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Studying Mesoscale Convective Systems and Embedded Storms in the Monsoon Zone Using Remote Sensing Observations and Model Simulations

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The largest type of deep convective storms, known as mesoscale convective systems (MCSs), form as convection grows upscale and aggregates, interacting with several storms to generate a unique mesoscale circulation. Storms are therefore crucial to the organization of MCS. MCSs generate high-impact extreme weather events like lightning, huge hail, gusty winds, and flooding because of their large size, longer duration, and larger precipitation. During the Indian summer monsoon (June-September), synoptic-scale weather systems move across the monsoon zone, causing MCSs to form frequently. MCSs often produce widespread and heavy rain throughout the monsoon zone. Thus, for a better understanding of MCS, studies on the structure and evolution of MCSs that emphasize the organization of convection in monsoon zone are required.

In this work, we employed remote sensing observations (radar and satellite) and numerical simulations to detect and track MCSs and embedded storms using an object-based cloud-tracking technique (Feng et al., 2018). There are three sections to the work. In the first part, we tracked MCSs over the monsoon zone from June-September, 2014 to 2019 using geostationary satellite infrared brightness temperature (IRTb) and GPM IMERG precipitation. We looked at different aspects of observed MCSs (n=2022), including land-ocean contrast, rainfall amount, and diurnal cycle. More than 60% of all precipitation occurs in MCSs, which are mostly located in the southeast-northwest portion of the monsoon trough. There existed distinct land-ocean contrast and different lifetime evolution for MCSs with varying lifespans. Compared to land-based MCSs, oceanic (Bay of Bengal) MCSs are deeper, persist longer, and produce more rainfall over a wider area. Aanalyses show that deep-layer shear and lower-free-tropospheric moisture have an important role in determining the lifetime rainfall of MCSs.

In the second half of the study, we used a storm classification algorithm to analyse embedded storm structures for those MCSs that are present inside the radar domain (n=65) using S-band Doppler radar measurements collected at Bhopal, India, from June to September 2015. We found that an MCS contain many precipitation features, particularly early in the formation when several convective clusters start to merge. In addition, we looked into the co-evolution of other storm parameters as a function of MCS lifetime, such as top heights, convective core length, and areas of convective/stratiform precipitation. Different vertical structures are noted for the MCSs' convective, stratiform, and anvil components.

In this third section, we investigate how well a convection-permitting Weather Research Forecast (WRF) model can simulate MCSs and their properties (initiation, size, intensity, longevity, and propagation) in the period from June to September 2015. To identify and track MCS in the simulation, a similar cloud-tracking method is used to WRF-simulated data (reflectivity, IRTb, and precipitation). Rather than using simulations to describe individual events, statistics of MCS properties were examined through analysis. The composite evolution and frequency distribution of convective area, precipitation amount, and MCS propagation speed produce reasonable agreement with observations, despite the model underestimating the number of observed MCSs. On the other hand, stratiform areas are underestimated. The simulated MCS parameters showed a progressive increase from convective initiation to approximately the first half of the MCS lifetime, which is consistent with observations. We found that an MCS has several precipitation features, especially in the early stages of development when several convective clusters start to come together. More details on observed MCSs and embedded storm structures, together with an analysis of how they are modeled in simulations will be presented at conference.