Abstract:

As solar insolation increases in the northern hemisphere during boreal summer, it is accompanied by an abrupt change in the circulation associated with the monsoons as well as heightened intraseasonal convective activity in the summer hemisphere tropics. These two aspects shape tropical weather regimes, and understanding their dynamics is crucial for subseasonal forecasting as well as interseasonal variability and change in a warming world. In this thesis, we investigate the dynamics of intraseasonal convection, particularly its interaction with circulation, and the seasonal transition of boundary layer winds through observations, idealized numerical modeling experiments, and theory.

The first part of the thesis investigates the structure and evolution of a key circulation variable, vertical vorticity, which is strongly coupled to intraseasonal convection at three dominant timescales of sub-seasonal rainfall variability: synoptic (2-10 days), high frequency (10-25 days), and low-frequency (30-70 days). We establish the appearance of latitude-dependent coupling between vorticity and convection, with stronger spatial and temporal association between the two farther away from the equator. Using the vertically resolved vorticity budget filtered to these timescales and for various ocean basins of the world, the systematic vertically uniform vorticity pattern during the mature phase of convection is explained. Next, we shift our attention to intraseasonal convection within the Indian monsoon region, specifically focusing on the northward propagating boreal summer intraseasonal oscillation (BSISO) and its evolution across latitude. Contrasting controls on BSISO convection are observed as a function of latitude, from composites of event-wise analysis of rainfall, showing dynamic control near the equator (through barotropic vorticity) evolving into thermodynamic control farther away from the equator (through boundary layer moist static energy). This latitude-dependent evolution of BSISO is important for its propagation and impacts.

In the second part of the thesis, we examine the seasonal transition of low-level winds during monsoons, specifically focusing on the rapid intensification of the Somali jet. Analyzing the processes controlling the kinetic energy (KE), we find distinct balances at different sections of the jet. These balances can be characterized by a non-dimensional parameter, local Rossby number (Ro), in the boundary layer. Higher values of Ro (O~(1)) support a special type of balance in the boundary layer in which advective terms become important. In this regime, cross-isobaric meridional winds are proportional to meridional geopotential gradients that intensify during boreal summer. This leads to a precise nonlinear (quadratic) dependence of KE generation on the local meridional pressure gradient, eventually resulting in the rapid intensification of the KE of the Somali jet. Finally, based on these observations, simple theoretical arguments are put forth to explain the emergence of the advective boundary layer and the resulting quadratic dependence of horizontal kinetic energy on geopotential gradient in the high Ro regime. These are further tested through idealized modeling experiments using Community Atmospheric Model version 4 (CAM4) in aquaplanet configuration.

Taken together, the results from this thesis advance our understanding of the abrupt seasonal transition into the summer monsoon and the enhanced intraseasonal convection that follows. This thesis also provides a framework for investigating interactions between seasonal and subseasonal timescales.