meeting summary

A Workshop on the MJO and ENSO

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ABSTRACT

A workshop was held 15–17 March 2000 to discuss the possibility that the Madden–Julian oscillation (MJO) interacts with El Niño–Southern Oscillation (ENSO). The workshop explored a number of topics related to the MJO–ENSO problem, proposed a set of competing hypotheses, and made recommendations for future studies on this issue.

1. Introduction

Whether and how the Madden–Julian oscillation (MJO) may influence El Niño–Southern Oscillation (ENSO) are intriguing and controversial issues. Extraordinary MJO events in the winter of 1996/97 coincided with the onset of the 1997/98 ENSO warm event, which was unusual in its magnitude and rapidity of onset. Many dynamical coupled models, which do not contain explicit MJOs, did forecast the occurrence of a warm event some 9 months in advance. But many aspects of this warm event, especially the rapidity of onset and the maximum intensity of the warming, were unsatisfactorily forecasted. These unusual aspects of the evolution and forecasts of the 1997/98 warm event rejuvenated research interests on the MJO–ENSO problem and motivated a 3-day workshop on the MJO and ENSO. This workshop was held 15–17 March 2000 at the National Oceanic and Atmospheric Administration's (NOAA's) Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, New Jersey. The objectives of the workshop were to (i) bring out a full range of views on possible MJO influences on ENSO, (ii) summarize the knowns and unknowns related to this subject, and (iii) identify the most critical research areas that need to be covered in order to advance our understanding of the MJO–ENSO problem. Over 70 people from 8 countries, including 17 graduate students, were in attendance. The expertise of the workshop attendees includes modeling, theory, and observation of the MJO and ENSO; dynamical and statistical forecast of ENSO; and climate diagnostics.

The workshop consisted of a mixture of review talks, focused research presentations, and free-form discussions. The workshop focused specifically on 1) current ENSO prediction skill; 2) dynamics, air–sea interaction, and predictability of the MJO; 3) oceanic response to forcing of the MJO and wind bursts; 4) MJO as a source of stochastic forcing of ENSO; 5) the MJO–ENSO relationship in observations; and 6) MJO effects on climate prediction. A brief summary of the workshop is given in section 2. Hypotheses proposed and recommendations made by the workshop are presented in sections 3 and 4, respectively. Concluding remarks are given in section 4.

The workshop itself was an experiment with a limited number of oral presentations and unlimited time for discussion. The experiment was a successful one, judged by the reaction from its attendees. (More information on the workshop, including its background, agenda, list of attendees, and abstracts of presentations, can be found at the workshop Web site, http://orca.rsmas.miami.edu/mjomip/mjo.enso.workshop.)

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2. Summary

The summary in this section is a collection of main points from reviews, research presentations, and discussions on the six topics. They in many cases are inconsistent and even contradictory to each other, reflecting the controversial nature of the issues. They by no means represent any consensus of the workshop.

a. *Current ENSO prediction skill*

W. Higgins (National Centers for Environmental Prediction) discussed the relationships among ENSO, MJO, and U.S. climate variability from perspectives of climate prediction and monitoring. B. Kirtman (Center for Ocean–Land–Atmosphere Studies) summarized the current status of ENSO prediction.

Coupled models can in some circumstances make skillful forecasts of the occurrence of ENSO warm/cold events at lead times of 6-9 months. For the 1997/98 warm event, a consensus forecast based on an ensemble of forecasts from different runs of different models is most skillful. Skill was most apparent when forecasts were judged against observations over the entire Pacific basin instead of a particular index (e.g., Niño-3 SST). For the 1997/98 warm event, models had no significant skill at lead times beyond 9 months.

Common model forecast errors include false alarms of extreme (warm or cold) events; underestimation of the rapid development, intensity of SST anomalies, and the duration of warm events; and dislocation of maximum SST anomalies. Prediction of the demise of warm events is less skillful than predicting the onset.

Current ENSO forecast models that are capable of skillful prediction of ENSO warm/cold events up to about 9 months in advance do not maintain explicit MJO signals. A possible interaction between the MJO and ENSO is the eastward extension of MJO activities into the central Pacific during warm events, which is represented by an EOF mode found in observations. This EOF mode is missing in model forecasts. It is unclear whether improvement of ENSO prediction will result more from improved initial conditions or from improved model physics, which presumably would help maintain realistic MJO signals.

b. *Dynamics, air–sea interaction, and predictability of the MJO*

B. Wang (University of Hawaii) introduced the recent advancement in MJO dynamics. D. Waliser (State University of New York at Stony Brook) summarized various aspects of air–sea interaction associated with the MJO in observations and modeling. J. Slingo (University of Reading) discussed the interannual variability and prediction of the MJO.

Equatorial Rossby waves play as important a role in MJO dynamics as do Kelvin waves and can be even more important for air–sea interaction because they constitute the surface westerlies of the MJO. The mean background state of the atmosphere, especially the vertical shear of the mean zonal wind, affects the instability and structure of the MJO and its interaction with the ocean.

Fluctuations in the ocean associated with the MJO (roughly 0.2°–0.5°C in SST, 10–20 m in the thermocline depth, and 10–20 cm s^{-1} in mixed layer current) are an order of magnitude smaller than the oceanic variability associated with ENSO. But the variability in atmospheric deep convection associated with the MJO and ENSO is similar in magnitude. These suggest that air–sea coupling for the MJO is weaker than for ENSO. Observational and modeling studies indicate that air–sea coupling is not fundamental to the dynamics of the MJO. Ensembles of GCM experiments suggest that interannual variability of the level of the MJO activity results largely from atmospheric internal dynamics, with only a small contribution from interannual variations in SST. This implies limited predictability of the MJO on the interannual timescales. Air–sea interaction may, however, be important to the detailed characteristics of the MJO (e.g., its strength, phase speed, and seasonality) that can be essential to the study of the MJO–ENSO problem.

There is no unique index that measures well the interannual variability of the MJO and its relationship with ENSO. Spatial structures, especially those near the surface, must also be considered in addition to the spectrum and propagation speed to define MJO indices. Distinctions between the MJO and other types of intraseasonal variability [including westerly wind burst (WWBs)] that produce near-equatorial variations of wind and heat flux forcing are not clear. Limited observational records and quality make the observational study of interannual variations in the MJO difficult. These issues are further discussed in section 2e.

Most current atmospheric GCMs (AGCMs) cannot simulate realistically the MJO. Even the seasonality of the MJO, one of the strongest signals in observations, is not consistently reproduced in ensembles of AGCM runs. But we do not understand why this is so because of a lack of a comprehensive understanding of fundamental dynamics and thermodynamics of the MJO. What we know is that MJO simulations are sensitive to model configurations (e.g., vertical resolution, heating profile, and cumulus parameterization). Improving AGCMs' capability of simulating realistic MJOs is urgently needed.

c. *Oceanic response to the MJO*

P. Deleculse (Laboratoire d'Oceanographie Dynamique et de Climatologie) summarized effects of wind bursts in an oceanic GCM (OGCM). T. Shinoda [NOAA/Climate Diagnostics Center (CDC)] presented a composite of oceanic response to MJO forcing based on a global model reanalysis. C.-H. Sui [National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC)] compared oceanic responses to daily and monthly mean surface momentum and heat fluxes.

The robust oceanic response in the western Pacific to MJO/WWB forcing includes enhanced surface cooling, increases in mixed layer depth and vertical turbulence, and changes in the zonal current and its vertical shear. Remotely forced intraseasonal Kelvin waves act to deepen the thermocline in the eastern Pacific. Eastward advection of the warm pool in the central Pacific sometimes is observed. The dominant mechanisms for driving equatorial SST fluctuations due to MJO forcing vary with longitude: Enhanced surface heat fluxes lead to a surface cooling in the western Pacific, zonal advection leads to a warming in the central Pacific, and reduced upwelling leads to surface warming in the eastern Pacific. The Kelvin wave forced by wind stress in the west is responsible for the ocean response to the MJO in the central and eastern Pacific. SST variations at the eastern edge of the warm pool, resulting from both surface heat flux and oceanic advection, might be critical to interaction with ENSO.

The oceanic response to MJO forcing is sensitive to the ocean background mean state (including the annual cycle) as well as forcing itself. Vertical and meridional shear of currents; depths of the mixed layer and the thermocline; the existence and strength of a barrier layer; mean surface zonal wind; and the location, strength, frequency, and zonal fetch of surface wind perturbations are among the important factors. The oceanic response is also sensitive to the temporal resolution of surface forcing. Cooling due to high-frequency mixing induced by daily winds, for example, is much stronger than that due to monthly mean winds calculated from the same daily data. The mean state of the ocean determines the stability of the system. An unstable, oscillatory system is less sensitive to high-frequency surface forcing than is a marginally stable one. The mean state of the atmosphere also determines the mean rectification of intraseasonal zonal wind perturbations on wind speed and surface heat flux.

One large uncertainty is the relative importance of horizontal advection in the oceanic response to the MJO. One-dimensional mixed layer models forced by surface fluxes from global model reanalyses over the western Pacific warm pool can reproduce fairly well the amplitude and phase of observed intraseasonal variations in SST, even though the mixed layer heat and salt budgets at individual points are not balanced in the absence of advective effects. But advection apparently is not spatially coherent within the warm pool.

d. *MJO as a source of stochastic forcing of ENSO*

R. Kleeman (New York University) discussed the importance of stochastic forcing of the MJO based on analyses of the optimals of a coupled model. D. Neelin (University of California, Los Angeles), in analysis of a different intermediate coupled model, pointed out the importance of the temporal irregularity of the MJO to ENSO. P. Schopf (George Mason University) demonstrated how effects of noise on ENSO should be put into the perspective of the long-term variability of the background mean state of the system. A. Moore (University of Colorado) compared different model frameworks in the context of high-frequency forcing on ENSO. C. Penland (NOAA/CDC) discussed the effect of noise on ENSO based on an analysis of a statistical model.

ENSO variability and its predictability depends on both deterministic dynamics and noise. Effects of high-frequency (e.g., intraseasonal) noise on low-frequency (interannual) variability of the coupled system depend on the temporal and spatial structures of the noise as well as the stability of the system (dynamics). High-frequency variability in zonal wind stress is a main component, but not all, of the stocastic forcing of ENSO. In a linear sense, ENSO can be directly affected by noise only if the latter has a broad spectrum with a substantial projection on the interannual frequency band. This projection from intraseasonal variability such as the MJO and WWB may come from their irregularity and seasonality. The MJO oscillatory aspects associated with the 30–60-day spectral peak are therefore unimportant to ENSO, suggesting attention to the low-frequency tail of the frequency spectrum, to which the temporal irregularity of the MJO may contribute. On the other hand, the coupled system is more susceptible to noise if the latter bears a spatial structure resembling the optimals of the system. The frequency of noise in this case seems to be irrelevant. The relative importance of the temporal versus spatial structures of noise to the low-frequency variability of the coupled system remains as an issue of controversy.

The effect of noise on ENSO sensitively depends on the stability (or predictability) of the coupled system. Stochastic forcing of ENSO can be important or even essential when the system is stable (e.g., in the 1990s) but it may influence only the irregularity of ENSO when the system is unstable and more predictable from its dynamics (e.g., in the 1980s). The stability of the coupled system depends on the phase of the ENSO, the annual cycle, and the background mean state which varies at frequencies lower than that of ENSO (e.g., on decadal scales). The importance of high-frequency noise is therefore nonstationary.

Optimals and susceptibility to noise appear to be model dependent. In one model, which is sensitive to small changes in SST when SST is above a threshold (e.g., 28°C), the optimal exhibits a large-scale spatial structure in the western Pacific resembling that of the MJO, suggesting the potential role of the MJO as the only significant source of noise that may contribute to the error growth in the model. In another model, which is oscillatory and not sensitive to perturbations in surface heat flux, the optimal suggests that the main noise source is in the eastern Pacific and may be completely unrelated to the MJO. A particular simple model with limited physics and a particular set of parameters, therefore, may not capture all sensitivities of the coupled system to noise.

e. MJO–ENSO relationship in observations

B. Kessler [NOAA/Pacific Marine Environmental Laboratory (PMEL)] and J. Gottschalck (University of Miami) demonstrated why MJO–ENSO relationships should be accounted for by using local MJO indices in the Pacific. Using Tropical Atmosphere–Ocean buoy observations, M. McPhaden (NOAA/PMEL) discussed different mechanisms by which equatorial SST anomalies can be induced by the MJO. J. Bergman (NOAA/CDC) presented a heat budget analysis for the onset of different warm events. E. Harrison (NOAA/PMEL) and G. Vecchi (University of Washington) explained why it is WWBs, rather than the MJO, that are important to ENSO. T. Nakazawa (Meteorological Research Institute) discussed MJO–ENSO relationships as observed from a case study.

Part of the problem of making a strong case that the MJO significantly influences ENSO is the lack of clear statistical relationship between the two. Significant correlation can hardly be found for ENSO indices and conventional MJO indices based on global winds and convection. This leads to several competing explanations: (i) The MJO affects ENSO only as a source of stochastic forcing. No simple statistical relationship between the two should be expected. (ii) Empirical relationships between the MJO and ENSO depend on MJO indices used. MJO effects on ENSO, if there are any, must take place through air–sea interaction in the Pacific. Conventional MJO indices based on global wind data, necessary as objective measures of the capability of AGCMs to simulate the MJO, may not reflect local MJO activity in the Pacific. When indices based on or including local signals of the MJO in the Pacific are used, stronger statistical relationships between the MJO and ENSO are found. (iii) Influences of the MJO on ENSO depend on the mean state of the coupled system and therefore on individual events. Cases of a strong ENSO warm event (1982/83) following a moderate MJO season (1981/82), strong MJO activity leading to no warm event (1989/90), and a warm event (1997/98) preceded by strong MJO activity (1996/97) can all be found. (iv) ENSO is influenced by intraseasonal or subseasonal variability because of WWBs instead of the MJO. Not all WWBs are associated with the MJO. The main distinctions between the two are the following: WWBs are more frequent, smaller in zonal extent, and potentially less predictable than the MJO; the MJO has more coherent structures in winds, cloud, and precipitation than WWBs; the MJO propagates eastward and WWBs do not necessarily. They both can induce oceanic Kelvin waves. The quantitative differences between the effects on the ocean by WWBs associated with the MJO and those independent of the MJO have yet to be determined.

f. Effects of the MJO on climate prediction

A. Rosati (NOAA/GFDL) introduced an experiment of ENSO prediction in which surface winds were modified in a coupled model. F. Vitar [European Centre for Medium-Range Weather Forecasts (ECMWF)] discussed the effect of wind bursts on the 1997/98 ENSO warm event in the ECMWF seasonal forecast system. J.-P. Boulanger (University of Pierre and

Marie Curie) presented OGCM simulations of the 1997/98 warm event with a set of surface wind forcing. J. Anderson (NOAA/GFDL) discussed the sensitivity of ENSO prediction to initial conditions in a coupled model. W. Lau (NASA/GSFC) demonstrated the role of the MJO in tropical climate prediction from both observational and modeling points of view.

Dynamical ENSO prediction can be improved by improving surface winds in the western Pacific. The improvement might result from the effects of these surface winds on surface and subsurface temperatures and currents, mixed layer and thermocline depths, and sea level. At the surface, the most obvious effect is the eastward expanse of the western Pacific warm pool. SST responses in the central and eastern Pacific are small. The improvement is nevertheless modest and limited to enhancing the amplitude of warming. It depends on events and initial time. ENSO forecast can be sensitive to surface winds in the initial conditions. Differences in the direction and magnitude of surface zonal winds in the central as well as western Pacific in the initial conditions may decide whether warm or cold events will develop in 3–6 months.

The possible effects of the MJO on ENSO should not be separated from other phenomena in the Tropics, such as the Asian and Australian monsoons, the annual cycle, and the tropical biennial oscillation. Also, it is recognized that the climatic effects of the MJO are not limited to ENSO. MJO activities can affect other aspects of the short climate variability, such as seasonal precipitation in the western United States and tropical cyclogenesis in the eastern Pacific and the Atlantic Oceans.

3. Hypotheses

The broad spectrum of opinions on the MJO–ENSO problem can be summarized into the following competing hypotheses.

Hypotheses I: *ENSO is a low-frequency mode that exists aside from weather noise such as the intraseasonal variations (ISV). The roles of the ISV, as with other weather systems, are to provide a source of irregularity of ENSO and to limit ENSO predictability.* This hypothesis is based on analyses of coupled models. The indistinct role of the ISV in this hypothesis warrants no special focus on studying MJO/wind bursts in the context of ENSO and ENSO prediction. Maintaining realistic ISV signals in models is not necessary for improving ENSO prediction.

Hypothesis II: *Influences of the ISV on ENSO are unique and distinct from other tropical weather systems. The timing and strength of an ENSO event can sensitively depend on the ISV, but the ENSO cycle would still exist without the ISV.* This hypothesis is based on empirical case studies and model forecast experiments of recent warm events. In this hypothesis, even though the ENSO cycle does not fundamentally depend on the existence of the ISV, the characteristics and predictability of individual ENSO events do. Surface cooling due to enhanced evaporation and reduced solar insolation in the western Pacific, warming due to zonal advection in the central Pacific, and warming due to reduced cooling by equatorial upwelling in the eastern Pacific may all contribute to decreasing the basin-scale zonal gradient in SST, which may lead to a relaxation of the trade winds. The zonal asymmetry of the MJO, nonlinearity in air–sea interaction and in oceanic response are among the essential features for the rectification of high-frequency variability on ENSO. MJO activities would mainly limit ENSO predictability if its effects on ENSO sensitively depend on individual MJO events. They may increase ENSO predictability if their seasonality is more important.

Hypothesis III: *Stochastic forcing of the MJO is essential for maintaining the ENSO variability.* This hypothesis is based on analyses of a coupled model and observations. It does not exclude other possible mechanisms that may also cause ENSO, but stresses that an ENSO cycle can still be maintained only by the MJO should the coupled system be stable.

4. Recommendations

The workshop did not intend to endorse any particular opinion on the MJO–ENSO problem or place any particular research topic as a higher priority than others. The high level of controversy on this issue was considered as a sign of the need for further study. The workshop recognized that the study of the MJO–ENSO problem is now hindered by a number of factors. The incapability of maintaining realistic MJO signals in most AGCMs is probably the most outstanding problem. There is no systematic documentation of MJO signals in coupled GCMs, which should be useful tools for study of the MJO–ENSO problem. Contradictory results of MJO effects on ENSO from different models suggest likely model dependence of these results. Studying the oceanic response to MJO forcing requires three-dimensional dynamic and thermodynamic oceanic data, which are currently unavailable. To help overcome these obstacles, the workshop made the following recommendations:

1) A hierarchy of simple to intermediate coupled models, which explicitly resolve intraseasonal atmospheric variability and its interaction with the ocean, are needed to complement coupled GCMs and empirical studies.
2) Coupled GCM groups, especially Coupled Model Intercomparison Project participants, are encouraged to save high-frequency (1–5 days) output for the study of the MJO–ENSO problem.
3) Weekly ocean simulation/assimilation products for the Pacific are needed for the study of the MJO–ENSO problem.
4) A systematic documentation on the sensitivity of simulated MJO by atmospheric GCMs to model parameterizations and numerics is needed for improving models' capability of simulating realistic MJO.

5. Concluding remarks

The MJO–ENSO workshop was the first organized forum for the advocates and skeptics of MJO effects on ENSO to directly exchange their opinions. The organizers of the workshop are pleased that the disagreements expressed at the workshop were as sharp as they should be and there was no winning argument. The workshop reached at least one consensus: There are more disagreements than agreements on the MJO–ENSO problem.

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