# System driven changes in aerosol-cloud interactions and its impact on the life-cycle of a Monsoon Depression – Inferences from Airborne Observations

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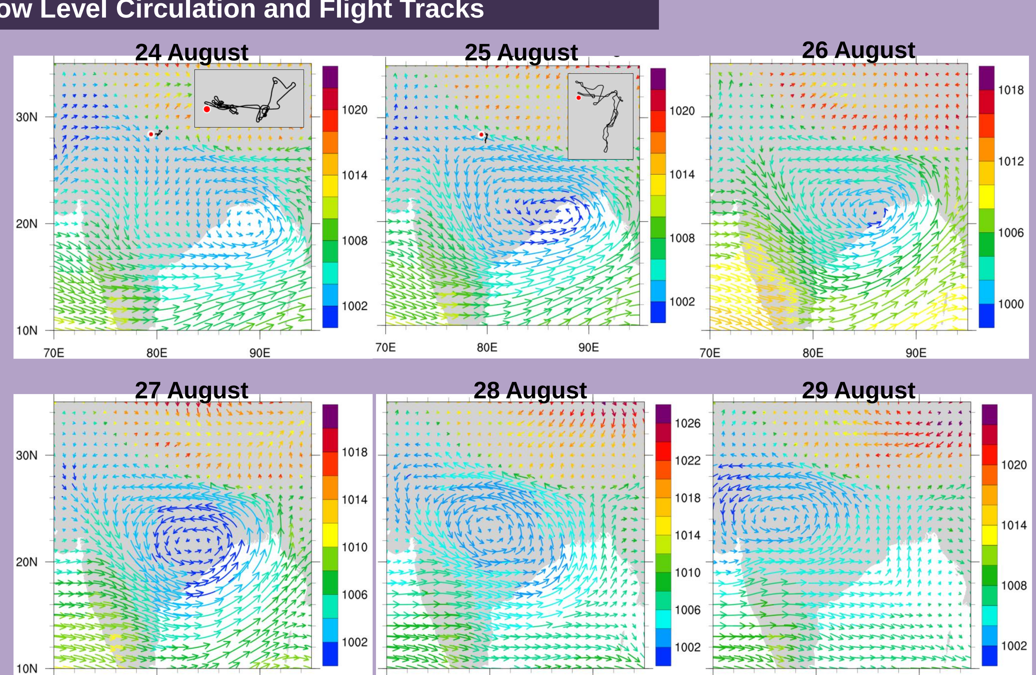
## Abstract

This study examines the aerosol effect on the life cycle of a monsoon depression ('MD' hereafter), particularly whether it could suppress the system as suggested by previous modeling studies. Airborne aerosol and cloud microphysical observations collected during an MD (24 and 25, August 2009) are analyzed and the interactions between aerosols, cloud microphysics and MD dynamics are discussed. The growth of warm rain processes during the MD life-cycle was also investigated. An absence of rainfall due to the SW-NE orientation of rain belt exposed the northwest region of India to dry conditions and the transport of dust and anthropogenic aerosols through westerlies and north-westerlies heavily increased the aerosol concentration ($N_{AERO}$) over the region which was favorable to suppress the convection. The results show an increase in regional convergence of zonal wind associated with high $N_{AERO}$ that led to an early transport of moisture to this region. The high $N_{AERO}$ under strong wind shear and dry to humid transition significantly affected the convective activity over the land during the initial phase of the MD. Over Central India, the combination of humid air and aerosols lead to the suppression and later redistribution of rainfall associated with the MD. However, these effects did not sustain for long as the continuous moisture transport part of the mesoscale convective system revitalized the system which is evident from surface latent heat flux. The strong low-level moisture transport supported by large-scale convergence from the Arabian Sea also weakened the aerosol effect helping in the good rainfall. The study also highlights that giant Cloud Condensation Nuclei (CCN) could play a positive role while the smaller CCN contributes to the suppression of rainfall.

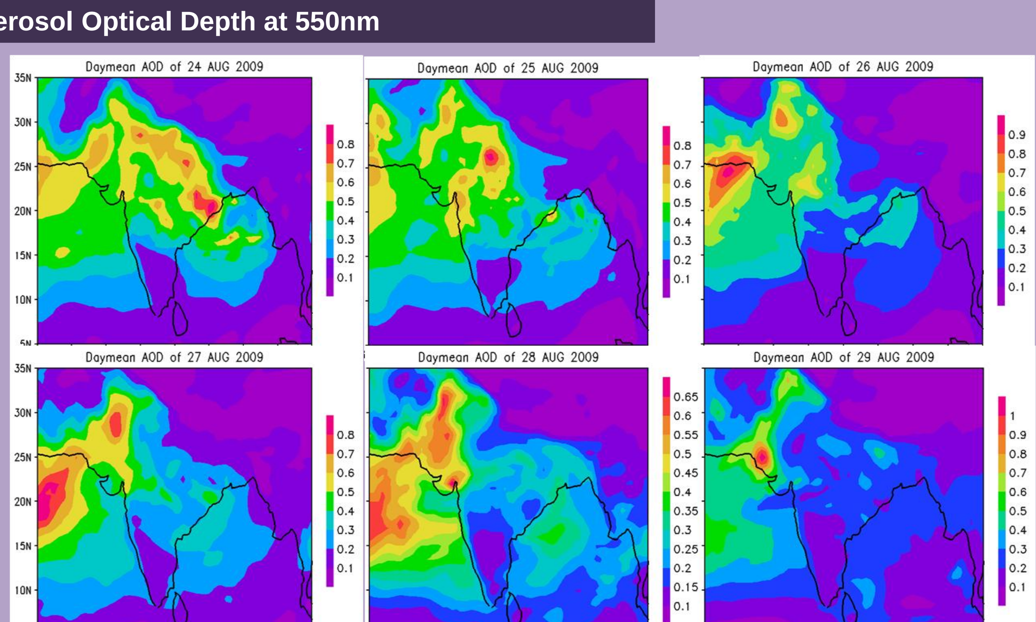
## Introduction

- ❖Monsoon Depressions are the most effective rain bearing systems of monsoon.
- ❖MDs contribute about 45-55 % of Total monsoon rainfall.

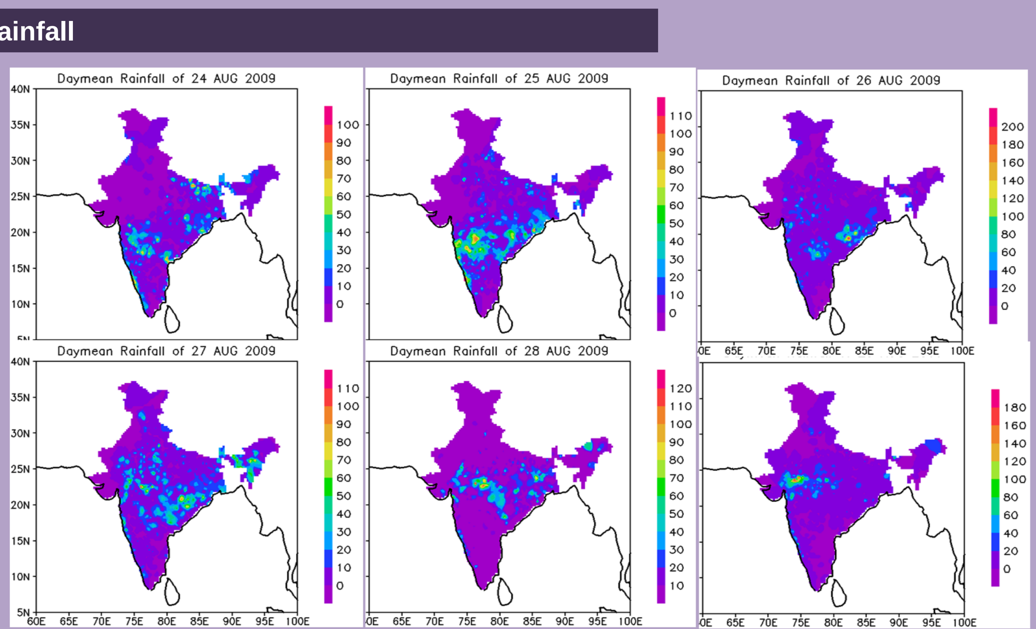
**Low Level Circulation and Flight Tracks**




**Aerosol Optical Depth at 550nm**



**Rainfall**



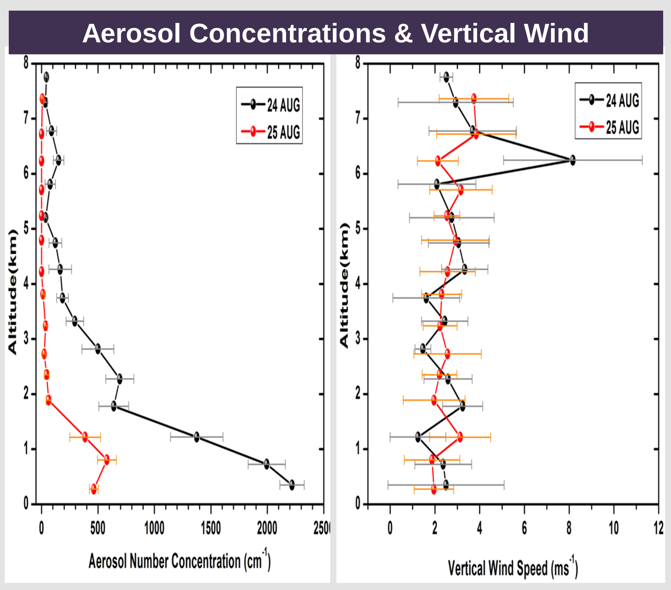
## Conclusions

- ➢ The main motivation behind this study was to understand the hypothesis that high $N_{AERO}$ could affect the growth of monsoon depressions through aerosol-cloud interactions driven by the changes in the system (MD).
- ➢A three-cell low-level convective cluster of the MD was observed confirming the conclusion of a previous study by *Houze and Churchill*, [1987] who also using airborne observations investigated the microphysics of a depression that occurred during MONEX-1977 experiment.
- ➢It was found that the aerosol concentrations were high on 24th August and were reduced to half to the very next day with the movement of the system on to the Indian subcontinent. From the decrease in rainfall, it could be understood that the system partially weakened on 26th August despite an improved vertical structure along 80°E longitude. The vertical wind shear shows a weakening which is again a favorable condition for strong convection. The system gradually weakened through 27th August but recovered again on 28th August where the replenished aerosol loading triggered convection through cloud invigoration. Therefore, it is concluded from this study that heavy pollution could suppress the initial growth of MDs as well as convective activity associated with the MD over the interior land areas such as over Central India particularly when the system is away from the oceanic region.
- ➢The combination of relatively humid air and pollution over the same region also contributed negatively. However, this negative effect on the rainfall is subject to the moisture supply both from the mesoscale convective structure of the MD and large-scale flow.
- ➢On the other hand, in presence of dry conditions similar to that over the Northwest Indian region aerosols and dust, in particular, can cause invigoration resulting in a good amount of rainfall over the region. Also, the current study highlights the role of aerosol-cloud interactions in the growing phase of MDs and it's response to the heavy aerosol perturbations driven by the changes in the system.
- ➢Considering the ongoing debate regarding the decreasing number of MDs in the recent period, better understanding of the complex role of aerosol-cloud interactions and the MD dynamics driven by the system itself helps us know how these systems would respond to climate change. Unlike the tropical cyclones, little is known about the sensitivity of various aspects of MDs to aerosol perturbations and needs further investigation.

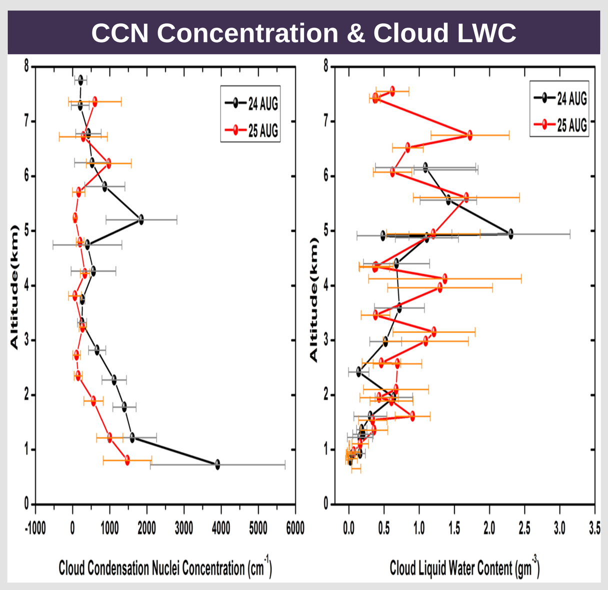
## Results

**24th August – Highly Polluted** **25th August - Less Polluted**

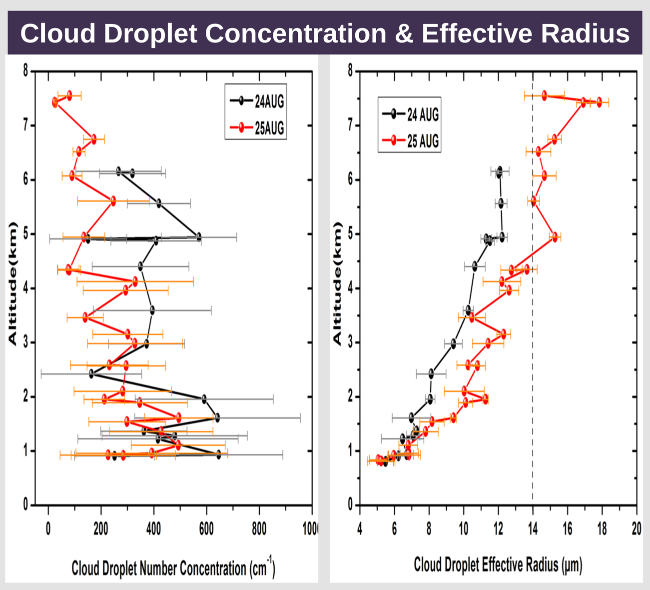
**Aerosol Concentrations & Vertical Wind**



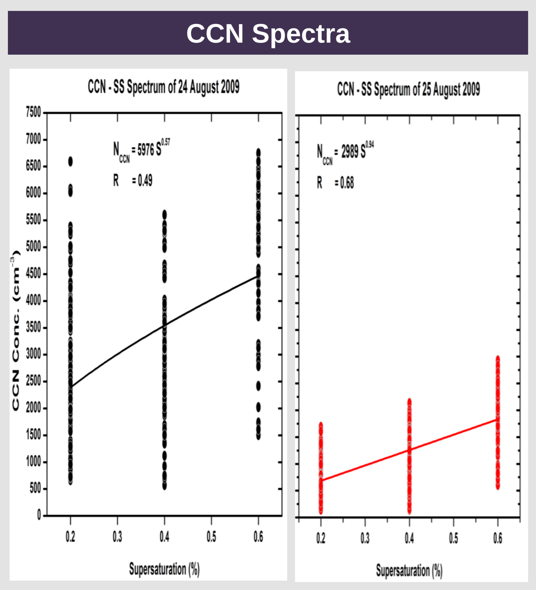
**CCN Concentration & Cloud LWC**



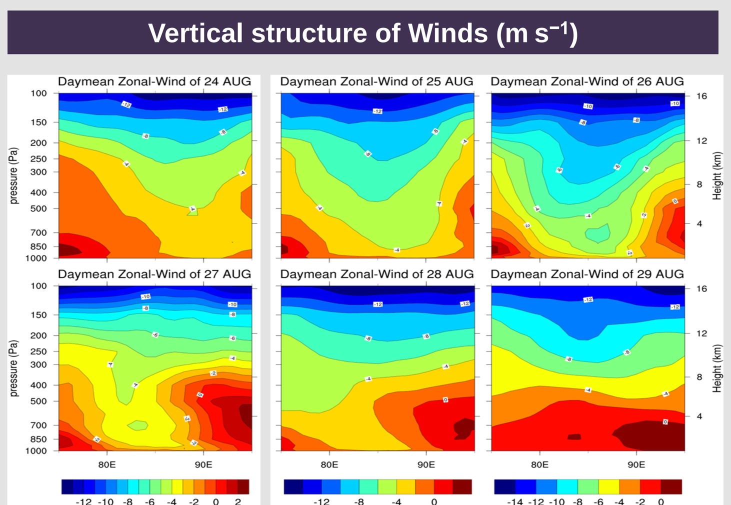
**Cloud Droplet Concentration & Effective Radius**



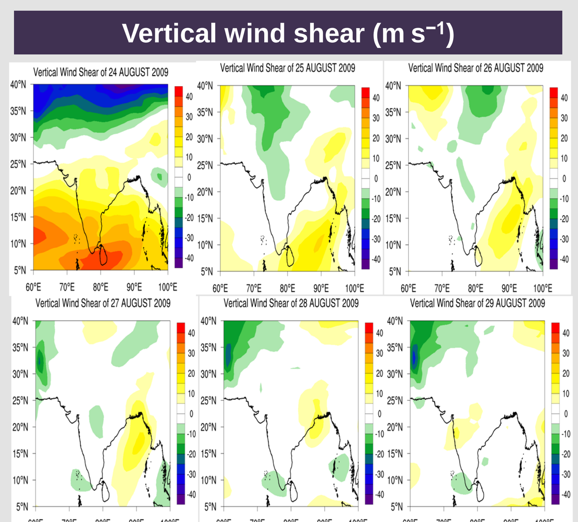
**CCN Spectra**



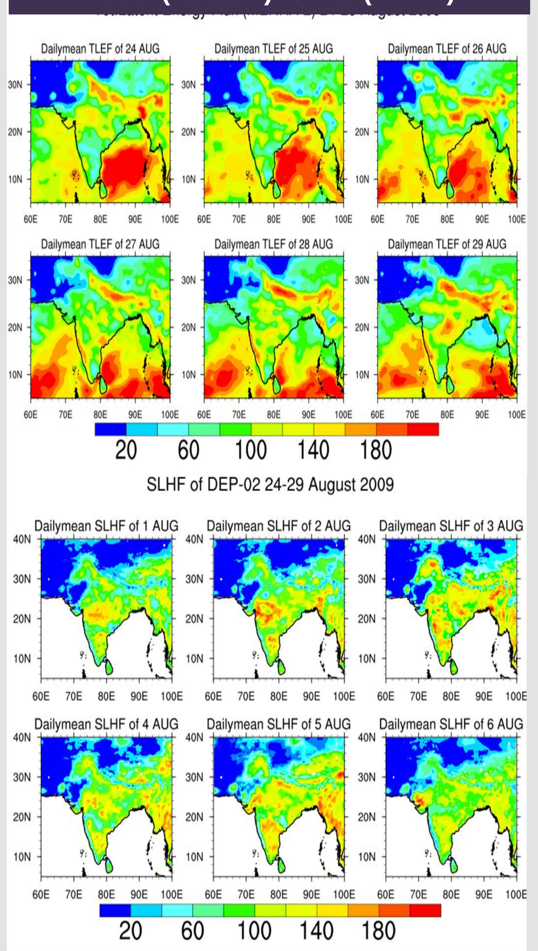
**Vertical structure of Winds ($m\,s^{-1}$)**



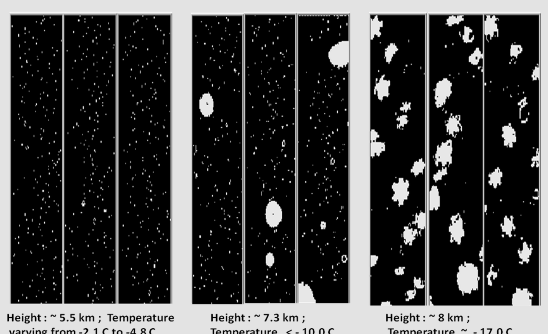
**Vertical wind shear ($m\,s^{-1}$)**



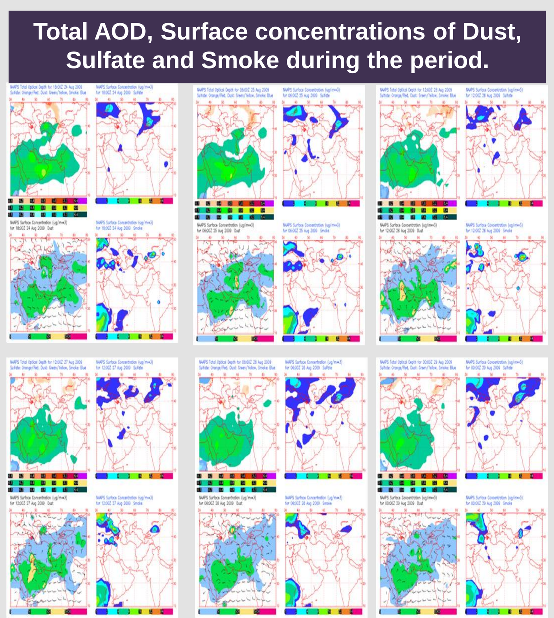
**Total LHF from MERRA-2 Reanalysis (Top) and (b) surface LHF from GLDAS Model (Bottom). Units ($W\,m^{-2}$).**



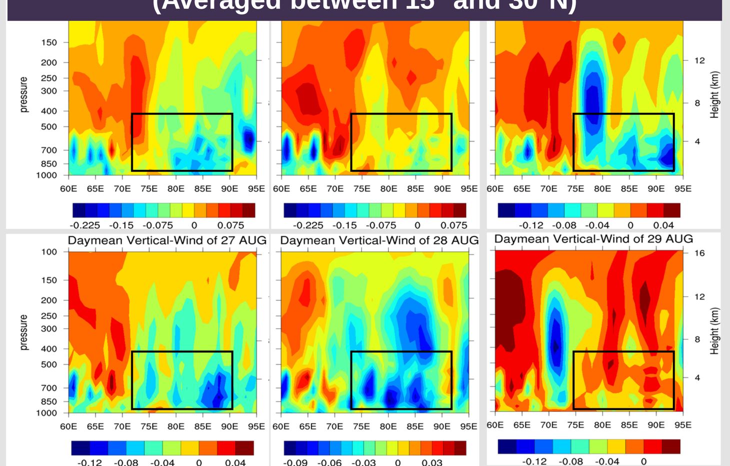
**CIP images of hydrometeors at different altitude of (a) 5.5 km, (b) 7.3 km and (c) 8 km**



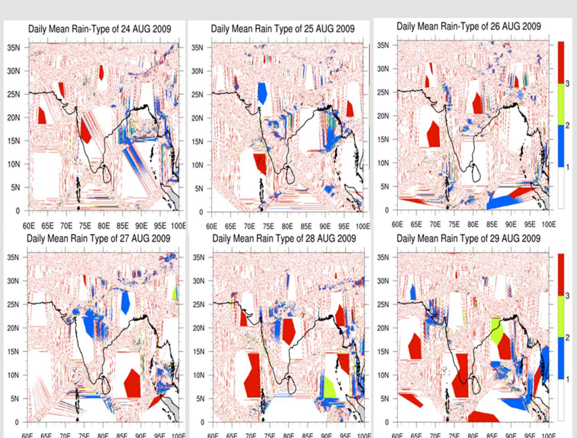
**Total AOD, Surface concentrations of Dust, Sulfate and Smoke during the period.**



**Vertical Wind ($Pa\,s^{-1}$) showing the Zonal circulation (Averaged between 15° and 30°N)**



**Rain Type from TRMM-2A23**



## Datasets

- ❑ Horizontal and Vertical winds, SLP, Temperature and Humidity data from ERA-Interim.
- ❑ Rain rate (TRMM-3B42) and Rain Type (TRMM-2A23) from TRMM.
- ❑ AOD data from MERRA-2 Reanalysis.
- ❑ Airborne aerosol and cloud data from CAIPEEX campaign.
- ❑ Total AOD and surface concentrations of the major Aerosol types (dust, sulfate and smoke) from the Navy Aerosol Analysis and Prediction System (NAAPS) model outputs.

## Acknowledgements

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