Simulating the MJO: Everybody Into the (Cold) Pool!

Research Highlight

Most general circulation models (GCMs) continue to have difficulty simulating the Madden-Julian Oscillation (MJO), the most important source of tropical precipitation variability on time scales shorter than seasons. In recent years, evidence has grown for viewing the MJO as a "moisture mode." Moisture modes differ from other equatorial waves in that they depend explicitly on variations of water vapor in time and space for their existence. In particular, the sensitivity of moist convection to tropospheric humidity (via turbulent entrainment of drier environmental air into the cloud) may explain the eastward propagation of the MJO. Thus, the MJO is a stringent test of whether GCMs realistically portray interactions among moisture, convection, and large-scale dynamics—a test that most models fail. Typically, MJOs are evaluated in GCM simulations with climatological sea surface temperatures or coupled to dynamic oceans, which allow the model's MJO climatology (or lack thereof) to be evaluated against observations but not its predictability for specific events constrained by real-world initial conditions.

By combining ARM MJO Investigation Experiment on Gan Island in the Indian Ocean (AMIE-Gan) observations of two MJO events during the 2011 Dynamics of the MJO (DYNAMO) field experiment and satellite observations of MJO precipitation anomalies during the 2009 Year of Tropical Convection (YOTC), GCM parameterized physics have been tested at the process level and determined the suitability of these tests as metrics for MJO predictability. Four versions of the GISS Model E2 GCM were compared: (1) The model version used in the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5), which allows both weakly and strongly entraining components of the cumulus mass flux; (2) A version with stronger entrainment in the weakly entraining part of the mass flux and stronger convective rain evaporation; (3) A version in which a new parameterization of downdraft cold pools is used to greatly restrict the occurrence of the weakly entraining component of mass flux; (4) A less restrictive version of the cold pool scheme that permits weakly entraining convection to occur somewhat more often.

The ARM AMIE-Gan large-scale forcing product was used to drive a Single Column Model (SCM) version of the GCM through the two observed MJO events, with temperature and humidity strongly relaxed toward observed values. Statistics were collected on the dependence of moist convection depth on column water vapor (CWV) and compared them to observational estimates obtained from Gan Ka-band ARM Zenith Radar (KAZR) reflectivity and Doppler velocity profiles. Figure 1 shows that the Gan KAZR data imply a transition from shallow to deep convection at about 50 mm CWV. Figure 2 shows the analogous plots for the four SCMs. The AR5 SCM clearly produces deep convection in drier environments than observed, indicating its entrainment is too weak. The stronger entrainment SCM version does a slightly better job but still produces considerable deep convection in drier conditions. The two cold pool SCMs do the best job of capturing the transition, since convection in these models entrains weakly only after the onset of sufficiently deep cold pools.

To explore the implications of these parameterization differences, a series of 20-day hindcasts of the MJO initiation phase were conducted with the 3D GCM initialized by the YOTC ECMWF analysis product. Longitude vs. time (Hovmoller) diagrams of rain anomalies in the tropical warm pool region from NASA Tropical Rainfall Measuring Mission (TRMM) satellite data were uses to assess each GCM version. The AR5 model produces no MJO, while the model with stronger entrainment and rain evaporation produces a modest MJO that weakens in the second half of the hindcast. The cold pool models produce the best correlation with the TRMM data. A subsequent GCM version intermediate between the more and less restrictive cold pool runs shown in Figure 2 sustains a vigorous MJO with significant predictability through the full 20 days of the hindcasts.

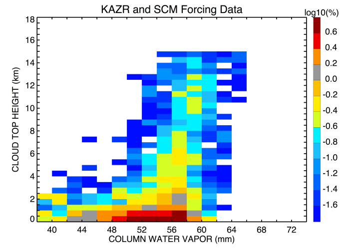

Figure 1. Histogram of Gan KAZR convective cloud top height vs. column water vapor during AMIE.

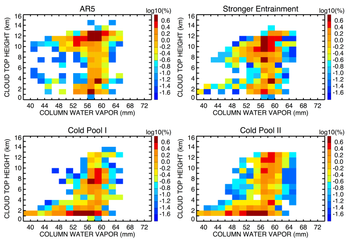

Figure 2. As in Figure 1 but for the 4 versions of the GISS SCM.

Analysis of the hindcasts indicates that dry conditions with suppression of rain upstream of the MJO disturbed area during the first day predict good model performance thereafter, and that models with the best convection sensitivity to CWV produce the best MJO. This supports the idea that the MJO is in fact a moisture mode, and that analysis of relationships between individual convective clouds and their environment helps constrain the relevant processes. The results further make the case for cold pools as the agent by which entrainment weakens as convection deepens, a result inferred from previous cloud-resolving model studies. In the GISS GCM, cold pools accomplish this this by isolating cold downdraft air from warm, humid boundary layer air and by their implied production of large eddies that reduce entrainment from its otherwise large values.

Reference(s)

Del Genio AD, J Wu, AB Wolf, Y Chen, M Yao, and D Kim. 2015. "Constraints on cumulus parameterization from simulations of observed MJO events." Journal of Climate, 28(16), doi:10.1175/JCLI-D-14-00832.1.

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Cloud Life Cycle