"From Matsuno-Gill theory to dynamics of Madden-Julian Oscillation"

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The Madden-Julian Oscillation (MJO) is a corner stone that bridges weather forecast and seasonal climate prediction. Understanding the origin and perpetuation of the MJO has eluded scientists for decades. In this presentation, I shall first discuss the fundamental features of MJO that request theoretical explanations. I shall then discuss essential physical processes that are involved in the MJO dynamics.

From a dynamical standpoint, the MJO can be defined as a tropical planetary-scale circulation system that is coupled with a multi-scale convective complex and moves eastward slowly (~5 m/s over the warm pool) with a rearward tilted upward motion and a mixed Kelvin-Rossby wave structure. Why does the MJO possess a coupled Kelvin-Rossby wave circulation structure? How can the circulation couple with convection and move eastward slowly, causing intraseasonal variability? What determines the MJO propagation speed and intensification rate?

A general theoretical model framework is advanced in an attempt to unify the existing MJO theories and to address these fundamental issues of MJO dynamics. The model extends the Matsuno-Gill theory by incorporating (a) full moisture feedback to precipitation heating and (b) a trio-interaction among low-frequency equatorial waves, boundary layer dynamics, and precipitation heating described by a simplified Betts-Miller (B-M) convective parameterization.

The model can robustly produce essential large-scale characteristics of the observed MJO: An equatorial planetary-scale unstable system moving eastward slowly with coupled Kelvin-Rossby wave structure and rearward tilted moisture and divergence anomaly. It is the boundary layer Frictional Convergence (FC) feedback that couples equatorial Kelvin and Rossby waves with convective heating and selects a preferred eastward propagation with a planetary zonal scale. In the presence of the FC feedback, the moisture feedback in the B-M scheme can enhance Rossby wave response, thereby slowing down eastward propagation, and reinforce the Kelvin and Rossby wave coupling, resulting in a more realistic horizontal structure. The eastward propagation speed is inversely related to the relative intensity of the MJO westerly and the sea surface temperature (SST) that controls effective static stability through altering convective heating. The cumulus parameterization scheme may affect propagation speed through changing the MJO horizontal structure. The SST or basic-state moist static energy has a fundamental control on MJO intensification/decay. The FC feedback generates instability, while the moisture feedback tends to reduce the growth rate.

A more general intermediate-complexity model will be further formulated to explain the observed characteristics of boreal summer intraseasonal oscillation (BSISO) by including the impacts of boreal summer mean states. Using this intermediate model, I will further discuss how the boreal summer mean state affects BSISO, in particular, why the BSISO has maximum variability centers in the monsoon trough regions, and why the BSISO features a NW-SE titled rainfall band and moves dominantly northward in the monsoon regions.
Ramifications of the model results to general circulation modeling are discussed.