Hurricane Forecasts with a Global Mesoscale-resolving Model on the NASA Columbia Supercomputer

Preliminary Simulations of Hurricane Katrina (2005)

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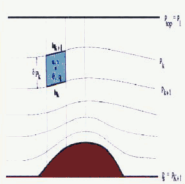
1. Introduction

It is known that General Circulation Models (GCMs) have insufficient resolution to accurately simulate hurricane near-eye structure and intensity. To overcome this limitation, the mesoscale-resolving finite-volume GCM (fvGCM) has been experimentally deployed on the NASA Columbia supercomputer, and its performance is evaluated choosing hurricane Katrina as an example in this study. In late August 2005 Katrina underwent two stages of rapid intensification and became the sixth most intense hurricane in the Atlantic. Six 5-day simulations of Katrina at both 0.25° and 0.125° show comparable track forecasts, but the 0.125° runs provide much better intensity forecasts, producing the center pressure with errors of only ±12 hPa. The 0.125° simulates better near-eye wind distributions and a more realistic average intensification rate. As convection parameterization (CP) is one of the major limitations in a GCM, the 0.125° run with CP disabled produces very encouraging results.

2. The Finite-volume GCM

The finite-volume GCM (fvGCM) is a next generation modeling system based on a state-of-the-art finite-volume dynamical core and the ***community built*** physical parameterizations and land surface model.



- Terrain following Lagrangian control-volume vertical discretization of the basic conservation laws.
  - –Mass
  - –Momentum
  - –Total energy
- 2D horizontal flux-form semi-Lagrangian discretization
  - –Genuinely conservative
  - –Gibbs oscillation free
  - –Absolute vorticity consistently transported with mass dp within the Lagrangian layers
- Computationally efficient

2003-2004: The 0.25° fvGCM

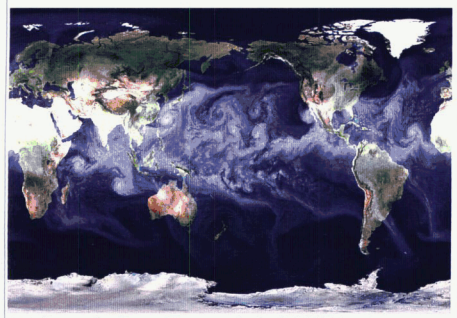
Improved and enabled global high-resolution (28 km) climate simulations and predictions of hurricane/typhoon tracks and snowstorms. As of February 2006, 10day forecasts can be done within one hour with 480 CPUs.

2005-2006: The 0.125° and higher fvGCM

9 - 14 km global resolution is making assessment of regional impact of climate change a reality. To our knowledge, the fvGCM is the first to simulate the formation of mesoscale vortices in a global environment.

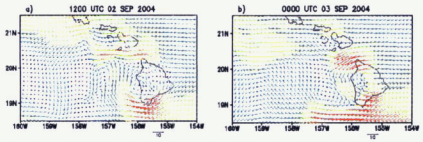
3. Model Validation

Numerical simulations of mesoscale vortices at 0.125°, unless stated, are conducted to demonstrate the model's capability of simulating scale interactions between high mountains and nonlinear flow, between coastal surface forcing and synoptic-scale flow, and between convection and large-scale flow.



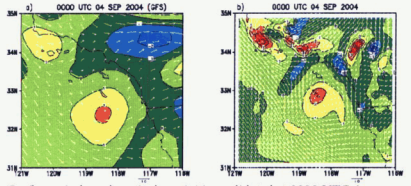
5-day forecasts of total precipitable water initialized at 0000 UTC 1 September, 2004 with the 1/12 degree fvGCM, giving a grid spacing of 9km in the equator.

3.1 Hawaiian Wakes



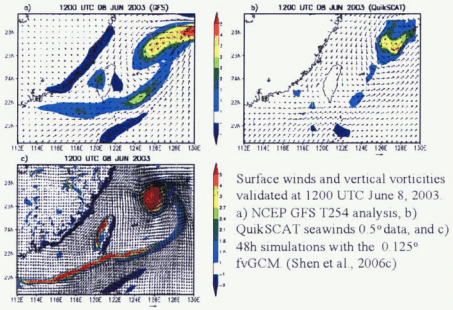
Simulations of the Hawaiian Vortices initialized at 0000 UTC 1 September 2004 at 36 h simulation (a) and 48 h simulation (b) to show an upstream stagnation point, vortex shedding and gap flows. (Shen et al., 2006a)

3.2 The Catalina Eddy



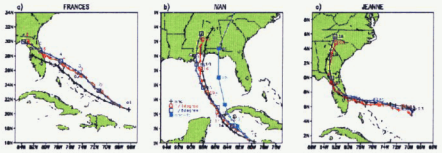
Surface winds and vertical vorticities validated at 0000 UTC 4 September 2004. (a) NCEP T384 GFS analysis, and (b) 72 h simulation. (Shen et al., 2006a)

3.3 A Mei-Yu Front accompanied by a Drifting Meso-cyclone



Surface winds and vertical vorticities validated at 1200 UTC June 8, 2003. a) NCEP GFS T254 analysis, b) QuikSCAT seawinds 0.5° data, and c) 48h simulations with the 0.125° fvGCM. (Shen et al., 2006c)

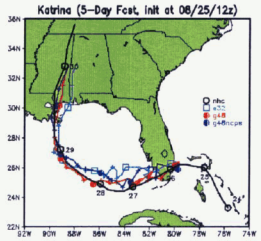
3.4 Atlantic Hurricanes (Frances, Ivan, and Jeanne, 2004)



High resolution five-day track predictions of hurricanes (a) Frances initialized at 0000 UTC 1 September, (b) Ivan initialized at 0000 UTC 12 September, and (c) Jeanne initialized at 0000 UTC 23 September, 2004. The blue (red) lines represent the tracks from 0.125 (0.25) degree simulations, while the black lines represent the best track from the National Hurricane Center. Each dot represents the center position at 6-hour time increments. (Shen et al., 2006a)

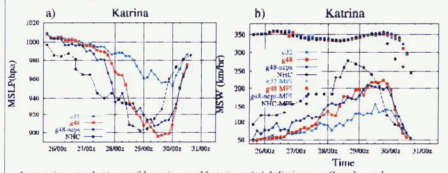
4. Results

4.1 Track Predictions



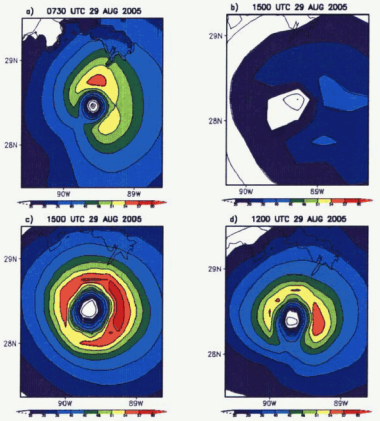
Five-day track predictions of hurricane Katrina initialized at 1200 UTC 25 August, 2005. The light blue, red, and blue lines represent the tracks from 0.25°, 0.125° simulations and 0.125° simulation with no cps. Each dot represents the center position at 3-hour time increments. The black line represents the advisory track with a 6-hour time increment from the NHC. (Shen et al., 2006b)

4.2 Intensity Predictions

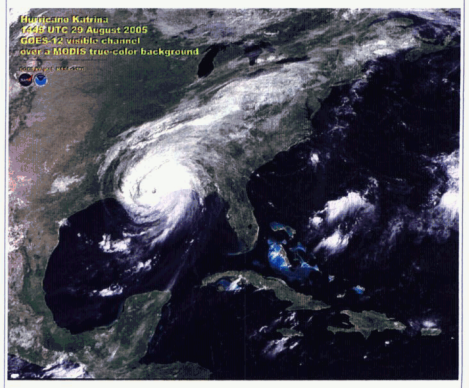


Intensity evolution of hurricane Katrina. (a) Minimum Sea Level Pressures (b) Maximum 10m Surface Winds (MSW) with solid lines and Maximum Potential Intensity (MPI) with points along the corresponding tracks. Each dot represents the intensity at 3-hour time increments. (Shen et al, 2006b)

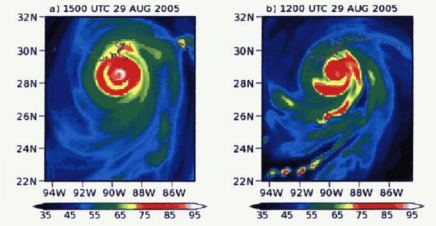
4.3 Near-Eye Wind Distributions



Comparison of wind distribution near the hurricane eye in a 2x2 degree box among (a) AOML high-resolution (0.0542°) surface wind analysis data at 0730 UTC AUG 29, (b) the 0.25° 10m winds at 99h simulations ending 1500 UTC 29, (c) the 0.125° 10m winds at 99h simulations ending 1500 UTC 29, and (d) the 0.125° 10m winds without convection parameterization at 96h simulations ending 1200 UTC 29. (Shen et al., 2006b)



4.4 Asymmetry of Spiral Bands



Simulated total precipitable water with the 0.125° fvGCM initialized at 1200 UTC 25 August, 2005, at (a) 99h forecast with convection parameterization and (b) 96h forecast without convection parameterization (Shen et al.,2006b).

5. Concluding Remarks

- In this work, we present preliminary simulations of hurricane Katrina's intensity and near-eye wind distributions obtained with the mesoscale-resolving fvGCM on the NASA Columbia supercomputer.
- Relatively larger intensification rates are observed in the 0.125° runs. Possible reasons for the over-intensification are 1) uncertainties of cumulus parameterizations, 2) lack of feedback from sea surface temperature changes associated with air-sea interaction and also longer time for model storms over ocean, and 3) lack of non-hydrostatic effects.
- To address the above issues, we are developing a global non-hydrostatic cloud- and eddy-resolving Earth modeling system, which should include Ocean, Atmosphere, and Land components.

References

Shen, B.-W., et al. (2006a), The 0.125 degree finite-volume General Circulation Model on the NASA Columbia supercomputer: preliminary simulations of mesoscale vortices. *Geophys. Res. Lett.*, in press.

Shen, B.-W., et al. (2006b), Hurricane Track and Intensity Forecasts with a Mesoscale-Resolving Global Model: Preliminary Simulations of Hurricane Katrina (2005). In review.

Shen, B.-W., et al. (2006c), Preliminary Simulations of a Mei-yu front accompanied by a Drifting Meso-Cyclone with a Mesoscale-Resolving Global Model. In preparation.