Extended-Range Predictions of Madden-Julian Oscillations with the Goddard Multi-scale Modeling System

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1. INTRODUCTION:

It is well known that accurate prediction of tropical activity at sub-seasonal scales (~30 days) is crucial for extending the predictability of numerical weather prediction (NWP) beyond two weeks. Among the challenges in predicting tropical activity is the accurate forecasting of an MJO (Madden and Julian 1972, 1994), which is one of the most prominent large-scale features of the tropical general circulation with a 45-60 day time scale. It is typically characterized by deep convection originating over the Indian Ocean and subsequent eastward propagation into the Pacific Ocean. Current understanding (including theory and hypotheses) indicates that (1) moisture convergence (e.g., Lau and Peng 1987; Wang 1988), (2) surface heat and moisture fluxes (e.g., Emanuel 1987; Neelin *et al.* 1987), (3) cloud-radiation feedback (e.g., Hu and Randall 1994, 1995), (4) convection-water vapor feedback (e.g., Woolnough *et al.* 2000; Tompkins 2001), and (5) "discharge-recharge" associated with moist static energy build-up and release (e.g., Blade and Hartmann 1993) are important for the MJO's initiation, intensification, and propagation (see a review by Zhang 2005).

By taking advantage of existing global and cloud models, the so-called MMF provides an innovative approach for understanding these multiple processes and multi-scale interactions. While the MMF approach has shown promising long-term simulations, its performance on short-term and/or extended range simulations is less understood. Compared to climate simulation, which is viewed as a boundary value problem, short-term weather simulation/forecasting is an initial-value problem. Therefore, it is argued that accurate sub-seasonal forecasts may depend on the accurate representation of both initial and boundary conditions, suggesting the importance of model initialization. In this case study, we will address the Goddard MMF's suitability for short-term and extended-range weather forecasts, which are aimed at improving the model's ability to simulate sub-seasonal weather systems.

2.THE MULTI-SCALE MODELING SYSTEM:

A multi-scale modeling system with unified physics (Figure 1) has been developed at NASA Goddard Space Flight Center (Tao et al., 2008). The system consists of an MMF, the coupled NASA Goddard finite-volume GCM (fvGCM) and Goddard Cumulus Ensemble model (GCE, a CRM), the state-of-the-art Weather Research and Forecasting model (WRF) and the stand alone GCE. These models can share the same microphysical schemes, radiation (including explicitly calculated cloud optical properties), and surface models that have been developed, improved and tested for different environments.

The Goddard MMF consists of the fvGCM at 2°x2.5° resolution and 13,104 GCEs, each of which is embedded in one grid cell of the fvGCM (Fig. 2a). The fvGCM was parallelized with both MPI and OpenMP paradigms. Since it would require a tremendous effort to implement an OpenMP parallelism into the GCE or to extend the 1D MPI domain decomposition to 2D in the fvGCM, the early version of the MMF merely inherited the fvGCM's 1D MPI parallelism.

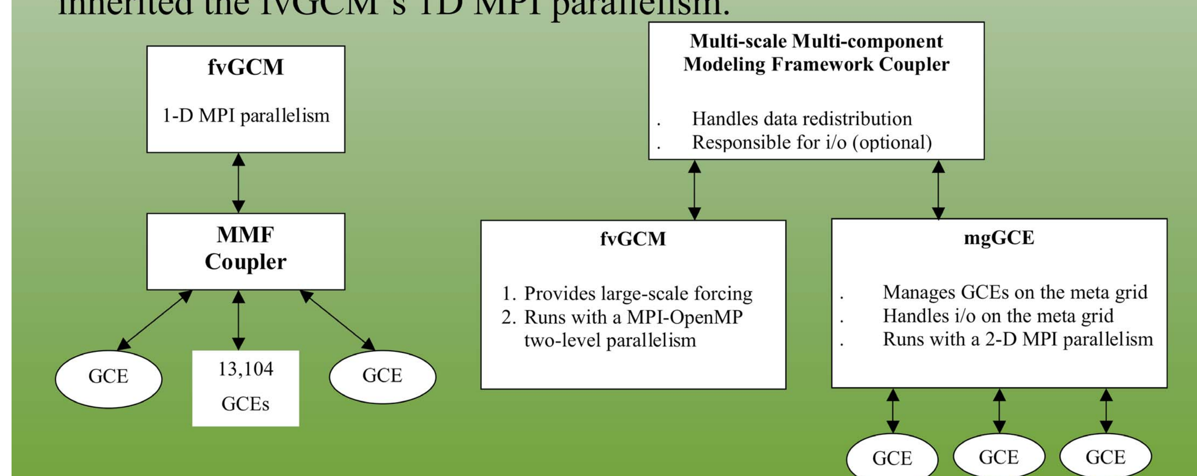


Figure 2: The original (left panel) and revised (right panel) parallel paradigms for the Goddard Multi-scale Modeling Framework.

3: RESULTS

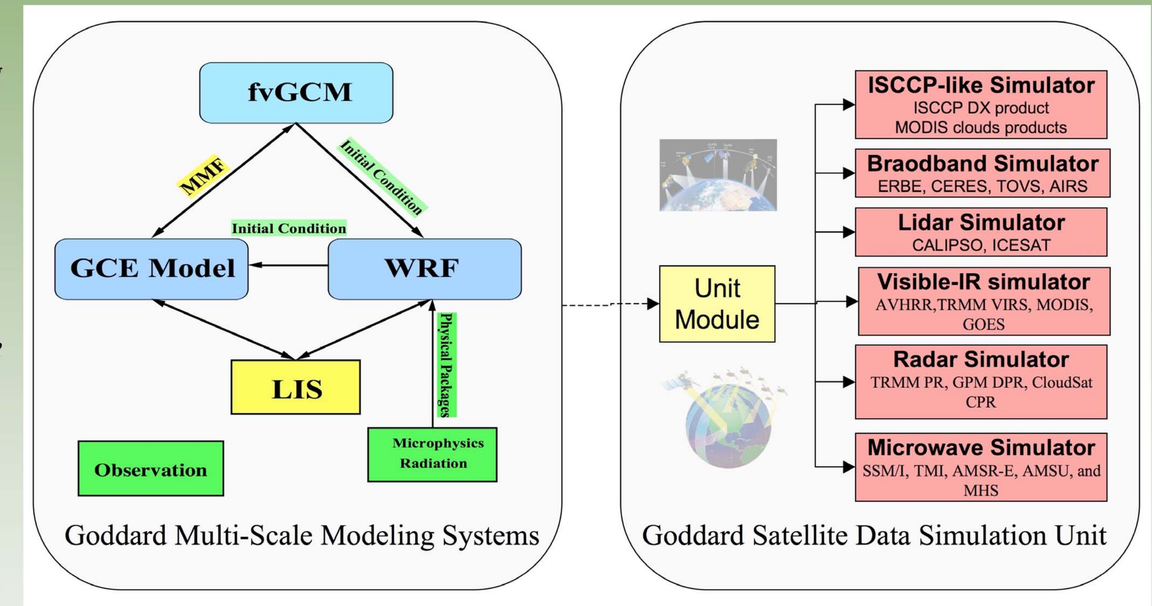


Figure 1. Goddard Multi-scale Modeling System with unified physics. The coupling between the fvGCM and GCE is two-way [termed a Multi-scale Modeling Framework (MMF)], while the coupling between the fvGCM and WRF and WRF and the GCE is only one-way. LIS is the Land Information System developed in the Goddard Hydrological Sciences Branch. WRF has been enhanced by the addition of the GCE model's physical packages (i.e., microphysical schemes, and short and long-wave radiation schemes; Tao et. al. 2008).

To relax this computational limitation, we take a different computational approach by viewing the 13,104 GCEs as a *meta global GCE* (mgGCE) in a *meta gridpoint system*, which includes 13,104 grid points. This grid system, which is not tied to any specific grid system, is assumed to be the same as the latitude-longitude grid structure in the fvGCM for convenience. With this concept, each of the two distinct parts (the fvGCM and mgGCE) in the MMF could have its own scaling properties (Fig. 2b). A prototype parallelism implementation shows very promising scalability, giving a super-linear speedup as the number of CPUs is increased from 30 to 364 and higher (Shen et al. 2008). Further computational improvement is being conducted.

Dynamic initial conditions (ICs) and sea surface temperature (SST) are derived from GFS analysis data and optimum interpolated SSTs from the National Centers for Environmental Prediction (NCEP). ICs for physics, land surface fields, and cloud fields are obtained from the 2-year run using the computationally-enhanced MMF. Figure 3 shows the annual mean cloud liquid water path (LWP) from the MMF, global analysis and satellite data. The MMF simulated LWP resembles, in some degrees, the ECMWF analyses and the satellite estimates in terms of overall morphology, although the modeled values are slightly higher in particular over Warm pool. In addition, the comparisons between modeled total IWP (snow, ice and graupel) and CloudSat total IWP agrees relatively well in terms of spatial distribution and magnitudes (Figure not shown; Duane et al. 2008, submitted).

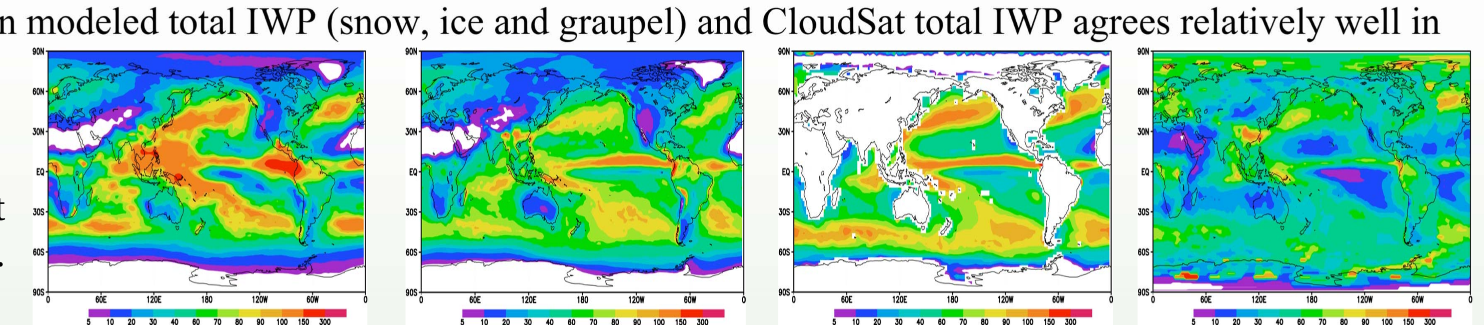


Figure 3. Annual mean values of cloud liquid water path (LWP, g m^{-2}) from (a) the fvMMF (01/2005-12/2006), (b) ECMWF R30 analysis (08/2005-07/2006), (c)SSM/I (7/2002-6/2007), (d) CloudSat (8/2006-7/2007) for total LWP (Li et al., 2008, GRL, submitted).

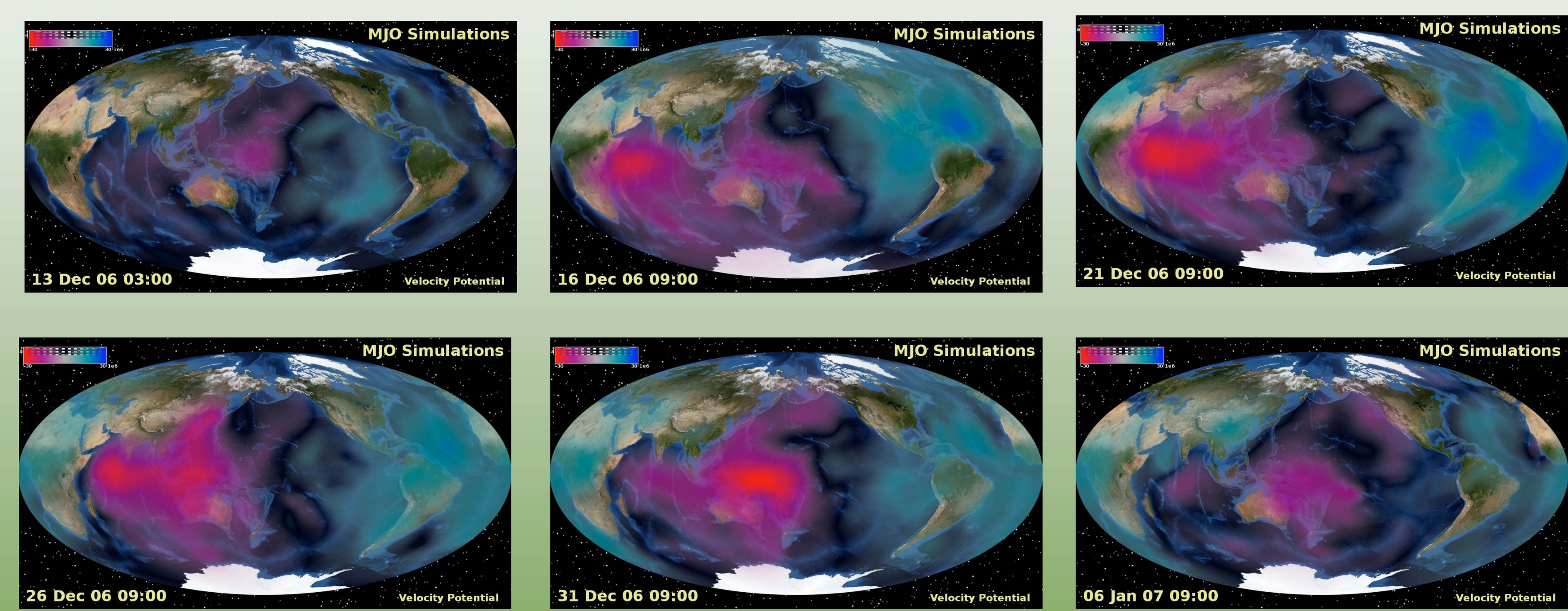
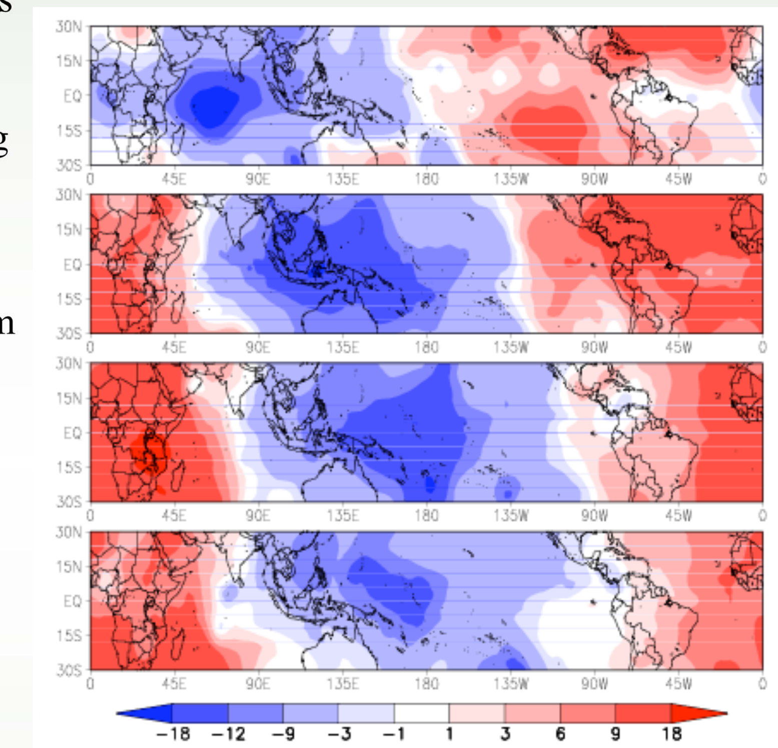


Figure 4: A 30-day simulation of an MJO initialized at 0000 UTC December 13, 2006. Top panels (from left to right) are 200 hpa velocity potential at 0300 UTC December 13, 16, and 21, respectively. Bottom panels (from left to right) are the 200 hpa velocity potential at 0300 UTC December 26, 31, 2006 and January 5, 2007. Compared to the NCEP/GFS reanalysis, this MMF simulation captures several major features usually associated with an MJO: (1) initiation of large-scale organized convection in the Indian Ocean in panel (b), (2) intensification as shown in panel (c), (3) slow propagation (prior to reaching the Maritime continent), (4) followed by fast propagation, and (5) weakening. However, this simulated MJO also produces stronger vertical motion than does the NCEP/GSF reanalysis.

4. CONCLUDING REMARKS:

In this study, we verify the performance of the Goddard MMF with extended-range (30 day) simulations of the MJO in December 2006. The simulated MJO captures several major features as compared with NCEP analysis. Additional numerical experiments for this MJO case suggest that the following additional factors for improving MJO simulations may be required: (a) accurate initial conditions (e.g., active or passive phases of an MJO), (b) accurate representation of the mechanical and thermal effects of the Maritime continent, and (c) a coupling strategy (to examine the "discharge-recharge" process). Therefore, we plan to perform the following sensitivity studies: (1) vary the initial conditions (start one to three days earlier or later), (2) increase the MMF-GCM's resolution for improved orography and land–ocean separation, (3) couple to an ocean model to allow for air-sea interaction and realistic surface heat and moisture fluxes, and (4) improve the microphysical packages for better latent heat release. In addition, we will use NASA satellite observations and global analyses (e.g., GMAO/MERRA) to determine the strengths and weaknesses of the MMF in simulating the MJO and its associated tropical weather and precipitation systems.



To understand how resolved small-scale processes provide positive feedbacks on large-scale MJO simulations would require examining the model simulations at small time scales. As our recent numerical experiments with the high-resolution fvGCM produced encouraging 15-day forecasts of an MJO in 2002 (Figure 5), we plan to perform high-resolution global model simulations for the 2006 MJO. It is our hope that inter-comparisons between simulations with the MMF and the high-resolution fvGCM could provide insightful formation and thus improve our understanding of MJO dynamics.

Figure 5: 15-day forecasts of velocity potential at 200 hpa initialized at 0000 UTC May 2, 2002 with the high-resolution fvGCM. Panels (a-d) show simulations at day 0, 5, 10, and 15, respectively.

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