Abstract

Precipitation during the Indian summer monsoon exhibits diurnal, intra-seasonal, and inter-annual variabilities. Among these variabilities, the diurnal convection cycle is the fundamental variability mode for tropical climates. In terms of the summer monsoon, this diurnal cycle of convection is an essential trigger that develops and organizes precipitation systems and contributes to the spatial and temporal distribution of monsoonal precipitation.

The developmental features of these diurnal convection and precipitation systems are not well represented in global and regional climate models across different monsoon regions. Such uncertainty in the diurnal convection representation undermines the fundamental reliability of the simulated physical processes in the climate models. This has encouraged an examination into the unpredictability of the Indian monsoon diurnal convection in climate models; this has received little research attention in the past.

Current research has focused on observations and modeling techniques to diagnose the observed diurnal convection cycle in a tropical monsoon and understand the importance of its representation in climate models. After simulating the diurnal cycle realistically in the regional climate model, we explored the sensitivity of diurnal precipitation characteristics to Indian land surface conditions over heterogeneous surfaces.

This study begins with an observational understanding of the diurnal convection cycle in terms of precipitation and its characteristics during the summer monsoon. This is carried out using satellite observations from the 21-y (1998–2018) climatology of the Tropical Rainfall Measurement Mission (TRMM) 3B42 V7 dataset. The diurnal cycle

in climatology has its peak precipitation during the afternoon or evening over land, and in the early morning over the Bay of Bengal. These climatological diurnal patterns show some exceptions near certain topographic features and coastal regions. For example, a mid-night or early morning diurnal precipitation peak was observed near the transition region between the Ganges Plains and the Himalayan foothills, and near the central-east and south-east coast of India. These mid-night or early morning diurnal peaks are associated with propagating convective systems.

The observed features of the diurnal cycle during the Indian summer monsoon were investigated using global and regional climate models. This evaluation identified uncertainties in the representation of diurnal characteristics in these models; for example, uncertainties occurred in the noon precipitation peak and the high frequency of precipitation events. These errors in diurnal precipitation representation are mainly associated with the horizontal resolution and cumulus parameterization of the model. High resolution regional climate models also cannot capture the diurnal cycle of precipitation accurately since these also tend to utilize cumulus parameterization. Cumulus parameterization has simulated varying diurnal cycle spatial patterns in different climate models, challenging the impact of different cumulus schemes.

The challenge was to understand the sensitivity of the diurnal precipitation cycle to different cumulus parameterizations as applied to the Indian summer monsoon precipitation using a suite of 30 regional climate experiments. These sensitivity experiments have exposed the uncertainty in the present generation cumulus parameterizations that simulate diurnal characteristics with a high frequency of precipitation events over each grid, poorly representing the organization of precipitation systems, unlike observations. These fundamental problems in the cumulus parameterizations arise due to closure assumptions and trigger functions that promote the linear growth of diurnal convection. Diurnal growth is explicitly non-linear, which fundamentally means that the regional climate models must simulate the conditions explicitly without cumulus parameterization to avoid these assumptions.

To understand the impact of the inclusion or exclusion of cumulus parameterization on diurnal convection, a suite of season-long 18 regional climate experiments were conducted at different model horizontal resolutions. These experiments demonstrate that the diurnal precipitation characteristics of the Indian summer monsoon are more dependent on the explicit representation of diurnal convection and were convincingly able to simulate the diurnal cycle close to observations without cumulus parameterization. A clear difference in the simulated precipitation systems was evident when convection was explicitly represented. For example, high-intensity localized, and organized precipitation systems were simulated by high resolution models without cumulus parameterization (convection-permitting) experiments. Reliable diurnal precipitation system reproducibility is attributed to the improved diurnal simulation of low-level summer monsoon circulation and its convergence.

The successful simulation of the diurnal cycle with convection-permitting experiments enables the exploration of the sensitivity of diurnal precipitation characteristics to surface heterogeneities such as topographic features and land surface conditions in India. Land surface heterogeneity influences the heat flux calculation by altering the roughness length, which in turn controls the convection initiation. This understanding of heterogeneous surface features may change in soil moisture-limited regimes. For example, the impact of dry and wet surface-limited regimes on diurnal precipitation characteristics has been examined in a suite of 30 experiments. These experiments demonstrated that wet surfaces favor a higher frequency of light-moderate and heavy precipitation events during the afternoon than dry surfaces. Further analysis showed the scale-dependency and Brown Ocean Effect of wet surfaces. The Brown Ocean Effect occurs over wet land surfaces with a deep saturation of soil moisture. Such a wet surface acts as a continuous source of moisture through evapotranspiration (e.g., over the ocean during daytime), and maintains the moist static energy throughout the day. As a result, short-duration precipitation events increase at noon and maintain this state over a long duration till nighttime by consuming moist energy from the evaporating wet surface.

The results presented in this research on the Indian summer monsoon diurnal convection cycle highlight two key findings: 1) convection-permitting simulations are reliable in representing convection; and 2) land surface features and conditions are the fundamental factors that require adequate representation in order to accurately simulate diurnal convection. These findings contribute to an improved simulation of the monsoon convection cycle.