

NEW APPROACHES TO UNDERSTANDING, SIMULATING, AND FORECASTING THE MADDEN–JULIAN OSCILLATION

BY KENNETH R. SPERBER AND DUANE E. WALISER

The 30–60-day MJO (see appendix for acronym expansions) has wide-ranging impacts on the atmosphere–ocean–land system. For example, it modulates Asian–Australian monsoon variability, tropical cyclone activity, weather patterns in the extratropics, ocean chlorophyll, and total ozone concentration. Recognizing that representing the MJO in climate models and NWP models remains a persistent challenge, the U.S. CLIVAR MJOWG was formed in 2006 with the goal of improving our ability to understand, simulate, and forecast the MJO. In particular, forecasting the MJO continues 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 attended by members of both the MJO research and forecasting communities. Its objectives

MJO WORKSHOP: NEW APPROACHES TO MEET THE CHALLENGE OF THE MADDEN–JULIAN OSCILLATION

WHAT: An invitation-only workshop gathered researchers and forecasters of the MJO to discuss new approaches to understanding, simulating, and forecasting the MJO in the context of weather–climate connections.

WHEN: 5–7 November 2007

WHERE: Irvine, California

included 1) introducing new diagnostics designed to systematically evaluate model simulations and forecasts of the MJO; 2) identifying key limits to our understanding of the MJO as well as to the processes that might be crucial for modeling the MJO; and 3) developing integrative approaches to tackle the problems associated with understanding, simulating, and forecasting the MJO.

The workshop was organized into 6 half-day sessions over 3 days. The first day emphasized diagnostics and models, and forecast metrics. The second day focused on vertical and multiscale 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 1-h discussion. Most of the oral and poster presentations can be found online (www.joss.ucar.edu/joss_psg/meetings/Meetings_2007/)

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[MJO/index.html](#)), and summaries of each day's sessions are included below.

DAY 1: DIAGNOSTICS AND MODELS, AND FORECAST METRICS.

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 www.usclivar.org/mjo.php). 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 two-dimensional CRMs at each grid point, 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, such as 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 clouds before and stratiform clouds after MJO deep convection are crucially important to the MJO's moisture, energy, and momentum budgets, consistent with the aforementioned numerical experimentation. Additional results suggest that the scale selection is dependent on 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 preexisting

observed multivariate EOFs of tropical outgoing longwave radiation and zonal winds at 850 and 200 hPa. The resulting principal components can be used to determine the amplitude and phase of the MJO lifecycle. As such, direct model–model and model–observed comparisons and the generation of the multimodel 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 midlatitude 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 multimodel 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.

DAY 2: VERTICAL AND MULTISCALE STRUCTURE, THEORY, AND MODELING.

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 midlevel cloud, suggesting that premoistening 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.

Multiscale interactions associated with the MJO have not been explored adequately. A self-similar (vertical) structure exists among 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 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 of Kelvin and other convectively coupled waves. Datasets (e.g., CLAU, 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 multiscale features.

DAY 3: INTEGRATIVE MODELING APPROACHES, EXISTING AND PLANNED EFFORTS, NEW INITIATIVES, AND NEXT STEPS.

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 datasets that are not necessarily overlapping or long term. Studies using these approaches will provide insight into a variety of MJO characteristics, including the 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 diurnal cycle over land and ocean.

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 MJO forecast metric at a number of operational forecast centers, the workshop developed the following recommendations for future work:

- 1) Where possible, develop scalar metrics of MJO model skill for use in multimodel 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 multiscale 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 (e.g., greater participation, boreal summer focus, multi-model ensemble); and
- 5) Develop an experimental modeling framework (e.g., a multi-model MJO hindcast data set) to assess MJO predictability as well as forecast skill from contemporary/operational models.

The new diagnostic tools and analysis approaches discussed at this workshop will foster investigation of MJO processes through the use of new satellite, analysis, and forecast products (e.g., EOS/A-Train, TIGGE) and over a range of currently available models, including those of ever-increasing cloud-resolved capabilities. Presently there are a number of programmatic and scientific points of collaboration that are integrating these resources and providing a greater focus for understanding the essential physics of the MJO (e.g., AMY, CASCADE, YOTC, CMMAP). Such efforts will provide avenues for the development of more robust model representations of the MJO, including improved parameterizations of key processes, and will help ameliorate our fleeting ability to simulate and predict this very important mode of tropical variability.

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APPENDIX: ACRONYM CHART

AIRS	Atmospheric Infrared Sounder
A-Train	Constellation of satellites (<i>Aqua</i> , CloudSat, CALIPSO, PARASOL, and <i>Aura</i>)
AMY	Asian monsoon year
CAS	Commission for Atmospheric Science
CASCADE	Scale interactions in the tropical atmosphere
CLAUS	Cloud Archive User Service
CLIVAR	Climate Variability and Predictability
CMMAP	Center for Multi-Scale Modeling of Atmospheric Processes
CRM	Cloud-resolving model
ECHAM4	European Centre Hamburg atmospheric model version 4
ENSO	El Niño–Southern Oscillation
EOF	Empirical orthogonal function
EOS	Earth Observing System
GCM	Global climate model
ISCCP	International Satellite Cloud Climatology Project
MJO	Madden–Julian oscillation
MJOWG	MJO Working Group
NWP	Numerical weather prediction
OPYC	Ocean isopycnal coordinate model
SPCAM	Super-parameterized Community Atmospheric Model
TIGGE	Thorpex Interactive Grand Global Ensemble
TRMM	Tropical Rainfall Measuring Mission
WCRP	World Climate Research Program
WMO	World Meteorological Organization
YOTC	Year of Tropical Convection