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Mesovortices in Hurricane Isabel (2003): A comparison of satellite, radar, and photographic observations

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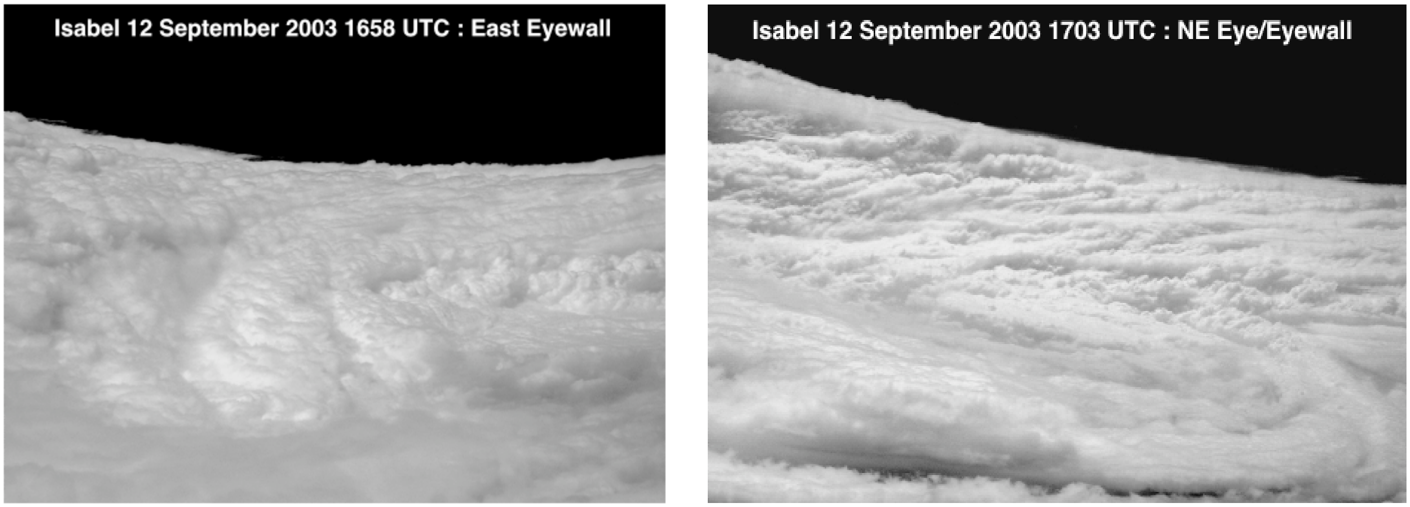

Figure 1: Photographs of Isabel's eyewall and mesovortex (middle right) inside of the eye. The photographs were taken from a NOAA P3 research aircraft at an altitude of 12,000 ft during an orbit inside the eye near 1700 UTC on 12 September 2003.

1. ISABEL MESOVORTICES

During 12-14 September 2003 while Hurricane Isabel maintained its intensity at or near Category 5, high-resolution satellite imagery revealed remarkable structure and evolution of mesovortices that appeared in Isabel's large eye and along the inner edge of the eyewall. NOAA P3 aircraft probed Isabel during each of the 3 days as part of the Hurricane Research Division's annual field program and in support of The Office of Naval Research Coupled Boundary Layers/Air-Sea Transfer initiative and the NOAA-NESDIS Ocean Winds program. The mesovortices, as viewed from the satellite, ranged in number from two to as many as ten (Kossin and Schubert 2004) and which were clearly rotating within the eye while undergoing considerable evolution and interaction with each other and with Isabel's eyewall. On 12 September, one of the mesovortices is tracked for over an hour on satellite imagery while completing more than one full orbit inside the eye. This same feature is visible on PPI and RHI radar sweeps from the NOAA aircraft during a penetration and orbit of Isabel's eye. The mesovortex was identified as the same one as on the satellite imagery and was tracked on radar for about 1/2 hour.

2. PHOTOGRAPHIC OBSERVATIONS

The NOAA research aircraft performed upwind orbits inside of the large eye of Isabel, providing ample time to collect digital still and video imagery of features inside of the eye and of the eyewall. The video imagery is currently being analyzed and reveals a complex structure of eyewall convection that is related to mesovortices inside of the eye. Portions of the digital video footage will be presented at the conference.

Examples of the types of structures viewed from the aircraft at an altitude of 12,000 ft are shown in Fig. 1. In the left panel are outward-sloping eyewall convective elements with individual convective towers that have cyclonic curvature with decreasing height. It is believed that these low-level (<4 km height) convective tubes are a manifestation of Kelvin-Helmhotlz instability along the high-shear region on the inner edge of the eyewall and may be the mechanism for which eyewall mesocyclones form and which, in some cases, grow and migrate into the eye (Montgomery et al. 2002). These features appear on radar as "fingers" of locally high reflectivity jutting into the eye from the eyewall (e.g., bottom of Figs. 2a, 2b, 2c) and may produce some exotic dynamics. A dropsonde observation into a similar feature on 13 Sep. had horizontal wind speeds of 107 m s^{-1} and updrafts exceeding 25 m s^{-1} at an altitude of 1200 m (Aberson et al. 2004).

The right panel of Fig. 1 shows a shallow (~2-3 km height) mesovortex with the center tucked up against the NE eyewall and appearing to merge with the taller eyewall convection. Shallow bands of cumuliform clouds can be seen spiraling around the center. These types of features, with horizontal diameters of ~10 km were frequently observed during the 3 days of aircraft observations.

3. RADAR AND SATELLITE OBSERVATIONS

Most clouds and eye mesovortices are difficult to track from airborne radar because of the combination of the shallow extent of the features, radar beam filling and attenuation effects, sea clutter, and limited time (usually) spent in the eye by the aircraft. On 12 Sep., however, during an upwind orbit in Isabel's eye, a large (20 km diameter) and deep (4-km height) mesovortex was observed and tracked on the 5-cm lower-fuselage (PPI) and 3-cm Doppler tail (RHI) radars. Comparisons of 3 nearly simultaneous PPI radar and visible satellite images of the eye and eyewall region during 1657-1710 UTC are in Figure 2.

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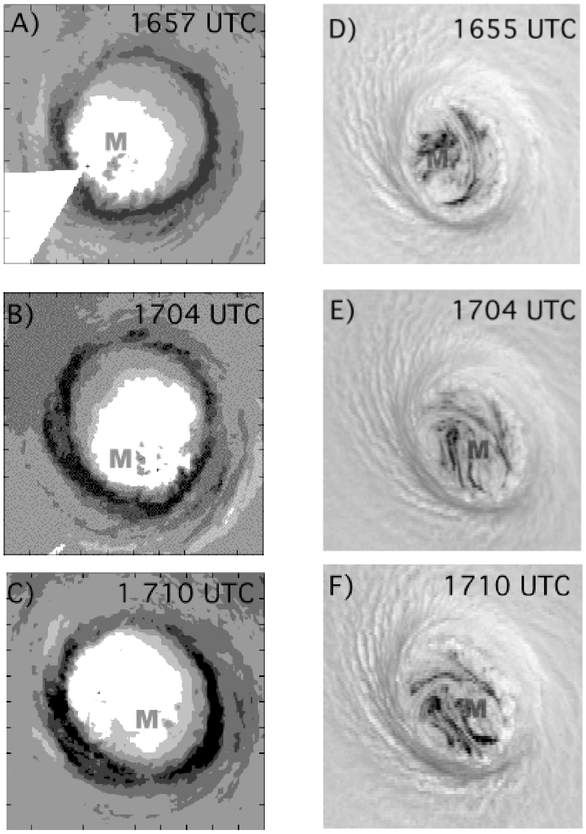

Figure 2: Radar and GOES-12 satellite images of the eye and eyewall region of Hurricane Isabel on 12 Sep. 2003. The PPI radar images are from the 5-cm radar on the NOAA P3 aircraft. The reflectivities are increasing with darker shading in increments of ~5 dBZ and ranging from 20-40 dBZ. North is at the top and the domain is 100x100 km for the radar and satellite images. The "M" is near the location of the mesovortex.

The mesovortex first appears on radar near 1645 UTC (not shown) in the SW portion of the eye as the aircraft is in the west eyewall but was more clearly evident near 1657 UTC (Fig. 2a) as the plane entered the eye. The radar signature is most pronounced near 1704 UTC (Fig 2b) when both the aircraft and the mesovortex are in the southern portion of the eye. Maximum radar reflectivities are 35-40 dBZ, modest values for convection, but large for clouds in the eye. The feature loses some of its robust appearance on radar after 1705 UTC as it translates to the SE eyewall and by 1710 (Fig. 2c) it is almost lost in the radar returns from the base of the eastern eyewall and from sea clutter. Nevertheless, with the aid of the satellite imagery, the mesovortex can be tracked until about 1723 UTC (not shown) by which time it has decreased in size and apparent intensity while moving faster near the inner edge of the north eyewall. The radar feature was tracked by identifying the locus of radar reflectivity and assigning a time and position to the loci. The mesovortex moved slowest while in the southern portions of the eye (~20 m s^{-1}) and fastest while near the edge of the northern eyewall (~35 m s^{-1}). It thus appears to be moving at a substantial fraction of the mean flow (as observed by aircraft) inside of the eye.

A vertical cross section of radar reflectivity across the mesovortex and Isabel's eye is in Fig. 3. Here, the mesovortex appears as a nearly vertical tower of modest (30-35 dBZ) reflectivity with echo tops near 4 km height. There is more than one high-reflectivity core in this cross section, suggesting that

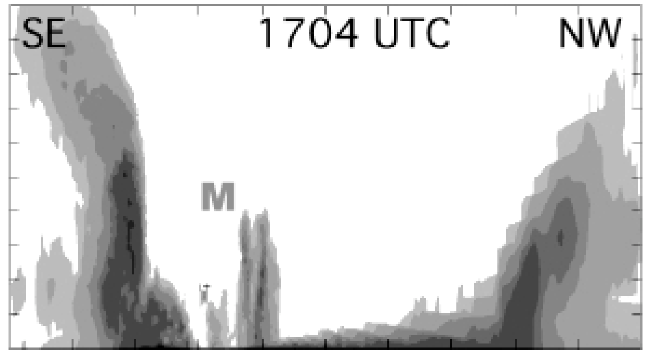

Figure 3: A SE (left) to NW (right) vertical cross section of radar reflectivity through the eye and eyewall from the NOAA 3-cm tail radar. The domain is 80 km in the horizontal and 12 km in the vertical. The reflectivity scale is the same as in Fig. 2. The aircraft is located between the SE eyewall and the mesovortex (M) at an altitude of ~2 km.

more than one updraft (or downdraft) channel may be present. This type of feature is unusually tall and large for an eye feature, except those associated with the remnants of an inner eyewall after a storm has undergone an eyewall replacement. Also, an inspection of raw Doppler radial velocities indicate that there are updrafts with magnitudes near 10 m s^{-1} within the core of the mesovortex which the appearance of overshooting cloud tops on satellite imagery tends to corroborate.

The mesovortex is more prominent and easier to track on satellite imagery than with radar. In fact, high-resolution (temporal and spatial) satellite animations have allowed us to track this particular mesovortex for over one hour, during which time it completes more than one full revolution around the eye. The mesovortex appears largest and tallest (as evidenced by brightness and protruding cloud tops) near 1645 UTC (not shown) while near the west-central portion of the eye. Afterwards, the cloud tops seem to collapse and the mesovortex decreases in size while orbiting around to the south, east, and northern regions of the eye. The cyclone undergoes another transformation along the western eyewall, growing in size and vertical extent once again before appearing to be disconnected from the eyewall at 1745 UTC.

Intriguing aspects found in the satellite animations are the appearance and evolution of "connecting tubes" of clouds from the eyewall to the mesovortices. These tubes undergo considerable evolution, as do the mesovortices themselves. The tubes move faster near the eyewall portion than at their connection point of the mesovortex, thus changing their shape and length as the mesovortices orbit inside the eye. Each mesovortex has at least one connecting tube attached to the eyewall and, at times, the satellite imagery shows the tubes merging and forming complex shapes as part of the evolution of the mesovortices.

4. REFERENCES

Aberson, S. D., M. T. Montgomery, and M. L. Black, 2004: A record wind measurement in Hurricane Isabel: Direct evidence of an eyewall mesocyclone? Preprints, Twenty-sixth Conf. on Hurricanes and Tropical Meteorology, 03-07 May 2004, Miami, FL.

Kossin, J. P., and W. H. Schubert, 2004: Mesovortices in Hurricane Isabel (2003). Bull. Amer. Met. Soc., **85,** 9–11.

Montgomery, M. T, V. A. Vladimirov, and P. V. Denissenko, 2002: An experimental study on hurricane mesovortices. J. Fluid Mech., **471,** 1–32.