Simulations of Multiple Tropical Cyclones with a Global Mesoscale Model: A Preliminary Study on the NASA Columbia Supercomputer

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1. Introduction:

Over the past several decades, hurricane track forecasts have steadily been improving, but progress on intensity forecasts and understanding of hurricane formation/genesis has been slow. Major limiting factors include insufficient model resolution and uncertainties in cumulus parameterizations (CP). A CP is required to "emulate" the statistical effects of unresolved cloud motions in coarse resolution simulations, but its validity becomes questionable at high resolutions. Facilitated by the NASA Columbia Supercomputer, the ultra-high resolution finite-volume General Circulation Model (fvGCM) has been deployed and run in real-time experimentally to study the impact of increasing resolution and disabling CPs on hurricane forecasts. While doubling the resolution of a numerical weather prediction (NWP) model requires an 8-16X increase in computational power, the unprecedented computing power afforded by Columbia enables us to rapidly increase the resolution of the fvGCM to $1/4^o$, $1/8^o$, and $1/12^o$. During the active 2004 and 2005 hurricane seasons, the mesoscale-resolving fvGCM produced promising forecasts of intense hurricanes such as Frances, Ivan, Jeanne, and Karl in 2004 and Emily, Dennis, Katrina, and Rita in 2005 (Atlas et al. 2005; Shen et al. 2006a-c). To further illustrate the capabilities of the fvGCM coupled with Columbia, we present simulations of multiple tropical cyclones.

2. The fvGCM and Model Validation:

The fvGCM is a unified NWP and climate model that runs on daily, monthly, decadal, and century timescales. The model has three major components: a finite-volume dynamical core (Lin 2004) and the community built physical parameterization schemes and land surface model at NCAR. Initial conditions are obtained from the state-of-the-art data assimilation system (Global Forecast System, GFS) at NOAA/NCEP.

The impact of increasing resolution (in this case, to $1/8^o$) and disabling CPs on the forecasts of hurricane Katrina has been documented in Shen et al. (2006b). They obtained comparable track predictions at different resolutions but better intensity forecasts at finer resolutions. The predicted minimum sea level pressures (MSLP) in the $1/4^o$, $1/8^o$, and $1/8^o$-no-CPs runs are 951.8, 895.7, and 906.5 hPa with respect to the observed 902 hPa (Figure 1). Consistent improvement as a result of using a higher resolution was illustrated from the six 5-day forecasts with the $1/8^o$ fvGCM, showing small errors in center pressure of only ±12 hPa. The notable improvement in Katrina's intensity forecasts was attributed to the sufficient fine resolution used for resolving hurricane near-eye structures. As the hurricane's internal structure has convective-scale variations, it was shown that the $1/8^o$ run with disabled CPs could lead to further improvement on Katrina's intensity and structure (asymmetry).

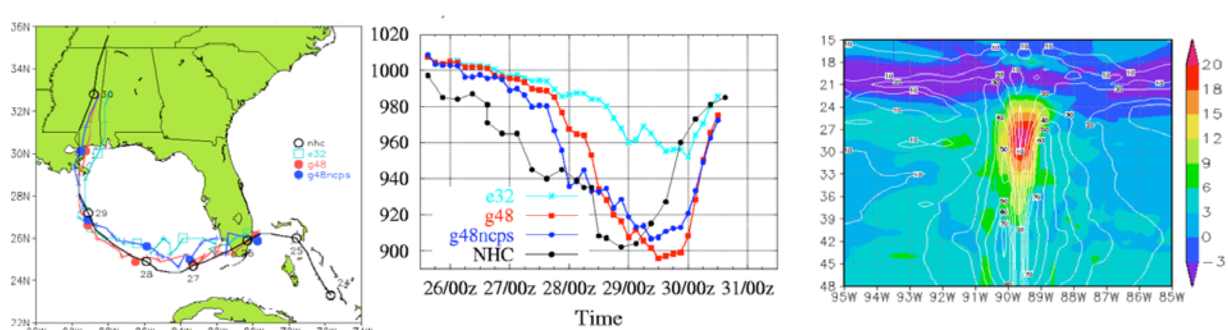

Figure 1: Track (left) and intensity (middle) forecasts of hurricane Katrina (2005) from 5-day simulations initialized at 1200 UTC August 25, 2005 with the fvGCM at different resolutions. e32 ($1/4^o$), g48 ($1/8^o$), g48ncps ($1/8^o$ without CPs). Simulated vertical structure (right) of Katrina along lat=28.5^o from the 96h run with no CPs. The vertical axis represents model levels. This panel shows realistic features such as maximum horizontal winds (white) near the top of the boundary layer, a narrow eyewall, and an elevated warm core with positive temperature anomalies (shaded).

3: Simulations of Multiple Tropical Cyclones in 2004:

The 2004 Atlantic hurricane season was very active. There were 16 tropical storms and 9 hurricanes, 6 of which were rated Category 3 and higher. Accurate forecasts of these storms posed a great challenge to global and mesoscale modelers. While our earlier studies with the high-resolution fvGCM showed promising track and intensity forecasts of intense hurricanes, we extend our study to understand the impact of increased resolution on the simulations of multiple cyclones. We conduct a series of 36h simulations initialized 0000 UTC 19 September 2004 at a variety of resolutions (1^{o}, $1/2^{o}$, $1/4^{o}$, and $1/8^{o}$). According to the reports by the National Hurricane Center (NHC) (http://www.nhc.noaa.gov/2004atlan.shtml), one extratropical cyclones (ETC) and three tropical cyclones (TCs) were reported at the end of time integration, 1200 UTC 20 September. They were Ivan (extratropical, 1009 hPa, 27.5^{o}N, 78.7^{o}W), Jeanne (tropical, 989 hPa, 26.6^{o}N, 71.7^{o}W), Karl (hurricane, 951 hPa, 17.5^{o}N, 46.0^{o}W), and Lisa (tropical, 1002 hPa, 13.5^{o}N, 35.4^{o}W). In the parentheses, storm stage, intensity, latitude (LAT), and longitude (LON) are listed sequentially. By comparison, GFS T254 (~55km) analysis data resolve these storms with weaker intensities (Table 1 and Figure 2). While the 1^{o} run could simulate three TCs, it gives the largest errors in the location and intensity predictions among our experiments. For ETC Ivan, higher resolution runs ($1/4^{o}$ and $1/8^{o}$) give remarkable location forecasts, but slightly stronger model storms. In the higher resolution simulations of Jeanne, Karl, Lisa, increased resolution could improve track forecasts slightly and intensity forecasts noticeably.

4: Concluding Remarks:

In this report, the capabilities and advantages of a global mesoscale model for hurricane simulations are illustrated with realistic forecasts of Katrina's track, intensity, and structure (see also Shen et al. 2006b). We further show the model's capabilities in simulating multiple storms at a variety of resolutions, producing noticeable (slight) improvement in intensity (location) predictions of tropical cyclones with increased resolutions. These confirm the model's stability and robustness from scientific and computational perspectives. In the future, we will conduct studies with this global mesoscale model on multiscale interactions among multiple cyclones and large-scale flows.

Table 1: The (MSLP, LAT, LON) (hPa, ^{o}N, ^{o}W) of Ivan, Jeanne, Karl and Lisa (2004) from the GFS analysis valid at 12Z UTC 20 SEP and model simulations at a variety of resolutions.

	Ivan	Jeanne	Karl	Lisa
NHC	(1009,27.5,78.7)	(989,26.6, 71.7)	(951,17.5,46.0)	(1002,13.5,35.4)
GFS	(1010,27.25,78.75)	(1001,26.4,71.7)	(1003,17.6,45.8)	(1013,12.6,35.4)
1^{o}	(---,---,---)	(1005,26,73.8)	(1007,17.7,47.2)	(1013,12.0,33.7)
$1/2^{o}$	(1008.5,27.25,80.1)	(1002,26.9,73.2)	(1004,18,47.6)	(1007.5,13.1,35.6)
$1/4^{o}$	(1006.5,27.25,79.9)	(1000,26.8,73.4)	(1000,17.4,47.9)	(1007.5,13.7,36)
$1/8^{o}$	(1005.5,27.25,79.9)	(997,27.2,72.6)	(997,17.8,47.5)	(1000,13.8,36.4)

References:

Atlas et al. 2005: *Geophys. Res. Lett.*, **32**, L03801.
Lin 2004: *Mon. Wea. Rev.*, **132**, 2293-2307.
Shen et al. 2006a: *Geophys. Res. Lett.*, **33**, L05801.
Shen et al. 2006b: *Geophys. Res. Lett.*, **33**, L13813.
Shen et al. 2006c:
http://atmospheres.gsfc.nasa.gov/cloud_modeling/docs/2006_AGU_Fall_Poster.ppt

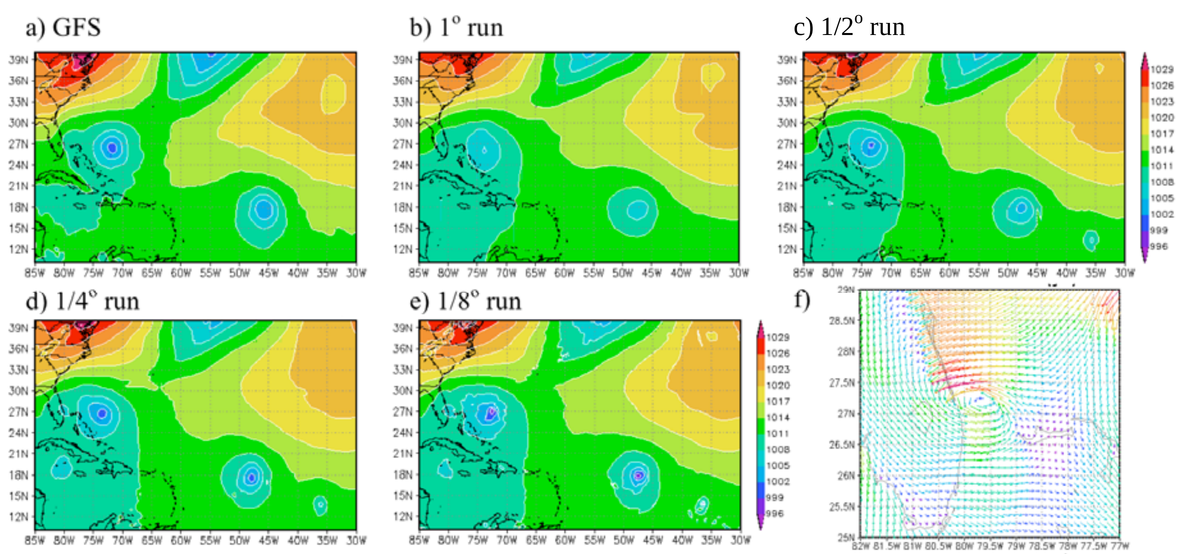

Figure 2: Comparisons between NCEP GFS data and 36h simulations of multiple tropical cyclones initialized at 0000 UTC 19 SEP. 2004 with the global mesoscale model at a variety of resolutions. (a) GFS analysis data valid at 1200 UTC 20 SEP., (b-e) 1^{o}, $1/2^{o}$, $1/4^{o}$, and $1/8^{o}$ run, respectively (f) Close up of the 10m winds simulated for Ivan in a 4x5 degree box from the $1/8^{o}$ run. The observed location of ETC Ivan is (27.5^{o}N, 78.7^{o}W).