

# MEETING SUMMARIES

## CHALLENGES AND OPPORTUNITIES IN MJO STUDIES

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The Madden–Julian oscillation (MJO) plays an essential role in connecting weather and climate. During the past decade, great progress has been made in observations, modeling, and theory of the MJO. There is a pressing need to synthesize our current understanding of the MJO, its impact on global weather and climate, and its prediction capabilities to gauge the progress in its study to be made in the coming decade. The International Workshop on the Madden–Julian Oscillation was held to meet this need.

The workshop included 128 participants from 39 institutes and universities from seven countries. There were 37 oral and 29 poster presentations. The workshop covered various scientific issues related to the MJO and included in-depth discussions. Recent progress in the MJO study was presented; gaps in

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### INTERNATIONAL WORKSHOP ON THE MADDEN–JULIAN OSCILLATION

**WHAT:** A workshop was held to synthesize our current understanding of the MJO, its impacts on global weather and climate, and its predictability to gauge the progress to be made in the study of the MJO in the coming decade.

**WHEN:** 6–9 August 2016

**WHERE:** Chengdu, China

our knowledge of understanding its global impact, dynamics, and predictability were identified; and future research targets were proposed. Highlights from the workshop are briefly summarized below. Presentation slides are posted at the workshop website ([www.lasg.ac.cn/mjo-workshop/](http://www.lasg.ac.cn/mjo-workshop/)).

**MAIN CONCLUSIONS.** *Interaction with other weather–climate phenomena.*

**PROGRESS.** The MJO is connected to many weather–climate systems globally. Its structure is crucial to its influence on the onset of the East Asian monsoon and tropical cyclone genesis in the western North Pacific and other basins. The MJO influences phenomena in remote areas, such as extreme precipitation in China and the western Himalayas, and the North Atlantic Oscillation (NAO) through its modulation on the western Pacific subtropical high, monsoon circulations, Rossby wave trains, subtropical jets, upper-level troughs, potential vorticity anomalies, and moisture and temperature advection. Its dipole heating structure produces a stronger extratropical response than monopole heating. Most MJO effects

on weather systems also depend on the El Niño–Southern Oscillation (ENSO) cycle and other factors. Even when MJO teleconnections are well reproduced in state-of-the-art numerical models, its impact on the Euro-Atlantic sector is still too weak.

ENSO modulation of the MJO is complex because of its diversities and interaction with the seasonal cycle. Interaction between El Niño and state-dependent MJO enhances El Niño’s amplitude and skewness, but limits El Niño predictability.

One of the most exciting discoveries in recent MJO studies is that MJO activities can be modulated by the quasi-biennial oscillation (QBO). MJO events with stronger amplitude, slower and more persistent eastward propagation, and longer periods tend to occur in the easterly phase of the QBO in boreal winter in both observations and global models. MJO prediction skill is usually higher during easterly phases of the QBO in boreal winter, especially when MJO convection is located over the Maritime Continent (MC).

#### RESEARCH RECOMMENDATIONS.

- The statistical significance of MJO effects on global weather–climate phenomena, especially for the extreme events, needs to be rigorously tested.
- Physical mechanisms for the MJO effects on NAO need to be identified.
- The degree to which the MJO impacts on the Euro-Atlantic sector are reproduced by numerical models needs to be explored.
- The potential impacts of El Niño on the predictability of the MJO should be further investigated.
- The possible physical connection between QBO and the barrier effect of the MC on MJO propagation should be explored.

#### *Initiation and propagation.*

**PROGRESS.** MJO initiation is still an unsolved problem. It may involve a number of processes. They include moisture advection by anomalous equatorial easterlies, anomalously high sea surface temperatures (SSTs) over the thermocline dome of the southern Indian Ocean, and anomalous ascending motion induced by anomalously warm advection, all associated with a preceding suppressed phase of MJO. Convergence of Rossby wave activity flux originating from mid-latitudes, especially the Southern Hemisphere, and internal stochasticity of organized convection may also play some roles in MJO initiation.

Eastward propagation of simulated MJOs depends on horizontal transport of lower-tropospheric mean moist static energy by its circulation, which is mediated by the seasonal mean low-level tropospheric

moisture pattern over the MC and western equatorial Indian Ocean.

The MC drew special attention at the workshop because of its barrier effect on eastward propagation of the MJO and the coming international project Years of the Maritime Continent (YMC) that will take place in 2017–19. A YMC pilot study (9 November to 25 December 2015) revealed a shift of maximum rainfall from land to the ocean during the active phase of the MJO. Propagation patterns of the MJO over the MC can be affected by the ENSO cycle, QBO, and the tropical Pacific–Indian Ocean combined mode. Furthermore, the percent of MJO events that do not cross the MC is higher in models than in reanalysis.

#### RESEARCH RECOMMENDATIONS.

- The barrier effect of the MC on MJO propagation should be more extensively documented in the observations and in model simulations.
- Physical mechanisms for the MC barrier effect and its exaggeration in numerical models and the dynamics that determine MJO behavior over the MC need to be further explored.
- The capability of general circulation models with stochastic parameterization of convection to simulate MJO convection may provide an important research opportunity.
- Special attention should be paid to initiation of the primary MJO events where stochasticity may play a central role.

#### *Theories.*

**PROGRESS.** This was a rare opportunity for four distinct MJO theories to be presented, compared, discussed, and evaluated by their leading proponents at the workshop. Moisture is explicitly included and the MJO is considered as a large-scale mode in the first three theories listed below.

#### *NEW “GENERAL” FRAMEWORK FRICTIONAL CONVERGENCE THEORY.*

This theory is an expansion of traditional frictional convergence theory in that it includes prognostic moisture and a simplified Betts–Miller cumulus parameterization scheme. The instability (growth), scale selection (planetary, slow eastward propagation), and vertical tilt of the MJO come from a three-way interaction among Rossby–Kelvin wave coupling, boundary layer frictional convergence, and moisture. The frictional convergence feedback plays an essential role in coupling Kelvin and Rossby waves with convective heating and selecting a preferred eastward propagation. The moisture feedback can enhance

the Rossby wave component, thereby substantially slowing down eastward propagation.

**“MOISTURE MODE” MJO THEORY.** This theory assumes that the free troposphere is regulated by weak tropical temperature gradients and that a strong coupling between MJO convection and free tropospheric water vapor regulates the dynamics of the disturbance. In this theory, prognostic moisture is advected by the steady-state Gill model response to convection heating. The MJO instability arises from cloud–radiation interaction and its impacts on moisture. The MJO propagates eastward because of the moisture advection induced by the wind anomalies. The most recent iteration of this theory uniquely produces an MJO that is dispersive with a westward group velocity.

**SKELETON MJO MODEL THEORY.** The MJO is presented as a neutrally unstable mode in a planetary-scale dynamical system forced by synoptic-scale convective activity. The model presented at the meeting is extended with inclusion of stochasticity of synoptic and convective activities to reproduce the intermittency, growth and decay, seasonal variation, and vertical tilt of the MJO through the inclusion of a passive second baroclinic mode which responds to congestus and stratiform heating. The important features of this theory include a slow eastward propagation; a quadrupole vortex structure in the horizontal; a vertical tilt; and the realistic interaction between the planetary dynamics, the planetary moisture field, and the planetary envelope of synoptic/convective activity, leading to intermittent statistical behavior of MJO events.

**GRAVITY-WAVE THEORY.** In contrast to the above theories that consider the MJO as a large-scale mode, this theory based on gravity wave dynamics treats the MJO as a large-scale envelope of high-frequency, small-scale gravity waves; their zonal asymmetry determines the eastward propagation of the MJO, and a scaling of convective strength and gravity wave speed selects its zonal scale.

Discussions covered different opinions on the roles of the second baroclinic mode, the MJO’s eastward propagation mechanism, the most salient structural elements needed to explain its dynamics, and the representation of the MJO dispersion relationship. The basic requirements that must be met by a successful MJO theory were also debated.

#### **Research recommendations.**

- A review article summarizing and comparing the existing MJO theories would facilitate their

general appreciation and further advancement of theoretical understanding of the MJO.

- Assumptions and parameters in MJO theories should be validated against observations in different seasonal mean backgrounds.
- Thought should be given to how to test all the theories against the observations and model outputs using the same diagnostic process.
- The observed irregularity of the MJO should be explained by successful MJO theories.

#### **Modeling and prediction.**

**PROGRESS.** What makes a model capable of simulating a realistic MJO has long been puzzling. It was reported that most global models capable of reproducing the MJO should exhibit realistic sensitivity of their parameterized convection to environmental moisture; a realistic convective adjustment time scale in response to departures from the moisture “quasi-equilibrium” state; and realistic vertical profiles in temperature, humidity, and diabatic heating. Different models disagree on the role of ocean coupling, surface flux feedbacks, and large-scale radiative–convective feedbacks to the MJO. While tuning model parameterizations can lead to improved MJO simulations, it is often at the expense of a deterioration elsewhere, including the mean state.

The MJO is a major source of predictability on subseasonal time scales (3–6 weeks). The predictability of precipitation over the United States can be enhanced by the MJO with its error growth slower than that on other scales. However, the current forecast skill of the MJO is good only around 3 weeks, in contrast to its intrinsic predictability of about 4–5 weeks. Several methods were reported to be useful for improving MJO prediction skill by several days. Coupling to an ocean model did not improve the MJO forecast skill significantly in the Beijing Climate Center’s model but did improve considerably in the NCEP forecast systems if accurate SST is produced. Stochastic perturbation ensembles such as SKEBS (Stochastic Kinetic Backscatter Scheme) and SPPT (Stochastically Perturbed Parameterization Tendencies) can improve the model mean state and variability, especially over the MC, and are valuable for exploring predictability and model predictive skill and uncertainty. To avoid ambiguity in prediction skill–translation from the anomaly correlation coefficient and root-mean-square error, several new methods of evaluating MJO prediction skill are proposed.

#### **Research recommendations.**

- The possible sensitivity of MJO diagnostics, for example, horizontal and vertical advection of

moisture static energy, to analysis domain size needs to be explored.

- The importance of radiation and surface flux feedbacks to the MJO should be quantified through cross-model comparisons.
- The possible dependence of the barrier effect of the MC on MJO propagation on model resolution should be explored.
- MJO forecast skill should be measured using new methods presented at the workshop.
- Possible relationships between forecast spread and skill among different models participating in the Subseasonal-to-Seasonal (S2S) Prediction Project should be identified.

#### *New data.*

**PROGRESS.** In situ observations play an invaluable role in validating global reanalysis and satellite data and in providing physical insights uncontaminated by deficiencies in numerical models and remote sensing retrievals. A large volume of in situ observations (atmospheric and oceanic profiles) have been collected from the South China Sea using GPS soundings, conductivity–temperature–depth (CTD) casts, and acoustic Doppler current profiler (ADCP) from ship cruises, automated weather stations, moored buoys, an air–sea boundary flux tower, a wind profiler, and other ground-based remote sensing instruments. Against these mooring and tower data, most biases in gridded latent heat flux products, which are relatively large in coastal regions, mainly

come from errors in near-surface specific humidity and wind speed. Networks of 170 surface stations, 34 weather radar sites, and 22 radiosonde sites have been established in Indonesia, augmented by measurements from ship cruises. These networks and the special field observations will constitute the main body of the YMC data archive.

The model database of the World Weather Research Programme/World Climate Research Programme S2S Prediction Project, already opened to the research community ([www.s2sprediction.net](http://www.s2sprediction.net)), provides a rare opportunity to quantify prediction skill of the MJO up to 2 months ahead as well as its global impacts.

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