Hurricane Forecasts with the Global Mesoscale Model on NASA Supercomputers

Bo-Wen Shen (UMCP/ESSIC, bo-wen.shen-1@nasa.gov), Wei-Kuo Tao (NASA/GSFC), and Robert Atlas (NOAA/AOML)
SC2008 NASA Research Exhibit --- Booth 1343.

When the NASA Columbia supercomputer came into operation in late 2004, its computing power enabled the deployment of the global mesoscale model (GMM, previously called the high-resolution finite-volume GCM or fvGCM) at very high resolution (i.e., 0.25°, 0.125° and 0.08°), which resulted in remarkable hurricane forecasts during the very active 2004 and 2005 Atlantic hurricane seasons (Atlas et al., 2005; Shen et al., 2006a,b,c). In this report, a brief summary of that work is given. Over the past several decades, tropical cyclone (TC) track forecasts have been steadily improving, but intensity and genesis forecasts have lagged behind. The GMM's ability to forecast hurricane intensity was first demonstrated with hurricane Katrina (2005), which was the sixth most intense hurricane in the Atlantic and devastated New Orleans and the surrounding Gulf Coast region. While both 0.25° and 0.125° runs showed remarkable track forecasts (Figure 1), the higher-resolution runs produced more realistic intensity forecasts. It has been suggested that the better intensity forecasts are due to the finer resolution, which becomes sufficient to resolve the near-eye wind distribution as shown in Figure 2. Further analysis of the 96h 0.125° simulations for Katrina with no cumulus parameterizations (CPs) showed realistic storm vertical structures, including maximum winds near the top of the boundary layer, a narrow eyewall, and an elevated warm core. This suggests that realistic intensities and structures of mature hurricanes can be simulated by the 0.125° model without the need for CPs, which are known to cause big uncertainties in simulations with traditional GCMs. The performance of the 0.08° model for Hurricane Rita (2005) was documented in Biswas et al. (2007), which showed improved track and intensity forecasts with increasing resolution (i.e., from 0.25° to 0.125° to 0.08° without CPs).

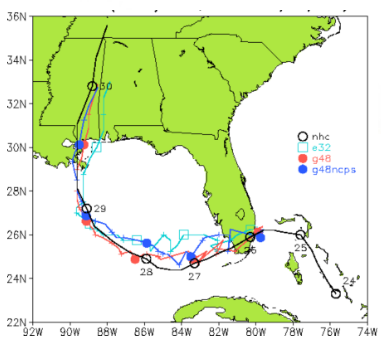

Figure 1: (a) Track forecasts for Hurricane Katrina (2005) from 5-day simulations initialized at 1200 UTC August 25, 2005 with the global mesoscale model at different resolutions: e32 (0.25°), g48 (0.125°), and g48ncps (0.125° without CPs).

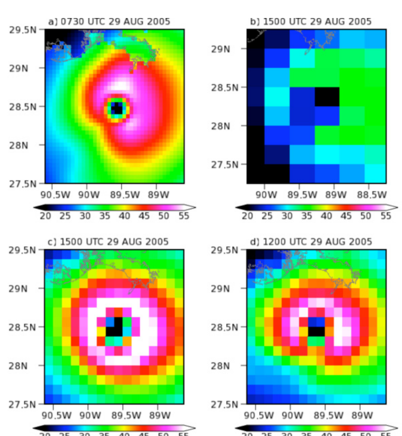

Figure. 2: Surface wind distribution near the eye of Hurricane Katrina (2005) in a 2 x 2 degree box. (a) AOML high-resolution (0.0542 degree) analysis at 0730 UTC Aug 29, (b) 99h 1/4 degree simulation ending 1500 UTC Aug 29, (c) 99h 1/8 degree simulation ending 1500 UTC Aug 29, and (d) 96h 1/8 degree simulation without cumulus parameterization ending 1200 UTC Aug 29. It should be noted that a 2 x 2 degree box has only one grid point in a typical global climate model.

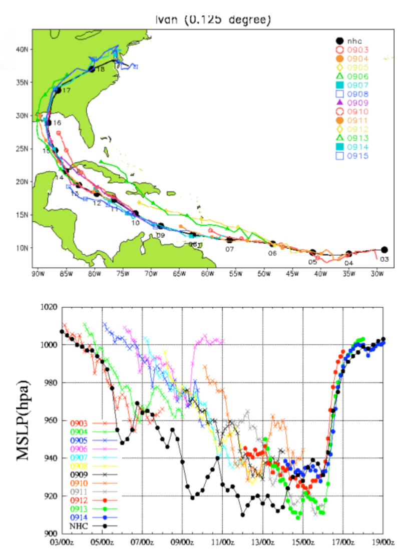

Figure 3: Thirteen consecutive five-day forecasts of Hurricane Ivan (2004) initialized at 0000 UTC from 3 to 15 September 2004 with the 1/8 degree global mesoscale model. Predicted tracks are shown at the top and intensities at the bottom. The black line shows the intensity evolution along the best track (e.g., the observed one). Due to a weaker initial vortex from the coarser-resolution analysis data, the predicted intensification rate (the slope of each curve) is verified against the one for the best track.

The performance of the 0.125° GMM was further verified with other intense hurricanes (i.e., Ivan and Karl in 2004, Dennis and Emily in 2005, and Daniel in 2006; see Shen et al. 2006c). Ivan (2004) was chosen first because the accurate prediction of its track posed a challenge. Early forecasts for Ivan both by the National Hurricane Center (NHC) and the 0.25° GMM (not shown) had a persistent bias toward the right-hand side of the best track. A similar bias for forecasts initialized at 0000 UTC 9 Sep with four different operational models was also reported. In contrast, thirteen consecutive forecasts from 3 to 15 Sep 2004 produced not only very encouraging track forecasts with a much smaller bias (Figure 3a), but also realistic intensity forecasts and intensification rates (Figure 3b). These forecasts could form a "validation" database for model verification and also provide a great opportunity to study the role of scale interaction on the evolution of Ivan's intensity. For example, it was found that scale interaction between the hurricane and an upper-level trough might have been contributed to Ivan's intensification. Over fifty additional 5-day forecasts of intense hurricanes were documented in Shen et al. 2006c. Since 2007, we have started to verify the model's ability to simulate the formation of tropical cyclones (TCs) in the Indian Ocean (Figure 4; see Shen et al. 2007). TC Nargis devastated Myanmar (Burma) in the Indian Ocean in early May 2008, causing over 133,000 fatalities and $10 billion in damage; our numerical experiments showed that the initial formation of TC Nargis can be realistically predicted at a lead time of up to 5 days (Shen and Tao, 2008). More cases will be conducted to see if the model can systematically increase the lead time in the prediction of TC formation, which could increase the warning time and as a result save lives and reduce economic damage. Further research will also be conducted with a focus on understanding multi-scale interactions among large-scale flows, mesoscale vortices, surface fluxes, and small-scale convection. During the supercomputing conference in 2008, we will show some preliminary results at the NASA booth with the Goddard multiscale modeling system (Tao et al., 2008), which has been developed to achieve the above goals.

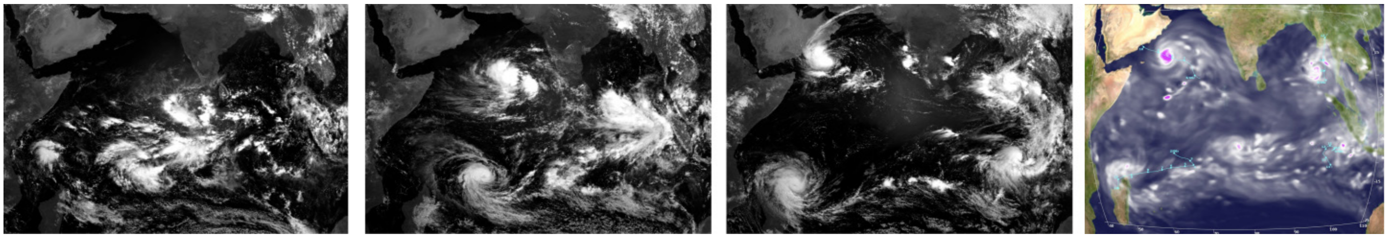

Figure 4: Predictions regarding the formation of twin TCs in the Indian Ocean. (a) MJO-organized convection over the Indian Ocean at 0630 UTC 1 May 2002. When the MJO moved eastward, two pairs of twin TCs appeared sequentially on 6 May (b) and 9 May (c, e.g., Moncrieff et al. 2007). (d) Four-day forecasts of total precipitable water with the global mesoscale model (see Shen et al., 2007 for more results).

References:

Atlas, R., O. Reale, B.-W. Shen, S.-J. Lin, J.-D. Chern, W. Putman, T. Lee, K.-S. Yeh, M. Bosilovich, and J. Radakovich, 2005: Hurricane forecasting with the high-resolution NASA finite volume general circulation model. Geophys. Res. Lett., 32, L03801, doi:10.1029/2004GL021513.

Biswas, R., M.J. Aftosmis, C. Kiris, and B.-W. Shen, 2007: Petascale Computing: Impact on Future NASA Missions. Petascale Computing: Architectures and Algorithms 29-46 (D. Bader, ed.), Chapman and Hall / CRC Press, Boca Raton, FL.

Moncrieff, M. W., M. A. Shapiro, J. M. Slingo, and F. Molteni, 2007: WMO Bulletin, 56 (3), 1-9.

Shen, B.-W., R. Atlas, J.-D. Chern, O. Reale, S.-J. Lin, T. Lee, and J. Chang, 2006a: The 0.125 degree finite-volume General Circulation Model on the NASA Columbia Supercomputer: Preliminary Simulations of Mesoscale Vortices. Geophys. Res. Lett., 33, L05801, doi:10.1029/2005GL024594.

Shen, B.-W., R. Atlas, O. Reale, S.-J. Lin, J.-D. Chern, J. Chang, C. Henze, and J.-L. Li, 2006b: Hurricane Forecasts with a Global Mesoscale-Resolving Model: Preliminary Results with Hurricane Katrina (2005). Geophys. Res. Lett., 33, L13813, doi:10.1029/2006GL026143.

Shen, B.-W., W.-K. Tao, R. Atlas, T. Lee, O. Reale, J.-D. Chern, S.-J. Lin, J. Chang, C. Henze, J.-L. Li, 2006c: Hurricane Forecasts with a Global Mesoscale-resolving Model on the NASA Columbia Supercomputer, AGU 2006 Fall Meeting, December 11-16, 2006.

Shen, B.-W., W.-K. Tao, R. Atlas, Y.-L. Lin, R. Reale, J.-D. Chern, C.-D. Peters-Lidard, K.-S. Kuo, 2007: Forecasts of Tropical Cyclogensis with a Global Mesoscale Model: Preliminary Results with Six Tropical Cyclones. Under revision.

Shen, B.-W. and W.-K. Tao, 2008: Predicting the Formation of Tropical Cyclone Nargis (2008) with the NASA High-resolution Global Model and Supercomputers. SC2008 International Conference for High Performance Computing, Networking, Storage and Analysis. Austin, Texas, November 15-21, 2008. (poster)

Tao, W.-K., D. Anderson, R. Atlas, J. Chern, P. Houser, A. Hou, S. Lang, W. Lau, C. Peters-Lidard, R. Kakar, S. Kumar, W. Lapenta, X. Li, T. Matsui, R. Rienecker, B.-W. Shen, J. J. Shi, J. Simpson, and X. Zeng, 2008: A Goddard Multi-Scale Modeling System with Unified Physics. WCRP/GEWEX Newsletter, Vol 18, No 1, 6-8.

National Aeronautics and Space Administration
Goddard Space Flight Center
Laboratory for Atmospheres, Code 613
Greenbelt, MD 20771

Bo-Wen Shen, UMCP/ESSIC
301-614-6251
bo-wen.shen-1@nasa.gov
http://atmospheres.gsfc.nasa.gov/cloud_modeling/Shen.html