

Scott R. Fulton*

Clarkson University, Potsdam, New York

1. INTRODUCTION

The concentration of convective heating in the eyewall of a hurricane tends to generate high values of potential vorticity (PV) there, which in turn can lead to a reversal of the radial gradient of PV and thus the possibility of barotropic instability. Such instabilities may ultimately be removed by complex nonlinear redistribution of PV. Recent studies have shown that this PV mixing process may play a role in hurricane spiral bands, polygonal eyewalls, asymmetric eye contraction, intensity change, and the development of mesoscale vortices (e.g., Guinn and Schubert, 1993; Montgomery and Kallenbach, 1997).

Schubert et al. (1999) [hereafter referred to as S99] reported results of numerical and theoretical studies of the evolution of a barotropically unstable initial vortex through chaotic nonlinear PV mixing toward a symmetric end state. While the effects on vortex structure were most pronounced in the inner-core region, there was also some effect on the winds outside the radius of maximum wind (associated with a decrease of about 20% in the maximum tangential wind). Since S99 considered only stationary vortices on an f -plane, the extent to which such changes in vortex structure might affect the vortex motion was not investigated. To address this question, we use an adaptive multigrid barotropic model to study the motion and evolution of a barotropically unstable vortex embedded in a large-scale zonal flow.

2. MODEL DESCRIPTION

We use the MUDBAR model of Fulton (2000). Based on the nondivergent barotropic vorticity equation on a sphere section, the model uses an adaptive multigrid method to refine the mesh around the moving vortex. Like conventional nested-grid models, this model achieves nonuniform resolution by superimposing uniform grids of different mesh sizes. Unlike nested-grid models, multigrid processing uses the interplay between solutions on fine and coarse grids—in regions where they overlap—to solve the implicit problem for the streamfunction with optimum efficiency, and to provide accurate truncation error estimates for use in an automatic mesh refinement algorithm.

For the model runs reported here we use a 4096 km-square domain. Seven nested computational grids with mesh spacings from 0.5 km to 32 km allow accurate and efficient solution for both the environmental flow and the details of the PV mixing. In addition to tracking the vortex, the adaptive method can automatically coarsen the grid by removing fine-grid patches when they are no longer needed, resulting in considerable savings of execution time.

*Corresponding author address: Scott R. Fulton, Dept. of Mathematics and Computer Science, Clarkson University, Potsdam, NY 13699-5815; email: fulton@clarkson.edu.

3. NUMERICAL EXPERIMENTS

For the initial condition we use the "PV ring" vortex of S99 embedded in a sinusoidal zonal current as used by DeMaria (1985) and Fulton (1997). We consider four cases as shown in Fig. 1; case (d) is the vortex used in S99, while the others use a wider but less intense ring of vorticity. All cases share the same the velocity and circulation outside radius $r = 65$ km. Since the model uses a finite-difference discretization (instead of the Fourier-spectral discretization of S99), we use a larger diffusion parameter ν of $300 \text{ m}^2 \text{ s}^{-1}$, corresponding to an e -folding time of 338 s for a wavelength of 2 km. All other parameters have the values given in S99.

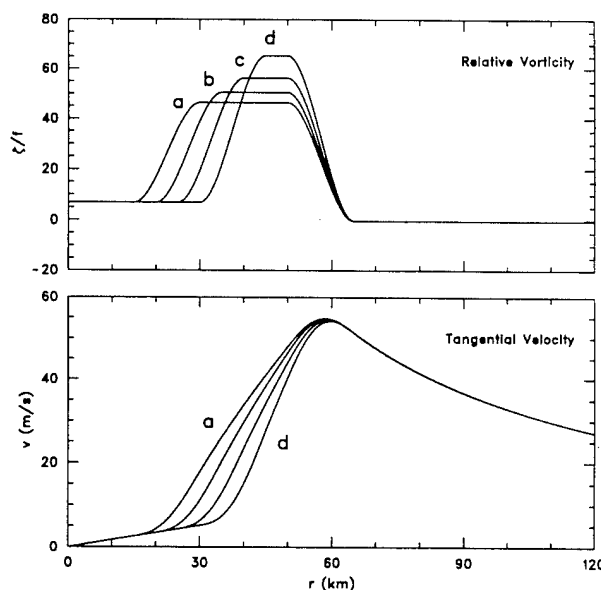


Figure 1. Initial vorticity and tangential wind profiles.

The relatively small differences in initial vortex structure lead to large differences in the flow evolution, as shown in Fig. 2. In case (a) the vortex is barotropically stable (or nearly so), and the vortex structure changes little during a 72 hour model run. Case (b) shows only weak instability; no significant change occurs during the first 24 hours, but by 72 hours the vortex has evolved partway toward a monopole (i.e., a circular vorticity distribution, decreasing monotonically with radius). Case (c) shows a strong wavenumber three perturbation by 12 hours—consistent with the linear stability analysis of S99—and again evolves toward a monopole. Case (d) quickly develops a strong wavenumber four perturbation, evolves chaotically from 6–24 hours, and by 72 hours is essentially a monopole.

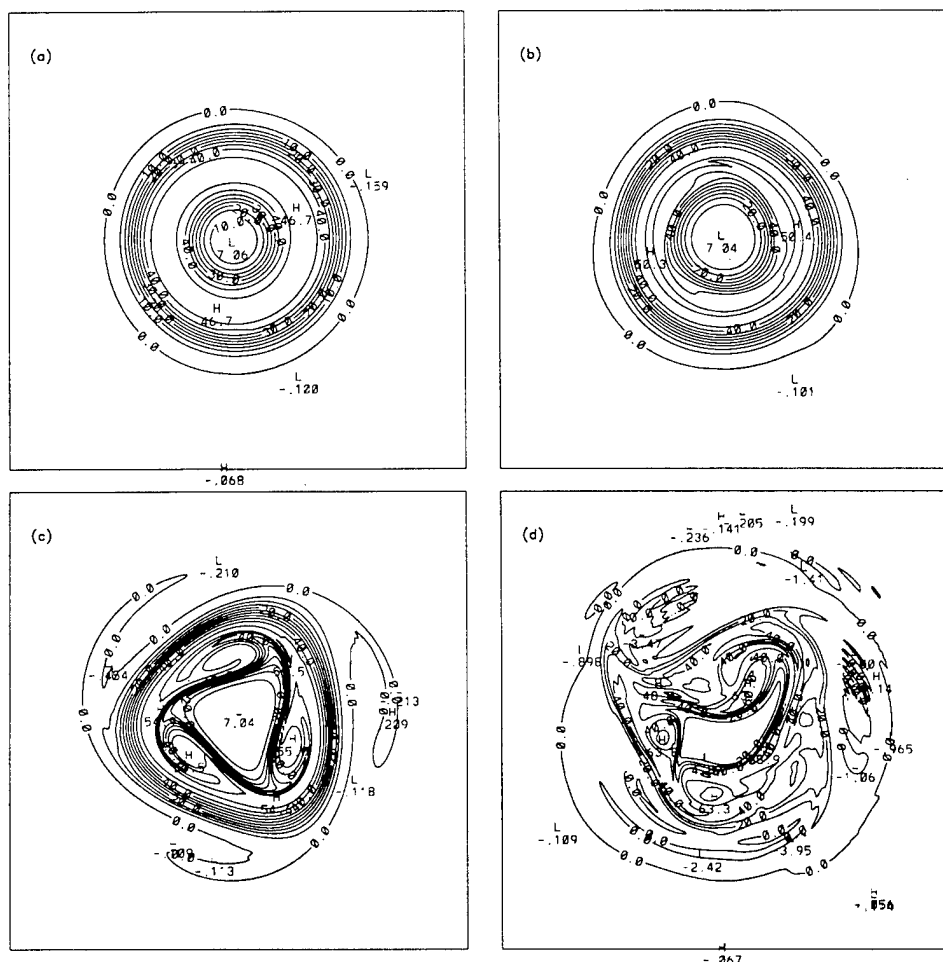


Figure 2. Relative vorticity over the inner 256 km $\times$ 256 km region for cases (a)–(d) at time $t = 12$ hours.

Given the significant differences in vortex structure in cases (a)–(d), one might expect some differences in the vortex track. However, these four runs produced tracks which are virtually identical: the mean track differences (for the vorticity centroid) over 72 hours are less than one kilometer. One explanation is that the changes in vortex structure are confined to the inner 100 km radius. This result—insensitivity of the vortex track to the small-scale details of vortex structure—is consistent with earlier studies (e.g., DeMaria, 1985; Fiorino and Elsberry, 1989) using simpler vortices which remain symmetric and models not capable of resolving any such fine-scale details of vortex evolution. The fact that so little effect is observed with such large differences in vortex evolution is interesting, and suggests that PV mixing has little direct effect on vortex motion. Any indirect effect (e.g., through the organization of convection and subsequent larger-scale structural change) is beyond the scope of the simple barotropic model used here. Also, it remains to be seen to what extent using insufficient resolution might alter the tracks in the cases examined here.

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REFERENCES

- DeMaria, M., 1985: Tropical cyclone track prediction with a barotropic model. *Mon. Wea. Rev.*, **113**, 1199–1210.
- Fiorino, M., and R. L. Elsberry, 1989: Some aspects of vortex structure related to tropical cyclone motion. *J. Atmos. Sci.*, **46**, 975–990.
- Fulton, S. R., 1997: A comparison of multilevel adaptive methods for hurricane track prediction. *Elec. Trans. Num. Anal.*, **6**, 120–132.
- Fulton, S. R., 2000: An adaptive multigrid barotropic tropical cyclone track model. Submitted to *Mon. Wea. Rev.*.
- Guinn, T. A. and W. H. Schubert, 1993: Hurricane spiral bands. *J. Atmos. Sci.*, **50**, 3380–3403.
- Montgomery, M. T., and R. J. Kallenbach, 1997: A theory for vortex Rossby waves and its application to spiral bands and intensity changes in hurricanes. *Quart. J. Roy. Meteor. Soc.*, **123**, 435–465.
- Schubert, W. H., M. T. Montgomery, R. K. Taft, T. A. Guinn, S. R. Fulton, J. P. Kossin, and J. P. Edwards, 1999: Polygonal eyewalls, asymmetric eye contraction, and potential vorticity mixing in hurricanes. *J. Atmos. Sci.*, **56**, 1197–1223.