6B.5 A NEW PATHWAY TO POLYGONAL EYEWALLS AND ASYMMETRIC EYEWALL CONTRACTION

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1. Introduction

Hurricane eyewall structures have been observed to attain shapes ranging from the most discernable circular form to the less obvious, more complex polygonal shapes. These non-circular eyewall distortions are believed to be associated with periods of rapid intensification of the storm. It is also believed that many of these features can be explained to a great degree of accuracy in terms of internal vortex dynamics and not so by the steering synoptic environment the storm is embedded in. Previous studies have linked these distortions to barotropic instability of eyewall flows and the mixing of low potential vorticity (PV) fluid in the eye of the hurricane with the surrounding high PV fluid in the eyewall (Schubert et al. 1999). In those studies, the number of vertices of the polygonal shapes was argued to be a function of the wavenumber of maximum dynamic instability of the eyewall flow.

Here we intend to extend the theory of polygonal eyewalls by considering a barotropically stable annulus of high vorticity and a small region of enhanced vorticity in the eye (see Figure 1 at 0h). Numerical integrations of these initial conditions reveal an axisymmetrization process that results in a variety of polygonal shapes and eyewall contraction. The dynamical aspects of the evolution of the vorticity field in our model are assumed to be highly nonlinear and owed to the horizontal advection of vorticity. The primary role of advective processes, with only a limited amount of diffusion applied, is easily described by looking at the two-dimensional (2D) barotropic nondivergent vorticity equation

$$\frac{\partial \zeta}{\partial t} + \frac{\partial(\psi, \zeta)}{\partial(x, y)} = \upsilon \nabla^2 \zeta, \qquad (1)$$

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where ζ is the relative vorticity, $\partial(\ ,\ )/\partial$(x,y) is the Jacobian operator, which contains the advective terms, and the diffusion term is the one at the right-hand side of the equation.

We systematically explore how the specific details of these eyewall shape evolutions depend on our initial conditions. We are considering the sensitivity of the evolutionary patterns of the hurricane eye and eyewall regions to the initial values of several parameters: 1) distance of the small region of enhanced vorticity from the center of the model's domain, 2) radius of the small added vortex, 3) number of added vortices, 4) thickness of the eyewall, 5) intensity of the added vortex, 6) vorticity of the eye region, and 7) vorticity of the eyewall. It is currently unknown what the internal dynamic processes are that determine what shapes an eyewall shall attain based on the initial values of the parameters listed above. It is our goal to obtain a better understanding of these processes by studying the response of unforced 2D barotropic flows to the initial values of the aforementioned parameters.

2. Results

Using an idealized, unforced 2D barotropic pseudo-spectral model (Schubert et al. 1999), we have found another mechanism by which a hurricane eyewall can evolve into polygonal shapes without the presence of dynamic instability. This mechanism is due to the addition of a small finite-amplitude asymmetry in our initial conditions consisting of a circular area of enhanced vorticity in the eye region. This 'blob' of vorticity is centered away from the geometric center of the hurricane as to ensure the inner-core mixing of vorticity by axisymmetrization processes. We have found that the development of polygonal shapes in the eye and eyewall regions appear to depend on some parameters more than others, namely: 1) the strength of the small added region of vorticity, 2) the vorticity of the central (eye) region, and 3) the number of small vortices in the

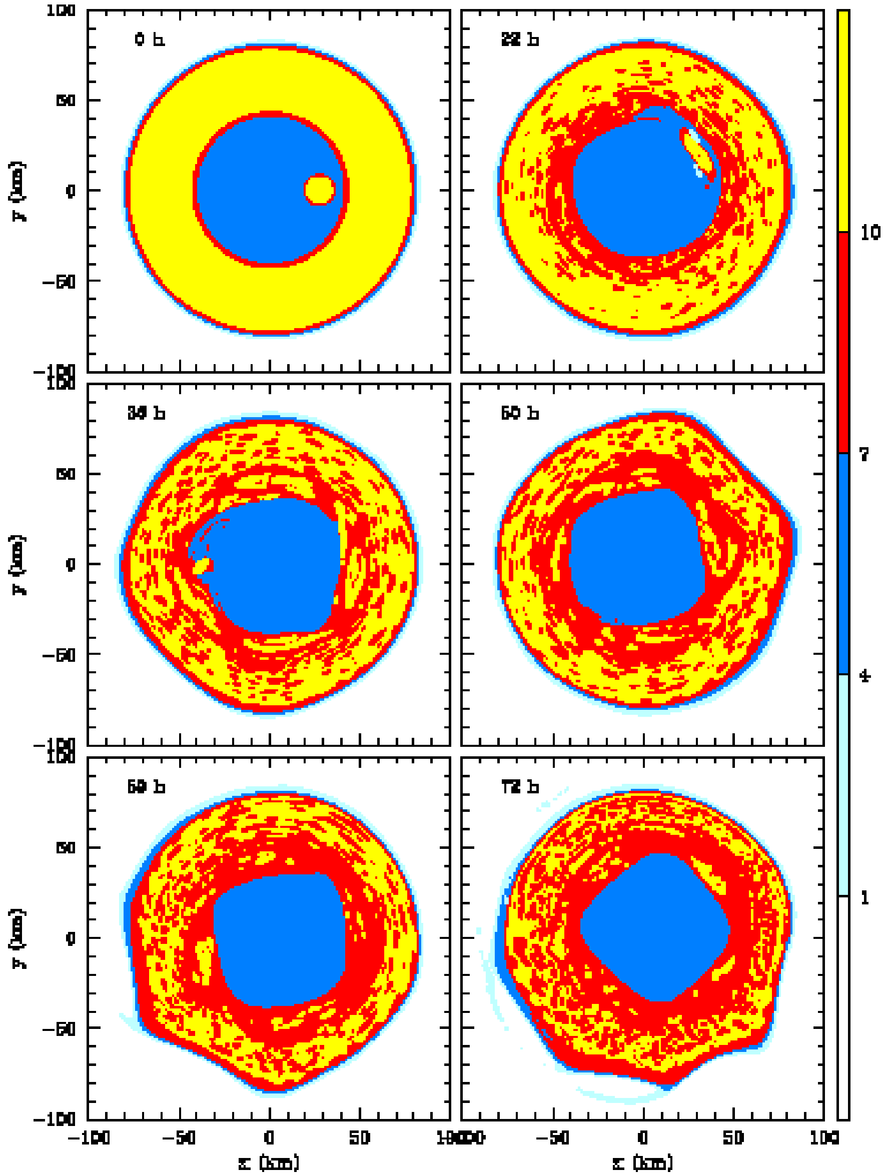

Figure 1: Vorticity Evolution (in 10^{-4} s^{-1}) in the 2D unforced barotropic model. Initial barotropically stable flows and the addition of a small area of enhanced vorticity in the eye perturb the eyewall and mixing takes place, allowing efficient transport of low vorticity from the eye into the eyewall. In this simulation, the inner-core vorticity mixing process leads to a well-defined 4-sided polygonal structure.

eye. Only limited asymmetric eye contraction occurs in association with the polygonal eyewalls and maximum tangential wind profiles show a small, but steady decrease in wind speeds throughout 72h on most of the experiments.

Figure 1 shows the most relevant hurricane eyewall evolutionary stages from one of our simulations. We initialize our model with four regions of vorticity: 1) the eye or central region 2) the annulus, 3) the outer or 'surrounding environment', and 4) the small region of enhanced vorticity embedded in the eye. The initial maximum tangential wind is ~55.1 m s^{-1} (Figure 2). Shortly after initialization, the inner edge of the annular region is perturbed by the small region of enhanced vorticity located in the eye. Low vorticity fluid from the center impinges on the inner edges of the annulus and start mixing with the high vorticity fluid found there. The lower vorticity fluid wraps around the high vorticity fluid of the annular region as it stretches and spirals cyclonically. For the first 48h of simulation, the eye and eyewall regions depict only slightly distorted circular shapes with rough boundaries. However, significant distortions to the circular geometry of the eyewall are seen shortly after ~50h. At ~58h, the eyewall evolves into a square with well-defined vertices and sharp edges. This polygonal feature remains intact for the remainder of the run, which ended at 72h. Only small contraction of the eyewall is evident at this stage, as seen from the slightly reduced area of the central low vorticity region. A slight but steady quasi-linear trend of decreasing tangential winds was observed during the 72h of simulation (Fig. 2).

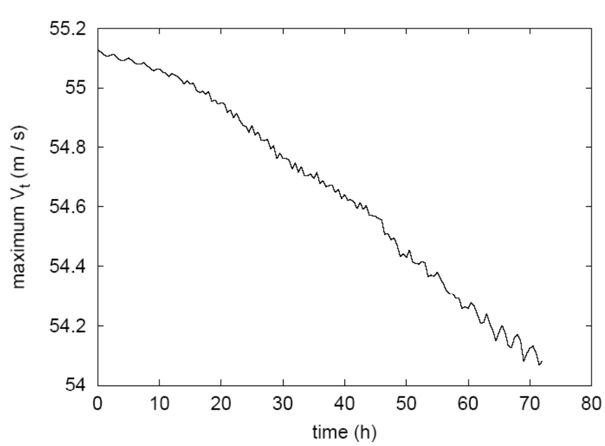

Figure 2: Evolution of the maximum tangential wind in the model.

A *Fourier decomposition analysis* showed a strong contribution of the wavenumber 4 spectral coefficient for the last 24h of the experiment, thus verifying the above discussed squared eyewall structure (not shown).

Figure 3 shows the initial conditions from another simulation. Here we added two equally-sized vortices with the same magnitude in the eye region. They both have the same distance from the center of the domain and are placed opposite to each other. Figure 4 shows the hexagonal structure that the eye acquired at 44h into the simulation. Only two hours later, the eye structure turned rectangular and quickly evolved into a more circular shape at ~48h, with no more eyewall polygonal shapes thereafter (not shown).

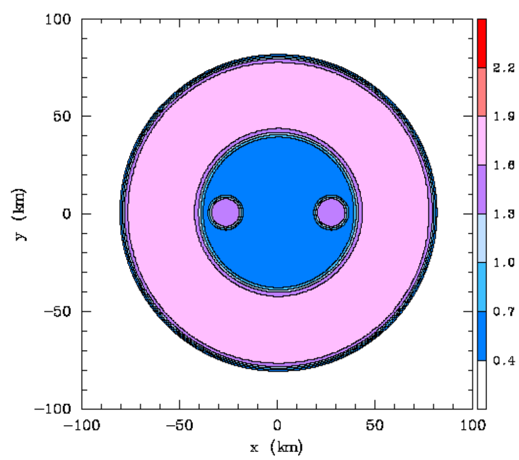

Figure 3: Initial vorticity field (in 10^{-4} m s^{-1}) of the experiment with two vortices added in the eye region.

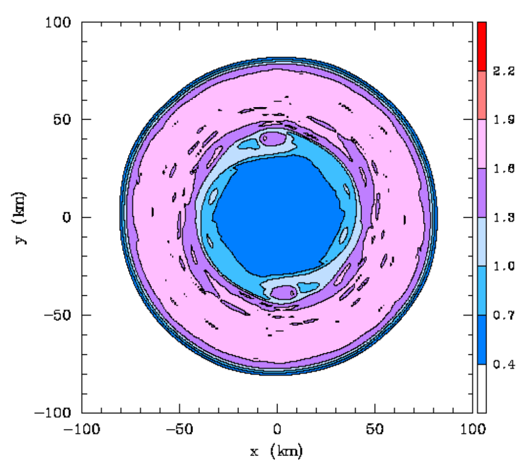

Figure 4: Vorticity field (in 10^{-4} m s^{-1}) showing a hexagonal-shaped eyewall at ~44h.

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Schubert, W. H., M. T. Montgomery, R. K. Taft, T. A. Guinn, S. R. Fulton, J. P. Kossin, and J. P. Edwards, 1998: Polygonal Eyewalls, Asymmetric Eye Contraction, and Potential Vorticity Mixing in Hurricanes. *J. Atmos. Sci.*, **56**, 1197-1223.