The Madden-Julian Oscillation in a Tropical Regional Model

Pallav Ray
MPO/RSMAS, University of Miami, Miami, FL

1. INTRODUCTION

The Madden-Julian Oscillation (MJO, Madden and Julian, 1971) is a dominant feature of low-frequency variability in the tropical atmosphere. The oscillation appears most clearly over the Indian and western Pacific Oceans, and involves large-scale coupled patterns in atmospheric circulation and deep convection. In essence, the MJO is a first baroclinic mode, equatorially trapped, convectively coupled, planetary scale (wavenumber 1-2) disturbance that propagates eastward at a phase speed of about 5 m/s. Convective coupling diminishes east of dateline and ceases to exist in the eastern Pacific, but the wind component may propagate eastward as free waves at about 12-15 m/s. The planetary zonal scale, slow eastward propagation, and coupling between the winds and deep convection, differentiates the MJO from other types of intraseasonal phenomenon in the tropics.

The MJO has been the subject of intense research as it tests our understanding of the tropical circulation, and also because of its apparent relationship with the Indian summer monsoon, likelihood of tropical storms, and the initiation of El Nino events. There have been considerable advancements in relation to the multiscale structure of convection, its vertical structure, and air-sea interaction. Yet, an understanding of the MJO has been elusive. Most MJO theories fall into one of the following categories. (i) Local forcing or discharge-recharge theories (e.g., Hu and Randall, 1994). (ii) Extratropical forcing (e.g., Matthews and Kiladis, 1999). (iii) Wave-CISK theories (e.g., Lau and Peng, 1987). (iv) Surface evaporation feedback theories (e.g., Emanuel, 1987). Most of them do not quantitatively predict the selection of the observed spatio-temporal scales of the MJO. The slow eastward propagation of the MJO has been the least explained by theories or simulated by global models. Most models underestimate the strength of the intraseasonal variability and fails to capture the seasonality. If a model cannot produce the MJO, it can produce errors by missing interactions within the tropics (e.g., MJO-ENSO interaction), and also by missing interactions between tropics and extra-tropics.

We use the fifth-generation Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model (MM5; e.g., Dudhia, 1993) to look at the MJO dynamics in relation to its initiation and propagation. In a regional model, any feedbacks with the rest of the globe are controlled through the boundary conditions, which allows for several MJO-related experiments that would not be possible using GCMs. For example, any signal related to prior MJOs can be filtered from the boundary forcing to see how external influences affect the MJO. Another advantage of using a regional model is the potential increase in resolution. This could allow to study the interaction between cloud clusters and the large-scale convective envelope of the MJO at different stages of its life cycle.

2. MODEL AND DATA

The standard MM5 is modified to require only north and south boundary conditions. The east-west boundaries join with a small overlap, which eliminates the need for a lateral boundary condition in the zonal direction. The model employs a mercator projection domain centered at the equator and the north-south boundaries can be moved according to the user's need. We call this as tropical MM5. The NCEP global tropospheric analysis (final or 'FNL' data, 1.0^o x 1.0^o, 6 hourly) is used to initialize and force the model boundaries. The model output is compared with several independent datasets such as NCEP-NCAR reanalysis. We run the model (111 km resolution, area coverage 0^o-360^o, 20^oS-20^oN) from March to September 2002 as there were strong MJO events during this time (May and June-July).

3. RESULTS

The first step to check the model's performance is to see whether the model is able to produce the mean background state (figure 1), since it has always been considered vital to the dynamics of the MJO. For the 200 mb level, the model and the observed means are quite similar with no apparent systematic bias. The wind direction (not shown) also agrees well in the domain. A strong wind of 15 m/s (easterly) south of India is not captured by the model. Looking next at the 850 mb winds, the model introduces an easterly wind bias of approximately 5 m/s in the eastern half of the domain. The seven month model run covered the south-west monsoon period (June to September). Thus, the difference in the Indian monsoon region in particular and for the whole domain in general, could be due to insufficient land area within the model domain to properly drive the monsoon. Comparison of other variables also yielded similar results.

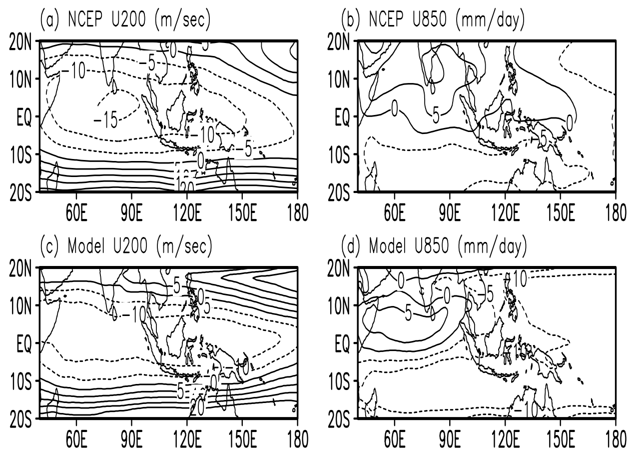

Figure 1: March to September (2002) means of zonal wind at 200 mb (U200) and 850 mb (U850) from the model and NCEP. Dotted contours show the easterly winds.

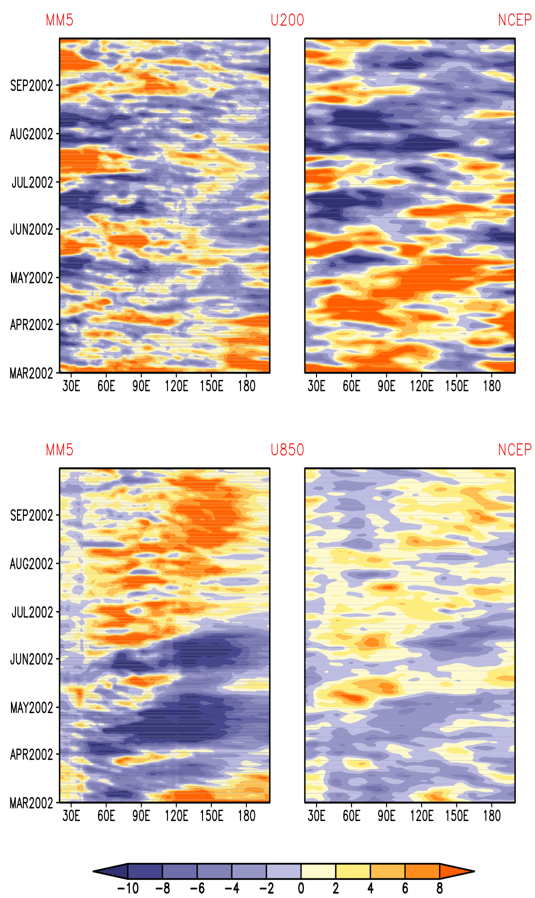

Figure 2: Hovmoller diagram for U200 and U850 daily anomaly (m/s) from the model and NCEP.

A qualitative idea about the model's performance in simulating the MJO can be gained from studying Hovmoller diagrams. A more quantitative approach like spectral analysis and EOF technique will be the next step. Figure 2 shows the model and NCEP zonal wind anomalies averaged over 10^oS-10^oN. The model is able to capture the MJO (clearly evident with strong, eastward propagating westerly wind bursts) occurring in the month of May and June-July. In these two events, the model matches well with the observation even with respect to the eastward propagation speed of about 5 m/s, which is thought to be the most difficult problem in simulating the MJO. The strength of the model anomalies at 850 mb are stronger than the NCEP. The stronger 850 mb wind in the model shows the similar bias seen in the 7-month means in figure 1. The model anomalies are also stronger compared to observations for OLR and precipitation (not shown).

4. CONCLUSION AND FUTURE WORK

Unlike the GCMs, the tropical MM5 can be utilized to diagnose a wide range of scales utilizing the nesting capability, and would be a great tool to investigate the circumnavigating features in the tropics associated with the MJO, which would not be possible using a regular regional model. The model was able to capture the mean state of the atmosphere, and eastward propagation of the anomalies associated with the MJO, although with bias in magnitudes. The fact that the observed large-scale atmospheric structure can be reproduced but is over/underestimated in our simulations suggests that its primary cause is related to large-scale dynamics, which are well represented in the model; but its strength might depend on physical processes that have to be parameterized well. Model resolution was somewhat coarser, which might have restricted the model's capability. We propose to conduct several numerical tests to understand the MJO mechanism, and to answer some of the existing questions such as (i) Are the circumnavigating equatorial waves important? (ii) Are the extra-tropical influences necessary and to what extent? (iii) To what extent local forcing (recharge-discharge) is important? (iv) How does the MJO affect other parts of the tropics? A detail procedure for numerical testing and data analysis to answer the above questions is beyond the scope of this report.

Acknowledgments

Thanks to Chidong Zhang for his advice. The help by Joe Tenerelli with the model is greatly appreciated.

5. REFERENCES

Dudhia, J., *MWR*, *121*, No.5, 1493–1513, 1993.
Emanuel, K.A., *JAS*, *44*, 2324-2340, 1987.
Hu, Q, and D.A. Randall, *JAS*, *51*, 1089-1099, 1994.
Lau, K.M., and L. Peng, *JAS*, *44*, 950-972, 1987.
Madden, R.A., and P.R. Julian, *JAS*, *28*, 702–708, 1971.
Matthews, A.J. and G.N. Kiladis, *MWR*, *127*, 661–667, 1999.