11C.5 COMPOSITE DISTRIBUTIONS AND ANALYSIS OF TROPICAL CYCLONE TORNADOES, 1950-2005

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1 INTRODUCTION

Although tornados spawned by a land-falling tropical cyclones have been reported about as far back as 1773 (Sadowski, 1961), there is still much to be learned about these dangerous and difficult to track phenomenon. These tornadoes are known to be typically less intense than their cousins of the Great Plains, and their preferred area of occurrence tends to stretch from the Gulf coast of Texas around the Florida peninsula and up to the Virginia coast and stretches inland two to three hundred kilometers (See Figure 1). In 2005 alone, the damage estimates totaled over 100 million dollars. Two recent hurricane seasons have had a combined higher count of tornado reports (over 500) than many decadal counts since 1950, causing an increase in public awareness and concern. This fact alone may be strongly related to the renewed interest in this weather phenomenon that has captured research interests for over fifty years.

Much work has gone into comparing TC tornadoes to their larger, more studied cousins in the Great Plains region of the United States. It is generally accepted that there exist similarities in the storm environments and dynamic ingredients needed for a tornado to form. The problem lies in the smaller size of the mesocyclones, the relative quickness with which the system forms and drops a tornado, and the ability to pick out these miniature super-cells on radar when they are embedded in a much larger system.

From a statistical standpoint, much of the work accomplished thus far has looked at limited datasets both due to the availability of information and the sheer amount of work involved in combing through the datasets by hand. The intent of this work is to look at the relationships identified by previous scientists and apply their concepts and hypotheses to the data from 1950 - 2005 of TC spawned tornadoes using the TORHUR program. The TORnado - HURricane database is assembled using the information listed in NHC's HURDAT database and SPC's ONETOR listing.

The tornadoes that occur within plus/minus three hours of each HURDAT six-hour location and a 750 kilometer range from the center are stored with the hurricane information. Segmenting the data in this way has allowed for an expanded look at previous work and hypotheses presented over the years, both covering the original work's span of time (for accuracy) as well as expanding the proposed trend to the fifty-six year record. Combining the information will allow a closer look at each of the tropical storms that have spawned tornadoes, their attributes, and locations.

As aforementioned, the distance of 750 km is currently used to limit the range. This value was chosen based on work accomplished by McCaul (1991), indicating likely candidates for consideration as hurricane (TC) tornadoes. Although this value has ensured assignment of all associated tornado reports to each tropical

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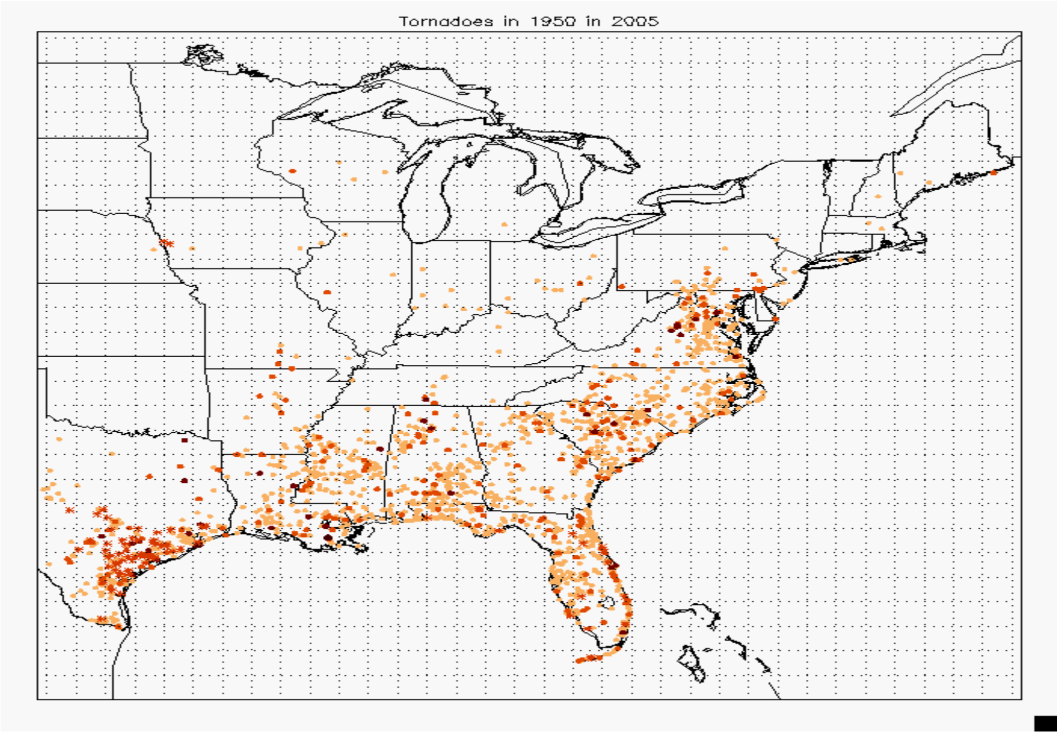

Figure 1: 1950-2005 Tropical Cyclone Tornadoes - U.S. Map. Light colors correspond to lower intensity (f-scale)

storm (within the limitation of the HURDAT location points), it does occasionally result in some error (note on Figure 1 some of the tornadoes in Nebraska, etc). Another source of error is the way tornadoes are listed in the ONETOR database. When a tornado crosses a state or county line, it gets an additional entry. Work is in progress to limit the double counting errors, while preserving the information stored for each event. The overall intent of the work is to provide a user with a quick, direct way to look at statistically relevant attributes concerning tropical cyclone-spawned tornadoes.

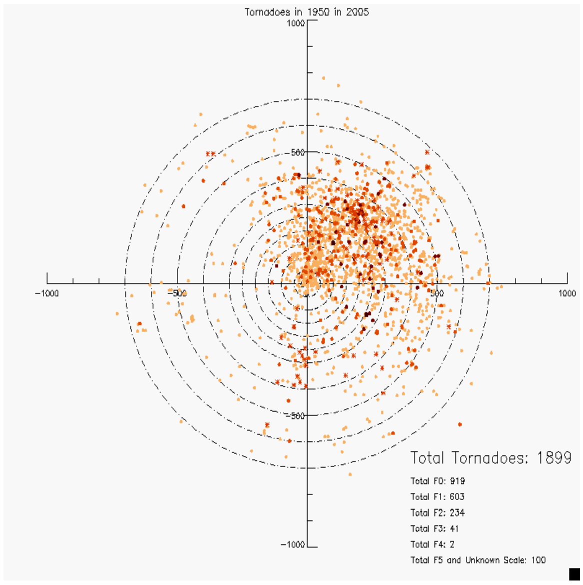

Figure 2: 1950-2005 Tropical Cyclone Tornadoes - Storm Motion Relative

2 CURRENT WORK

Where and When: Defining where and subsequently when, these systems occur within the structure of the tropical cyclone was the first order of business for early researchers. Work accomplished by Dunn (1965), Malkin and Galway (1953), Smith (1965) and through

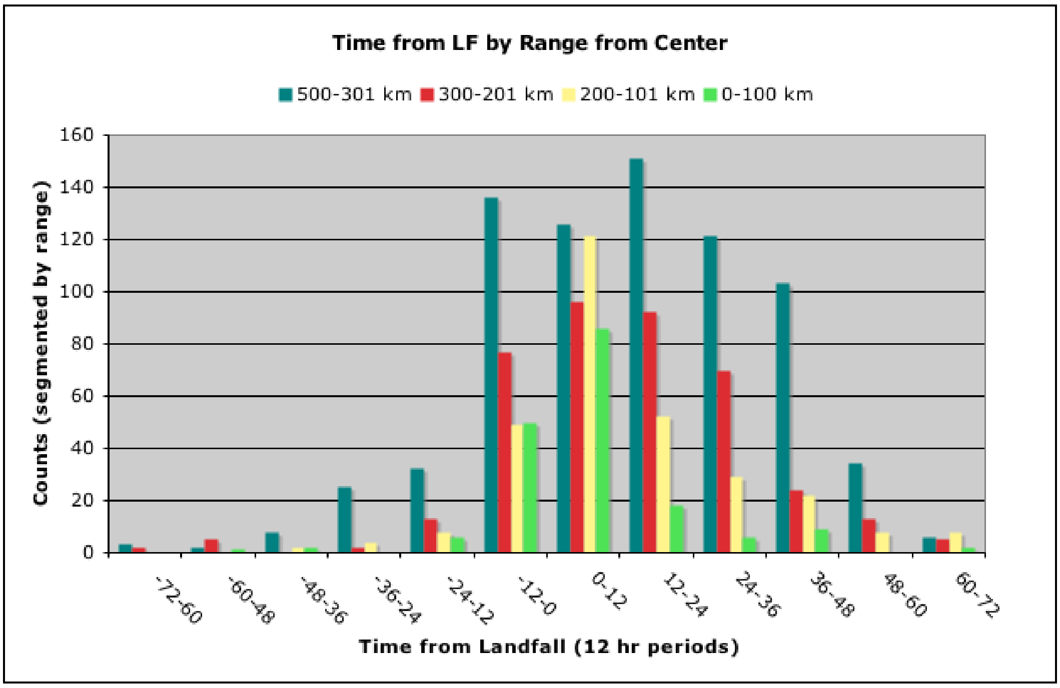

Figure 3: Tornado counts segmented by time from landfall vs range from the center

to Novlan and Gray (1974, NG74) and Gentry (1983, G83) defined a "significant sector" between 30° and 120° from the path of the hurricanes movement and 100 to 250 miles (160 - 400 km) from the hurricane center. The front-right quadrant, followed by the right-rear quadrant, ranked highest in tornado counts, becoming known as the "preferred quadrant" for tornado occurrence (see figure 2). This quadrant was especially preferred when it came ashore first, due to increased convergence, frictional contributions and shear as the hurricane transitioned from over the ocean to land. Following this line of thought, TC tornadoes are more likely to occur in the Gulf states than on the Atlantic coast. A distance of approximately 200 nautical miles (370 km) from the coast (NG74, G83) was also shown to be at a larger risk for tornadoes than further inland. Looking at figures 1 and 2, in 56 years, these early identified statistics continue to hold true. Looking at the "when" aspect of the climatology also dominated early research. In MCC91, of the 39-year data sample used, it was found that 59% of landfalls produced at least one tornado, usually in the first 24 - 48 hours, but with some occurring as long as five days after landfall. It was also found from composite profiles built from proximity soundings that values of helicity remained high, even up to three days after landfall. As such, one could ask if there is an intensity change in the tornadoes as the cyclone moves inland and decays with time, and how much does range from the center of the cyclone contribute to that intensity change.

Range and Intensity: MCC91 discussed a bimodal signal he labeled "core" and "outer rainband" hurricane tornadoes that occurred when plotting the tornadoes' locations on the radial plot. By his definition, outer rainband tornadoes occur approximately 200-400 km from the hurricane center while core tornadoes are classified as those occurring inside this limit. Looking at the radial plot in Figure 2, this signal would be hard to denote. Re-plotting the information as a histogram, as shown in Figures 3, 4 and 5 allows a closer look at which intensity tornadoes are occurring in each of the 100 km ranges as the TC moves inland and decays in time.

Figure 3 shows a histogram of tornadoes from the 56-year sample sorted by time from landfall, and further separated by range from the center of the cyclone. In agreement with previous work, there is an overall peak in all ranges 12 hours before to about 2 days after landfall with tornadoes occurring well into the 3 day range after landfall.

In the histogram, there is an expected maximum signal at 12 to 48 hours after landfall in all ranges from the center. For the "core" classification, if we were to use the 300 km limit as used in the paper, the tornado occurrence (green and yellow) inside of 300 km peaks within 12 hours of landfall and declines from there. For the "outer rainband" classification (red and blue), the peak occurs earlier, and a substantial number of tornadoes occur well into the period 48 hours after landfall, with some occurring out to 72 hours after. This signal is in line with what is understood and has been proposed about the dynamics of the embedded cells that produce the tornadoes. A greater number of tornadoes occur further away from the center of the storm, especially as time passes after landfall. It is important not to forget that a portion of the storms occurring in the 300-500 km range also include tornadoes that occur while the center of the tropical cyclone is still off shore.

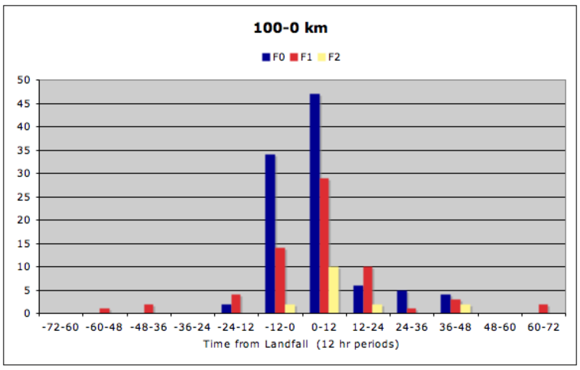

Figure 4: Tornado counts, segmented by time from landfall vs. range and colored by f-scale for the 100 - 0 km range. Axes is in Figure 3

Taking this histogram and further segmenting the range information by f-scale further tunes the number of tornadoes temporally and spatially. Looking specifically at the 100 km inwards to 0 km (Figure 4), the area that coincides with the defined core tornadoes, you can see how the intensity breaks down in the storms closest to the core of the tropical cyclone. F0 and F1 tornadoes peak in the 0-12hr range after landfall. As shown, there are F0 tornadoes that occur after, as well as F1s and a few F2s, but overall the number of tornadoes within 100 km of the center of the storm decays rapidly 12 hours after landfall. It is of interest to note that there are not a lot of stronger tornadoes (F2 - F4) in this area. This is an area where more research is needed to better determine and understand the dynamics occurring at this close range.

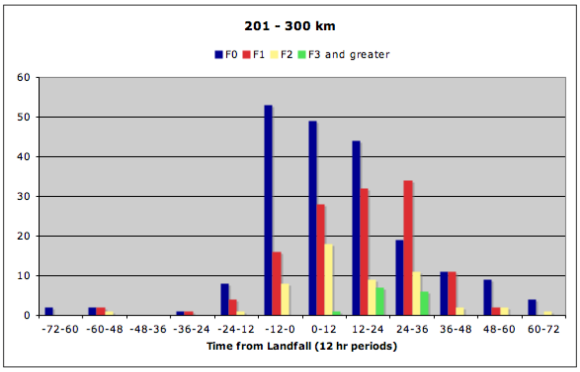

Figure 5: Tornado counts, segmented by time from landfall vs. range and colored by f-scale for the 300 - 200 km range. Axes is in Figure 3

Moving out further in range, the first thing that is apparent is the presence of F3 and greater storms. Also, an interesting signal in the F0 tornado count appears. There is still a maximum occurring within 12 hours of landfall as there was in the 100 - 0 km range, but the counts decline as the storm moves forward in time. Concurrently the number of F1 tornadoes increases. If the counts of F2 and F3 tornadoes are counted together, their number also increases the further the cyclone moves from landfall. This trend also shows up in the 500 - 300 km plots that are not shown here.

This signal lends itself to questions concerning how the cyclone is interacting with its environment and what factors are contributing to the genesis of stronger tornadoes when the cyclone itself is decaying.

3 CONCLUSIONS AND FUTURE AREAS OF WORK

The examples given in this paper of the reanalysis of previous studies make up a small portion of the work that is ongoing at this time. Correlations that may support the work investigating the core versus outer rainband relationships addressed in MCC91 are being pursued and include links to time of day, intensity changes in the cyclone, as well as the TC strength (intensity) and location at landfall. Theories concerning frontal boundary formation in the boundary layer (Knupp, 2006), dry air intrusions (Curtis, 2004) and links to intensity change in cyclone strength are also being investigated and encompass a large portion of the intended future work.

The work completed thus far provides an objective, quick way to search through a combined tropical cyclone/tornado database to locate attributes seen during one's course of study. Previously, when an observation was made in one or two events, much time and effort had to be invested to manually comb through the datasets to find similarities in other cases. Although this database allows a quick way to investigate possible relationships between TC and tornado attributes spanning 56 years, it is not intended to replace the individual case study work accomplished on the small scale. Rather, it should enhance the fine scale studies by providing the user with other cases exhibiting attributes similar to the one(s) currently being studied in a quick, meaningful way.

4 ACKNOWLEDGMENTS

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5 REFERENCES

Curtis, L., 2004: Midlevel Dry Intrusions as a Factor in Tornado Outbreaks Associated with Landfalling Tropical Cyclones from the Atlantic and Gulf of Mexico. *Wea. Forecasting*, **19**, 411- 427

Dunn, G.E., and STAFF, 1965: The Hurricane Season of 1964. *Mon. Wea. Rev.*, **93**, 175 - 187.

Gentry, R.C.,1983: Genesis of tornadoes associated with hurricanes. *Mon. Wea. Rev.*, **111**, pp. 1793 -1805

Knupp, K.R., J. Walters, and M. Biggerstaff, 2006: Doppler Profiler and Radar Observations of Boundary Layer Variability during the Landfall of Tropical Storm Gabrielle. *J. Atmos. Sci.*, **63**, 234 - 251

Malkin, W., and J.G. Galway, 1953: Tornadoes associated with hurricanes. *Mon. Wea. Rev.*, **81**,299 - 303

McCaul, E.W., 1987: Observations of the Hurricane "Danny Tornado Outbreak of 16 August 1985. *Mon. Wea. Rev.*, **115**, 1206 - 1223.

McCaul, E.W., 1991: Buoyancy and Shear Characteristics of Hurricane-Tornado Environments. *Mon. Wea. Rev.*, **119**, 1954 - 1978

McCaul, E.W., and M.L. Weisman, 1996: Simulations of Shallow Supercell Storms in Landfalling Hurricane Environments. *Mon. Wea. Rev.*, **124**, 408 - 429

McCaul, E.W., D.E. Buechler, S.J. Goodman, and M. Cammarata, 2004: Doppler Radar and Lightning Network Observations of a Severe Outbreak of Tropical Cyclone Tornadoes. *Mon. Wea. Rev.*, **132**, 1747 - 1763

Novlan, D.J., and Gray, W.M.,1974: Hurricane spawned tornadoes. *Mon. Wea. Rev.*, **102**, pp. 476 - 488

Pearson, A.D. and Sadowski, A.F., 1965: Hurricane-induced tornadoes and their distribution *Mon. Wea. Rev.*,**93**, pp. 461- 464

Sadowski,A.F.,1962: TORNADOES ASSOCIATED WITH HURRICANE CARLA. *Mon. Wea. Rev.*, **90**, No. 12, pp. 513 - 516

Smith, J.S., 1965: The Hurricane - Tornado. *Mon. Wea. Rev.*, **93**, 453 - 459

Verbout, S.M., Schultz, D.M., Leslie, L.M., Brooks, H., Karoly,D., Elmore, K.L. 2006: Tornado Outbreaks Associated with Landfalling Hurricanes in the North Atlantic Basin: 1954 - 2004 *Meteorology and Atmospheric Physics.*, **97**, Nums 1 - 4/August, 2007