

MODELING MONSOON INTRASEASONAL VARIABILITY

From Theory to Operational Forecasting

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Better understanding and improved modeling capabilities of the Madden–Julian Oscillation (MJO)—and, more broadly, monsoon intraseasonal variability (MISV), to which the MJO is a major contributor—are deemed critical to achieving skillful and useful forecasts of the Asian–Australian monsoon. Accurate representation of MISV in weather and climate models is necessary to simulate and accurately predict the all-important onset and break periods of the monsoon. Moreover, MISV represents a crucial link in the seamless chain of multiscale interactions that span from low-frequency variability such as ENSO to high-frequency, high-impact synoptic systems such as tropical cyclones and monsoon lows, and even to the diurnal cycle. Fundamental issues regarding the MJO and MISV include 1) a lack of well-accepted theories that describe their most basic features, such as characteristic frequency and spatial scales, poleward versus zonal propagation, mechanisms of amplification, dependency on coupling with the ocean and land surface, and interannual modulation; 2) the inability of the models to robustly simulate many of their observed

WORKSHOP ON MODELING MONSOON INTRASEASONAL VARIABILITY

WHAT: A workshop gathered researchers, students, and forecasters to discuss existing and new approaches to understanding, simulating, and forecasting monsoon intraseasonal variability
WHEN: 15–18 June 2010
WHERE: Busan, South Korea

features; and 3) the development of operational prediction frameworks that focus on the intraseasonal time scales of the monsoon (i.e., between the traditional foci of weather and seasonal-to-interannual climate predictions). To address these issues, the World Climate Research Program (WCRP) Climate Variability and Predictability (CLIVAR) Asian–Australian Monsoon Panel (AAMP; www.clivar.org/organization/aamp/aamp.php) and the Year of Tropical Convection (YOTC) MJO Task Force (MJOTF; www.ucar.edu/yotc/mjo.html) convened a workshop¹ on modeling MISV with the following goals:

- (i) Provide an up-to-date assessment of the current capability to predict and simulate MISV, and particularly the MJO;

¹ The meeting was graciously hosted by the Asia–Pacific Economic Cooperation (APEC) Climate Center (APCC) located in Busan, South Korea. There were 66 attendees, including 15 graduate students and early career researchers whose attendance was supported by travel grants from the U.S. National Science Foundation (NSF), the World Weather Research Program (WWRP)/The Observing System Research and Predictability Experiment (THORPEX), and the WCRP.

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DOI:10.1175/2011BAMS3164.1

In final form 25 March 2011
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- (ii) Provide insight into the problems and issues that need to be addressed to move forward the capability to simulate and predict the MJO/MISV;
- (iii) Assess and promote process-oriented diagnostics/metrics that target underlying physical mechanisms of the MJO/MISV to facilitate improvements in model parameterizations; and
- (iv) Based on (i)–(iii), provide a prioritized assessment of future research needs and directions to improve simulation and prediction capability of the MJO and MISV.

The workshop was organized into six sessions, each with a distinct focus. Each session was introduced by three 30-minute review talks, followed by one hour for posters, and concluded with an hour of discussion. Ample time for discussion was purposely built into the program to facilitate interaction and the exchange of ideas. The six sessions were focused on the following issues:

- 1) Current capability to model the MJO/MISV with GCMs,
- 2) Convective parameterizations and development of process-oriented diagnostics,
- 3) Insights from theory and simplified models,
- 4) Simulation diagnostics and forecast metrics for boreal summer MISV,
- 5) Forecasting capabilities and challenges for the MJO/MISV, and
- 6) Global interactions and impacts of the MJO/MISV.

A summary of the important findings and discussions is included below. (The complete program, including the review talks and posters, is available online at www.ucar.edu/yotc/documents/mjo/KoreaWkshp.html.)

GCM MODELLING. A decade ago, most GCMs had weak MISV with features that propagated eastward too fast and lacked coherent large-scale structures. However, tangible progress has been made in simulating the MJO using traditional GCMs, whereby many now have significant, and in some cases overly strong, MJO-like variability relative to observations, and with slowly propagating, large-scale features. While precise determination of the model features that have contributed to this progress is elusive, a number have been found to provide some benefit. These include increases in resolution (mainly vertical), improved sensitivities of the convective parameterization to the environmental moisture profile, air–sea coupling, and improved mean states. Whereas

it is easy to point to instances and evidence demonstrating improvements in our MJO simulations, it is more difficult to highlight our gains in the theoretical underpinnings associated with these improvements, specifically in regards to the MJO’s initiation and maintenance/instability mechanisms. The latter includes considerations of cloud–radiation interaction, multiscale cloud–convective interactions, convective momentum transports, and air–sea feedbacks such as wind-induced surface heat exchange (WISHE).

Relative to a decade ago, two new experimental modeling strategies have arisen that offer additional promise of increasingly realistic MJO simulations. The first is the so-called superparameterization methodology and the second stems from global cloud system–resolving models (GCSRM). The former has demonstrated considerable realism in its representation of the MJO, both in uncoupled and coupled ocean configurations. While being computationally expensive relative to a traditional GCM, it at least affords the ability to carry out multiyear simulations so that many standard diagnostics can be used for its evaluation. Analysis to date for the GCSRM looks quite promising in representing the MJO and the associated multiscale interactions involving aspects such as mesoscale interactions, convective momentum transport, and influences on other synoptic features. Unfortunately, the computational demands are so considerable for GCSRMs that simulations/hindcasts of only a few weeks or months have been possible. Workshop participants recommended continuing to apply these sorts of novel numerical frameworks, particularly through more initialized hindcasts in conjunction with long-term climate simulations, and made a strong recommendation for community involvement in their evaluation and the development of insightful diagnostics.

CONVECTIVE PARAMETERIZATION AND DIAGNOSTICS. Experimentation with convective parameterizations has revealed that improved simulation of the MJO stems from making the convection scheme more sensitive to environmental moisture. This can be achieved by imposing minimum entrainment rates, increasing entrainment rates, and increasing the evaporation of falling rain. The strong sensitivity of rainfall to environmental moisture is well established in observations and is motivated by simple considerations of convective adjustment time scales. However, a realistic sensitivity of rainfall to environmental moisture is apparently a necessary but not sufficient condition for a parameterization to produce a realistic MJO—some models with poor MJO representations have realistic moisture/rainfall

sensitivities. This points to other processes being important as well, including the variation in vertical structure of humidity and diabatic processes through the life cycle of the MJO. These variations are detectable with new satellite observations from Atmospheric Infrared Sounder (AIRS) temperature and moisture soundings, *CloudSat* cloud water profiles, and Tropical Rainfall Measuring Mission (TRMM) diabatic heating profiles, as well as from corresponding reanalysis fields. However, obtaining well-validated agreement between the two types of observational information is not always forthcoming because of the satellite algorithm sensitivities and biases and the strong model dependencies in the reanalyses, particularly those related to clouds, convection, and diabatic heating. Realistic evolution of temperature and moisture fields through the life cycle of the MJO have been relatively well simulated in superparameterized models (i.e., whereby diabatic parameterizations are replaced by embedded cloud-resolving models at each grid point), which provides hope that parameterized models can eventually be more successful. Workshop recommendations noted that the development of parameterized convection will be facilitated by more coordinated exploitation of cloud-resolving simulations that are stringently evaluated against in situ and satellite-based observations in order to reveal critical dependencies. The need to continue development of diagnostics that target physical processes underpinning the MJO, as undertaken by the MJOTF, was also endorsed.

THEORY AND SIMPLIFIED MODELS. A complete theory of the MJO (and MISV in general) remains a contentious issue, with little consensus regarding the cause of some of the MJO's core properties such as its characteristic time and space scales and slow eastward phase propagation. Consequently, many theoretical models still require certain core properties to be built in, for instance by using observations to set some of the model parameters (as opposed to deriving them from first principles). Theory does, however, have a lot to offer for understanding some key features of the MJO. For example, the wind structure of the MJO is now known to be well represented by the quasi-steady response to heating from convection (Matsuno–Webster–Gill theory). A large body of evidence has also been amassed from observations and models that suggest that surface fluxes and cloud–radiation interactions are important to the MJO's destabilization. Theory is also providing valuable guidance for the development of new process-oriented diagnostics of the MJO, such as the precipitation/saturation fraction

diagnostic that provides insight into the convective adjustment time scale. Two areas that garnered considerable discussion are the degree to which multiscale properties of convective organization are needed to explain large-scale features of the MJO and MISV, and the additional mechanisms required for poleward propagation during certain times of the year. Recommendations included continued support for theoretical work, especially that which can guide the development of models.

BOREAL SUMMER MISV. Compared to the past generation of GCMs, many current GCMs have an improved simulation of MISV during boreal summer, whose key distinction compared to boreal winter is the northward propagation of a northwest–southeast-tilted large-scale rainband from the equatorial Indian Ocean into India and Southeast Asia. Similar simulation fidelity has been achieved using conventional convective parameterization (e.g., in the European Centre Hamburg Atmospheric Model version 4 coupled to the Ocean Isopycnal Coordinate model) and with embedded cloud-resolving models [e.g., in the superparameterized National Center for Atmospheric Research (NCAR) Community Climate System Model]. Further study of Rossby wave interactions with the background flow and air–sea and atmosphere–land interactions is required since these are the mechanisms by which models and theory produce northward propagation of the tilted rainband. In order to diagnose and assess simulations and predictions of the northward propagation, alternative metrics and basis functions from those used to diagnose the eastward-propagating MJO (e.g., Gottschalck et al. 2010) have been developed and are now being evaluated using an intraseasonal hindcast set from multiple models that spans 1989–2010 [the Intraseasonal Variability Hindcast Experiment (ISVHE); www.ucar.edu/yotc/iso.html]. Models should be further challenged by validating the statistics of the duration of intraseasonal active and break phases. Furthermore, there were workshop recommendations to study both the mechanism(s) involved in intraseasonal northward propagation that occur independent of eastward equatorial propagation and the impact of land surface processes that modulate intraseasonal variability.

FORECASTING. In the last several years there has been an increasing emphasis on forecasting MISV, especially the MJO, by global numerical weather prediction models at operational centers. An initial step in assessing the current capability to forecast the MJO and its impacts has been the real-time MJO forecast display and associated activity that is hosted

at the NOAA Climate Prediction Center (Gottschalck et al. 2010; www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml). A common forecast display has been developed that tracks the ensemble mean, individual members, and ensemble spread of forecasts of large-scale indices of the MJO, and provides a framework for assessing MJO forecast performance. A number of forecast models show skill in predicting the large-scale evolution of the MJO with a lead time approaching three weeks. Transferring this success into the prediction of impacts on local and remote weather remains a challenge, which reflects the demand on the forecast model to faithfully simulate the detailed three-dimensional structure of the MJO, including its multiscale interactions. Besides improving the representation of the MJO in global forecast models and developing and applying additional and refined forecast metrics, workshop participants determined that improved multiweek forecasts of the MJO should benefit from novel initialization techniques such as a “slow manifold” modeling approach, whereby the initial conditions are temporally filtered to remove noise. It was recommended that support for exploration of such techniques be provided.

IMPACTS AND INTERACTIONS. Intraseasonal variations of convection across the Indian Ocean to the western/central Pacific generate worldwide impacts. As well as strongly modulating the Asian–Australian monsoons, the MJO and MISV are now understood to trigger intraseasonal convective activity over the eastern Pacific and in the West African monsoon. In the summer hemisphere the MJO affects the genesis of tropical cyclones, while in the winter hemisphere atmospheric Rossby wave trains are excited, giving rise to extratropical teleconnections that impact the southern annular mode and Antarctic Circumpolar Current in austral winter and the North Atlantic Oscillation and North American weather in boreal winter, and thus providing a source for the extended range predictability of these associated impacts. Forecast models are now capable of capturing the MJO such that weather and tropical cyclone forecast skill is improved when the MJO is present during the forecast. Recent investigations suggest a more complicated air–sea interaction in the Indian Ocean whereby the MJO drives sea surface height perturbations that might possibly feedback onto development of subsequent episodes of the MJO. Additionally, analysis of newly available observations from ocean floats indicates impacts of the MJO to at least 1000-m depth. Because of the global impacts of the MJO and its potential for driving predictability at

the extended range, it was recommended that forecast products based on prediction of the MJO and their systematic evaluation based on hindcast experiments such as the ISVHE continue to be developed.

CONCLUSIONS. While the impact and effectiveness of a workshop such as this is difficult to judge, the opinion of all involved is that a focused, limited-attendance workshop is a wonderful alternative to an open scientific meeting or a much more limited panel meeting. The success of this workshop will ultimately be judged by the advancements in our modeling and prediction capabilities and by our increased understanding of the intricacies of the MJO and MISV. Ongoing activities of the AAMP and the MJOTF focusing on assessing predictions and simulations of the MJO and MISV now have new impetus and direction, presenting a challenge to these programs to build on the success of this workshop. At the very least, this workshop offered the opportunity for 15 early-career researchers to meet and interact with a broad selection of established scientists who are engaged in MJO/MISV research, and it exposed them to the challenges and issues of improving predictions and simulations of the MJO and MISV. Hopefully, they have been encouraged to continue to pursue research careers that are focused on the challenges of simulating and predicting the MJO/MISV.

ACKNOWLEDGMENTS. This workshop would not have occurred without the assistance and hospitality of the APCC and its director, C.-S. Chung. Thanks also to the NSF, WCRP, and WWRP/THORPEX for their support for the workshop and to Carlos Ereño, the AAMP liaison to the International CLIVAR Project Office, for significant help with the organization. Duane Waliser’s contribution to this activity was carried out on behalf of the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. Ken Sperber was supported under the auspices of the U.S. Department of Energy Office of Science Regional and Global Climate Modeling Program by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Matt Wheeler and Harry Hendon are supported by the Centre for Australian Weather and Climate Research which is a partnership between CSIRO and the Bureau of Meteorology.

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