DOMINANT TROPICAL CYCLONE OUTER RAINBANDS RELATED TO TORNADIC AND NON-TORNADIC MESOSCALE CIRCULATION FAMILIES

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1. INTRODUCTION

Doppler (WSR-88D) radar sampling of Tropical Cyclone (TC) outer rainbands over recent years has revealed a multitude of embedded mesoscale circulations (e.g. Zubrick and Belville 1993, Cammarata et al. 1996, Spratt el al. 1997, Cobb and Stuart 1998). While a majority of the observed circulations exhibited small horizontal and vertical characteristics similar to extra-tropical mini supercells (Burgess et al. 1995, Grant and Prentice 1996), some were more typical of those common to the Great Plains region (Sharp et al. 1997). During the past year, McCaul and Weisman (1998) successfully simulated the observed spectrum of TC circulations through variance of buoyancy and shear parameters.

This poster will serve to document mesoscale circulation families associated with six TC's which made landfall within Florida since 1994. While tornadoes were not associated with all of the circulations (manual not algorithm defined), those which exhibited persistent and relatively strong rotation did often correlate with touchdowns (Table 1). Similarities between tornado-producing circulations will be discussed in Section 7.

Contained within this document are 0.5 degree base reflectivity and storm relative velocity images from the Melbourne (KMLB; Gordon, Erin, Josephine, Georges), Jacksonville (KJAX; Allison), and Eglin Air Force Base (KEVX; Opal) WSR-88D sites. Arrows on the images indicate cells which produced persistent rotation.

2. TC GORDON (94) MESO CHARACTERISTICS

KMLB radar surveillance of TC Gordon revealed two occurrences of mesoscale families (first period not shown). The second episode of mesocyclogenesis occurred within a dominant rainband which resembled a reverse-oriented line echo wave pattern (LEWP). As the LEWP rotated northwest and inland within the outer periphery of the TC circulation, three distinct mesocyclones evolved (Fig. 1; R and SRM images). The westernmost circulation within the family eventually experienced a low-level contraction of the (rotational) core diameter, resulting in a shear increase. Occurrence of a brief F0 tornado occurred coincident with the shear peak. Tornadoes were not reported in association with the other two circulations, nor did their observed shears reach similar magnitudes.

3. TC ALLISON (95) MESO CHARACTERISTICS

The initial cell of the Allison family developed along the northeast Florida coast shortly prior to 0700 UTC. The cell moved northward along the coast and had spawned two tornadoes by 0830 UTC. The cell possessed a tight reflectivity gradient and developed a bounded weak echo region (BWER) during times of tornado occurrence. During the first touchdown, the diameter of the rotational couplet and corresponding shear were unimpressive. However, near the time of the second tornado, the rotational velocity increased and the mesocyclone diameter decreased, resulting in a very large shear value of greater than .030 s^{-1}.

As the first mesocyclone lifted northward into Georgia, two additional circulations developed just upwind along the northeast Florida coast (Fig. 2; R and SRM images). The two recently developed circulations quickly acquired tight reflectivity gradients and hook echoes as they lifted northward along and just inland from the coast. Although tornadoes were not reported with these cells, velocity signatures revealed the likelihood of touchdowns within sparsely populated regions along their tracks through extreme southeast Georgia.

Just prior to the radar-detected dissipation of the initial mesocyclone around 1015 UTC, a final brief tornado occurred. This circulation was manually detected for nearly 2 h along a track of about 80 km across northeast Florida and southeast Georgia.

4. **TC ERIN (95) MESO CHARACTERISTICS**

As TC Erin exited into the Gulf of Mexico after traversing the peninsula, a rainband within the far eastern periphery of the TC circulation moved northeast into east coastal Florida. As the TC rainband approached the coast, a marine outflow boundary moved onshore and a collision occurred, maximizing convergence. The collision temporarily transformed the feature into a dominant rainband as it become stationary and heavy precipitation echoes trained northward. Several of the echoes acquired rotation as they reached the northern portion of the rainband and became detached from the main portion of the band (Fig. 3; R and SRM images).

The central mesocyclone developed the greatest reflectivity core and rotational velocity signature. A brief F1 tornado occurred in association with this mesocyclone, nearly 10 minutes after Fig. 3. During the time of the tornado, detected rotational velocity was only 7.5 ms^{-1} and shear approached .010 s^{-1}.

Although the three mesocyclones were persistent, they only remained identifiable for approximately 30 min., compared to the several hour duration of the Gordon and Allison circulations.

Two additional very brief F0 tornadoes also occurred near the radar site within the heaviest rainband cells. Velocity data did not resolve any circulations associated with the reported tornadoes.

5. **TC OPAL (95) MESO CHARACTERISTICS**

A (radar) visually impressive dominant outer rainband associated with TC Opal moved onshore the Florida panhandle during the morning of 4 October 1995. Numerous isolated, high reflectivity echoes developed well offshore and moved towards the coast within a line oriented parallel to the concave coastline (Fig. 4; R and SRM images).

Well ahead of the line, several mesocyclones also developed on land (not shown) and were responsible for brief tornado touchdowns. These mesocyclones, which preceded the dominant band, were more typical in horizontal/vertical scales for TC mesocyclones.

The circulations within the dominant band were very long-lived and deep, allowing many to become identifiable as soon as they moved within range of KEVX velocity sampling. The northwest motion of the cells over the open Gulf waters allowed them to be observed for an average of 1-2 h before reaching the coast. Several of the circulations moved onshore as waterspouts/tornadoes, while others didn't produce tornado touchdowns until well inland. A few of the mesocyclones were associated with cyclic tornado production.

Generally, the stronger the radar-observed mesocyclonic shear, the greater the correlation to TC Opal tornado touchdowns. However, several strong circulations were observed which did not produce documented tornadoes. A conclusive answer as to whether or not tornadoes occurred in association with these stronger circulations can not be made. Several of the potentially tornadic cells traversed sparsely populated areas, made even less populated by hurricane evacuation orders. Additionally, the inner hurricane rainbands and destructive winds affected much of the same area hours later, making damage survey distinctions impossible.

6. **TC JOSEPHINE (96) MESO CHARACTERISTICS**

Although the circulations which developed in association with TC Josephine occurred in families, they were not associated with a long-lived dominant rainband. Instead, they formed inland in-situ, within a highly favorable shear environment. Surface heating during the day likely contributed to higher than normal instability (for TC landfall tornado events) which allowed the cells to initiate over land. During the morning and early afternoon of 7 October 1996, several brief tornadoes occurred across central Florida in association with radar-detected circulations. During the mid to late afternoon, the number and intensity of the observed circulations increased (Fig. 5; R and SRM images).

During the hour preceding Fig. 5, the family of circulations began to develop far to the southwest. The cells initially were isolated in nature and contained tight reflectivity gradients. Soon after their formation, the cells began to acquire rotation. All three cells intensified into strong mesocyclones, containing rotational velocities of >17 m s^{-1} and shears >.015 s^{-1}. The two inland cells each produced several brief F0 touchdowns, whose times were coincident with observed peaks of mesocyclonic shear. The easternmost cell produced a waterspout over a large inland lake on the Seminole/Volusia county line (Fig. 5), then nearly 20 minutes later spawned a long-track F2 tornado as the cell neared the east coast. Observed shear within this cell peaked twice, at levels similar to that which occurred with the inland cells. The greatest shear occurred prior to and during the waterspout event, then again near the time of the strong tornado.

6.1 TC GEORGES (98) MESO CHARACTERISTICS

A tremendous number of shallow mesocyclones formed within several narrow bands over the Atlantic during the early morning hours of 25 September 1998 and persisted until mid day (Fig. 6, R and SRM images). The bands drifted slowly northward during the morning, causing each successive circulation to affect an area near or slightly north of the previous one. Although observed rotational velocities and shears were not as large as those detected during some of the earlier TC-tornado events, several did possess rotation sufficient enough to prompt tornado warnings. While several waterspouts were observed over the near shore waters, only one damaging (F0) tornado was documented. This tornado was photographed by a NWS MLB forecaster.

7. DISCUSSION AND CONCLUSIONS

Over the past half decade, five tropical cyclone landfalls resulted in 60+ documented tornadoes (Table 1) and countless more non-tornadic mesocyclones across Florida. The majority of the mesocyclones occurred within families of three or more, often within dominant TC rainbands. All mesocyclones and tornadoes developed within or slightly beyond far outer right-front quadrant rainbands of a poleward moving Gulf of Mexico TC (Hagemeyer 1997). The radar-observed mesocyclones associated with five of the six TC-tornado events resembled mini-supercells of small horizontal and vertical extent. Only TC Opal produced a series of circulation families more reminiscent of Great Plains supercells.

A majority of the observed circulation families initiated over the Atlantic, Gulf of Mexico, or along an immediate coastline, then moved onshore. Many of the tornadoes which formed within these marine-originated circulations evolved from waterspouts. There appeared to be no preferred time of day for the marine mesocyclones and subsequent waterspouts/tornadoes. TC tornadoes which occurred well inland were less frequent, and tended to occur during the afternoon when instability was greatest. Persistence of the low-level rotational couplet was the most common trait among all circulations. Manual (not algorithm) mesocyclone designation ranged from 30 min to well beyond 3 h for all of the cells.

The five TC events examined in this paper revealed that the most favorable tornadic shear profiles often were confined to a relatively small geographic area within a dominant rainband.

However, within these particular bands, potentially tornadic mesocyclones were abundant. Therefore, when a dominant band impacted land, multiple, simultaneous tornado threats quickly became a reality. Dealing with such a succession of imminent tornadoes at once can be overwhelming for radar operators, emergency managers, and the public. To lessen such an impact, forecasters need to anticipate TC-tornado outbreaks well in advance, then must prepare the emergency management community and public once the threat becomes highly probable.

Observational studies such as this, combined with model simulations (e.g. McCaul and Weisman 1998) can be used to anticipate synoptic and mesoscale patterns conducive to TC mesocyclogenesis. Thorough radar analyses must be performed as outer rainbands approach. Although land-based soundings may not yet indicate a significant tornado threat, dominant rainbands containing mesoscale circulation families can develop within radar range. Approach of a dominant rainband will maximize convergence and vorticity, resulting in a sub-synoptic scale environment conducive to tornadogenesis.

The authors plan to further examine the local environment within TC dominant outer bands. Data from NOAA aircraft dropsondes, along with air and ground based radars will be used to examine rainbands containing circulation families within TC's Bonnie and Georges (1998).

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8. **RELATED LINKS**

- Tornadoes in TC's Gordon (1994) and Allison (1995) & warning strategies
- The observed TC mesocyclone spectrum
- Radar characteristics of TC mesocyclones
- Lightning signals associated with TC-tornado cells
- Examining the Pre-Landfall Environment of Mesovortices within a Hurricane Bonnie (1998) Outer Rainband
- Dual-Doppler Analyses of Mesovortices in a Hurricane Rainband (HRD)
- Tornadoes associated with TC Bertha (1996) across the Mid-Atlantic (NWS Wakefield, VA)
- Tornadoes associated with TC Danny (1997) across the Mid-Atlantic (NWS Wakefield, VA)
- Tornadoes in West-Central Florida during TC Josephine (1996) (NWS Tampa Bay, FL)
- Hurricane Opal (1995) tornadoes (NSSL)
- Tornadoes within TC Bertha (1996) (NSSL)

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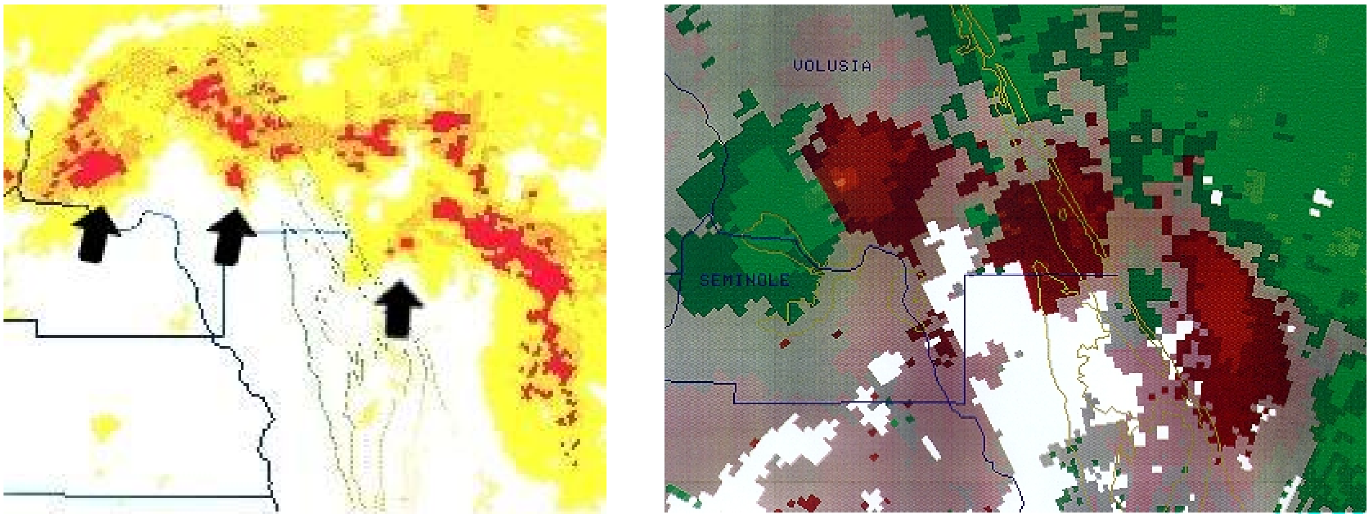

Fig. 1a (left). Dominant rainband (LEWP configuration) associated with TC Gordon at 0900 UTC 16 November 1994. Unobstructed inflow and persistent rotation occurred with each of the cells shown. The westernmost cell produced a brief F0 tornado. Fig. 1b (right). Storm Relative Velocity image corresponding to Fig. 1a. Note the large overall size of the mesocyclones.

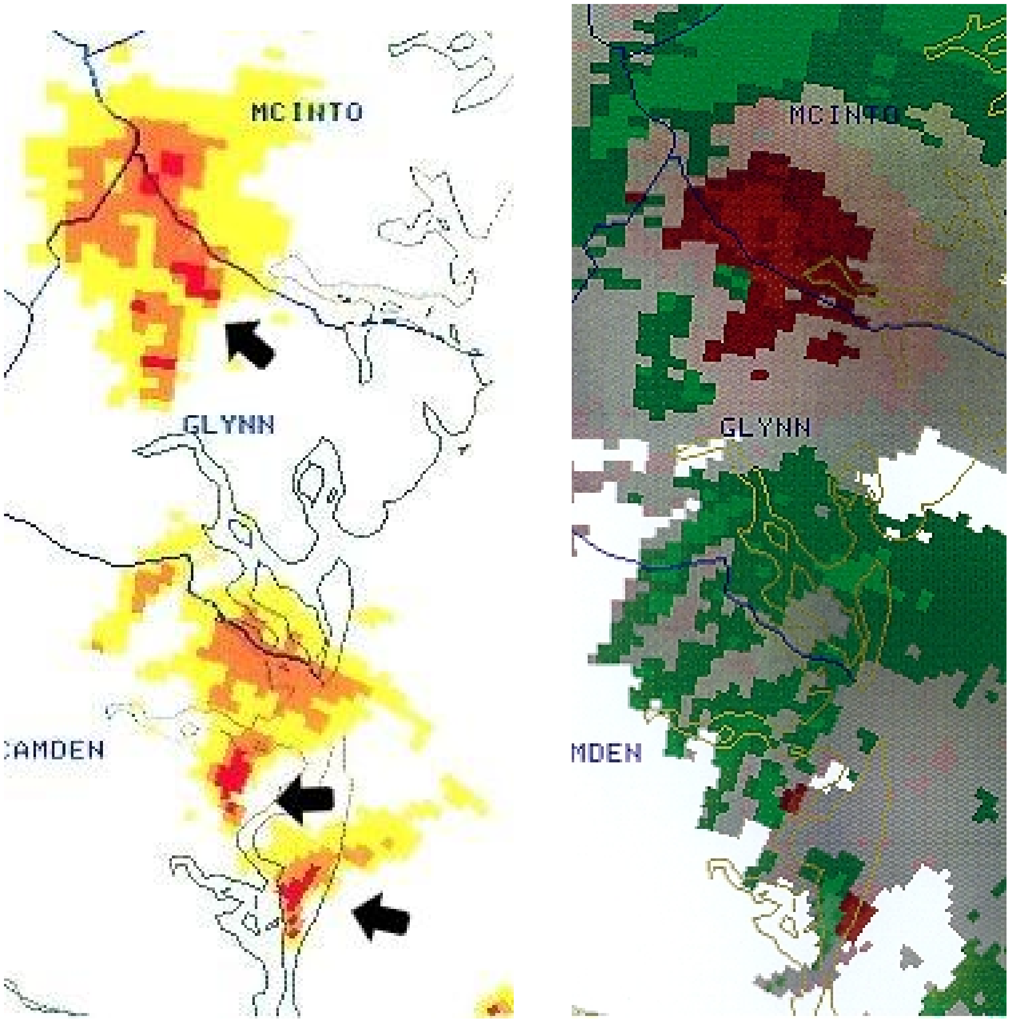

Fig. 2a (left). Isolated high reflectivity cells associated with TC Allison at 0957 UTC 5 June 1995. Classic (mini) hook echoes and persistent rotation occurred with each of the cells shown. The northernmost cell produced a series of tornadoes and the central one produced at least one. Fig. 2b (right). Storm Relative Velocity image corresponding to Fig. 2a.

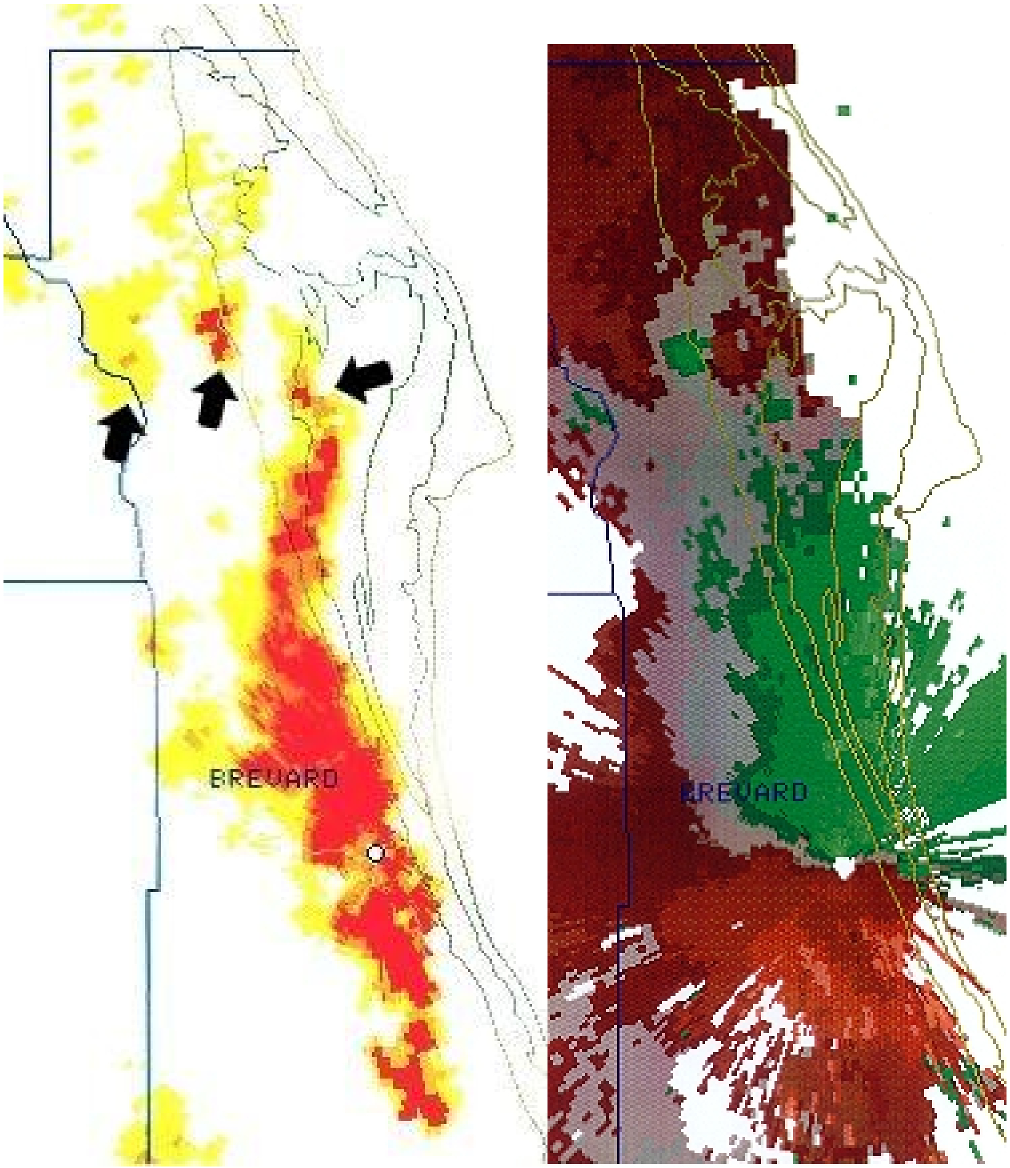

Fig. 3a (left) Boundary on extreme eastern periphery of TC Erin wind field at 1836 UTC 2 August 1995. Meso circulations developed within the stationary band and lifted north, then northwestward through the band. Note the three cells which correlated with persistent rotation. The central one produced several weak tornadoes. Fig. 3b (right) provides a Storm Relative Velocity view of the mesocyclones.

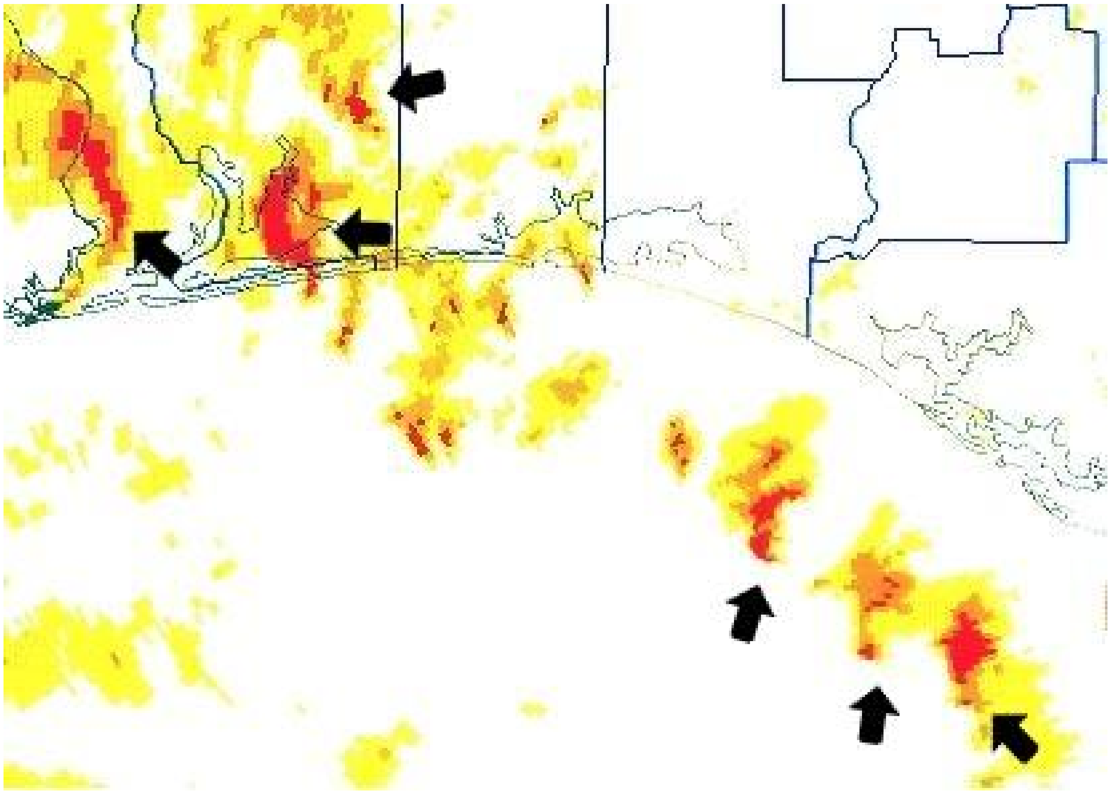

Fig. 4a. Numerous high reflectivity isolated cells associated with TC Opal at 1548 UTC 4 October 1995. Classic hook echoes and strong, persistent rotation occurred with each of the cells shown. Many of the circulations lasted for more than 2 h and exhibited rotational velocities above 17 m/s averaged over the lifetime of the cell. Depths were much greater than typical TC mini-supercells.

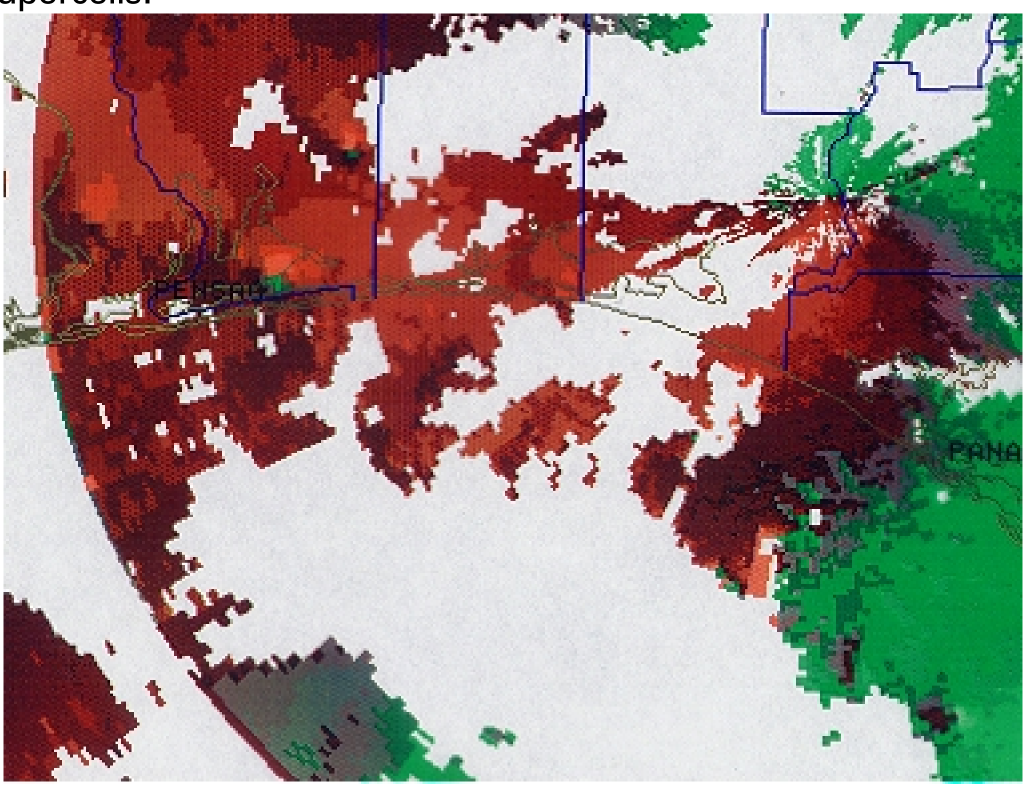

Fig. 4b. Storm Relative Velocity image corresponding to Fig. 4a.

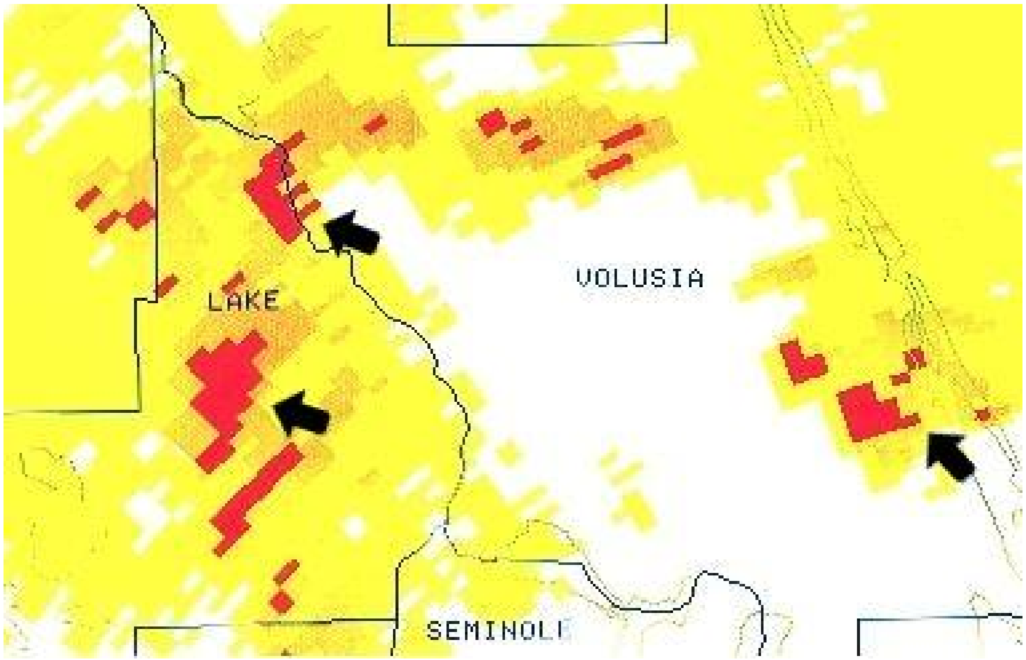

Fig. 5a. Areas of enhanced reflectivity associated with strong low-level mesoscale circulations during TC Josephine at 2117 UTC 7 October 1996. Although all three features began as isolated cells, the two western cells eventually became embedded within surrounding areas of rainfall. At the same time of this image, all three mesocyclones were producing tornadoes. Brief F0 touchdowns occurred in association with the inland cells, while the easternmost cell produced a long-track F2 tornado.

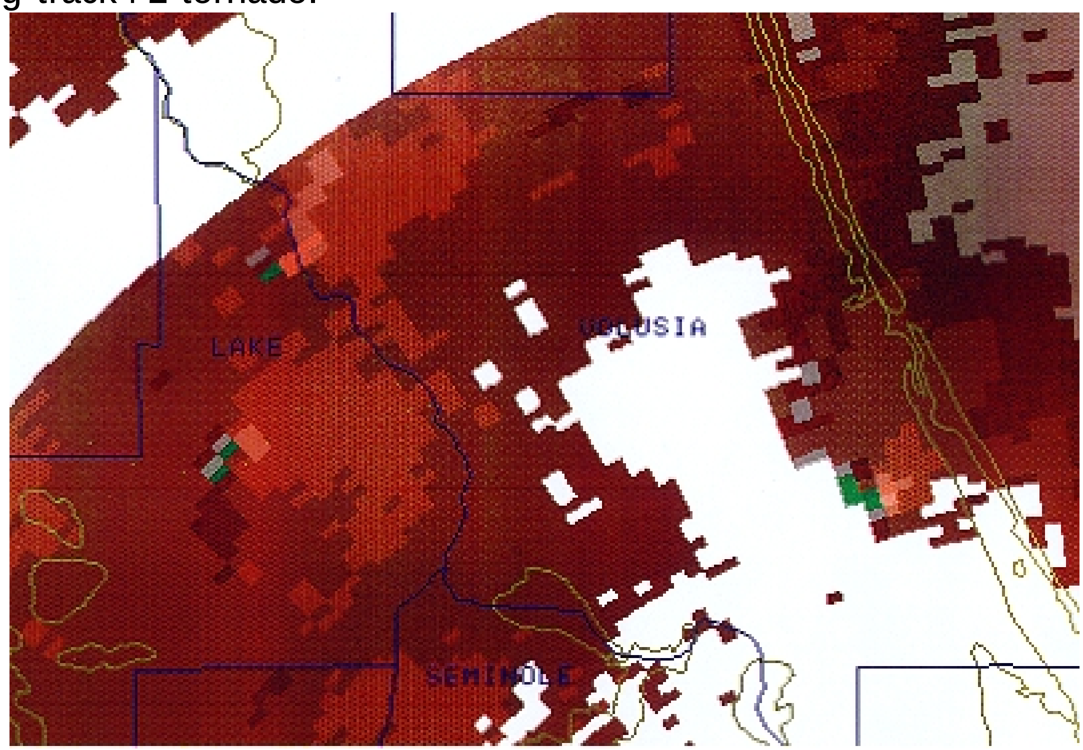

Fig. 5b. Storm Relative Velocity image corresponding to Fig. 5a.

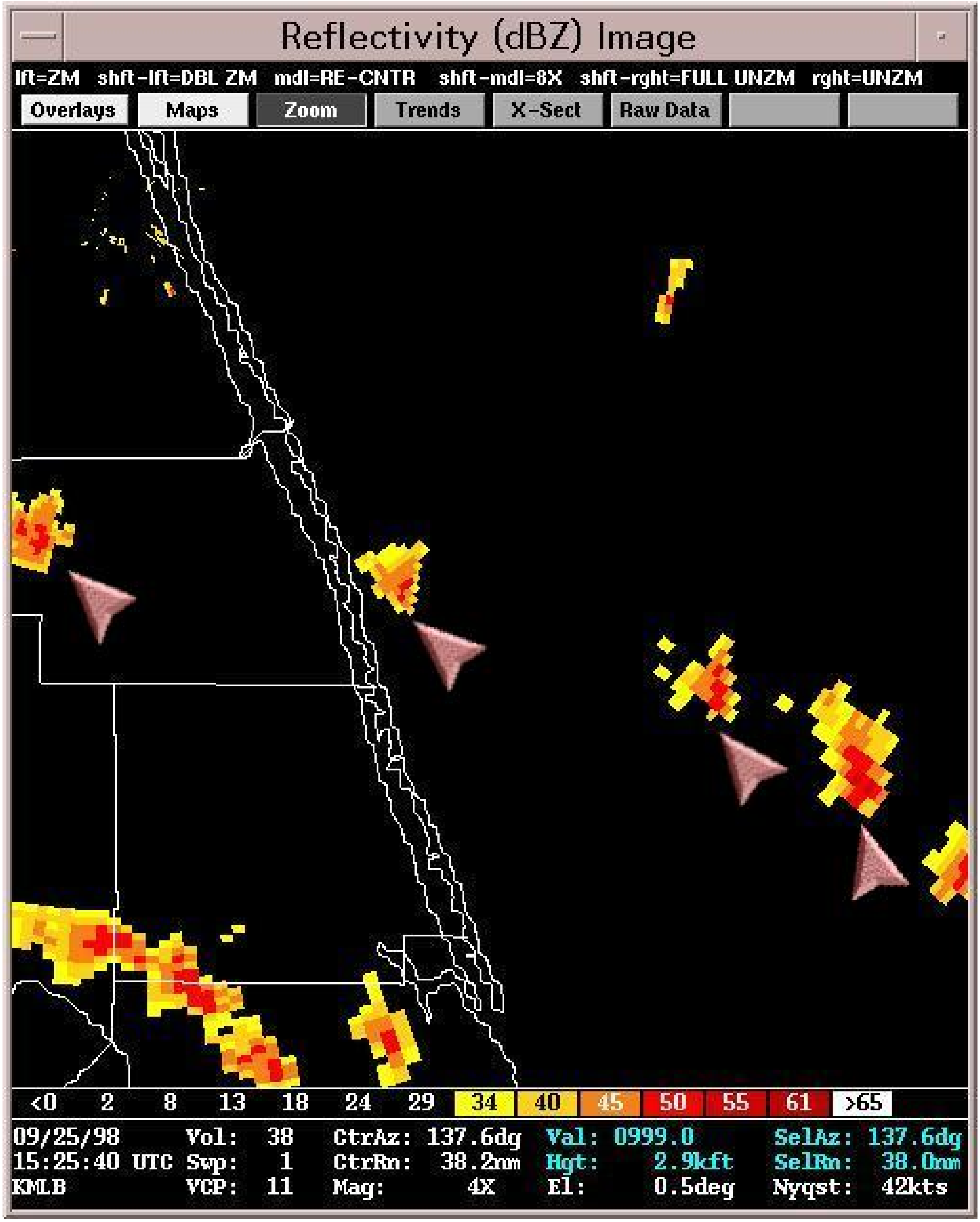

Fig. 6a. Base Reflectivity at 1525 UTC 25 September 1998 indicating scattered heavy showers within a outer rainband associated with TC Georges. The indicated cells exhibited rotation. The cell approaching the coast produced an F0 tornado 30 minutes later (see photograph taken by NWS meteorologist).

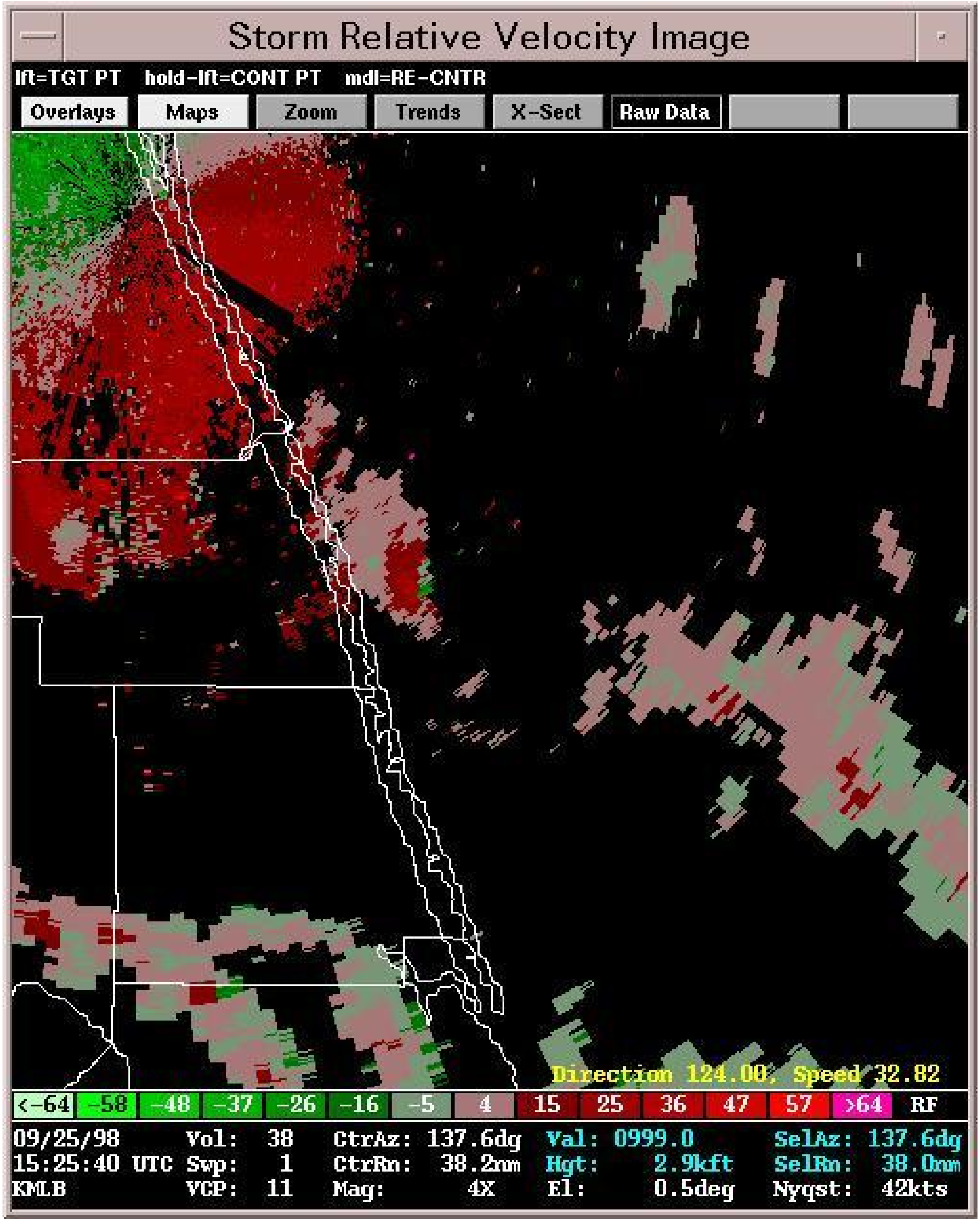

Fig 6b. Storm Relative Velocity image corresponding to Fig. 6a. Note the relatively strong rotation associated with the cell about to move onshore and the weaker circulations with the other cells.

Photograph of a **Tropical Cyclone Tornado** (by Stephen Hodanish; NWS Melbourne). The tornado produced a 2.5 mile discontinuous path of F0 damage in Sebastian, Florida, 7 miles southwest of Steve's location. The tornado developed within a mini-supercell at 1605 UTC 25 September 1998 in association with Hurricane Georges.

TC Name (Year)	Number of Tornadoes	F-Scale Total	Fatalities/Injuries
Gordon (1994)	6	10	1 / 40
Allison (1995)	7	9	0 / 1
Erin (1995)	4	5	0 / 0
Opal (1995)	10	13	1 / 3
Josephine (1996)	23	25	0 / 0
Georges (1998)	10+ (preliminary)	10 (preliminary)	0 / 0
TOTAL	**60**	**72**	**2 / 44**

Table 1: Documented tornadoes associated with 6 recent TC events in Florida. "F-Scale Total" represents the cumulative Fujita damage scale ranking for all tornadoes per TC (where F0=1, F1=2, F2=3).