Radar Characteristics of Mesocyclones Associated with Tropical Cyclones (TC) and a Simulation of the Mesocyclonic Characteristics Using MM5

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1. Introduction

Tropical Cyclones (TC) may spawn tornadoes either ahead of, during or after landfall. Outer rainbands can cause tornadoes in advance of landfall. The climatological synoptic conditions associated with TC tornadoes have been studied for the past 50 years. Studies of radar characteristics of the individual mesocyclones that produce tornadoes is, however, more recent. The Doppler radar studies of TC mesocyclones since the mid-1990's have enabled meteorologists to understand characteristics such as the life-time, horizontal and vertical extents of the circulations and the development of storm-scale horizontal vorticity (shear). (see Spratt *et al*. 1997; Suzuki *et al.* 2000; Scheck, 2001: and Rao *et al*. 2002).

2. Objectives

The main objective of this study is to document the mean kinematic and thermodynamic characteristics of mesocyclones producing tornadoes in landfalling TCs. Specifically, mesocyclones within TCs Frances (1998), Earl (1998) and Floyd (1999) that produced tornadoes were investigated in addition to two Floyd (1999) mesocyclones, which did not produce documented tornadoes. It is hypothesized that the mean characteristics and the trends so studied will offer clues about their dynamics and thus lend themselves to short-term prediction of their ability to produce tornadoes. All together

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fifteen individual mesocyclones were examined. Mesocyclones of the TCs seem to belong to a wide variety (Sharp, *et al*. 1997). Some are small, both in terms of horizontal and vertical extents. Some of them are short-lived while others are long-lived. A few of them are typified by large Convective Available Potential Energy (CAPE) while others, by small amounts. All of them appear to be identified by strong Storm Relative Helicity (SRH). The SRH amounts vary slightly but non-uniformly depending on whether the default motion of the mesocyclone or its observed motion is used.

3. Methodology

The methodology has been to locate the tornado occurrence from the Storm Data publication (NOAA, 1998 and 1999) and gather the relevant WSR-88D data from the closest National Weather Service Forecast Office (NWSFO). WATADS (NSSL 2001) software equipped UNIX workstations were employed to study the plan position indicators at 0.5^{o} and 1.5^{o} elevation angles and construct cross-sections nearly normal to the radar beam enclosing the Weak Echo Region (WER), if available, and separating the inbound and outbound couplet. Adopting a methodology similar to that employed by Spratt *et al.* (1997), we tabulated values of several parameters such as the diameter of the couplet, the outbound and inbound Doppler velocities and the maximum reflectivity, etc. at 0.5^{o} and 1.5^{o} elevations of the radar beam. The coordinates of the mesocyclone are also tabulated with time, enabling the derivation of the observed mesocyclone translation. Over the life-time of each mesocyclone at least 12 such observational data pieces were developed. However, the tables in section 4 below contain only a restricted (15 minute) sample relating to Floyd (1999) including the radar volume scans immediately prior to, during and after the time of the reported tornadoes.

4. Floyd (1999) Mesocyclones

Details of the mesocyclones (Radar Site: Morehead City, KMHX) that produced tornadoes on 15 September 1999 in North Carolina are shown below:

a. Onslow County at 2011 UTC- F1 damage (Meso-A)

b. Pamlico County at 2011 UTC -F0 damage (Meso-B)

c. Emerald County at 2041 UTC- F2 damage (Meso-C)

d. Carteret County at 2155 UTC-F0 damage (Meso-D)

The following non -tornadic mesocyclones (Radar site: Morehead City, KMHX) were studied:

a. Carteret County at 2020-2050 UTC (Meso-E)

b. Carteret County at 2200-2241 UTC (Meso-F)

Table 1

Meso-cyclones	Range	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
Meso-A	31	8	-12	10	2.83	0.007
Meso-B	37	-3.5	-28	12.5	1.88	0.013
Meso-C	15	16	0.5	8.25	7	0.002
Meso-D	11	5.5	-6	5.75	1.2	0.008

Table 1 shows the radar features of Tornadic mesocyclones in Floyd (1999) based at 0.5^o elevation angle at the time of tornado touchdown (corresponding times are given above). The diameter shows variation and the shears are significant as discussed in Spratt., *et al*. (1997).

Table 2

Meso-cyclones	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
Meso-A	12	-12	12	2.66	0.008
Meso-B	-3.5	-23	9.75	1.461	0.013
Meso-C	12	1.5	5.25	4.2	0.002
Meso-D	6.5	-7.5	7	2.30	0.006

Table 2 shows the radar characteristics of the Tornadic mesocyclones at 1.5^o elevation angle at the time of Tornado touchdown. The diameter shows some decrease from 0.5^o elevation.

Table 3

Meso-cyclones	Range	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
Meso-E	18.2	4.5	-18	12	2.34	0.01
Meso-F	40	13	-8.5	11.25	1.78	0.01

Table 3 shows the radar features of non-Tornadic mesocyclones when they are close to radar in Floyd at 0.5^o elevation angle at 2036 and 2211 UTC respectively. The shears are similar in magnitude to that of tornado bearing mesocyclones.

Table 4

Meso-cyclones	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
Meso-E	9.5	-13.5	15.25	2	0.01
Meso-F	13.5	-14	13.75	1.3	0.02

Table 4 shows the radar characteristics of the non-tornadic mesocyclones at 1.5^o elevation angle for the corresponding times above.

Table 5

Range	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
65.1	11.48	-14.25	13.23	6.05	0.006

Table 6

V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
12.48	-13.09	12.85	6.93	0.004

Tables 5 and 6 show the mean characteristics revealed by the tornadic mesocyclones at 0.5^o and 1.5^o elevation angle respectively. The diameter shows a small increase at 1.5^o elevation. The above mean includes mesocyclones from TC Earl (1998) and TC Frances (1998) as well (Radar sites: Tampa, KTBW; Charleston, KCAE; Fort Polk, KPOE).

Table 7

Range	V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
26.43	7.625	-14.75	10	2.503	0.0085

Table 8

V_{OUT} (m/s)	V_{IN} (m/s)	V_R (m/s)	DIA (km)	SHEAR (s^{-1})
12.88	-14	13	2.163	0.013

Tables 7 and 8 show the mean (entire life) characteristics revealed by the non-tornadic mesocyclones at 0.5^o and 1.5^o elevation angles respectively.

5. Storm Relative Helicity (SRH) Comparison

Table 9 shows storm relative helicity (SRH) with respect to default and observed motions of mesocyclones. Default storm motion is simply 30^o to the right and 75% the strength of the mean wind between 0-6 km. The observed movements are faster and the directions more backed than the default motions, resulting in smaller SRH. Table 9 shows the SRH for mean and observed motions for the Floyd (1999) case. Meso-F did not produce any tornadoes and shows much less SRH for observed motion compared to default. This is an important deduction.

Table 9

Time UTC	**Observed Motions** Degrees /knots	**SRH for observed motions** 0-3 km J/kg	**Default Motions** Degrees /knots	**SRH for default motions** J/kg
Meso-A	121.92 /35.5	222	148/28	329
Meso -B	128 /31.87	253	148/28	329
Meso -C	123.3 /52.9	253	148/28	329
Meso -D	118.9 /33.39	205	148/28	329
Meso -F	109.3 /55.5	120	148/28	329

6. PPI and Vertical Cross sections

An example of PPI at 0.5^o elevation is shown in Figure 1. Of interest is the storm (Meso-A) shown 30 km south-southwest of the radar center. A four-panel display of a reflectivity PPI, a Doppler wind PPI and vertical cross-sections of reflectivity and storm relative velocity are shown in Figure 2.

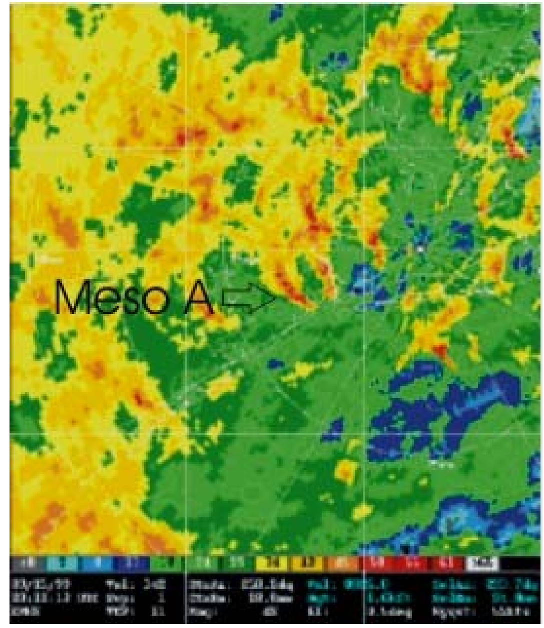

Fig. 1 Doppler radar PPI at 0.5^o elevation from Morehead city, NC reveals strong storms south southwest of KMHX 2011 UTC, 15 Sept 1999. The cross sections of this storm are shown below.

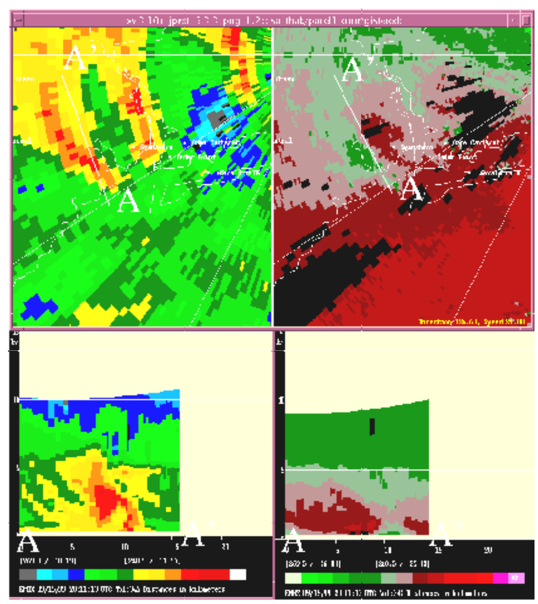

Fig. 2 Morehead City, NC (KMHX) WSR-88D imagery showing a four panel display comprising of a) top left, reflectivity, b) top right, storm relative velocity, where red colors show motion away from the radar and green colors show motion towards the radar, c) bottom left, the vertical cross-section, along AA', of reflectivity, and d) bottom right, the vertical cross-section, along AA', of storm-relative radial velocity of the cell at 2011 UTC 15 September 1999, which was responsible for the F0 tornado in Onslow County, NC.

7. Simulations

So far we have simulated (Gallagher, 2002) using MM5 the mesoscale features of the mesocyclones that were produced by TC Earl in September 1998 in Florida, in the vicinity of Tampa and in South Carolina, in the vicinity of Charleston. The vertical component of vorticity at 925 mb served to identify the mesocyclones. These will be discussed at the conference. The simulations of the vertical component of vorticity and convergence fields at 925 mb agreed in time and in space with the positions of reported tornadoes.

8. Conclusions

The following conclusions were drawn based on the full sample of 15 pieces of data from three TCs.

a. Mesocyclones were produced in the right front quadrant of the TC at a mean angle of 56^{o}.

b. The mean duration of the tornadic mesocyclone was 75 minutes significantly higher than the non-tornadic one which was 40 minutes.

c. Mean diameter and shear values were found to be nearly the same for both tornadic and non-tornadic mesocyclone cases.

d. The mean diameter of the mesocyclone at 0.5^{o} elevation (nearly 570 m above ground) was 6.05 km while at 1.5^{o} elevation (nearly 1.7 km above ground) the mean diameter was 6.92 km. This shows that the mesocyclone was slightly wider at a higher elevation.

e. The depth of the mesocyclones in Floyd (1999) varied between 3 and 3.5 km. According to Hodanish *et al*. (1997)., the average depth of TC tornadic mesocyclones was 3 km with none exceeding 4.4 km for TC Josephine (1996), TC Opal (1995), TC Erin (1995) and TC Gordon (1994).

f. The mean lateral shear at 570 m was 0.006 s^{-1} while at 1.7 km it was 0.004 s^{-1}. This shows that the shear decreased at a higher elevation. Shear value at the time of tornado occurrence was higher and offer itself as a valuable parameter for warning purposes.

g. SRH is an important parameter for the forecasting of tornadoes (Sharp *et al*. 2002) as the non-tornadic mesocyclone showed a low value of SRH for the observed storm motion. Non tornadic cases will be extended to cover a broader sample.

Acknowledgements.

This research was sponsored by the UCAR-COMET Partners grant. SO2 – 32807

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