POTENTIAL PREDICTABILITY OF THE MADDEN-JULIAN OSCILLATION

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The goal of this study is to provide an initial estimate of the dynamic predictability of the Madden-Julian Oscillation (MJO). While there have been a number of predictive skill studies of the MJO (i.e., comparing forecasts to observations) with statistical forecast models (e.g, Waliser et al. 1999a; Lo and Hendon 2000; Mo 2001) as well as with dynamical models with rather poor representations of the MJO (Chen and Alpert 1990; Lau and Chang 1992; Jones et al. 2000; Hendon et al. 2000), none of these provide a useful or adequate measure of dynamical MJO predictability. The NASA GLA general circulation model was chosen for this study due to its relatively realistic MJO representation e.g., Slingo et al. 1996; Sperber et al.1996). A 10-year control simulation using specified annual cycle SSTs was performed in order to provide initial conditions from which to perform an ensemble of twin predictability experiments. The initial conditions were taken from periods of strong MJO activity identified via extended empirical orthogonal function (EOF) analysis of 30-90 day bandpassed tropical rainfall.

From the above analysis, 15 cases were chosen when the MJO convection was located over the Indian Ocean, Maritime continent, western Pacific Ocean, and central Pacific Ocean, respectively, making 60 cases in total. In addition, 15 cases were selected which exhibited very little to no MJO activity. Two different sets of small random perturbations were added to these 75 initial states. Simulations were then performed for 90 days from each of these 150 perturbed initial conditions. A measure of potential predictability was constructed based on a ratio of the signal associated with the MJO, in terms of rainfall or 200 hPa velocity potential (VP200), and the mean square error between sets of twin forecasts. Predictability was considered useful if this ratio was greater than one, and thus if the mean square error was less than the signal associated with the MJO. The results indicate that useful predictability for this model's MJO extends out to about 20 to 30 days for VP200 and to about 10 to15 days for rainfall. This is in contrast to the time scales of useful predictability for persistence, which for this model is about 7 days for VP200 and 5 days for rainfall. Figure 1 illustrates these results for a representative region in the tropical western Pacific Ocean.

The predictability measure shows modest dependence on the phase of the MJO, with greater predictability for the convective phase at short (< ~5 days) lead times and for the suppressed phase at longer (> ~15 days) lead times. In addition to the dependence on the convective phase of the MJO, the model's predictability also exhibits dependence on the strength of the MJO. During periods of weak MJO activity, the predictability associated with the region of strong MJO variability (i.e. Eastern Hemisphere) is diminished compared to periods of strong MJO activity. Effectively, the same predictability ratios are found at significantly shorter lead times (~ 5-10 day difference) for the null cases versus the active MJO events. This diminished predictability is a result of an error growth rate comparable to the strong MJO activity cases in combination with weaker intraseasonal signals. Mean square forecast errors were also computed for EOF amplitude time series of the bandpassed model output to highlight the fact that the enhanced predictability at extended range is derived mostly from the first 2 modes, i.e., those that capture the model's representation of the MJO.

The above results have important implications for both the local regions that the MJO rainfall variations impact directly as well as regions that are influenced by the MJO via teleconnections. Present day atmospheric forecasts are largely directed toward predicting short-term weather variations from analyzed initial conditions as well as seasonal climate variations associated with seasonal/interannual changes in surface boundary conditions, namely from tropical SSTs. As yet, operational weather forecasts have largely been unable to exploit the relatively strong signal and slow evolution associated with the MJO (e.g., Waliser et al. 1999a; Jones et al. 2000; Hendon et al. 2000). This is due to the generally poor representation of the MJO in most AGCMs, except for a few research-oriented models (e.g., Slingo et al. 1996; Waliser et al. 1999b; Waliser and Hogan 2000). However, if the MJO could be better represented in operational weather forecast models, the above results imply that extended-range tropical forecasts in the regions directly impacted by the MJO could be greatly enhanced and/or extended. This includes a means to better predict the onset and break periods of the Asian-Australian summer monsoons that are so strongly determined by intraseasonal variations such as the MJO. In this regard, the improvement in forecast skill that might be possible with a model capable of simulating the MJO over one that poorly represents the MJO can be inferred from the enhanced predictability associated with the active versus null MJO cases discussed above (i.e. about 10 day improvement in lead time).

In addition to the local impacts that improved MJO prediction might offer, there are a number of remote processes whose prediction may improve as well. These include winter time mid-latitude circulation anomalies (e.g., Ferranti et al., 1992; Weickmann et al. 1985; Lau and Philips 1986; Higgins and Mo 1997; Mo and Higgins 1998b) as well as summer time precipitation variability over Mexico and South America (Nogues-Paegle and Mo 1997; Jones and Schemm 2000; Paegle et al. 2000). For example, a strong link has been found between rainfall variability along the western United States, including extreme events, and the longitudinal position of MJO convective anomalies (Mo and Higgins 1998a; Jones 2000; Higgins et al. 2000). If the results above represent even an approximate estimate of the predictability of the observed MJO, then extended range predictions (> 10 days) of this region’s rainfall variability could be greatly improved if our operational model representation’s of the MJO were more realistic. In addition, recent studies have also shown that particular phases of the MJO are more favorable than others in regards to the development of tropical storms/hurricanes in both the Atlantic and Pacific sectors (Maloney and Hartmann, 2000; Mo, 2000; Higgins and Shi, 2001). Again having operational forecasts that provide useful skill in predicting the MJO out to even 10-15 days would be of benefit to predicting periods of enhanced or diminished periods of hurricane and tropical storm development.

There are a number of caveats that should be noted regarding the above results. For example, there are model shortcomings that suggest the above results might be an underestimate of predictability of the MJO. For example, the model tends to have too much high frequency, low wave-number activity (Slingo et al. 1996). First, while the intraseasonal peak of equatorial wave-number one, upper-level velocity potential and zonal wind for the model is quite similar, in terms of magnitude and frequency, to observations, the model spectra has too much high frequency (~days) variability. Relative to the MJO, this variability would be considered to be un-organized, errant convective activity that may erode the relatively smooth evolution of the MJO and thus diminish its predictability. Second, these simulations were carried out with fixed climatological SST values. A previous study with this model showed that coupled SSTs tend to have an enhancing and organizing influence on the MJO, making it stronger and more coherent (Waliser et al. 1999b). Thus the exclusion of SST coupling may lead to an underestimate of the predictability as well. The third aspect that may lead to an underestimate the predictability is the fact that the model contains too little variability over the western Indian Ocean and southern Maritime continent region. The weakened MJO rainfall variations over this region may lead to a reduced predictability due to the model's relatively weak convection passing through this region, a region that exhibits a relatively robust convective signal in the observations. This tendency for underestimating the predictability is somewhat analogous to the manner the null cases showed reduced predictability, not because of an increased error growth rate but because of a reduced MJO signal.

A number of aspects associated with the model and/or analysis suggest that the above results might over estimate the predictability of the MJO. The first is that the model's coarse resolution and inherent reduced degrees of freedom relative to the true atmosphere may limit the amount of small-scale variability that would typically erode large time and space scale variability. However, it is important to note in this regard that the low order EOFs of intraseasonally filtered model output typically don't capture as much variability as analogous EOFs of observed quantities. Thus while it may be true that the model lacks sufficient small-scale variability which may erode MJO predictability, the model's MJO itself, as indicated above, still has room to be more robust and coherent which would tend to enhance predictability. In addition to model shortcomings, the simple manner that perturbations were added to the initial conditions may also lead to an overestimate of the predictability. The perturbation structure and the size of the perturbations may be too conservative and not adequately represent the type of initial condition error that would be found in an operational context. However, even if that is the case, it would seem that adequate size "initial" errors would occur in the forecast in a matter of a day or two and thus one would expect this aspect to overestimate the predictability by only a couple days, if at all. Future studies will examine the sensitivity of these results to the AGCM employed, to winter versus summer conditions, to SST coupling, mid-latitude variability, and El Nino state, as well as examine how sensitive these results are to the initial condition perturbations and definition of predictability.

For more complete details, see Waliser et al. (2001).

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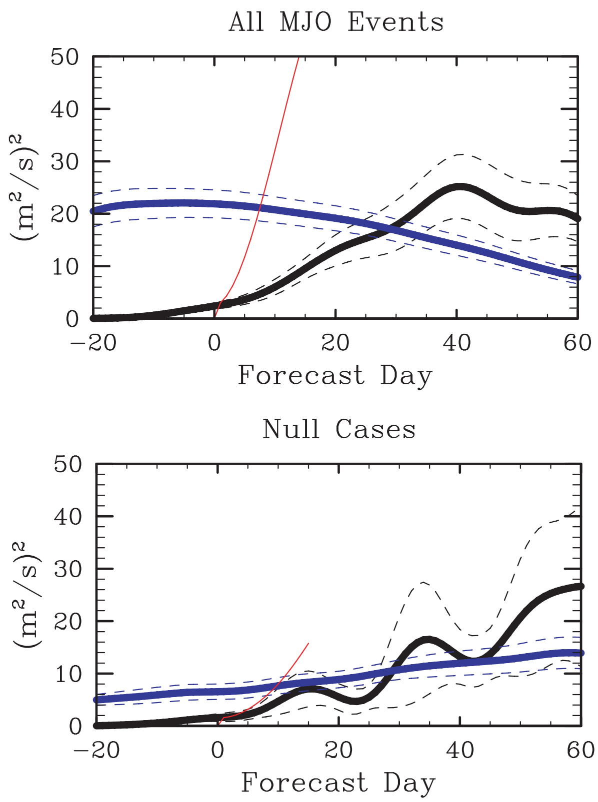

Figure 1: The thick solid black and gray lines are the mean squared forecast error and mean MJO signal, respectively, for the filtered (30-90 day) 200 hPa velocity potential over the western Pacific Ocean (4ºN-12ºS; 147.5ºE-162.5ºE) for the selected MJO events [upper panel (N=120)] and for the null cases [lower panel (N=30)]. The thin dotted black and gray lines depict the 95% confidence limits for these means using a student t-test. The thin solid gray lines are the mean squared forecast error for a persistence forecast; these are only plotted out to a lead-time of 15 days.