11D.5 MESOVORTICES IN HURRICANE ISABEL (2003)

James P. Kossin[1]*, Wayne H. Schubert[2], Chris Velden[1], Michael Black[3], Peter Black[3], Raymond Zehr[4], Sim Aberson[3], Jason Dunion[3]

[1]CIMSS/University of Wisconsin-Madison, [2]Colorado State University, [3]NOAA/AOML/Hurricane Research Division, [4]NOAA/NESDIS/RAMM

As the first visible satellite images of Hurricane Isabel (2003) became available after local sunrise on 12 Sep, a remarkable pentagonal pattern resembling a starfish was clearly evident in Isabel's eye (Fig. 1). The pattern was due to the presence of six distinct mesovortices – one in the center and five others arranged fairly symmetrically around the center – and remained fairly steady for a few hours while rotating cyclonically within the eye.

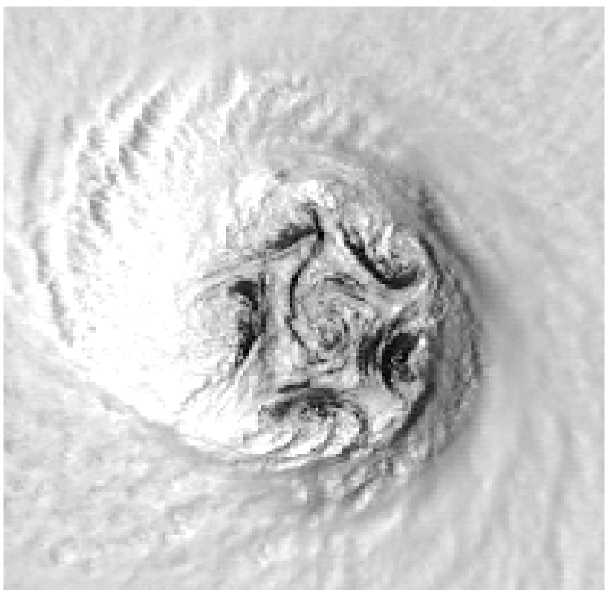

Figure 1: DMSP image of Hurricane Isabel at 1315 UTC 12 Sep 2003. The "starfish" pattern is caused by the presence of six mesovortices in the eye – one at the eye center and five surrounding it.

During Isabel's lifetime, a myriad of convoluted patterns revealed themselves in the low-level clouds in its eye. In addition to the starfish pattern, a distinct four-mesovortex pattern (forming a square) was seen on 13 Sep. Prior to the four-mesovortex pattern, at 1525 UTC, about eight to ten small mesovortices were arranged in a circle near the interface between the eye and eyewall (Fig. 2). These mesovortices underwent multiple merger events in the following two hours. At 1745 UTC, only four mesovortices – larger than the original eight and arranged in a square pattern – remained.

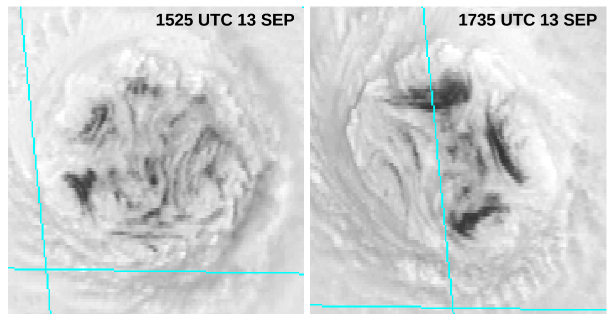

Figure 2: GOES-12 images of Isabel on 13 Sep. At ∼15 UTC, multiple small mesovortices were arranged around the eye-eyewall interface. Very fast multiple mergers occurred in the following two hours, resulting in four large mesovortices arranged in a square.

One of the exciting aspects of the appearance of the pentagonal and square patterns in Isabel's eye is that these patterns were previously found (Kossin and Schubert 2001) within a theoretical framework of maximum simplicity – unforced two-dimensional barotropic flow. Using aircraft flight-level data, the authors found that the tangential flow in the eyewalls of intense hurricanes can resemble a vortex sheet (their Fig. 1), and that these flows can support barotropic instability at high azimuthal wavenumbers and fast growth rates. To study how such instability might evolve within the hurricane inner-core, a fully nonlinear two-dimensional barotropic model was initialized with flow analogous to the observed flows. They found that the eyewall vorticity can "roll-up" into a large number of small mesovortices that undergo rapid mergers with each other, but don't always merge into one central vortex (a monopole). Instead the mesovortices can form preferred persistent patterns that are maintained for many rotation periods. Examples from the numerical experiments of Kossin and Schubert (2001) are shown in Figs. 3 and 4, and are remarkably similar to the observed patterns in Isabel's eye.

*Corresponding author address: James P. Kossin, CIMSS/UW-Madison, Madison, WI 53706; kossin@ssec.wisc.edu

At some time after local sunset on 13 Sep, the four-mesovortex pattern in Isabel's eye evolved to a less organized mass of convoluted clouds. Contrary to this evolution, the four vortex pattern in the unforced two-dimensional barotropic model is in fact stable and can rotate in that configuration for an indefinite period of time. Thus while the mesovortices in Isabel's eye on 12–13 Sep aligned themselves in various patterns that were predicted by Kossin and Schubert (2001), the evolution and associated time scales of the actual mesovortices measurably differed from their idealized cases. The local divergent flow is a likely culprit for the disparity. According to preliminary analyses performed at the NOAA Hurricane Research Division, some of the clouds associated with the mesovortices in Isabel's eye appeared to have a significant vertical depth and contained substantial vertical velocities, as determined from various aircraft-based measurements taken on numerous missions into Isabel's eye.

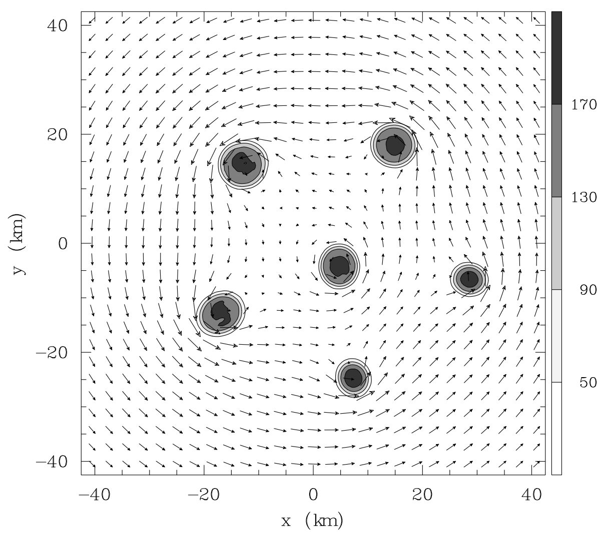

Figure 3: One of the preferred persistent vorticity configurations from the numerical experiments of Kossin and Schubert (2001). Values along the label bar are in units of 10^{-4} s^{-1}.

In addition to being beautiful to look at, the mesovortices that form in hurricanes play an essential role in hurricane intensification. Some previous studies have shown that axisymmetric models – which filter the barotropic instability mixing mechanism described above – can not produce a strong hurricane vortex without introducing an artificial mixing parameterization (e.g., Emanuel 1997). The parameterization is usually in the form of eddy diffusivity. However, Kossin and Schubert (2003) showed that diffusion is a particularly poor parameterization when mixing is accomplished via mesovortices. The reason for this is the mesovortices can protect their inner-cores from further mixing and are thus able to transport very high angular momentum from the eyewall directly into the low angular momentum environment of the eye.

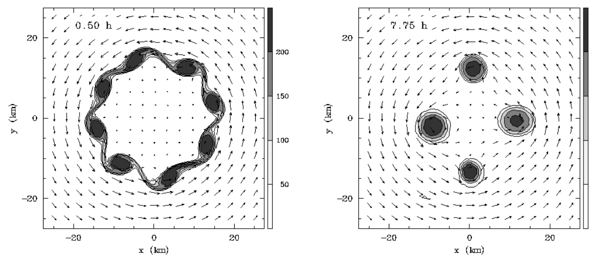

Figure 4: Numerical evolution of vorticity from a multiple mesovortex state to a four-mesovortex equilibrium state. In an unforced nondivergent framework, the four-mesovortex pattern can exist indefinitely. In electron-plasma laboratory experiments, such nonergodic equilibrium states are known as "vortex crystals".

Hurricane Isabel gave us an unprecedented glimpse into the turbulent dynamics of the hurricane inner-core, and helped to validate previous predictions based on the equations of motion. The appearance and behavior of the mesovortices in Isabel's eye strongly suggest that barotropic dynamics play a key role in hurricane evolution and that diffusive parameterization in numerical models may be a poor choice when considering the structure and intensification of the inner-core. It is expected that future collaborative analyses of the unique data collected in Hurricane Isabel – a large portion of which is the result of the ONR-sponsored CBLAST experiment – will serve to clarify much of the fundamental dynamics and thermodynamics occurring in the hurricane eye and eyewall.

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Satellite animations are available at
http://cimss.ssec.wisc.edu/tropic/isabel_2003.html