

Mesovortices in Hurricane Isabel

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On 12 September 2003, satellite images of Atlantic Hurricane Isabel astounded the tropical cyclone science community as a myriad of elaborate patterns revealed themselves within the clouds in Isabel’s eye. Patterns of convoluted clouds in hurricane eyes have been previously documented (Fletcher et al. 1961; Kossin et al. 2002, Montgomery et al. 2002), but Isabel showed us something new. As the first visible satellite images became available after local sunrise (~ 1100 UTC), a remarkable pentagonal pattern resembling a starfish was clearly evident in Isabel’s eye. 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 (Fig. 1).

One of the exciting aspects of the appearance of the “starfish” pattern in Isabel’s eye is that this pattern was 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. One outcome of such numerical integrations is shown in Fig. 2 (their Fig. 9). The maximum growth of the instabilities of the initial flow occurred at wavenumber 13, and 13 mesovortices were “rolled up” from the vorticity in the eyewall. Rapid merger events followed as the mesovortices migrated into and around the eye while rotating cyclonically. After 4.5 hours, the six remaining mesovortices formed pentagonal (starfish) patterns in the local streamline field that were remarkably similar to the features observed in Isabel. Further integration of the model showed the mesovortices alternating between pentagonal and hexagonal configurations.

During 11–14 Sep, while Hurricane Isabel was at peak intensity, super rapid scan operations (SRSO) were active on the eastern Geostationary Operational Environmental Satellite (GOES-12). Animations of the SRSO visible imagery from this period are available at http://cimss.ssec.wisc.edu/tropic/isabel_2003.html. As shown in these animations, another remarkable period occurred at around 1400–1500 UTC on 13 Sep. At least eight small mesovortices appeared to be arranged in a circle near the interface between the eye and eyewall. These mesovortices underwent multiple merger events in the following few hours. At 1745 UTC, only four mesovortices – larger than the original eight and arranged in a square pattern – remained. A very similar evolution was found in another of the experiments of Kossin and Schubert (2001; their Fig. 4). In that experiment, the model eyewall vorticity rolled up into eight small mesovortices that merged over the following six hours into four larger mesovortices.

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, as seen in the early near-sunrise images on 14 Sep. 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 using a model of maximum simplicity,

the evolution and associated time scales of the actual mesovortices measurably differed from the 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 (M. Black and S. Aberson, personal communication).

The mesovortices that form in hurricanes play an essential role in hurricane intensification. 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 (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.

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 analyses of the large and unique data set collected in Hurricane Isabel will serve to elucidate much of the fundamental dynamics and thermodynamics of the hurricane eye.

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Additional satellite imagery can be found at:

http://cimss.ssec.wisc.edu/tropic/isabel_2003.html

<http://www.cira.colostate.edu/ramm/rmsdsol/isabel-web.htm>

<http://rapidfire.sci.gsfc.nasa.gov/gallery/?search=isabel>

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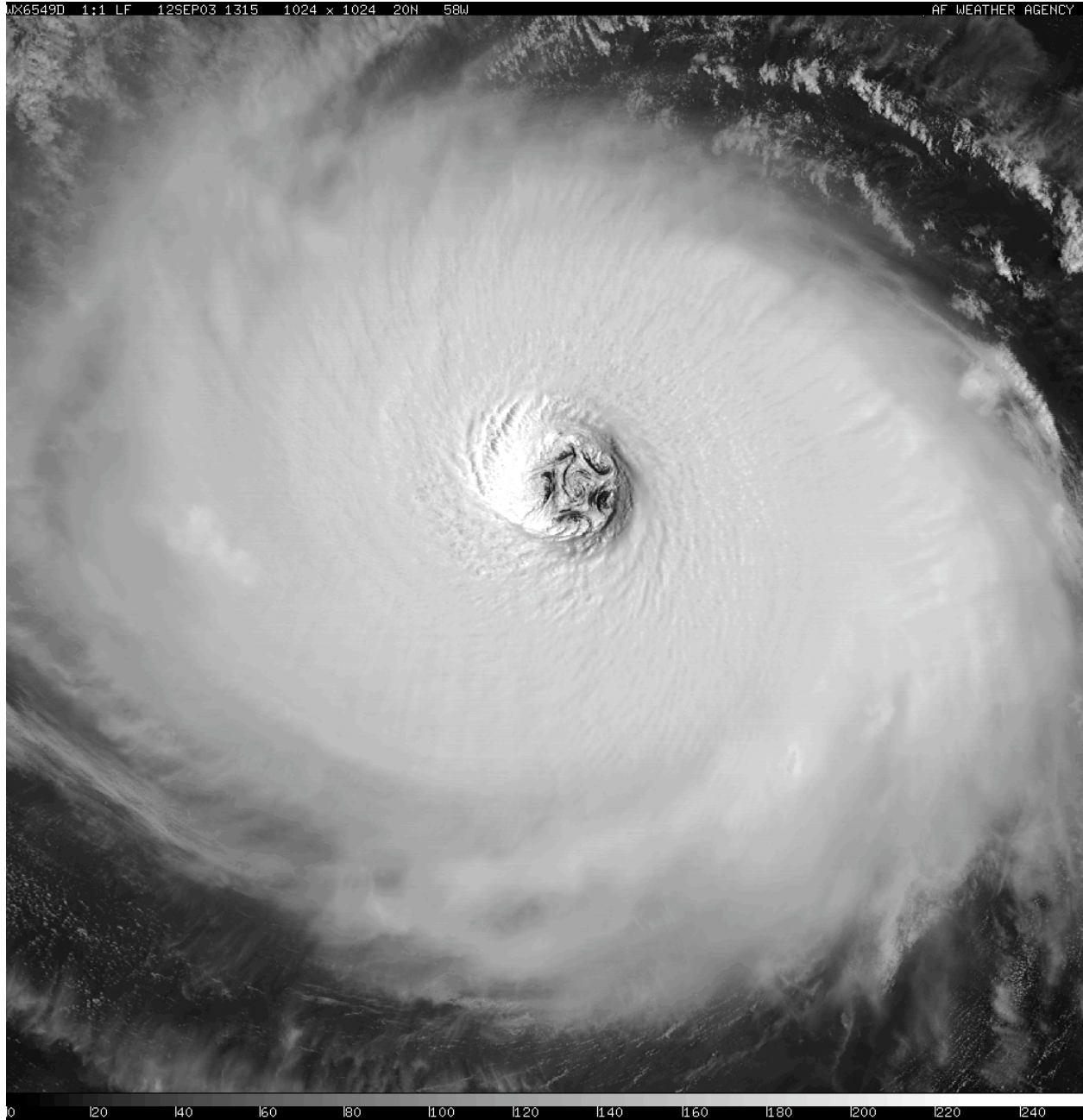


Figure 1: Defense Meteorological Satellite Program (DMSP) image of Hurricane Isabel at 1315 UTC 12 Sep 2003. The “starfish” pattern is caused by the presence of six mesovortices in the eye – one at the eye center and five surrounding it.

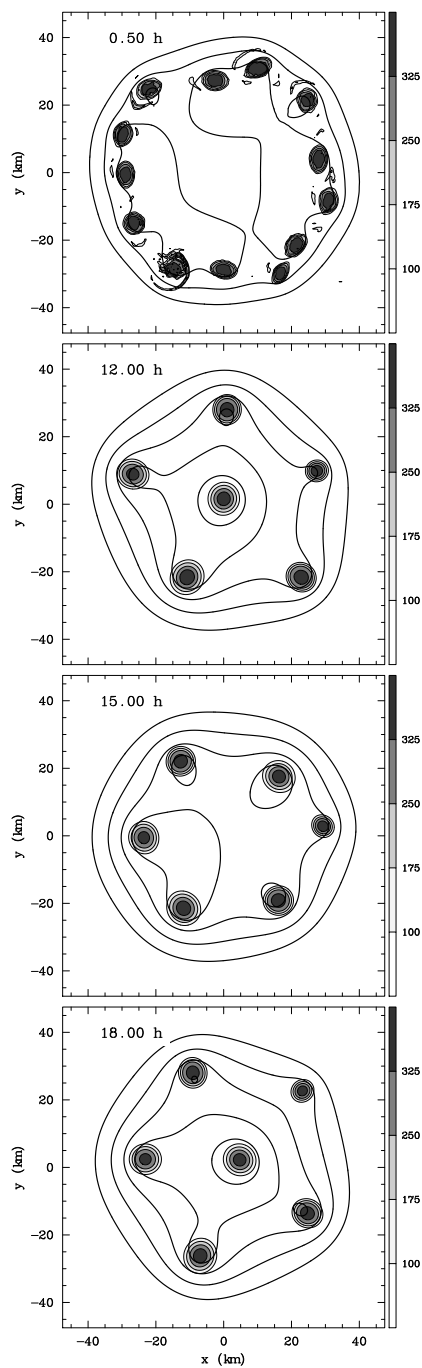


Figure 2: Evolution of vorticity (shaded) and streamfunction contours (bold) for the numerical experiment of Kossin and Schubert (2001). Values along the label bar are in units of 10^{-4} s^{-1} . The shape of the streamlines transitions from a pentagon to a hexagon and back to a pentagon over 6 hours.