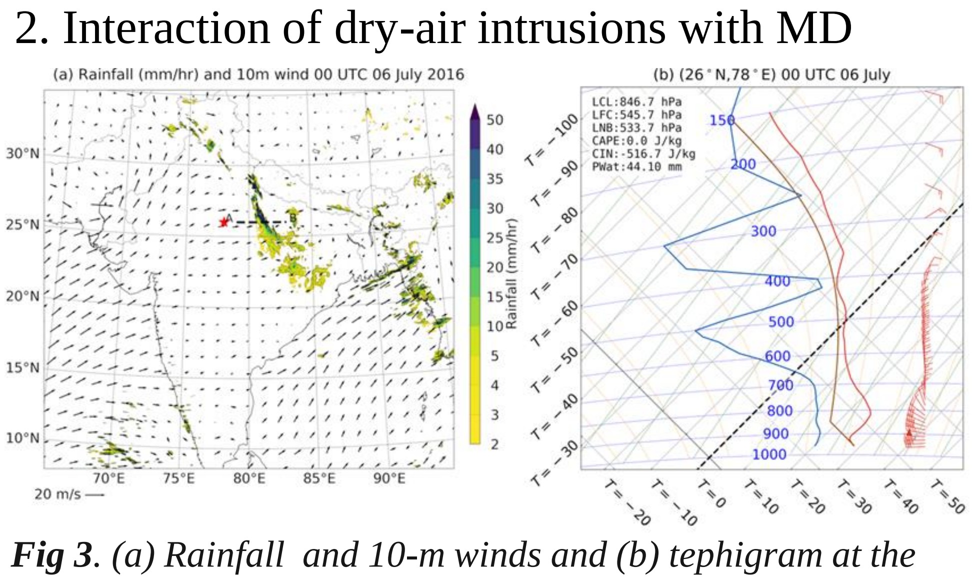

Fig 3. (a) Rainfall and 10-m winds and (b) tephigram at the location to the west of the rainfall convergence line (red start in a) at 00UTC on 6 July 2016. Line AB represents the cross section shown in Fig. 4.

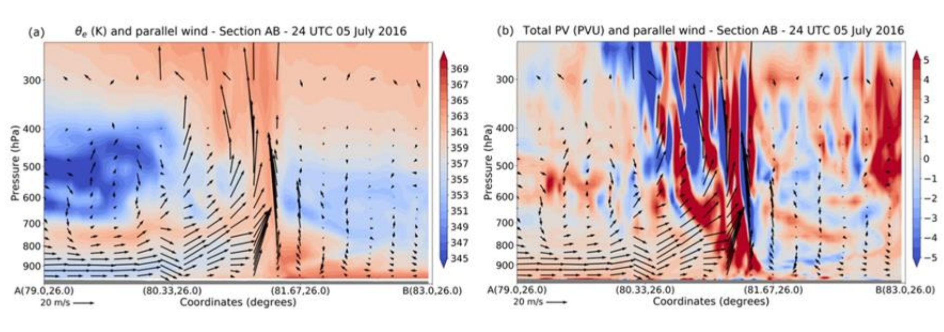

Fig 4. Vertical structure of (a) theta-e (K) and (b) total PV (PVU) along the cross section AB shown in Fig. 3a on 6 July 2016 at 00 UTC.

Dry-air intrusions are approaching the MD from lower and mid troposphere by around 6th July. Vertical cross section of theta-e on 6 July shows the presence of dry intrusions at 900 and 500 hPa approaching the depression from the west.

This dry intrusion is disrupting the vertical PV structure of the MD.
Lagrangian trajectory analysis is done to find where these dry intrusions are coming from.

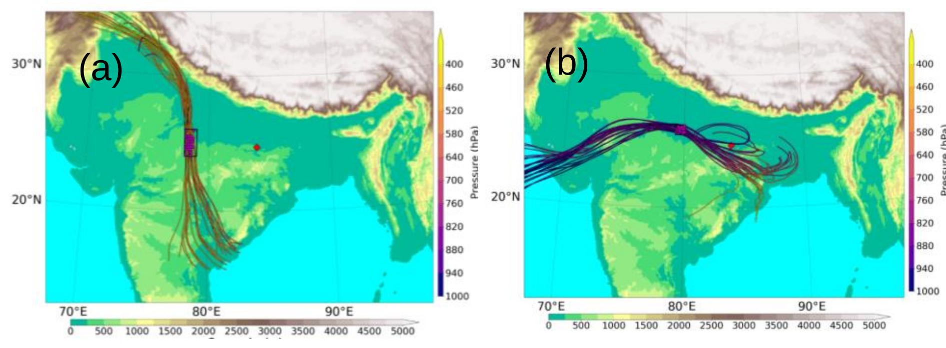

Fig 5. Trajectories starting at (a) 500hPa and (b) 900 hPa at 00UTC on 6July, 30 hours backward and forward. Shown are 25 trajectories with the lowest θ_e at their starting time.

Trajectory analysis show that dry-intrusions at 500 hPa trace back to northwesterly dry-intrusions from the Afghanistan region. At 900 hPa, trajectories are approaching from the west-southwest direction, all the way from over the northern Arabian Sea. This is a coherent air stream that remains at the lower levels through out its path from over the Arabian Sea, until they start interacting with the MD.

Summary/Conclusion

- The convection permitting simulation captures the detailed structure and evolution of the depression and convective plumes
- During the development phase of MD, MCS form along the MD-induced convergence lines. From the Lagrangian trajectory analysis, we found that the high-theta-e air from the MCS is approaching the depression during its development phase. This heating from moist convection could enable the growth of the depression, assisting it to reach its maximum intensity phase
- The second phase is associated with the intrusion of dry air into the depression from the west which carries low PV air into the depression which distrupts the high-PV structure at the centre of the MD

Acknowledgements & References

This work was funded by the INCOMPASS project (NERC grant numbers NE/L01386X/1, NE/P003117/1, NE/L013819/1), a joint initiative between the UK Natural Environment Research Council and the Indian Ministry of Earth Sciences.

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

M. Sprenger, H. Wernli.(2015) The LAGRANTO Lagrangian analysis tool version 2.0. *Geoscientific Model Development* **8**, 2569–2586 Copernicus GmbH,

IWM-7 (22-26 March 2022)
IMD, MoES, NEW DELHI, INDIA