P1.8 A DISCUSSION OF THE F-SCALE TORNADOES FROM QUASI-LINEAR CONVECTIVE SYSTEMS

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1. INTRODUCTION

In the meteorological community there appears to be a pervasive, yet unwritten, belief that tornadoes that form from quasi-linear convective systems such as squall lines and bow echoes are, in general, not as intense or long-lived as those from more isolated cells.

This ongoing study addresses this belief by investigating the distribution of tornadoes by parent-storm type, Fujita scale, and local time of occurrence, and will attempt to answer the following questions regarding tornadoes from different parent-storm types:

- Are they different in terms of intensity, as represented by Fujita scale?
- Are they distributed differently in time?

In our future work, we will answer this additional question:

- Are the environments in which they form different?

These are all related to the bigger question: do they form differently? The theoretical question is beyond the scope of this paper. Herein we focus on the practical and statistical differences between QLCS and cell tornado occurrence. Considering that radar precursors to tornado occurrence are not as clearly defined in QLCSs as they are for cells (Trapp et al. 1999), such differences have operational importance.

2. DATA

The statistical analyses in this study were performed on the same dataset used in the Tessendorf and Trapp (2000) (hereinafter TT2000) study. The data were developed by comparing National Climatic Data Center (NCDC) tornado report data over the 1-yr period from March 1998 to February 1999 with U.S. composite radar images from NCDC and other sources, and then determining a tornado parent-storm type of either cell, line, or hurricane rainbands. The authors classified a line signature to be ”a quasi-linear region of radar reflectivity greater than or equal to 40 dBZ, continuously distributed over a horizontal distance greater than 100 km,” and identified 19% of all tornadoes during that year as having developed under such a signature. Of the year’s tornadic events, 76% were associated with a cell, or ”an effectively isolated, roughly elliptically shaped region of radar reflectivity with maximum values greater than or equal to 50 dBZ.” The remaining 5% formed in hurricane rainbands; these events were omitted from the analyses that follow. The TT2000 dataset contained 1533 individual tornadic events and excluded duplicate reports, such as those from tornado paths crossing county and state boundaries (Table 1).

	Cells	**Lines**	**Hurr/Other**
F0	748	124	44
F1	266	114	31
F2	99	41	7
F3	40	8	0
F4	7	2	0
F5	2	0	0
Total	**1162**	**289**	**82**

Table 1: Distribution of tornado intensity between March 1998 and February 1999, as classified by parent storm type by Tessendorf and Trapp (2000).

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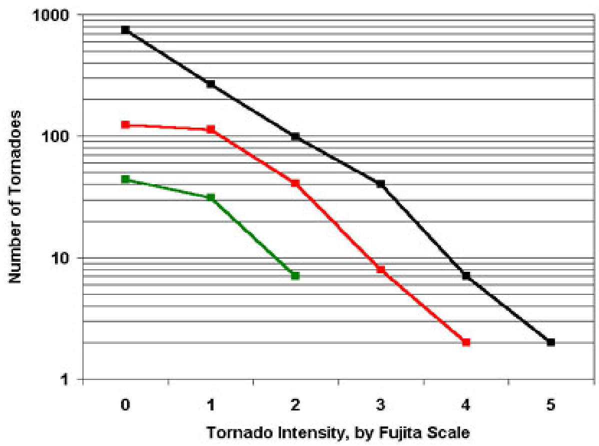

Figure 1: Distribution of U.S. tornadoes by intensity from cells (black), lines (red), and hurricane rainbands(green).

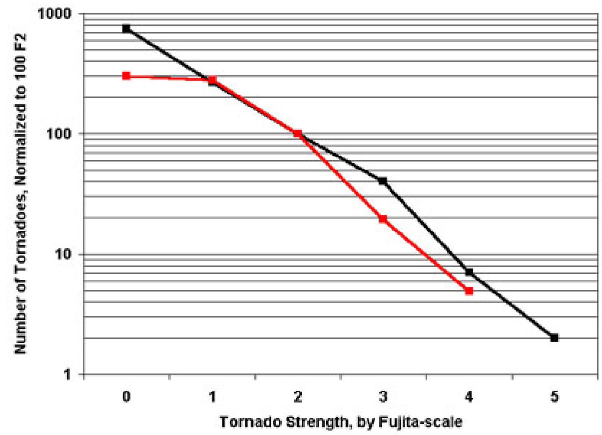

Figure 2: Distribution of the intensity of tornadoes from cells (black) and lines (red), normalized to 100 F2 events.

3. RESULTS

a. Tornado intensity

A log-linear plot of tornado occurrence versus Fujita scale shows that QLCS tornadoes do not exhibit the log-linear distribution demonstrated by Brooks and Doswell (2001) for all tornadoes (Figure 1). We now further compare and contrast the QLCS tornado distribution with that due to cells using statistical analyses, to determine, for example, whether or not the lowest-intensity tornadoes produced by QLCSs are underreported.

Since the dataset contains significantly varying tornado numbers between classifications, the distributions of the two primary tornado-producing parent storm types were normalized to 100 F2 tornadoes for comparison (Figure 2). Tornadoes from linear storms display approximately the same distribution as those from cells for F1, F2, and F4 tornadoes. There are however, many more F3 tornadoes from cells than from QLCSs in this normalized dataset. This difference will be discussed later in this section. F5 tornadoes are relatively infrequent, comprising less than 0.2% of cell tornadoes in the dataset. Therefore, it is not surprising that no F5 tornadoes developed from quasi-linear storms during this one-year period.

Comparing the normalized data between cells and QLCSs, the multiple R-squared value is $R^2 = 0.76$. The probability that the two datasets came from entirely different distributions is 2.4%. (Thus, only two percent of all randomly generated tornado distributions would contain the similarities evident between the observed distributions.) This is consistent with the hypothesis that QLCS and cell tornadoes have comparable intensity distributions. Since only one year of storm-classified data is available for analysis, the dataset remains relatively small. Thus, it may not be possible to distinguish between the two distributions, even if there are physical differences. For example, if an event (such as an F5 tornado) were expected 0.1% of the time, it would take many years of smaller datasets (such as only 250 events/yr) before the lack of this violent event was significant.

Ideally, we would have many more years of storm-classified data. As we do not, there are statistical methods proven useful in producing a larger sample dataset. In effect, we've created artificial data that are consistent with the observed data. The Monte Carlo method simulates the observed statistical data under the assumption that Ho, the null hypothesis, is true. The computer generates a large number of realizations of the test statistic, which are used to construct "an empirical estimate of the distribution of [the test statistic] under Ho" (Von Storch and Zwiers 2002). The estimated distribution is used to determine the critical value, which would otherwise be available had the original dataset been large enough.

A Monte-Carlo resampling test was performed (e.g., Wilks 1995) to evaluate the null hypothesis that the probability of a violent tornado, given a QLCS, is much less than the probability of a violent tornado, given a cell. The observed distribution of tornadoes from cells was defined to be 'truth.' Ten thousand years of realizations were generated, consisting of 165 tornadic events each, since the observed data contained 165 QLCS tornadic events at or above the F1 level. (F0 tornadoes were neglected in this analysis since these events are likely underreported.) At the 92% confidence level, there were significantly more F1 tornadoes from QLCS parent storms than from cells and more F2 tornadic events at the 35% confidence level. At the 98% confidence level, there were significantly fewer F3 tornadoes from QLCS parent storms than from cells (Figure 3). The confidence levels for F2 tornadoes is 35% and for F4-F5 is $\sim$55%; in particular, no significant conclusions can be drawn about F4 or F5 tornadoes because the events are particularly rare, even in cell parent-storm types.

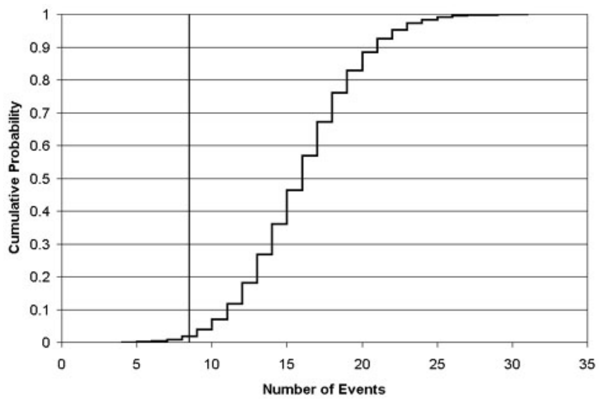

Figure 3: Cumulative probability distribution of F3 tornadoes generated from 10,000 realizations based on observed data. Line indicates observed number of QLCS F3 tornadoes.

As mentioned above, it is likely that the lowest-intensity (F0) tornadoes produced by linear convective storms are underreported. As documented by Brooks and Doswell (2001), tornado intensity appears to approach a log-linear distribution. Dotzek et al. (2003) indicated that the actual distribution may fall short of log-linear at high F-values. Ideally, we would be able to generate another dataset to compare the number of F0 tornadoes occurring in cells and lines. However, we cannot simulate data unless we know the actual size of the QLCS dataset. If the weakest tornadoes are indeed underreported, a dataset composed of 289 events (the number of all observed tornadoes from lines) and similar to the distribution of cells would simply decrease the number of stronger tornadoes. Thus, simulations would not be useful for comparison. TT2000 documented a high percentage of QLCS tornadoes along the south-central Gulf Coast region as well as in the Midwest. Perhaps clouds, precipitation, and/or trees obscure weak tornadoes that occur in these parts of the country, and their damage resembles (or is embedded within) straight-line

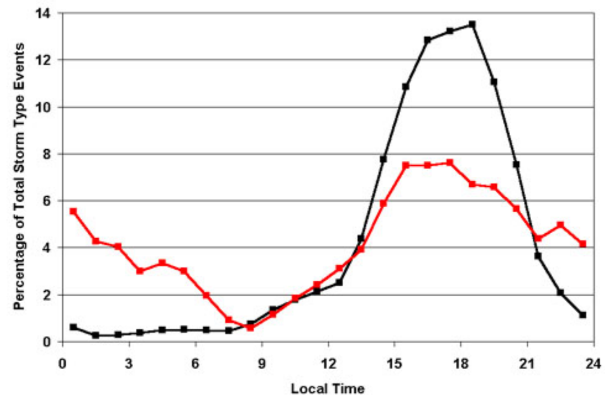

Figure 4: Running three-hour mean of local time tornado distribution. Cells are shown in black, and lines in red. Vertical axis is the percentage of total events for each storm type.

wind damage. A further possibility, which we investigate next, is that tornadoes from QLCSs occur more frequently at night than do those from cells.

b. Temporal distribution

Figure 4 shows the three-hour running mean distribution of cell and line-based tornadoes over a 24-hour period, based upon the TT2000 dataset. There appears to be a strong diurnal cycle in the cell-type tornado distribution, but not in the QLCS tornado distribution. To determine the statistical significance of the higher occurrences of QLCS tornadoes in the nighttime hours, a second Monte-Carlo technique was performed. Each realization contained 289 events, corresponding to the total number of QLCS tornadoes in the TT2000 dataset. The results were significant at the 100% confidence level for the hours between eleven p.m. and six a.m. local time and at or above 95% between four and nine p.m. local time. Therefore there is a statistically significant difference between the observed daily tornado distributions of QLCSs and cell type storms.

These results are shown in Figure 5, averaged in three-hour time blocks. A clear diurnal cycle is evident. Tornadoes from cell parent storms display a strong preference for the late afternoon, while lines, compared to cells, prefer overnight. It is not clear which of the two distributions is special. When the hourly tornado data are separated by

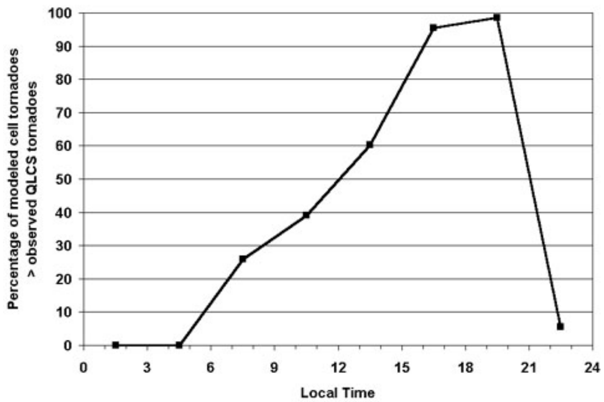

Figure 5: Three-hour mean percentage of modeled cell tornadoes greater than observed QLCS events. Bottom axis displays local time.

intensity (Table 2), apparent differences between the strong and weak cycles can be seen (Figure 6). The higher percentage of strong (F2-F3) line tornadoes than weak (F0-F1) during the overnight hours may indicate missing reports of weak tornadoes. Preliminary calculations indicate a need for about fifty more weak line tornadoes from 11 p.m. to 2 a.m. local time to match the diurnal cycle of strong line tornadoes. That means about fifteen percent of all tornadoes from lines are likely not reported. Similarly, the small rise in strong cell tornadoes overnight does not occur in weaker ones, leaving approximately forty tornadoes (3.5%) from cells unreported. Perhaps the diurnal cycle difference between cells and lines has been underestimated.

This difference can account for much of the underreporting. Cell-type storms typically produce tornadoes in the afternoon and evening, when most people are awake, alert, and funnel clouds are clearly visible. If many QLCSs produce tornadoes during the late night hours, relatively fewer people are awake and visibility for those who are is very poor. Strong tornadoes will leave a much more evident damage path than weaker ones, the latter of which may resemble strong wind events (such as a few downed trees, shingles off, etc). It is then concluded that the weakest tornadoes from QLCSs are underreported due to a large number of occurrences during the late night hours.

	Cells						Lines				
	F0	F1	F2	F3	F4	F5	F0	F1	F2	F3	F4
0-1	3	0	0	0	0	0	3	5	2	0	0
1-2	3	0	0	0	0	0	4	8	6	1	1
2-3	1	2	0	0	0	0	2	4	1	0	0
3-4	2	0	1	1	0	0	2	4	1	1	0
4-5	4	0	0	2	0	0	5	5	1	0	0
5-6	1	3	3	0	0	0	4	6	0	0	0
6-7	2	2	0	1	0	0	1	3	0	1	0
7-8	4	1	0	0	0	0	0	2	0	0	0
8-9	4	2	0	0	0	0	1	0	0	0	0
9-10	11	1	2	1	0	0	2	0	0	0	0
10-11	21	3	2	0	0	0	4	3	0	0	0
11-12	19	1	1	0	0	0	3	2	2	0	0
12-13	21	6	0	0	0	0	4	2	1	0	0
13-14	30	8	2	0	0	0	4	4	5	0	0
14-15	65	13	7	1	0	0	3	8	3	0	0
15-16	97	37	5	4	1	1	10	12	1	1	0
16-17	94	37	10	5	1	0	17	7	2	1	0
17-18	100	39	8	8	1	0	7	3	4	0	0
18-19	96	29	25	6	1	1	14	6	2	2	1
19-20	92	42	16	6	1	0	10	6	3	0	0
20-21	36	20	10	2	2	0	7	6	0	0	0
21-22	25	5	3	3	0	0	10	5	2	0	0
22-23	9	11	1	0	0	0	2	5	1	0	0
23-24	8	4	3	0	0	0	5	8	5	1	0
Total:	748	266	99	40	7	2	124	114	41	8	2

Table 2: Hourly distribution of tornado intensity between March 1998 and February 1999, in local time, classified by parent storm type.

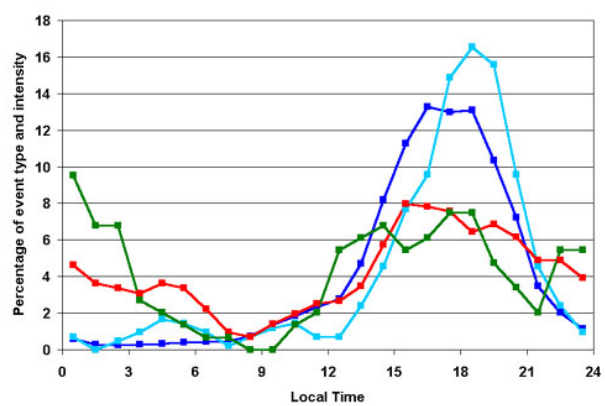

Figure 6: Three-hour running mean of tornadoes by parent storm type and intensity. Light blue is strong tornadoes from cells; dark blue is weak. Green represents strong tornadoes from lines; red is weak. Bottom axis is local time, vertical axis indicates the percentage of each type and intensity.

4. CONCLUSIONS

Based on TT2000 data, QLCS tornadoes do not have the same distribution by F-scale as do cell tornadoes. Specifically, there are statistically more F1 line tornadoes in a normalized distribution than there are F1 cell tornadoes, and statistically fewer F3 line tornadoes than cells. Overall, there are many fewer F0 line tornadoes, which tend to occur at night and are thus likely to be underreported.

5. Future Work

Although much is understood about the environmental conditions surrounding squall line and bow echo development, the conditions around linear convective storms that favor tornadogenesis within QLCSs remain unknown. Much study exists on tornadogenesis from supercell and ordinary cell-type parent storms and on the structure and formation of bow echoes and squall lines, but few studies specifically examine tornado formation within QLCSs. Consequently, meteorologists face many difficulties when forecasting tornado likelihood from linear convective storms. These pose a significant problem in public warnings, as about 20% of all yearly tornadoes form from linear convective systems.

More type-classified data are presently being collected in order to further pursue this hypothesis and examination. More research on the environments surrounding tornadogenesis in quasi-linear storms is also currently underway and should be introduced during the poster presentation. A further question to investigate is whether or not these environmental conditions will correspond to F-scale values.

Results will be available online at http://weather.ou.edu/~savageau/research

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