Global Multiscale Modeling on NASA Supercomputers:  
Extended-Range Simulations of MJOs and AEWs

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I. INTRODUCTION

It has been suggested that large-scale tropical weather systems, such as the Madden-Julian Oscillations (MJOs) and African Easterly Waves (AEWs), may regulate the activities of tropical convection (e.g., CAMm and Hartmann, 2000), thereby influencing regional precipitation. To this end, improving predictions of MJOs or AEWs might be helpful for extending the lead-time of TC predictions. Due to insufficient resolution in traditional climate models, cumulus parameterization (CP) plays a major role in simulating the effects of unresolved convection for over 40 years. Though the assumption of CP in Madden-Julian Oscillations (MJOs) is consistent with the multiscale interactions between large-scale and convective-scale flows in numerical models, the artificial equilibrium scale for the interactions (e.g., relaxation time) is now believed to restrict the timing and location of the convection initiation, thereby creating uncertainties in the initiation of MJOs and TCs in numerical simulations. In this study, we newly developed a high-resolution global model (e.g., Shen et al., 2006a,b) using a multi-scale modeling framework (BMF, e.g., Tao et al., 2009), both of which can run without CP dependence, are used to examine the impacts of resolved convection (over ocean and land) and their interactions with the troposphere using the simulations of MJOs and AEWs. Finally, we show that improved representations of the convection interactions with our modeling system are key for extending the lead-time of predicting severe storms (e.g., Nargis, 2008), which devastated in Burma (Myanmar) in May 2008 and caused tremendous damage.

2. NASA SUPERCOMPUTERS AND GLOBAL MULTISCALE MODELING SYSTEMS

Global multiresolution simulations in late 2004 with (1) 72-ES Grid supercomputers, each with 512 CPU cores (2.2 GHz) for 1,000 h total memory (Brown et al., 2007), in a new supercomputer, we used up to 33,000 CPU cores (4,500 GHz) to run the 128-kernel simulations (Figure 2), which allows us to examine numerical results while model is still running.

The NASA high-resolution global model (a.k.a. Global Multiscale Modeling System (GMMS)) can be decomposed into the following components: (1) finite-volume dynamical core (e.g., Lin, 2004, M04); (2) NCAR Community Land model; Facilitated by NASA SUPERCOMPUTERS and GLOBAL MUSIMULATION SYSTEMS. Developing and implementing new models and simulations of an MJO in May 2002, which is found to be a crucial element for the prediction of TC activity (Figure 8). This model TC resembles the Hurricane Helene (2006) and, in addition, we demonstrate with the TC Nargis, which was the last case in this study, we perform extended-range simulations of an MJO in 2005 and 2006 in the NASA high-resolution models. Caribbean activity (Figure 10), which is the deadliest named tropical cyclone (TC) in the Indian Ocean in May 2005. It caused tremendous damage and numerous fatalities (Table 1). The increased lead-time in the prediction of TC Nargis would have increased the warning time and may therefore have saved lives and reduced economic damage. Our global high-resolution simulations using real data show that the initial formation and subsequent evolution of TCs can be realistically predicted well in advance of the time of formation (Figure 11). Experiments also suggest that the accurate representations of a weakly-sheared wind burst (Figure 12) and an equatorial trough, associated with monsoon circulation (Figure 13) and a Madden-Julian Oscillation (MJO), may be important for predicting the formation of this kind of TC. Favorable factors for the formation and intensification of TCs are summarized in Table 2. More detailed discussions can be found in Shen, Tao, and Luo (2008, to be submitted).

Table 2: TC Nargis fast facts

- Deadliest named cyclone in the North Indian Ocean Basin
- Short lifecycle: from 04/27 03Z to 05/03 00Z (by the JTWC)
- Very intense with 108 hPa and peak winds of 120 m/s

Table 1: TC Nargis fast facts

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- A high-intensity storm with 108 hPa and peak winds of 120 m/s
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Figure 7: Time-longitude of 200-hPa velocity potential. This shows the movement and intensity of the model MJO is modulated by a semi-diurnal cycle.

Figure 8: A comparison of GPS analysis data (left) and 15-day simulations of an MJO initialized at 0000 UTC May 2 2002 with the global reanalysis model (GSM, middle) and BMF (right) simulations of an MJO (dotted line) shows good agreement in 10-day resolution. Both simulations produce realistic representation of MJO signals. However, GSM simulates the MJO with a faster propagating speed than BMF with an overestimated intensity.

Figure 9: Genesis of a TC in the 20-day simulation validated on September 11, 2005. Left panels from left to right show minimal sea level pressure and low-level wind vectors at 0000, 0600, 1200, 1800 UTC, respectively. This model TC resembles the Hurricane Katrina (2005) with respect to genesis location and timing.

5 RESULTS

Figure 6: A comparison of forecasts of genesis location and timing. This shows the movement and intensity of the model MJO is modulated by a semi-diurnal cycle.

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Figure 10: Satellite images over the Indian Ocean in late 2005. (a) Tropical cyclones Durge and Rose south of a weak wind burst (BMF) at 0000 UTC 22 April. (b) When the BMF moved northeast, TC Nargis formed at 0200 UTC 22 April 2005.

Figure 11:Intense development of TC Nargis from 104 to 144 h of integration (red) in a 7-day simulation, as compared to the observed satellite derived intensity (blue).

Figure 12: Northward movement of the weekly wind burst, as shown in time-longitude of averaged zonal winds from 22 to 29 April. (Panels from left to right) 850-hPa zonal winds averaged over 11°S (0.9%), 15°S (1.9%), and 25°S (10%) respectively.

Figure 13: Minimum temperature equatorially as shown in the height-latitude cross section of zonal winds. This figure shows favorable conditions for TC formation: low-level (upper-level) cyclonic (anticyclonic) circulation.

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In this study, we performed extended-range simulations of an MJO in 2005 and 2006 in the NASA high-resolution models. Our results show excellent agreement in 10-day resolution. We believe that these simulations can improve our understanding of the complex interactions between the MJO and TCs. However, additional studies are needed to further improve our understanding of these interactions.

Acknowledgments

This research was supported by the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the Department of Energy (DOE). We would like to thank Drs. B. Bryan and D. C. Herring for helpful discussions. This work was funded by the NASA Global Modeling and Assimilation Office (GMAO) and the National Center for Atmospheric Research (NCAR). E. Chesser, M. Kuo, and W. Shen would like to thank the NASA Headquarters and the NASA Earth Science Technology Office (ESTO) for financial support. We also thank the Supercomputing Applications Center (SAC) at the University of Maryland and the Center for Climate Simulation for their support.

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