A Spectrum of Outer Spiral Rain Band Mesocyclones
Associated with Tropical Cyclones

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1. Introduction

The initial deployment of next generation radars in Florida began in 1991 with the installation of the Weather Surveillance Doppler Radars (WSR-88D) at both the National Weather Service Office in Melbourne (NWS KMLB) and at the United States Air Force Base at Eglin (USAFB KEVX). These were the first WSR-88Ds to be deployed in a near-tropical environment and in proximity to climatologically preferred tropical cyclone paths. Since that time, numerous outer spiral rain bands have traversed the state associated with fully mature tropical cyclone (TC) systems. Several of these bands have been observed to possess discrete mesocylonic circulations which have been correlated both temporally and spatially with confirmed tornadoes.

Real-time and post analyses of base moment and derived radar products have led to the identification of a spectrum of mesoscale circulations within TC outer rain bands. This paper will compare and contrast the radar sampling conditions of two outer spiral rain band tornadic mesocyclones and offer them as models of circulation scale on each end of a proposed radar sampling spectrum. In particular, investigation of Hurricane Opal (1995) using the KEVX radar showed a series (or family) of tornadic mesocyclones over the northern Gulf of Mexico moving onshore the Florida panhandle. These mesocyclones were associated with a preceding outer rain band and possessed physical characteristics similar to those of the average Southern Plains mesocyclone. At least one of the tornadoes was known to reach F2 intensity as it moved through the town of Crestview, FL. Conversely, although Tropical Storm Gordon (1994) also produced a family of tornadic mesocyclones along the lower peninsular east coast, these mesocyclones were more similar in physical dimension to those of low- topped mesocyclones which occur in non-tropical, low- buoyancy environments. The Gordon mesocyclones, as observed by the KMLB radar, were associated with an outer detached rain band with at least one tornado also reaching F2 intensity, crossing the coastline at Barefoot Bay, FL. In each case, characteristics of the mesocyclone which produced the F2-tornado were found to be representative of its family and serve as the model mesocyclone when defining the respective ends of the spectrum

In recent years, much work has been done to raise the level of understanding and anticipation of the TC-tornado threat through climatological patterns, statistical correlations, buoyancy/shear assessments, and case study analyses. However, the remaining difficulty resides in the real-time assessment of a given TC-mesocyclone for proper diagnosis of its potential to become tornadic. Proper diagnosis is governed by sampling the strength, depth, and diameter of the core mesocyclone crossed with the radar's ability to resolve such features. At one end of the sampling spectrum, the Crestview mesocyclone exemplifies those larger outer rain band mesocyclones whose character is more classical in nature. They have a higher probability of detection by both manual and automated means. In contrast, the Barefoot Bay Mesocyclone was much smaller in physical dimension making it more difficult to detect by manual methods and extremely difficult through current automated schemes. Therefore, it is used to define the opposite end of the spectrum. A better understanding of the variance in size of deadly TC outer rain band mesocyclone cores will help operators mentally overcome the known sampling limitations of the radar and hopefully increase lead-time for future tornado warnings.

2. The Barefoot Bay Mesocyclone

Upon inspection of the Barefoot Bay mesocyclone, radar data revealed a temporally persistent, small diameter but shallow mesocyclone core which formed along an outer spiral rain band, moved inland and produced significant tornado damage at 2350 UTC. Noted similarities exist between the observed updraft which evolved in the low thermodynamically unstable but strongly sheared environment for this case and the findings of numerical modeling studies conducted by Weisman and McCaul (1995) for a similar pre-storm environment. Weisman and McCaul found that individual updraft diameters (and depths) substantially decreased with decreasing Connective Available Potential Energy (CAPE). Since low-CAPE environments are usually inherent with tropical cyclones, it is surmised that mesocyclones with compact dimensions may occur more often in such situations. The 1600 UTC Cape Canaveral, FL sounding (XMR), yielded a CAPE of only 274 J/kg. A hodograph was constructed for the time period just prior to tornado using the actual storm motion, observed surface winds within 50-km, and vertical wind information from the KMLB Velocity Azimuth Display (VAD). The hodograph rendered a 0-3 km storm relative helicity (SRH) of 295 m2/s2. When comparing this pre-storm environment to McCaul's (1991) average TC-tornado environment, we again find similarities. McCaul found an average CAPE of 253 J/kg and SRH of 300 m2/s2 which was taken from 10 soundings where tropical cyclone related tornadoes occurred within 2 hr and 40 km of the event.

Considering its small physical dimensions, it is fortunate that the Barefoot Bay mesocyclone passed within close range (within 32 km) of the KMLB radar thus limiting aspect ratio and radar horizon problems. Due to the optimum sampling conditions for such a bantam feature justifies its use as the model mesocyclone for the proposed small-shallow end of the spectrum. The computed aspect ratio at that time was approximately 0.5 indicating that 90 to 100 percent of the true maximum of radial velocity was detected. Cell information from the 0.5 deg elevation slice was also at or below cloud base up to one hour before tornado. Low- level rotational velocities reached 16 m/s with horizontal shear increasing as high as .022 radians prior to tornadogenesis. During its life-cycle, the average diameter of the low-level core mesocyclone was only about 2.5 km with an updraft depth of about 3.5 to 4 km. Traditional reflectivity signatures such as a bounded weak echo region (BWER) and low-level hook were evident but subtle and far less dramatic than those that evidence average-sized mesocyclones.

3. The Crestview Mesocyclone

In an attempt to represent the Crestview mesocyclone pre-storm environment, a 1625 UTC modified hodograph was constructed for a location within 50-km of where the Crestview mesocyclone passed 30 minutes prior to tornadogenesis. KEVX VAD winds and surface data were used to construct the hodograph. Given the observed storm motion and vertical wind shear profile, 0-3 km storm relative helicity values were computed as 512 m2/s2. Significant storm- relative winds existed below 2 km, averaging 15-16 m/s throughout the inflow layer. The 1500 UTC CAPE, calculated from a modified 1200 UTC Tallahassee, FL sounding, was estimated to range between 1900-2000 J/kg prior to the release of deep convective instability and during the arrival of the outer spiral rainband. In this event, both the CAPE and 0-3 km SRH values well exceed McCaul's (1991) average findings for pre-storm environment.

Time trends of rotational depth and intensity indicate that the storm had over a three hour radar- observed history of persistent rotation prior to making landfall and producing considerable tornado damage. At closest range, the storm passed within 46 km of the KEVX radar. Mesocylone core rotation remained in excess of 3.5 km deep with notable upper level storm- top divergence during the entire event period. Just prior to and during tornado, the Crestview mesocyclone exhibited an operator-defined tornadic vortex signature (TVS), whereby the maximum inbound/outbound pixels were observed to be gate-to-gate and azimuthally adjacent. After moving onshore the mesocyclone transitioned into the tornadogenesis stage as the diameter of core rotation contracted and radial shear values increased to between .035 and .050 radians throughout the lowest 2 km. The 0.5 deg elevation slice also provided information at or below cloud base up to 45 minutes before tornado. The computed aspect ratio was approximately 1.84 suggesting that 60 to 70 percent of the true maximum radial velocity was detected. Of note was both the persistent low-level hook and the capped BWER which are manisfestations of a vertically erect and persistently rotating updraft whose rotation has extended to near ground level. Shortly after the BWER collapsed, the F2 tornado formed. The dimensions of the Crestview mesocyclone are in stark contrast to the Barefoot Bay mesocyclone. Due to its stout nature, it is put forth as the model mesocyclone for the proposed larger-deeper end of the spectrum.

4. Discussion and Conclusions

A variation exists among the spectrum of TC outer spiral rainband mesocyclones (Fig. 1). It has been demonstrated that on one end of the spectrum, there exists a mesocyclone core which is characterized by the dimensions and intensity of the Southern Plains supercell as exemplified by the Crestview mesocyclone associated with Hurricane Opal. These types of mesocyclones possess classic reflectivity characteristics such as low level hooks and persistent BWERs with deeper, broader mesocyclones. They form in TC-environments with a greater than average CAPE and are more readily detected by radar,

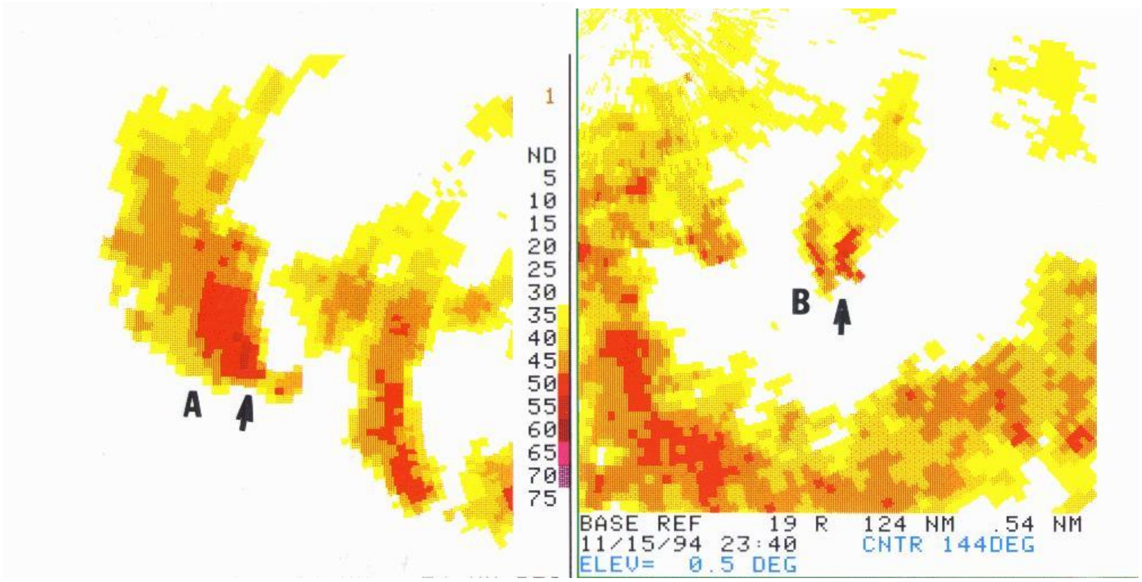

Fig. 1. Depiction of each model mesocyclone on either end of the proposed spectrum as viewed in base reflectivity at 0.5 degree elevation. They are proportional in scale and shown near the times of their respective F2 tornadoes. A.) The Crestview mesocyclone (Hurricane Opal); B.) The Barefoot Bay mesocyclone (Tropical Storm Gordon).

especially at farther ranges. On the other end of the spectrum, there exists a smaller dimension mesocyclone core that occurs with greater frequency and is characterized by much shallower and weaker rotation much like the Barefoot Bay mesocyclone associated with Tropical Storm Gordon. Its radar signatures are far less dramatic and form within an environment similar to that of the average TC-environment. Both are capable of producing strong and deadly tornadoes.

References:

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