P 3.1 TROPICAL CYCLONE TORNADO RECORDS FOR THE MODERNIZED NWS ERA

Roger Edwards[1]
Storm Prediction Center, Norman, OK

1. INTRODUCTION and BACKGROUND

Tornadoes from tropical cyclones (hereafter TCs) pose a specialized forecast challenge at time scales ranging from days for outlooks to minutes for warnings (Spratt et al. 1997, Edwards 1998, Schneider and Sharp 2007, Edwards 2008). The fundamental conceptual and physical tenets of midlatitude supercell prediction, in an ingredients-based framework (e.g., Doswell 1987, Johns and Doswell 1992), fully apply to TC supercells; however, systematic differences in the relative magnitudes of moisture, instability, lift and shear in TCs (e.g., McCaul 1991) contribute strongly to that challenge. Further, there is a growing realization that some TC tornadoes are not necessarily supercellular in origin (Edwards et al. 2010, this volume).

Several major TC tornado climatologies have been published since the 1960s (e.g., Pearson and Sadowski 1965, Hill et al. 1966, Novlan and Gray 1974, McCaul 1991, Schultz and Cecil 2009). While these studies undoubtedly have provided valuable insights into TC tornado distribution, the tornado data have evolved markedly during that time span, as have the ways the data are collected. Throughout these changes, and even though TC tornado prediction is evolving out of historically dominant empirical and climatological (Weiss 1987) modes, an understanding of tornado frequency and distribution in TCs remains foundationally crucial to their research and prediction. That understanding can be hindered or misled by often subtle or inconsistent influences of underlying secular artifacts on the data, and by changes in those artifacts with time.

Nationwide, tornado data have experienced a pronounced increase in reports over the decades, roughly doubling the mean yearly tally since the mid-1900s. This trend largely is attributed to a combination of technological advances in documentation capabilities (e.g., digital cameras, camcorders and, more recently, cell-phone imaging), increasing population, greater media attention, proliferation of spotters and storm chasers, and intensified National Weather Service (NWS) emphasis on warning and verification efforts in the WSR-88D radar era. More discussion of such secular influences can be found in Doswell and Burgess (1988), Brooks and Doswell (2001), McCarthy (2003) and Doswell (2007). In addition to covering such factors, Verbout et al. (2006, 2007) quite vividly illustrated that the increase in nationwide tornadoes over five decades since 1954 was attributable to the weakest (F0) bin of damage rating (Fig. 1). This is the very class of tornado that is most common in TC records, and most difficult to detect in the damage above that from the concurrent or subsequent passage of similarly destructive, ambient TC winds. As such, it is possible (but not quantifiable) that many TC tornadoes have gone unrecorded even in the modern NWS era, due to their generally ephemeral nature, logistical difficulties of visual confirmation, presence of swaths of sparsely populated near-coastal areas (i.e., marshes, swamps and dense forests), and the presence of damage inducers of potentially equal or greater impact within the TC envelope.

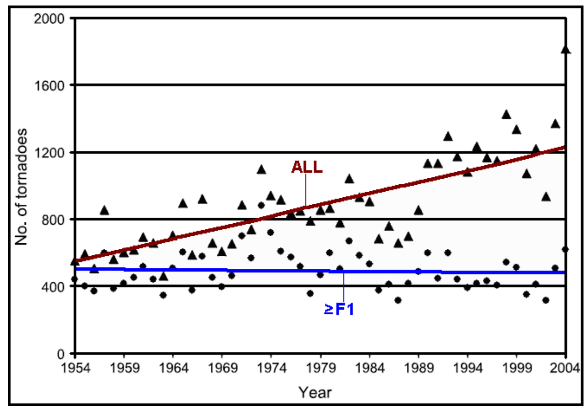

Figure 1. Annual tornado counts (triangles) and tornadoes ≥F1 (dots), 1954-2004. Linear regression lines for each series in red and blue, respectively. Adapted from Fig. 2 in Verbout et al. (2007).

As specifically applied to TCs, increasing trends in tornado records were apparent as long ago as the 1960s (Hill et al. 1966). Since TC tornadoes tend to be distributed more toward the low end of the F/EF scales (hereafter, EF) than the national figures at large (Schultz and Cecil 2009, and as demonstrated herein), any enhanced emphasis toward gathering of records of weak (EF0-EF1) tornadoes hypothetically should contribute to increased TC tornado numbers.

2. THE "TCTOR" DATASET

a. Justification and tornado-record characteristics

Given the aforementioned concerns with the tornado data overall, and by extension, with TC tornado records, a more focused, updated and

[1] *Corresponding author address:* Roger Edwards, Storm Prediction Center, National Weather Center, 120 Boren Blvd #2300, Norman, OK 73072; E-mail: roger.edwards@noaa.gov

consistent basis of analysis should be used than those available in existing literature. This is in order to: a) ameliorate impacts of systematic "shocks" to the data record (Thorne and Vose 2010), such as that resulting from NWS modernization in the early 1990s, and b) still offer a large sample (see Doswell 2007 for thorough discussion on sample size issues with tornado data). To those ends, this study analyzes TC tornado records spanning 1995–2009 (mapped in Fig. 2). The chosen period corresponds essentially to the full national deployment of WSR-88D units, and as such, is entirely within the framework of modern warning and verification practices based thereon.

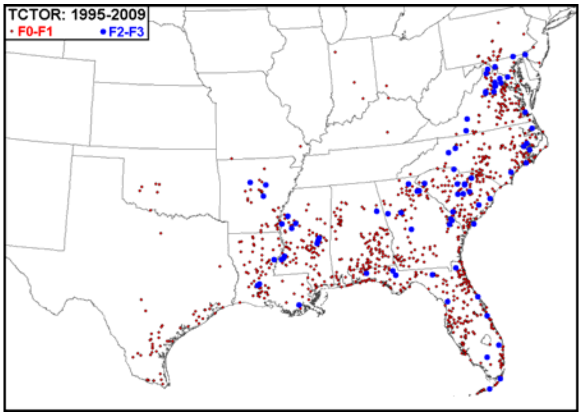

Figure 2. Geography of TC tornado (TCTOR) records plotted at individual path-starting points for 1995-2009. Weak (F0-F1) rated tornadoes are in red, overlain by significant (F2-F3) in blue, as in legend. No F4-F5 events occurred in the period of record.

Each potential TC tornado record in the conterminous U.S. was examined individually, by comparison with surface and upper air maps, archived satellite photos and/or imagery derived from archived NEXRAD Level II data (Kelleher et al. 2007), to determine its presence within the circulation envelope of either a classified or remnant tropical cyclone. Qualifying events were segregated from the nationwide Storm Prediction Center (SPC) one-tornado (ONETOR) database and assigned to their respective TCs by name. TC tornado records initially retained all information from the parent ONETOR database (e.g., identification number, time, date, states, latitude/longitudes for path ends, EF rating, casualties, monetary damage estimates, etc.). A "smooth" TC-tornado dataset (TCTOR) was compiled, expunging categorical redundancies (e.g., multiple columns specifying the same date and time), omitting any ONETOR categories impertinent to this study (e.g., county FIPS numbers and a useless constant "3" that denotes the CST time zone already given), as well as incorporating metric and UTC unit equivalents.

During the conversion of NCDC segmented data to ONETOR, intrastate county segments are stitched together to form whole-tornado tracks. However, a state border-crossing tornado in ONETOR still is parsed into one segment per state, albeit with a duplicate entry number so the state-segments still can be plotted as a single track with mapping software. Seven such events (0.06%) populated the 1995-2009 TC tornado record, each of which was combined into a single TCTOR path entry with two states listed (e.g., GA-SC in the "State" column).

b. Incorporation of TC information

National Hurricane Center (NHC) best-track records (Hurricane Data, a.k.a. HURDAT) then were examined for each tornado event, from which the most recent 6-hourly central pressure and wind intensity were applied to each tornado. Using those wind maxima (for classified systems), tornadoes were binned according to their correspondence with a tropical depression (TD), tropical storm (TS), hurricane (H), or a combination of all non-tropical and post-classification categories (N). An N may include either official extratropical classifications, a change to subtropical (as with Allison of 2001), or as with TC Erin in 2007, a remnant low with tropical characteristics (e.g., Brennan et al. 2009, Monteverdi and Edwards 2010). Linear interpolation between 6-hourly HURDAT center positions yielded a cyclone-center estimate at tornado time. The distance ***D*** from that to the starting position of each tornado then was computed across a great-circle surface arc, in a variation of the spherical law of cosines (e.g., Sinnott 1984) that uses latitude (**lat**) and longitude (**lon**) in radians, as follows:

$$\boldsymbol{D = r_e * (\cos^{-1} \{ [\sin(lat_{TOR}) * \sin(lat_{TC})] + [\cos(lat_{TOR}) * \cos(lat_{TC}) * \cos(lon_{TOR} - lon_{TC})] \})} \quad (1)$$

where r_e is the mean radius of earth. The subscripts TOR and TC signify tornado and TC-center positions respectively, neglecting any error at such relatively small radial angles that might arise from the centrifugal difference between polar and equatorial r_e. The Cartesian bearing of tornado reports relative to the TC center was included in TCTOR, to provide opportunities for additional analyses of cyclone-relative tornadic traits.

For each tornado, the most recent 6-hourly TC classification (hurricane, tropical storm or tropical depression), central pressure and maximum wind also were retained from HURDAT. For TC-remnant tornadoes occurring post-HURDAT, the surface-low location, pressure, and maximum wind were estimated subjectively from surface analyses, while the system also was assigned a post-classification category N (not classified as tropical cyclone). For numerical sorting and ranking purposes, TC classifications were assigned as in Table 1.

Table 1. Convention for TCTOR sorting of TCs by Saffir-Simpson intensity category (Simpson and Riehl 1981) at tornado time: MH is major hurricane (category 3-5); H is hurricane (category 1-2); TS is tropical storm; TD is tropical depression; N includes extratropical, remnant low and unclassified stages. Colors match 2010 NHC online tracking-chart conventions (available via http://www.nhc.noaa.gov).

Cat	MH	MH	MH	H	H	TS	TD	N
No.	5	4	3	2	1	0	-1	-2

Records in TCTOR do include inland TC remnants interacting with low-level baroclinic zones, as long as: a) a closed surface low can be identified; and b) upper air data at the nearest 12-hourly synoptic times (0000 and 1200 UTC) indicate warm-core characteristics in the mid-troposphere (i.e., 700-500 hPa). Records also are included from any TCs that failed to make U.S. landfall (e.g., TCs recurving just offshore from the Carolinas or Florida Keys, or entering northern Mexico with tornadoes in Texas), yet still produced tornadoes in the U.S.

For post-landfall stages where NHC classifications had been discontinued, yet TC remnants still were apparent, the nearest hour's surface data were analyzed to estimate location of the pressure low — which, for this dataset, always corresponded within analytic scale to the cyclone center derived from drawing streamlines. Each TC-related datum was incorporated into TCTOR alongside the corresponding tornado information.

c. Caveats

Several sources of potential error or uncertainty exist in TCTOR, as in ONETOR at large, that are neither linear nor readily quantifiable, with the addition of some from HURDAT as well. Position errors of tornadoes, may arise from either: a) uncorroborated location estimates provided to NWS, especially for non-damaging events or weak tornadoes not causing damage detectable above that from the TC; or b) the inherent imprecision of the locations given in *Storm Data*, whereby azimuth and range (in miles) from a town typically is logged, then converted to latitude and longitude out to two decimal places. Also, preliminary radar work with a 6-year subset of this database to determine associated convective modes (Edwards et al. 2010a) has revealed several apparent human errors in time and location entry, that will be checked further for probable correction (see Section 4).

Linear interpolation of 6-hourly center fixes becomes less reliable where rapid changes in translational motion occur between them. Sharp accelerations or decelerations within temporal bins are possible, but uncommon, and introduce some potential error on calculations of tornado distance and direction from center. So do any temporal imprecisions in tornado reporting. In fact, a marked tendency exists—e.g., 64% of TCTOR records to date—for times in whole minutes to end in the digits 0 or 5. In the atmosphere, no physical basis is apparent for any amount >20% of such timing; and these characteristics in the data are likely the result of reporting practices that approximate the time of occurrence. HURDAT records, meanwhile, truncate TC center fixes to 10^{-1} degree of latitude and longitude. Inland center-fixes for decaying systems, particularly those of less than TD strength or located between relatively sparse surface observations, also may be subject to the same precision uncertainties that afflict any subjective analysis of a low's location. Therefore, TC center-relative tornado positions given in TCTOR should not be interpreted too precisely on an individual basis, spatially or temporally, but instead assessed with respect to relative characteristics and broader, TC-scale tendencies. Previous studies incorporating tornado positions relative to TC positions also are encumbered with such uncertainties, whether or not explicitly mentioned therein, simply by virtue of the imprecisions intrinsic to the ONETOR and HURDAT data.

The primary difference with TCTOR, aside from the decadal domain, is in the individually-assessed, "manual" technique for selecting TCTOR events. While time-intensive, this method is believed to offer the most accurate possible record as compared to existing TC-tornado climatologies. This is because TCTOR logs events without regard to fixed radii from TC center, inland extent, temporal cutoffs before or after landfall, or other such arbitrary and readily automated thresholds that either may: a) exclude bonafide TC tornadoes outside the spatial cut-offs, or b) include somewhat proximal but non-TC tornadoes unnecessarily.

While not as voluminous as other recent climatologies in an absolute sense, this dataset so far offers a robust sample size of 1139 whole-tornado records over 15 years (6% of all tornadoes in the conterminous U.S.).

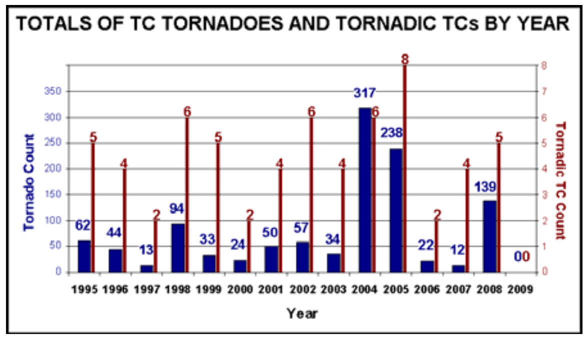

Figure 3: Yearly tally of TCTOR events (blue) and of tornadic TCs (red).

3. ANALYSES AND INTERPRETATIONS

Events in TCTOR can be sorted in at least as many ways as there are categories of data; and this analysis is not intended to cover every possible comparative permutation. Instead, some summary highlights follow for the 1995-2009 period.

a. General trends

While current TCTOR (1995-2009) yields an average of 76 events yr^{-1}, the distribution is quite erratic (Fig. 3), ranging from 317 in 2004 to none in 2009. These totals and means, as well as any other bulk computation done with TCTOR, are heavily influenced by the two consecutive, extraordinary hurricane seasons of 2004-2005, which collectively produced 49% of all TC tornadoes over the 15-yr period. Only 4 (0.35%) events occurred with category-5 storms on the Saffir-Simpson scale, 31 (3%) with category-4, and 72 (9%) with major hurricanes altogether. The great majority of TC tornadoes (73%) occurred with non-hurricanes, nearly half of which (35% of all TC tornadoes) were spawned by systems classified as TDs at the time of the

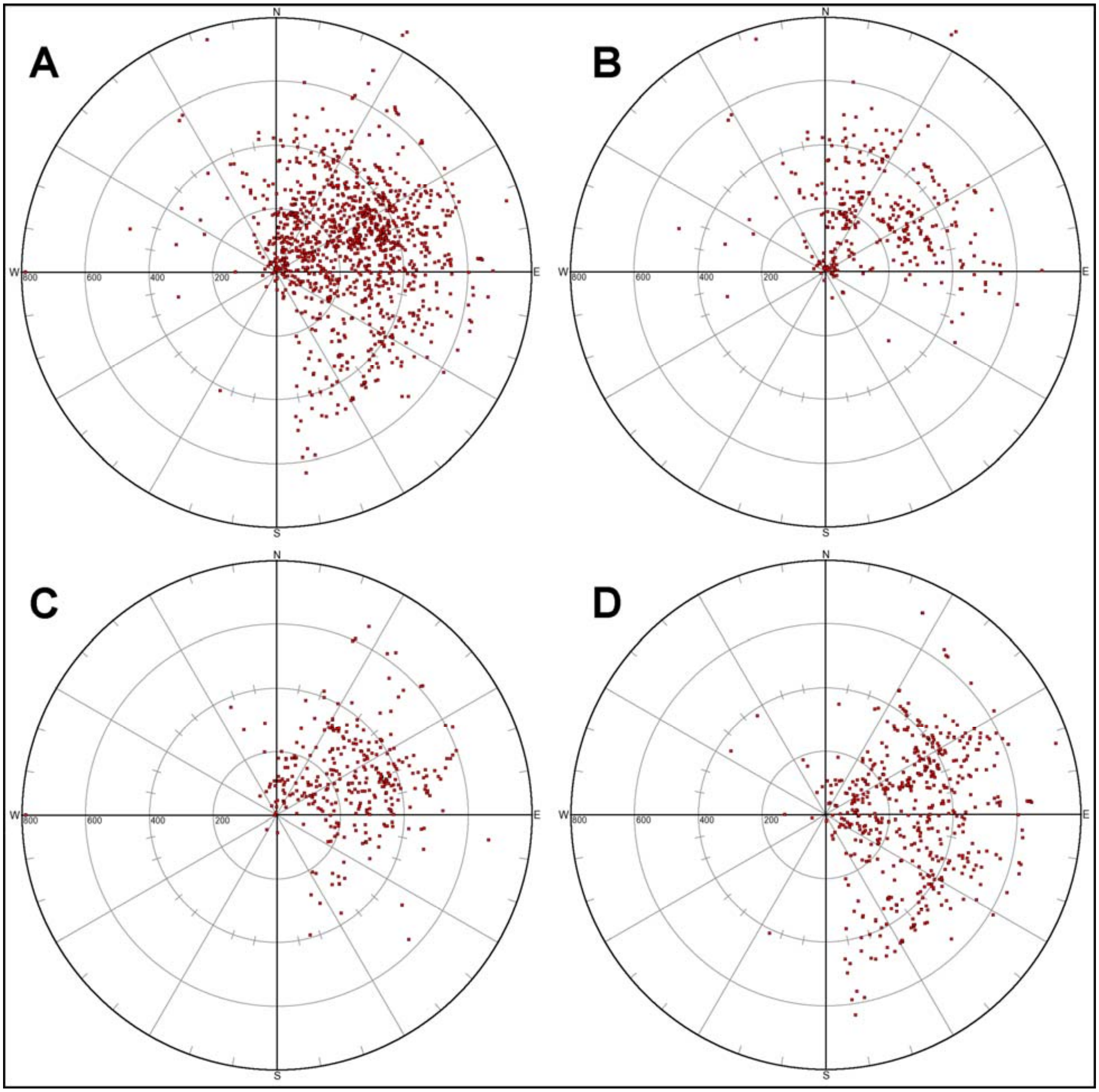

Figure 4. Cartesian plot of U.S. TC tornado reports (red dots) from: a) all TCs 1995-2009; b) hurricanes; c) tropical storms; and d) tropical depressions and post-classification categories "N" as defined in the text. Range rings at 200-km intervals, radials at 30˚ intervals. Origin represents interpolated center position of TC or remnant low.

tornadoes. This tendency may be a manifestation not only of the relative uncommonness of major hurricanes threatening land, but also, the center fixes more commonly lying offshore for hurricanes in general. By extension, large swaths of the supercell-favorable circulation envelopes of systems classified as hurricanes often are over water prior to landfall (and prior to the inland weakening stages). The frequency and distribution of TC tornadoes over water is unknown, though TC supercells often have been observed over water (e.g., Spratt et al. 1997, Eastin and Link 2009), and TC tornadoes have been known to move onshore, including the violent tornado with Carla in 1961 (rated F4 by Grazulis 1993). This indicates that any overly literal usage of recorded tornado distributions from hurricanes in particular, without accounting for geography, should be considered with caution. Analogously, out of concern for aforementioned event-reliability caveats, researchers studying TC tornadoes are strongly encouraged to focus on overall distribution patterns and not individual events or outliers.

b. Distributions in Cartesian framework

Tornado reports were plotted with respect to Cartesian (relative to true north) distance and direction from system center overall (Fig. 4a), by TC classification bins (e.g., Fig. 4b-d), and by EF-scale. Cartesian plotting of the whole TCTOR dataset (Fig. 4a) showed less scatter about the origin than TC motion-relative plots by McCaul (1991), instead more closely resembling both TC-relative and Cartesian plots by Schultz and Cecil (2009). This may be related to the considerable overlap between the time domains of the Schultz and Cecil dataset with TCTOR;

whereas McCaul's data were entirely prior to (exclusive of) TCTOR. In TCTOR, the northeast quadrant contained 68% of tornado reports, compared to 26%, 0.7% and 5.6% for SE, SW and NW quadrants respectively. Figure 4a and Fig. 5 show the dominance of a sector from north-northwest to south-southeast of center, with a peak distribution to the east-northeast. Fig. 4b-d indicates that the locus of tornado reports tends to "shift" around the storm clockwise from NE toward SE as the classification weakens, a tendency also seen in an independent dataset analyzed by Weiss (1987). A subtle rightward shift in tornado position also was noted with distance from TC center, consistent with the analyses of Schultz and Cecil (2009). When plotting such distributions for TCs whose maximum wind at the most recent classification before tornado time was <100 kt (51 m s^{-1}) versus the remainder, the rightward shift was pronounced as well (not shown). A strong rightward redistribution also was evident for storms with interpolated center positions north of 31º latitude at tornado time, compared to the remainder. Both the intensity and latitudinal trends in tornado distribution may be a function of the presence of more land beneath the southeast quadrant of higher-latitude and lower-intensity storms. When sorted using a threshold of 90º longitude (roughly that of New Orleans), the radial trend was for a slight rightward shift overall and marked loss of tornadoes in the western semicircle, for western versus eastern TCs (not shown).

The 49 tornadoes with ≥10 mi (16 km) path length overwhelmingly (98%) favored the eastern semicircle (not shown), the greatest concentration being between from 40º-100º (NE-ESE). Longer path-length events also were nonexistent within 68 mi (110 km) from the TC center, despite the tendency for the core region of TCs to contain the strongest ambient (gradient) winds and fastest cell motions. Core-region tornadoes, therefore, tend to be brief—even more so than in the rest of the TC envelope. The 78 significant (F2 and F3) tornadoes occurred between 25-373 mi (40-600 km) from center, all but one in the eastern semicircle, with the greatest concentration in northeast quadrant from 20º-90º. Significant tornadoes, therefore, tend to exhibit less scatter around the circulation envelope than weak ones.

Again, an unknown magnitude of missing reports in the southern semicircle of TCs is related to the presence of ocean in that part of the TC envelope for most U.S. TCs near and before landfall, in addition to the better-documented climatological impact of distributions of buoyancy and shear (McCaul 1991) that tend to disfavor western portions of the TC envelope. Weaker inland systems do not experience as much of a loss of tornado records due to water, with trailing rainbands and any accompanying supercells having moved inland where spotter networks and damage indicators are more likely to yield tornado reports.

Radial distributions also can be plotted for any given storm, the most productive offering comparable sample sizes to general categories such as damage rating or long path length. In particular, Ivan (2004), the most prolific tornado producer at 118 events,

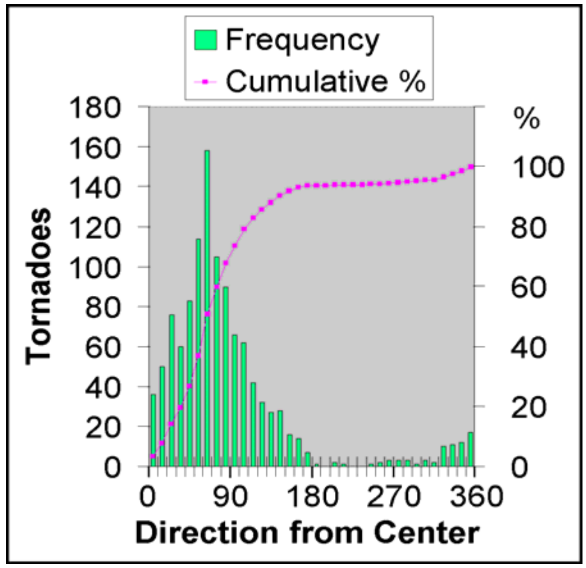

Figure 5. Histogram of Cartesian 1995-2009 tornado frequency from center (green). Tick marks on the abscissa represent 10˚ angular bins. Cumulative percentage is plotted on the magenta curve.

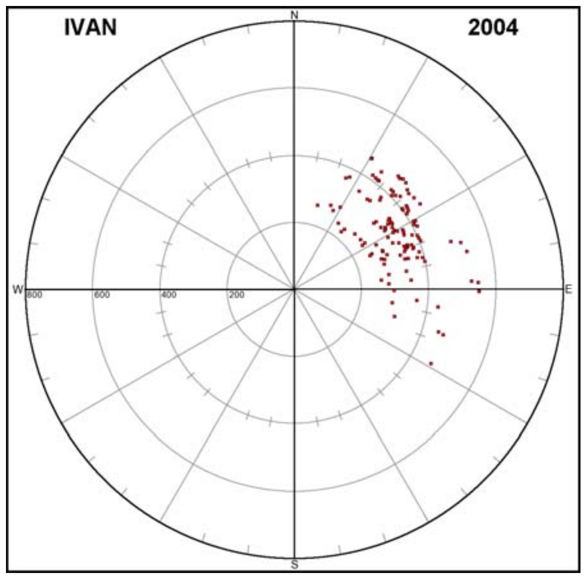

Figure 6. As in each panel of Fig. 4, but for the combined 3-day tornado production of TC Ivan (2004).

exhibited a strikingly compact concentration, in terms of both distance and direction, during its 3-day period of tornado production (Fig. 6). All but two of Ivan's tornadoes were within 20º-110º Cartesian; and all tornadoes occurred between 137-342 mi (220-550 km) from center. Similar plots indicate that Ivan, despite spawning the greatest number of tornadoes, had the tightest clustering of any of the top-10 (see Table 2) tornado-producing TCs for this period. The lack of tornadoes southeast through south of Ivan's center cannot be explained simply as an artifact of that sector's being over water, given that the majority of its tornadoes occurred on days two and three after landfall, with the center moving from the southern Appalachians toward the mid-Atlantic region (cf. Fig. 1 in Edwards 2008). Clearly, ingredients for tornadoes consistently became juxtaposed in the same small sector of Ivan from day to day. Ivan also represents a much tighter concentration of tornadoes with respect to center than the only other comparably productive TC on record, Beulah of 1967 (cf. Fig. 4 in Orton 1970), which is even more remarkable considering that the latter's southeast quadrant *did* remain over water during the bulk of the system's tornadic phase. A visual comparison of several of the most prolific tornado-producing TCs reveals a unique shape or "character" to the radial tornado distribution of each, suggesting distinct differences from storm to storm in the spatial overlap of favorable environmental ingredients. This indicates that 1) TCs are not monolithic tornado producers, but do so in patterns unique to each, and 2) environment-hour analysis (e.g., Schneider and Dean 2008), but on a center-relative cyclone-by-cyclone basis and following each TC, may be a worthy pursuit for a future study, as a follow-up to multi-TC work of Edwards et al. (2010a).

Table 2. Ten most prolific tornadic TCs from 1995-2009. $\mathbf{C_L}$ is category at landfall (from HURDAT), $\mathbf{C_{MAX}}$ is category at maximum intensity in the entire TC lifespan. Coloring matches C_L (following Table 1).

TC NAME	TORNADOES	C_L	C_{MAX}
Ivan (2004)	118	3	5
Frances (2004)	103	2	4
Rita (2005)	98	3	5
Katrina (2005)	59	3	5
Fay (2008)	50	0	0
Gustav (2008)	49	2	4
Cindy (2005)	48	1	1
Georges (1998)	48	2	4
Jeanne (2004)	42	3	3
Opal (1995)	35	3	4

c. Distributions in TC motion-relative framework

Proxy vectors for TC translation, at the time of each tornado, were computed with Eqn. 1, but using the latitudes and longitudes of the 6-hourly center point before and after the tornado. Using the distance from center already computed and a TC translation-relative azimuth, tornado locations were plotted versus TC motion, both for all events (not shown) and various subsets (e.g., Fig. 7). Though the right-front region still was favored, TCTOR events plotted in a TC-motion framework showed considerably more azimuthal scatter around the origin than for Cartesian direction, a trend not evident in the Schultz and Cecil (2009) climatology. A motion-relative, left-rear tornado cluster suddenly appeared when the translational vector of Beulah (Orton 1970) turned toward the southwest. That indicated that the tornado-suitable ingredients remained in the same Cartesian quadrant of Beulah, independent of storm motion; i.e., the pertinent physics of the storm were unrelated to its translation. That single TC case, in turn, prompted a hypothesis that *Cartesian positioning matters more than motion-relative*, and that only the relatively small sample size of TCs with equatorward motion components keeps accordingly displaced azimuthal distributions from appreciably affecting the relative climatological record of Cartesian versus motion-relative distributions. Figures 7 versus 4a seem to support this hypothesis. Only 26 TCTOR events (Fig. 7b) in 8 TCs occurred during an episode of equatorward component of TC translation; but they overwhelmingly favored the *left* semicircle in a motion-relative framework. Those corresponded generally to the *east* side of the TCs.

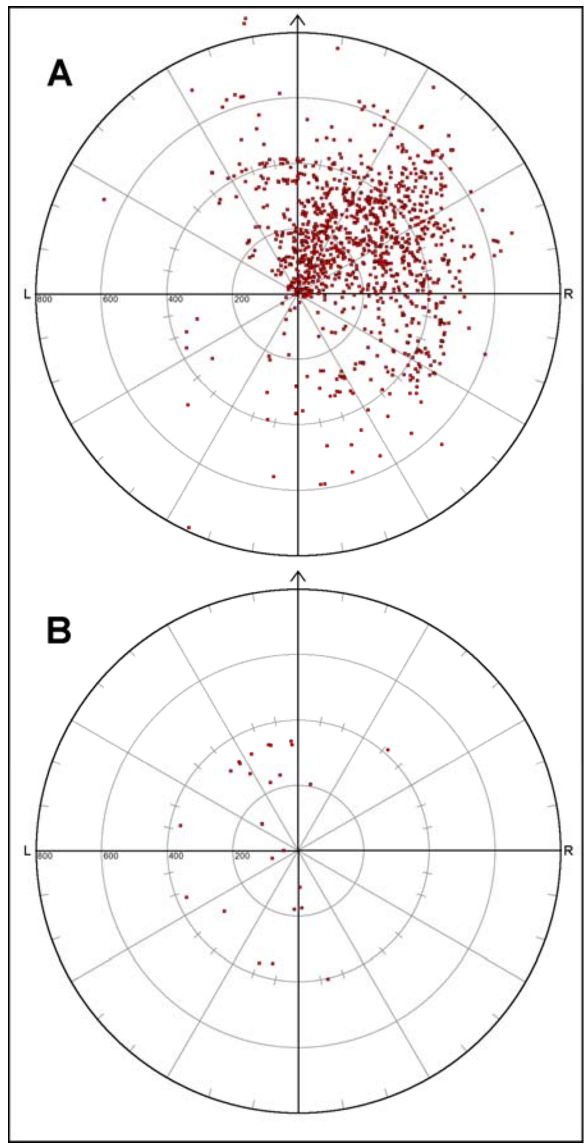

Figure 7. Polar plots of TC tornadoes where up arrow represents TC translation at tornado time, L is 90º leftward and R is 90º rightward, for all TCs moving with any component toward the north (a) south (b). Other plotting conventions as in Fig. 4.

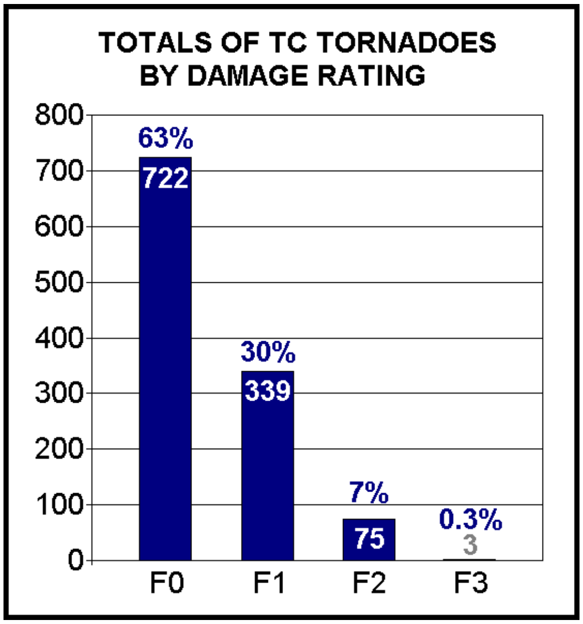

Figure 8. Percentage and number of 1995-2009 TC tornadoes by damage rating. No F4 or F5 events occurred.

d. Tornado damage ratings

As with tornadoes as a whole nationwide, TC tornadoes tended to decrease rapidly in number with increasing damage rating (Fig. 8), with ~93% categorized as weak (F0-F1), 7% strong (F2-F3), and none violent (F4-F5). This compares to a nationwide rate for the same years of ~90% weak, ~10% strong and 0.5% violent. The proportion of F0 tornadoes (63%) in TCTOR nearly matches that of ONETOR (64%). This supports a tendency noted by Schultz and Cecil (2009) for the disparity between proportion of F0 ratings for TC versus all tornadoes to close markedly after 1995, when essentially full WSR-88D deployment had been completed and modern warning-verification practices became well-established.

e. Temporal distributions

Temporally, TC tornadoes showed a marked diurnal tendency (Fig. 9), 48% occurring during 1800-0000 UTC and 72% during the bins most closely corresponding to local daylight hours during summer into early autumn. The pronounced diurnal boost in TC tornado production indicates the importance of diabatic surface heating and resultant boost to CAPE, as increase in sounding analyses by McCaul (1991). When translated to approximate sun time, the same two bins peaked in TCTOR as in McCaul's climatology, with the same nocturnal bins being smallest, and similar trends between corresponding bins. For forecast purposes, these strikingly similar temporal trends in independent datasets (McCaul's and TCTOR) reinforce a climatological baseline for greater probabilities of TC tornadoes during the day versus at night, except when situational factors, such as atypically high nocturnal instability or a distinct lack of any diurnal meteorological ingredients, clearly compel otherwise. The occurrence of TC tornadoes was more common at night during the landfall period, here defined as the convective day (12 UTC–1159 UTC) within which landfall occurred, than with inland systems; however, diurnal tornadoes still comprised the majority of landfall-phase TC tornadoes as well. TCTOR showed a generally upward but more erratic temporal transition from night to day for significant (≥F2) tornadoes (not shown), but with a far smaller sample size (78 events or ~7%).

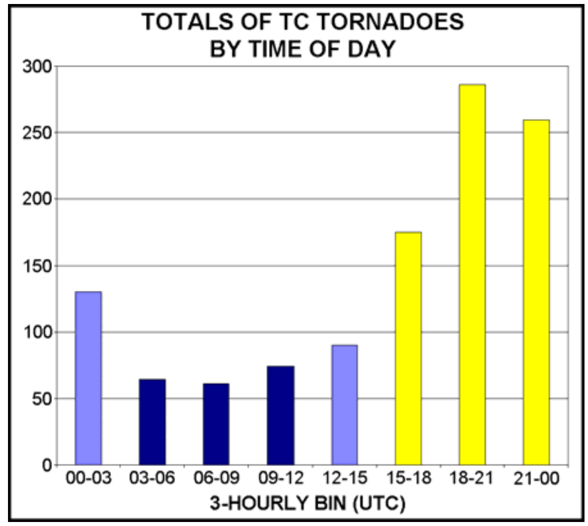

Figure 9. TCTOR events by UTC time, in 3-hourly groupings. Yellow bars correspond to the largest 3 bins and the local diurnal cycle along the Gulf and Atlantic coasts, while dark blue bars mark the smallest 3 bins, corresponding to the nocturnal cycle. Bins end in the minute before the labeled times, e.g., "21-00" covers 2100-2359 UTC.

f. Variation from TC to TC

Great variability exists in tornado production from TC to TC, as evident in Fig. 3 and Table 2. Eight TCs produced one tornado report each, while Ivan (2004) arguably produced the largest number of TC tornadoes of any single storm on record (discussed in Edwards 2008). Each of the top 10 tornadic storms also exhibited its own unique distribution of tornadoes with respect to cyclone center, as discussed above. Each TC carries a unique *combination* of size, wind strengths at various lower-middle tropospheric levels, translational speed (duration over a given area), geography impacted, and inflow-layer air mass characteristics such as instability, each of which can influence the number and distribution of tornadoes therein. Many contain mesoscale and smaller features such as baroclinic and kinematic boundaries (Edwards and Pietrycha 2006) that can focus or inhibit tornado potential. These factors reinforce the idea that, from a forecast perspective at all levels (outlook, watch and warning), each TC needs to be treated *individually* in terms of its tornadic potential.

4. SUMMARY and FUTURE

TCTOR contains records of all TC tornadoes distilled from the national ONETOR record from the 1995 hurricane season onward, using direct examination of meteorological data for each event (e.g., surface, radar, satellite) to ascertain categorically each event's occurrence in a TC. This database is flexible, in that it will grow with time and be open to evidence-based revision. The author intends to update TCTOR on an annual basis as HURDAT and ONETOR data become available for the previous hurricane season's activity. Additionally, TCTOR will be made available online for research and independent analysis, and may be amended on a post-facto basis as any errors are discovered, new information arrives and/or additional analyses are performed by other researchers on any historical TC tornadoes therein. Such adjustments made to variables common to the two datasets (i.e., occurrence time, location, path width, etc.) will be passed to corresponding ONETOR entries for consistency.

Since any entry in TCTOR is open to revision, given sufficient evidence, any analyses derived from the dataset (including this study) should be considered "best available" at the time, and potentially subject to change as well. As noted earlier, several individual entries already appear to be affected by time displacements, mostly by 1 h, and after verifying corrected information, will be submitted to internal NWS procedures for *Storm Data* and ONETOR revision. Some changes may occur in the future in the way that tornado data are recorded overall, such as addition of decimal places to latitudes and longitudes for greater spatial precision, or greater texturing of path and damage information (Edwards et al. 2010b).

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