The Experimental MJO Prediction Project

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Weather prediction is typically concerned with lead times of hours to days, while seasonal-to-interannual climate prediction is concerned with lead times of months to seasons. Recently, there has been growing interest in "subseasonal" forecasts—those that have lead times on the order of weeks (e.g., Schubert et al. 2002; Waliser et al. 2003; Waliser et al. 2005). The basis for developing and exploiting subseasonal predictions largely resides with phenomena such as the Pacific North American (PNA) pattern, the North Atlantic oscillation (NAO), the Madden–Julian Oscillation (MJO), midlatitude blocking, and the memory associated with soil moisture, as well as modeling techniques that rely on both initial conditions and slowly varying boundary conditions (e.g., tropical Pacific SST). An outgrowth of this interest has been the development of an Experimental MJO Prediction Project (EMPP). The project provides real-time weather and climate information and predictions for a variety of applications, broadly encompassing the subseasonal weather–climate connection. The focus is on the MJO because it represents a repeatable, low-frequency phenomenon. MJO's importance among the subseasonal phenomena is very similar to that of El Niño–Southern Oscillation (ENSO) among the interannual phenomena. This note describes the history and objectives of EMPP, its status, capabilities, and plans.

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One of the fundamental components in the development of this project was the recent activity in empirical prediction of the MJO. This not only indicated a strong interest in the problem, but also resulted in schemes that provided potential skill with lead times of 2–4 weeks. More formally, the project arose from two parallel developments. One was the first NASA-sponsored Subseasonal Workshop in April 2002, which recognized the importance of the MJO to potential skill in subseasonal predictions (Schubert et al. 2002). The second ensued from the U.S. Climate Variability and Predictability (CLIVAR) Asian–Australian Monsoon Working Group (AAMWG), which recommended the development of an experimental MJO prediction program due to the significant influence that the MJO has on the Asian–Australian monsoons.

An e-mail discussion among MJO forecast enthusiasts during the summer and fall of 2002 developed the framework for such a program. The program needed the technical and electronic management of a host, however—one with expertise in subseasonal phenomena and forecasting. Fortunately, the Climate Diagnostics Center of NOAA offered to host the project. Project organizers wrote to a number of forecast agencies, modeling centers, and empirical MJO modelers, inviting them to participate in the program. The overwhelming majority accepted the invitation, and the program proceeded to define its objectives and develop a framework for both science and logistics. These aspects were finalized at a meeting during the U.S. CLIVAR/NASA-sponsored second Subseasonal Workshop in June 2003.

OBJECTIVES. The overarching target of the project is the delivery of skillful predictions, with lead times of 1–4 weeks, of the tropical intraseasonal variability

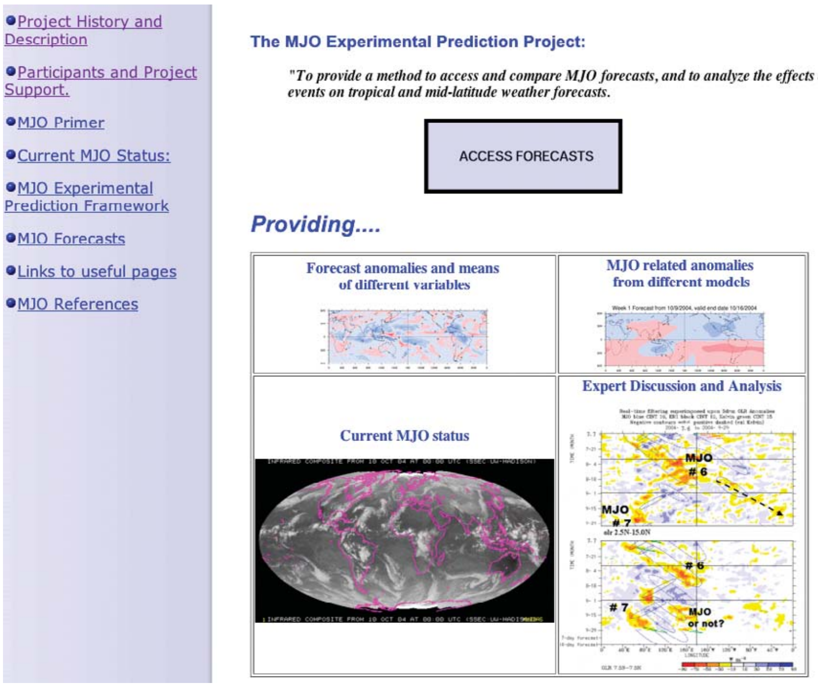

Fig. 1. The home page for the MJO Experimental Prediction Web site.

(namely the MJO), with an eye toward improving predictions of regimes and processes influenced by this variability. We recognize that the state of the MJO and its evolution is crucially important for the prediction of tropical variability at these lead times. In addition, skillful prediction of the MJO seems to be somewhat, or at least intermittently, important for extratropical weather forecasts at lead times of 1–2 weeks. At lead times of 3–4 weeks, the MJO may provide some forecast skill for predicting regime changes in the extratropical flow. In both the tropical and extratropical cases, skillful MJO forecasts could lead to useful predictive information on the probability of extreme events (e.g., U.S. West Coast storms and tropical cyclones). At lead times longer than 4 weeks, there is little expectation that the deterministic aspects of MJO forecasts will be of much use. At these and longer lead times, the importance of initial condition information starts to give way to the importance of boundary condition information, such as tropical SSTs (e.g., phase of ENSO). This indicates that the utility of the MJO forecasts at these longer leads may stem mainly from information regarding the predominant location of MJO activity which has been shown to be

Table 1. Participants and their forecast model contributions.

Contact	E-mail	Affiliation	Type of Forecasts
Matthew Wheeler	m.wheeler@bom.gov.au	BMRC, Melbourne, Australia	Mulitple linear regression
Matthew Newman	matt.newman@noaa.gov	NOAA–CIRES CDC	Linear inverse model
Huug van den Dool Hua-Lu Pan Suranjana Saha	vandendool@ncep.noaa.gov	NCEP/CPC	NCEP GFS ensemble GCM
Jeffrey Whitaker	Jeffrey.Whitaker@noaa.gov	NOAA–CIRES CDC	Circa-1998 MRF ensemble GCM
Oscar Alves	O.Alves@bom.gov.au	BMRC, Melbourne, Australia	BOM POAMA ocean–atmosphere coupled model
Matthew Wheeler	m.wheeler@bom.gov.au klaus.weickmann@noaa.gov	BMRC, Melbourne, Australia	Extrapolation of space–time filter of tropical OLR
Charles Jones	cjones@icess.ucsb.edu	UCSB	Regression model using filtered EOFs
Huug van den Dool	vandendool@ncep.noaa.gov	NCEP/CPC	Empirical wave-propagation model
Frederic Vitart	Frederic.Vitart@ecmwf.int	ECMWF	ECMWF ensemble GCM

influenced by El Niño and La Niña SST anomalies. Such relationships could be exploited to anticipate the level of subseasonal activity in a given season and region of the Tropics.

Once it can be established that useful forecast skill can be derived from the contributing models, whether empirical or dynamical, EMPP will collaborate with forecast agencies by contributing this forecast utility to their activities focused on week-2 and monthly predictions. In addition, the forecast and diagnostic information provided by the EMPP will make it easier to routinely diagnose and explain subseasonal weather anomalies. Finally, apart from its prediction purposes, EMPP is intended to be a basis for model comparisons. This includes using the forecasts and model error growth to learn more about, and possibly rectify, model shortcomings associated with the MJO.

Since the Web page (see Fig. 1) became active in November 2003, the project has been improving data transfer, pre- and post-processing of forecasts, Web page design, graphical delivery, and other issues. The Web site (**www.cdc.noaa.gov/MJO**) includes a project history, a primer on the MJO, a multi–time scale synoptic model based on the MJO, as well as a description of the forecasting and project framework, and of course the forecasts and validation analyses. The Web site came online just in time for a moderately active MJO season (December 2003–March 2004). By October 2004, forecasts from nine prediction systems—three GCM ensembles, one coupled GCM, and five statistical models—were being displayed (see Table 1).

SUBSEASONAL PREDICTIONS. In order to retain flexibility for future applications, contributed forecasts are expected to have daily resolution, consist of global 2.5° × 2.5° grids, and be updated daily, or at least weekly. These subseasonal predictions are displayed in a common graphical format so synoptic features and weather patterns can be easily compared. A real-time report synthesizes the forecast fields and discusses the dynamics of recent subseasonal climate anomalies.

To provide a focus, two different types of forecasts are emphasized: 1) the phase and amplitude of the MJO, and 2) the circulation variability in the Pacific/Americas (P/A) region. Currently, five models[1] more or less explicitly forecast the state and evolution of the MJO, as measured by either tropical outgoing longwave radiation (OLR) or diabatic heating. The other models are primarily general circulation models (GCMs) or coupled prediction models and require postprocessing of the forecasts in order to extract the MJO signal. A goal for the Web site is to use two-dimensional phase diagrams of the state and evolution of the MJO for both GCM and statistical model predictions (Wheeler and Hendon 2004). The MJO phase can then be used to help predict any number of variables or conditions (e.g., extreme precipitation over Australia and flooding in the Pacific Northwest).

The second type of forecast is of circulation anomalies in the P/A region, which is downstream of the evolving convection of the MJO. The impacts there should be large because of Rossby wave dispersion emanating from the convection anomalies. Coherent tropical–extratropical interactions and hemispheric symmetry in Rossby wave trains are prevalent in the region. The focus for this forecast type is on "regime" transitions over the P/A region and the extent to which they are associated with tropical forcing. The GCM forecast skill during transitions in the circulation will be studied (e.g., Weickmann and Berry 2006) as part of the project and will connect with similar studies on hindcast model datasets that are part of a larger community effort to assess subseasonal predictability (Waliser et al. 2003).

A linear inverse model developed by Winkler et al. (2001) for weekly averages will serve the project as a skill standard for predictions of both the MJO and subseasonal variability in general. It has been used in real time during two northern winters (1999–2000, 2000–2001) and proven to be a useful diagnostic tool. Forecast skill is derived from the MJO, the PNA, and El Niño, and the forecast skill can be predicted at the initial time as part of the model dynamics (Newman et al. 2003).

WEATHER–CLIMATE DISCUSSIONS. A weather–climate discussion posted on the project Web site highlights current subseasonal anomalies and physical processes for possible attribution and evaluates the predictions posted on the Web site. In addition, a subseasonal synoptic model (Weickmann and Berry 2006) is used to facilitate diagnosis, prediction, and attribution. The model consists of fast (synoptic-scale energy dispersion), medium (teleconnections), and slow (MJO) time-scale phenomena and their interactions in space and time.

[1] Multivariate regression, CDC experimental ensemble mean, lag regression, coherent OLR modes, and NCEP ensemble mean models.

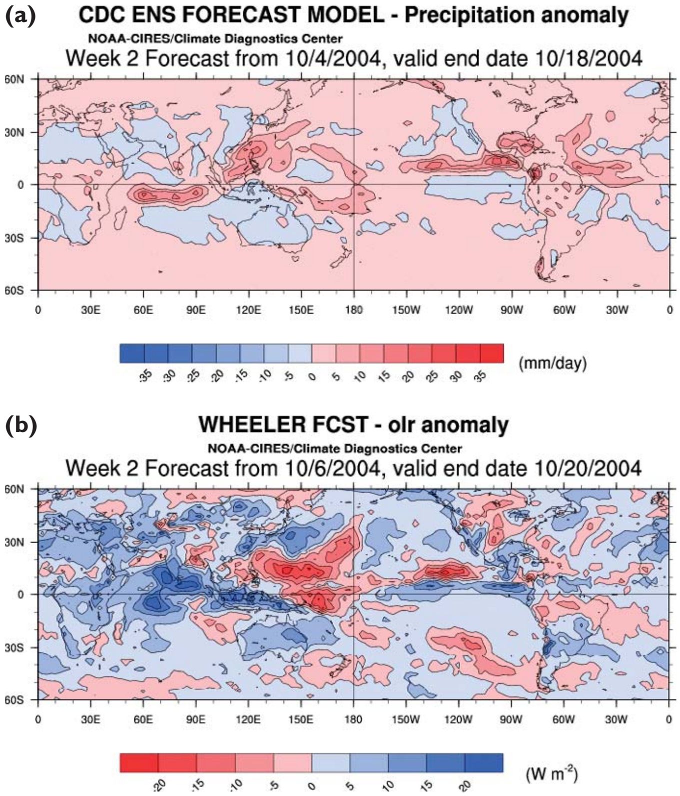

Fig. 2. An example of week-2 forecasts from the experimental website. They include (a) ensemble precipitation anomalies from a circa-1998 version of the MRF, and (b) outgoing longwave radiation anomalies from the Wheeler and Hendon statistical model.

The synoptic model has four stages that depict the growth, movement, and decay of multiple time-scale subseasonal phenomena during an MJO. The model is a subseasonal analogue to the well-known synoptic models of the extratropical cyclone and its life cycle. A primary goal of the development and application of this model is to understand the dynamical–physical processes that give rise to current circulation and weather patterns and to use this information to evaluate predictions from statistical and general circulation models. While the focus is on the MJO, transient continental-scale mountain effects and hemispheric-scale wave energy dispersion are also considered.

EXAMPLE FORECAST PRODUCTS. The forecast products available include: 1) spatial weekly means of five different variables; 2) time–longitude Hovmöller diagrams depicting a sequence of forecasts valid at a selected lead time; and 3) forecast verifications using spatial anomaly correlations. The Hovmöller diagrams provide a history of the forecasts and are useful for spotting systematic model errors or differences in climatology. They can also be verified by superimposing an observed field. A more conventional verification statistic is provided by the anomaly correlation.

Figure 2 shows week-2 predictions of precipitation and outgoing longwave radiation. When implemented, the LIM model will predict tropical diabatic heating. The diversity of variables presents a challenge, but the similarity of large-scale patterns can be assessed subjectively. In this particular example, the two model forecasts exhibit rather poor agreement between themselves. Additionally, not all model forecasts are up-to-date and valid at the same time. Efforts are underway to rectify such inconsistencies. Other variables available in a similar format as either means or anomalies include 500-hPa height, 200-hPa streamfunction, and 200-hPa velocity potential. The initial focus is on global anomaly fields, but eventually regional plots will be added, especially in the Tropics where the MJO is active. Not all models predict all fields, although in principle they could. Velocity potential is the most commonly predicted variable, but the vertical levels available are not the same. The project is striving to provide as much uniformity as possible of products across the models to facilitate interpretation and model forecast intercomparison.

Figure 3 shows a time–longitude Hovmöller diagram for tropical precipitation anomalies based on 12-h forecasts from the operational NCEP ensemble. The contours superimposed depict convectively coupled tropical modes, including the MJO, and are obtained using space–time filtering applied to outgoing longwave radiation data (for more on this technique, see Wheeler and Kiladis 1999). Subjectively, the 12-h predicted precipitation and the MJO envelope correspond fairly well, more so than for the CDC ensemble (not shown). The initial conditions generate realistic precipitation forecasts, at least for short leads. Figures 4a and 4b show week-2 forecasts from the NCEP GFS and the circa-1998 MRF ensemble (hereafter, CDC ensemble), both of which exhibit poor skill for this case. There is slight skill relative to the Wheeler and Kiladis coherent modes for the NCEP GFS, whereas the CDC ensemble responds mainly to near-equatorial positive SST anomalies (not shown), one in the Indian Ocean

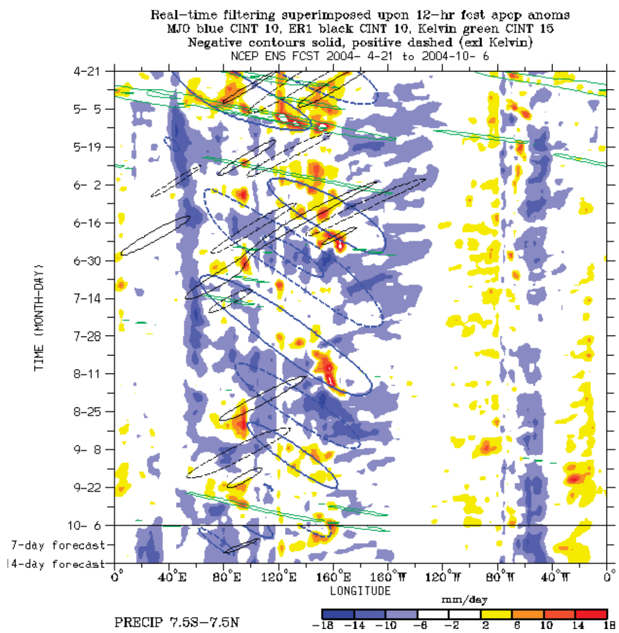

FIG. 3. Twelve-hour forecasts of precipitation anomaly for the NCEP GFS ensemble shown in time–longitude format, with color shading. Data are averaged between 7.5°N and 7.5°S. The line contours represent observed coherent OLR modes (Wheeler and Kiladis 1999) based on the outgoing longwave radiation anomalies; blue is the Madden–Julian Oscillation (MJO), black are equatorial Rossby waves (ER1), and green are equatorial Kelvin waves. The contour intervals are 10, 10, and 15 W m^{-2} for the MJO, ER1, and Kelvin modes, respectively. Good correspondence can be seen between the initial model predictions of precipitation and the envelope of the MJO. Beyond the date of 6 October 2004, the shading represents an actual 14-day forecast.

(~0.5°C) and another near the date line (~1.0°C). Quantitative verifications to be discussed below confirm the low skill.

Another difference between Figs. 4a and 4b is caused by using a consistent, lead-dependent model climatology when computing anomalies for the CDC ensemble, but an inconsistent reanalysis climatology when computing the GFS ensemble anomalies. Using the NCEP reanalysis precipitation climatology for the latter leaves a residual that is similar in magnitude to the actual anomalies (e.g., along 60°W). The reanalysis climatology has much more precipitation over the Eastern Hemisphere warm pool and much less over the Western Hemisphere ITCZs than the (apparent) GFS precipitation climatology. This illustrates problems that can be encountered when computing anomalies without a lead-dependent climatology for each model.

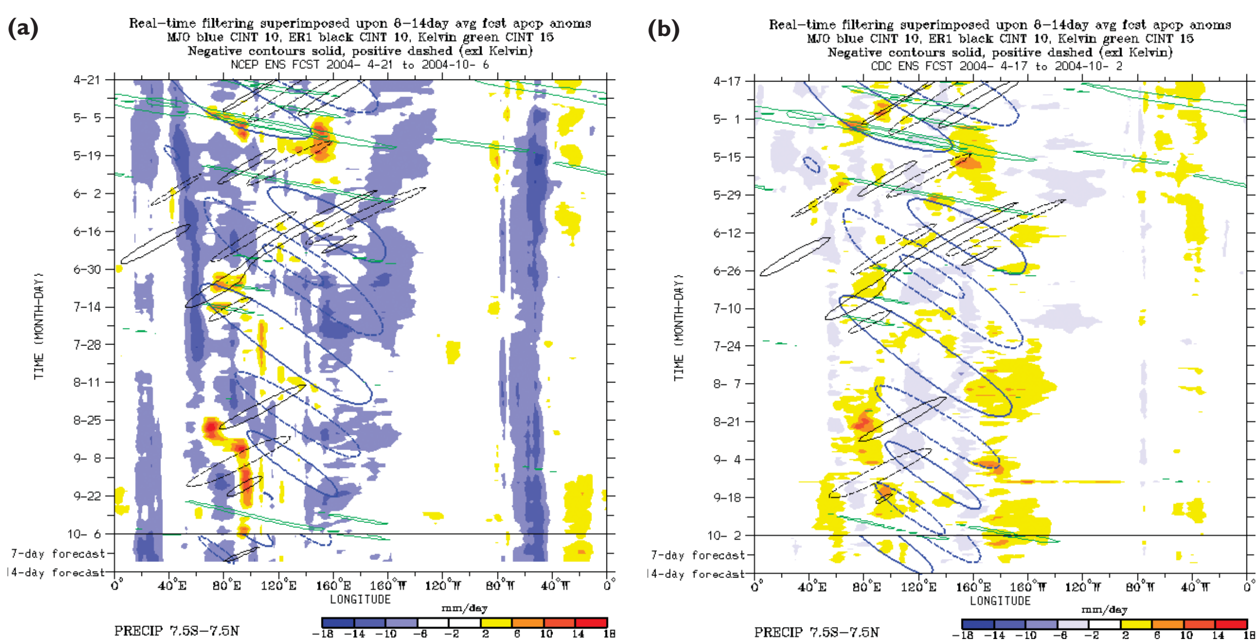

FIG. 4. Same as Fig. 3 except for week-2 (i.e., day 8–14) predictions of equatorial precipitation from (a) the NCEP GFS ensemble and (b) the MRF ensemble. Poor correspondence is seen between the MJO envelope (contours) and the precipitation predictions. In (a), the differences in the climatology between the GFS and the NCEP reanalysis dominates; in (b) where a consistent circa-1998 MRF climatology is used, the model is primarily reacting to persistent SST anomalies.

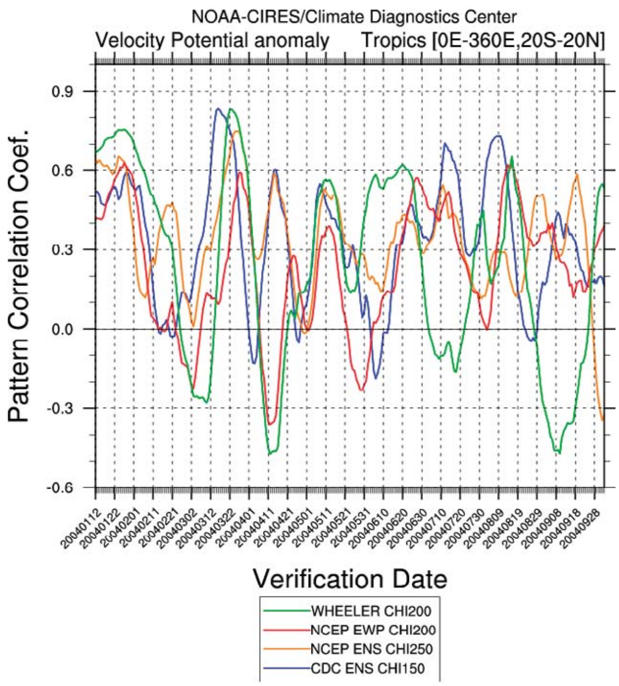

Fig. 5. The pattern correlation between day-11 predictions of the tropical velocity potential anomaly and the NCEP reanalysis "observed" anomaly for predictions made during 2004.

FORECAST VERIFICATIONS. The Web site includes simple verification statistics for some of the models using spatial anomaly correlations. In all cases, the verification field is the NCEP reanalysis, and, except for the CDC ensemble, the reanalysis climatology is used to compute anomalies. For the CDC ensemble, a lead-dependent model climatology is available. The ensemble mean forecast for day 11 is verified against the total daily anomaly from the reanalysis. Since daily data are being verified, the correlations are relatively low.

Figure 5 shows verifications of tropical velocity potential for four of the forecast models. On average, the correlation is about 0.3, but there are large swings in the coefficients, especially for the statistical models. The time variations do not appear simply related to the phase of the MJO. As expected, the skill is lower for GCM precipitation forecasts, about 0.1 over the warm-pool region (not shown). These preliminary assessments of day-11 forecast skill for the period of record are sobering and leave much room for improvement. An experimental program such as the one discussed here should help facilitate these improvements.

SUMMARY AND PLANS. The project plans to archive the forecasts so that diagnostic case studies can be performed. Currently, only the previous month is available, pending acquisition of additional computer hardware. Apart from this, other implementation issues concern how to deal with forecast models that do not have a lead-time dependent climatology (usually due to a limitation on computational resources), which is necessary to remove a model's systematic biases; the degree that coupled models and ensembles need to be or can be incorporated into the project; and the manner in which the MJO signal(s) are to be consistently extracted from the heterogeneous set of models (e.g., empirical and numerical).

Finally, the format, content, and length of the weather–climate discussions are still undergoing experimentation. There were some outstanding examples of MJO activity and tropical–extratropical interaction presented in the 15 weather–climate discussions posted to the Web site thus far. However, to date, the initiation and completion of these discussions has tended to be driven by available time, resources, and the current state of MJO activity. Ideally, these should be issued weekly and contain a section that explicitly summarizes the various predictions of the MJO; we hope to achieve this during the 2006–07 Northern Hemisphere winter season.

In summary, we hope this project will allow the community to take advantage of the potential skill in forecasting the MJO that is now present, and that will hopefully increase in the near future, as well as lend a modeling resource to those trying to remedy MJO simulation problems or diagnose interactions between the MJO and other aspects of weather and subseasonal variability (e.g., PNA, NAO). We would welcome any commentary, suggestions, or additional contributions. U.S. CLIVAR has recently accepted a proposal to establish a Subseasonal Working Group to, in part, focus on MJO modeling and forecasting issues; the goals and near-term plans for this working group are presently being formalized. Plans are also underway for a third workshop in 2007 to consider refinements to the project and Web site, new focus areas, and how to implement additional validation analyses, as well as to promote better connections to the operational forecasting communities.

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FOR FURTHER READING

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