New Approaches to Understanding, Simulating, and Forecasting the Madden-Julian Oscillation

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Summary and Recommendations
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The 30-60 day Madden-Julian Oscillation (MJO) has wide-ranging impacts on the atmosphere-ocean-land system. For example, it modulates Asian-Australian monsoon variability, hurricane activity over the Atlantic sector, weather over the northern hemisphere extratropics, ocean chlorophyll, and total ozone concentration. Recognizing that representing the MJO in climate models and numerical weather prediction (NWP) models remains a persistent challenge, the U.S. Climate Variability and Predictability (CLIVAR) MJO Working Group (MJOWG) was formed in 2006 with the goal of improving our ability to understand, simulate, and forecast the MJO, with the latter continuing to be a limiting factor for maximizing medium-range to seasonal forecasting skill. To facilitate this effort, the MJOWG organized a workshop to discuss new thinking and approaches to the MJO, using strategies that integrate observations, modeling, and theory. The workshop was well-attended by members of both the MJO research and forecasting communities. The objectives of the workshop included (1) The introduction of new diagnostics designed to systematically evaluate model simulations and forecasts of the MJO, (2) Identification of key limits to our understanding and processes that might be crucial for representing the MJO, and (3) The development of integrative approaches to tackle the problems associated with understanding, simulating, and forecasting the MJO. The workshop was organized into six half-day sessions over three days. The first day emphasized Diagnostics and Models, and Forecast Metrics. The second day focused on Vertical and Multi-Scale Structure as well as Theory and Modeling. The theme of the third day was Integrative Modeling Approaches with sessions on Existing and Planned Efforts, and New Initiatives and Next Steps. Each session included three invited talks, a poster session, and a one-hour discussion. Most of the oral and poster presentations can be found at: http://www.joss.ucar.edu/joss_psg/meetings/Meetings_2007/MJO/index.html.

The disparate approaches used over the past decade to diagnose simulations of the MJO have made it difficult to ascertain relative MJO skill among contemporary models, and among models of different generations. Thus, the MJOWG developed diagnostics that allow novices and experts interested in the MJO to assess its fidelity using a series of increasingly complex and insightful diagnostics (a link to the diagnostics and calculations codes can be found at: http://www.usclivar.org/Organization/MJO_WG.html). The initial application of the diagnostics to six GCMs revealed that the SPCAM and ECHAM4/OPYC models gave reasonably realistic representations of the MJO, though the reason(s) for this have yet to be elucidated.. In SPCAM, convection is represented using embedded 2-dimensional cloud resolving models (CRMs) at each gridpoint, while ECHAM4/OPYC uses a more conventional convective parameterization. Other model evaluations demonstrated that the ability to represent the MJO improves with the sophistication of the convection scheme employed, including how the scheme relates to other aspects of model physics, including moistening of the boundary layer and the free troposphere, the diurnal cycle of shallow convection, the incorporation of convective downdrafts and convective momentum transport, and surface fluxes. The implication is that convective

parameterizations that discharge convective available potential energy too quickly have poor representations of the MJO, while the inclusion of processes that inhibit convection and allow the troposphere to more gradually moisten provide an improved representation of the MJO. Though a theory of the MJO initiation mechanism, phase speed, and spatial scale selection remains elusive, analytic modeling suggests that convective inhibition and the development of congestus (stratiform) cloud before (after) MJO deep convection is crucially important to the MJO's moisture, energy, and momentum budgets, consistent with the afore-mentioned numerical experimentation. Additional results suggest that the scale selection is dependent upon low-level moisture convergence and downdrafts from the stratiform region.

Generating diagnostics for evaluating MJO forecasts is more challenging compared to those for climate simulations. Real-time forecasting precludes intraseasonal bandpass filtering to isolate the MJO. Thus, the MJOWG has adopted an approach based on the projection of forecast data onto pre-existing observed multivariate empirical orthogonal functions (EOF's) of tropical outgoing longwave radiation and zonal winds at 850hPa and 200hPa. The resulting principal components can be used to determine the amplitude and phase of the MJO life-cycle. As such, direct model-model and model-observed comparisons and the generation of a multi-model ensemble prediction are facilitated. Benchmarking the skill of present forecast models will require hindcast experiments, with the selection of recent years preferable due to the availability of new satellite observations (e.g. CloudSat). Important topics to address include assessing the skill as a function of MJO phase and amplitude, the impact of interannual variability (e.g., ENSO) and mid-latitude conditions, the role of an interactive ocean, the role of initialization shock in making hindcasts/forecasts, and consideration of weighting models in the development of a multi-model ensemble forecast. Since the workshop, the WMO CAS/WCRP Working Group on Numerical Experimentation has recommended that NWP centers contribute the necessary data to the MJOWG to allow the calculation of MJO forecast diagnostics to monitor performance and assess predictability of the MJO in a standardized framework.

The development of mechanistic diagnostics is required to gain insight into the processes that are essential for robust simulation of the MJO. The vertical structure of clouds and related quantities, as measured by CloudSat and other A-Train sensors, already reveals that models fail to represent mid-level cloud, suggesting that pre-moistening of the atmosphere in advance of deep-convection is not adequately represented. As such, new candidate diagnostics associated with the cycling of moisture in the atmosphere were discussed, including the relationship of rainfall rate to relative humidity, saturation fraction, total precipitable water, cloud population statistics, and surface latent heat flux. Additionally, the use of satellite-derived vertical moisture and heating profiles (e.g., AIRS, TRMM) is essential for analyzing models. As such, heating profile components from models, which have heretofore not been typically archived with sufficient temporal sampling (i.e., daily) for the diagnosis of the MJO, need to be saved and made available to the diagnostic community.

Multi-scale interactions associated with the MJO have not been explored adequately. A self-similar (vertical) structure exists amongst the MJO and other atmospheric modes (e.g., westward inertial gravity waves), and when the variance of the MJO increases, the variance of other waves/modes also increases. Despite this self-similarity, in some cases such as higher-frequency waves (e.g. 2-day waves) can be simulated by a model, but this does not necessarily translate into the capability to simulate the MJO, suggesting the importance of nonlinear interactions and upscale energy transport for generating the MJO. With regard to the initiation of the MJO, the role of equatorial Rossby waves needs to be better understood, as does the

possibility of extratropical triggers. A more basic understanding of atmospheric waves needs to be obtained, especially that associated with Kelvin and other convectively-coupled waves. Data sets (e.g., CLAUS, ISCCP) are available that may allow a comprehensive examination of the dependencies that exist between the amplitude and phase speed of the MJO and its finer multi-scale features.

The full range of modeling (cloud-resolving, regional, and global) needs to be exploited to help improve the simulation of the MJO. Since observations are lacking for many important processes (e.g., convective momentum transport), high resolution (1-2 km grid spacing) regional modeling approaches are needed. In addition, model error diagnosis in a forecasting framework offers the benefit of direct comparison with field programs and satellite data sets that are not necessarily overlapping or long-term. Studies using these approaches will provide insight into a variety of MJO characteristics, including transition to and from the convective phase, and scale interactions that include mesoscale convective systems, African easterly waves, other convectively-coupled equatorial waves, and the diurual cycle over land and ocean.

Investigation across the range of currently available models and the use of new satellite, analysis and forecast products (e.g., EOS/A-Train, TIGGE), including programs that integrate these tools (e.g., AMY, CASCADE, YOTC), provides an avenue for understanding the essential physics of the MJO, and the development of more robust parameterizations to ameliorate our fleeting ability to simulate the MJO. Based on the expectation that the MJOWG will complete the development, analysis and/or writing of peer-reviewed journal articles during 2008 on: 1) MJO simulation diagnostics, 2) the application of these diagnostics to a contemporary set of GCMs, and 3) the implementation of an operational MJO forecast metric, the workshop developed the following recommendations for future work:

1) Where possible, develop scalar metrics of MJO model skill for use in multi-model comparisons and for tracking model fidelity.
2) Work with the observation, model-development, and theoretical communities to develop process-oriented diagnostics that improve our insight into the physical mechanisms necessary for robust simulation of the MJO.
3) Continue to explore multi-scale interactions within the context of convectively-coupled equatorial waves, both in observations and by exploiting recent advances in high-resolution modeling frameworks, with particular emphasis on vertical structure and diabatic processes.
4) Expand efforts to develop and implement MJO forecast metrics under operational conditions.
5) Develop an experimental modeling framework to assess MJO predictability as well as forecast skill from contemporary/operational models.