Multi-Scale and Multi-Cloud Models for the MJO

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The lecture surveys recent theoretical progress in understanding the multi-scale features of the MJO in idealized settings. Recent observational analysis reveals the central role of three multicloud types, congestus, stratiform, and deep convective cumulus clouds, in the dynamics of large-scale convectively coupled Kelvin waves, westward-propagating two-day waves, and the Madden–Julian oscillation. Systematic model convective parameterizations highlighting the dynamic role of the three cloud types have been developed recently (Khouider and Majda, JAS, 2006, 2007; JAS in press 2007) through two baroclinic modes of vertical structure: a deep convective heating mode and a second mode with low-level heating and cooling corresponding respectively to congestus and stratiform clouds. A systematic moisture equation is developed where the lower troposphere moisture increases through detrainment of shallow cumulus clouds, evaporation of stratiform rain, and moisture convergence and decreases through deep convective precipitation. A nonlinear switch is developed that favors either deep or congestus convection depending on the relative dryness of the troposphere; in particular, a dry troposphere with large convective available potential energy (CAPE) has no deep convection and only congestus clouds.

A multi-scale model of the MJO is briefly surveyed here (Majda & Biello, PNAS, 2004; Biello & Majda, JAS, 2005, DAO, 2006; Biello, Majda, Moncrieff, 2007) which accounts, in a simplified fashion, for both the upscale transfer from synoptic to planetary scales of momentum and temperature from wave trains of thermally driven equatorial synoptic scale circulations in a moving warm pool anomaly as well as direct mean heating on planetary scales. This model involves idealized thermally driven congestus synoptic scale fluctuations in the eastern part of the moving wave envelope and super convective clusters in the western part of the envelope the model self-consistently reproduces qualitatively many of the detailed structural features of the planetary circulation in the observations of the MJO including the vertical structure in both the westerly onset region and the strong westerly wind burst region as well as the horizontal quadruple planetary vortex structure. The westerly midlevel inflow in the strong westerly region and the quadruple vortex are largely produced in the model by the upscale transport of momentum to the planetary scales while the midlevel easterly jet in the westerly onset region is substantially strengthened by this process. The role of wave trains of tilted organized synoptic scale circulations is crucial for this fidelity with observations. The appeal of these multi-scale models with prescribed heat sources is their firm mathematical underpinnings, simplicity and analytic tractability while remaining self-consistent with many of the features of the observational record. On the other hand, they require a prescribed phase speed for the MJO.

In another direction, there are several new results surveyed here using the multi-cloud models directly in the idealized setting of flows above the equator without rotation to produce “MJO-like” multi-scale wave patterns with several key features of the MJO (Khouider and Majda, JAS 2007; JAS in press 2007; Majda, Stechmann, Khouider, PNAS 2007). The multi-cloud models do not have WISHE radiative instability, boundary layer frictional convergence, or convective momentum transport yet have multi-scale packets of convectively coupled waves moving in one direction at 15/20 m/s with their large scale envelopes moving in the opposite direction at speeds of 4 to 7 m/s, reminiscent of the MJO. The large scale envelopes resemble the zonal structure of the MJO but the westerly wind burst is too weak, probably due to the absence of upscale momentum fluxes. Current research includes blending the two different theories to incorporate convective momentum transport in the multi-cloud models.

All these papers are available on Andrew Majda’s NYU faculty website:
http://math.nyu.edu/faculty/majda/index.html