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POSSIBLE IMPACTS OF THE ENHANCED FUJITA SCALE ON UNITED STATES TORNADO DATA

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1. INTRODUCTION and BACKGROUND

The National Weather Service (NWS), with occasional augmentation by private assessors and universities, often uses damage surveys to determine path characteristics of wind events in general and tornadoes in particular. The results flow into a wide variety of utilizations, primarily involving:

- Climatological recordkeeping, including the county-segmented *Storm Data* listing and its whole-tornado "ONETOR" counterpart at the Storm Prediction Center (SPC), as described in Schaefer and Edwards (1999),
- Applied research on severe storms, including case studies and forensic meteorology,
- Preparedness and hazard-mitigation activities involving the NWS, risk-reduction companies in the private sector, and all manner of public-sector emergency management agencies, and,
- Verification of NWS watches and warnings.

For tornadoes, this process began systematically in the 1970s with nationwide NWS use of the original Fujita (F) tornado damage scale (F Scale, Fujita 1971, Fujita and Pearson 1973). Concerns gradually developed among meteorologists and engineers about the inconsistent application, subjectivity and imprecision of the F Scale (e.g., Minor et al. 1977, Doswell and Burgess 1988). These issues eventually motivated the collaboration of meteorologists and wind engineers to increase formally the number of damage indicators (DIs) that could be used to indicate tornado strength, and enhancing the accuracy of the F Scale accordingly. One result was to lower the wind speeds responsible for the higher damage ratings (McDonald et al. 2003), and to calibrate the EF and F Scales for climatological consistency. For more thorough overviews of that process and related commentaries, refer to Doswell et al. (2009) and Edwards et al. (2010, this volume).

The NWS officially began the use of the Enhanced Fujita Scale (EF Scale) in February 2007 (LaDue and Ortega 2008). The Enhanced Fujita (EF) Scale contains 28 DIs, each of which carries degrees of damage (DoDs) that indicate a range of responsible wind speeds (WSEC 2006, Edwards et al. 2010). As such, the EF Scale is far more precise and thorough than the F Scale. Conceptually the EF Scale is less prone to the subjectivity in evaluating wind damage (the F-Scale had only one DI compared to 28 DIs for the EF Scale), given the sound engineering foundation for wind speeds assigned to DoDs. Still, even with the use of comparative photography that is embedded in guiding software used afield, the EF-Scale inherently and unavoidably involves judgment calls regarding damage levels. Surveying practices also are undergoing major changes that are expected to become more prevalent in coming years (Edwards et al. 2010), including the use of fine-scale GIS-based mapping of DIs for some events (LaDue and Ortega 2008), with high-resolution and integrated mapping of tornado paths incorporating abundant supporting documentation in many forms of digital metadata.

Despite the beneficial intent of calibrating the F and EF Scales for the sake of continuity across the historic data, all these changes in DIs and surveying practices hypothetically yield a form of "shock" (Thorne and Vose 2010) to the climatological tornado record. This possibility compels the fundamental question: "What effect has the EF Scale had on tornado climatology?" The following analyses will address that question to the greatest extent possible, given the limited time since the EF Scale's adoption.

2. ANALYSES and INTERPRETATIONS

a. Basic trends within the modernized NWS timeframe

Nationwide deployment of the WSR-88D radar network was largely completed in 1995, and this as associated with the dawn of the "modernized" NWS era including emphases on verification and report-gathering practices now in place. Such shifts were discussed by Verbout et al. (2006), along with the need to use statistical detrending methods when examining the entire tornado record since 1950. In order to perform some "apples to apples"

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Table 1. Absolute numbers of tornadoes by time bin (columns) and categories (rows). "Any 3 Avg" constitutes a sum of the entire 15 years divided by 5 to yield an "average 3-year bin." Red (blue) colored values represent those above (below) the "average 3-year bin" for their categories. Weak, strong and violent tornado categories represent EF/F0-1, EF/F2-3, and EF/F4-5 respectively, following common conventions in the literature dating back to Fujita (1976). Significant tornadoes were rated ≥EF/F2. The EF-Scale era is shaded in gray.

COUNTS	**2007-2009**	**2004-2006**	**2001-2003**	**1998-2000**	**1995-1997**	**Any 3 Avg**
EF/F 0	2360	2717	2324	2436	2308	2429
EF/F 1	1145	1106	849	972	878	990
EF/F 2	326	281	256	300	277	288
EF/F 3	96	73	75	106	69	83.8
EF/F 4	15	8	19	21	22	17
EF/F 5	2	0	0	3	2	1.4
Weak	3505	3823	3173	3408	3186	3419
Strong	422	354	331	406	346	372
Violent	17	8	19	24	24	18.4
Significant	439	362	350	430	370	390
EF/F 1 & 2	1471	1387	1105	1272	1155	1278
Total Tors	*3944*	*4185*	*3523*	*3838*	*3556*	*3809.2*

Table 2. As in Table 1, except expressed as *percentages* of the total number of tornado records in each 3-year bin. Percentages may not add precisely to 100 due to rounding.

PERCENTS	**2007-2009**	**2004-2006**	**2001-2003**	**1998-2000**	**1995-1997**	**Any 3 Avg**
EF/F 0	59.8	64.9	65.9	63.4	64.9	63.8
EF/F 1	29.0	26.4	24.1	25.3	24.6	26.0
EF/F 2	8.2	6.7	7.2	7.8	7.8	7.6
EF/F 3	2.4	1.7	2.1	2.8	1.9	2.2
EF/F 4	0.4	0.2	0.5	0.5	0.6	0.4
EF/F 5	0.05	0	0	0.08	0.06	0.04
Weak	88.9	91.4	90.0	88.8	89.6	89.8
Strong	10.7	8.5	9.4	10.6	9.7	9.8
Violent	.43	.19	.54	.62	.67	.48
Significant	11.1	8.6	9.9	11.2	10.4	10.2
EF/F 1 & 2	37.3	33.1	31.3	33.1	32.4	33.6
Total Tors	*100*	*100*	*100*	*100*	*100*	*100*

comparisons of raw trends during this era (e.g., without the obvious need for detrending), basic tendencies are examined in the nationwide SPC "ONETOR" data across the 1995-2009 time frame, containing 19,046 records. The data could be examined in the form of five three-year bins, the last covering the EF Scale era. Because January 2007, which was one month prior to the implementation of the EF Scale, contained only 21 tornado records (out of 1117, or 1.9% of the yearly total), for temporal continuity they are included with those for the rest of 2007, and for the 2007-2009 bin as a whole.

Various absolute tornado totals for the entire period, and for each three-year bin, are shown in Table 1. Table 2 takes each 3-yearly bin's contents from Table 1 as a percentage of total tornadoes in the bin, in order to compare *relative occurrence* of different damage classes across bins, and independently of the changes in *absolute numbers* of tornadoes from period to period. From these data, several trends become apparent. The period containing the most tornadoes, 2004-2006, also contained the fewest violent tornadoes, nearly an order of magnitude beneath any other period. Brooks and Dotzek (2008) discussed the complete absence of F5 tornadoes and an apparent increase in the number of weak tornadoes from 2000-2005 compared to years prior, trends also evident in our two bins covering 2001-2006 when compared to earlier bins. A sharp drop in absolute numbers of violent tornadoes, as well as a more subtle decline in percentages of all tornadoes being violent, also is evident between 2001 and the adoption of the EF Scale in 2007.

With the EF Scale, however, the patterns found by Brooks and Dotzek appear to have reversed, in that EF5 tornadoes have appeared once again, and the number and percentages of weak tornadoes has fallen. The number and ratio of violent tornadoes also has increased; however, great caution should be used when interpreting violent-tornado trends, given the comparatively paltry sample size of these events. It only can be speculated whether violent tornadoes have reappeared in the record because of damage rating changes inherent to the EF Scale[2], other non-meteorological aspects of the rating process, meteorological chance, and/or the spatially happenstance positioning of EF5-allowing house DIs in Greensburg, KS (Marshall et al. 2008a) and Parkersburg, IA (Marshall et al. 2008b) squarely inside large and violent tornado paths, while tornado tracks of similar geometry fortuitously may have missed such DIs before.

The most noteworthy change from the F Scale era in relative percentages of damage ratings may be in EF1 and EF2 bins, both individually and combined, seemingly at the expense of EF0. F1 and F2 tornadoes combined claimed a remarkably steady portion of overall tornado events in each bin prior to 2007, about 31-33%. The EF1+EF2 group jumped to 37.3% of tornadoes from 2007-2009, the only one of the periods above the "average 3-year bin" for that category. Meanwhile, tornadoes rated F/EF0 fell to their lowest level in any of the bins, at ~60%. While still not definitive, the much larger sample sizes of these tornado categories more confidently suggest that tornado rating practices in the EF Scale era have favored EF1-2 events and disfavored EF0s, compared to the rest of the WSR-88D era. As shown in Section 2b, however, the evidence for impact of the EF Scale on longer-term tornado climatology is more nebulous.

b. The EF-Scale era in context of multidecadal trends

Brooks and Doswell (2001) discussed the relative consistency of tornado reports by damage scale over time and in different countries. Some evidence for at least a general consistency over that last three decades can be seen by looking at the number of tornadoes equal to or exceeding a given damage threshold during 1980-2009 (Fig. 1). The slopes of the distributions for (E)F1+ and greater are at least somewhat similar. Verbout et al. (2006) provided evidence that tornadoes prior to 1975 were rated higher than tornadoes after that and Doswell et al. (2009) show that another lowering of assessed tornado damage occurred in the early 2000s.

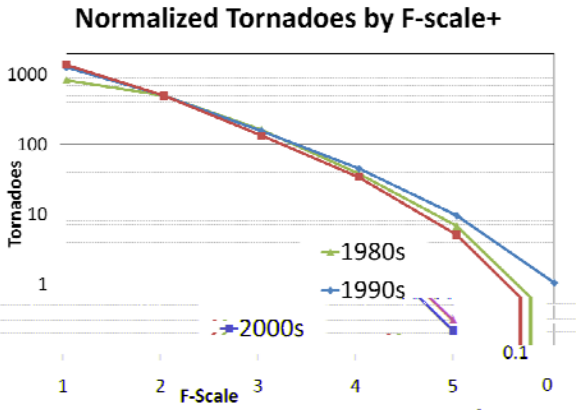

Figure 1: Tornado reports by decade by minimum damage class, normalized to 500 tornadoes of at least F1 damage (F1+). For comparison, the average number of F1 and greater tornadoes per year in 2000-2009 was 460.

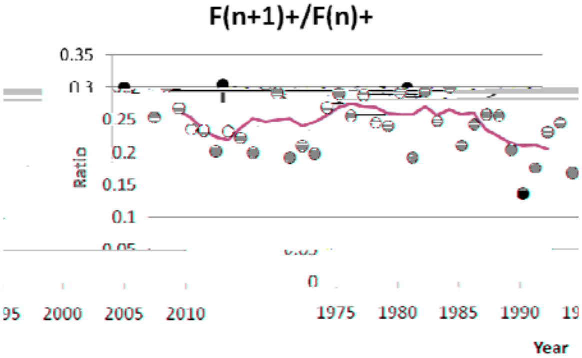

Figure 2: Average number of tornadoes of at least F(n+1) damage divided by at least F(n) damage, averaged over n=1 to 3, by year (black dots) for 1975-2009. Five-year running value shown by blue line.

One way to look at these changes in detail is to look at changes in the slope of the line shown in Fig. 1 by fitting a linear regression through it. Clearly, including the F0 tornadoes (note that for simplicity, we will refer to all tornadoes as "F" in analyses combining both scales) provides problems for an analysis going back even into the 80s, in that statistical results can be dominated by this highly populated damage class. Similarly, the very small sample size of F5 tornadoes does not allow a meaningful statistical analysis to be performed on that damage class. Thus, a linear regression line is fit from F1+ through F4+. The slope can be expressed as the number of tornadoes at one class divided by the number at the previous class. This can be thought of as answering the question, "Given that a tornado is at least F(n), what's the probability it will be at least F(n+1)?" From 1975-2009, this overall value was approximately 0.25 (Fig. 2). Beginning in 2000, however, that has been the maximum for any year and the years 2005, 2006, and 2009 have been lower than any year on record back through 1975. The values in the 2000s were lower than the values prior to that at a significance level of p=0.05, using a Mann and Whitney (1947) test. The recent multi-year average has been closer to 0.21. That implies a reduction of F4 and greater tornadoes

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[2] Curiously, the appearance of *any* EF5 events again after a long absence, and the reversal of the prior violent-tornado decline, *seem* to contradict the Doswell et al. (2009) notion that "the minimum criteria for producing EF5 damage effectively have been increased: complete destruction of a typical frame home in the USA would no longer be considered adequate for an EF5 rating and perhaps not even for EF4." It remains to be seen whether these events are an aberration or a longer-term shift.

by approximately 40% in the 2000s. Given the relative consistency in previous years, it seems unlikely to be of meteorological origin.

The EF-scale era is short in duration, but two of the three years since 2007 provide values closer to the long term average. Preliminary indications are that 2010 will be as well given that there have been more EF4 tornadoes this year than in eight of the years since 2000.

3. CONCLUDING SUMMARY

The change to the EF-scale has had an impact on damage assessment practices for tornadoes. Those changes, however, have taken place in a background of relatively large interannual variability in tornado intensity distributions. In particular, the years just prior to the adoption of the EF-scale were characterized by historically low numbers of strong and violent tornadoes, likely as the result of changes in subjective assessment practices. As a result, it appears possible that the adoption of the EF-scale with its more structured assessment procedures has led to a slight increase in assessed damage, perhaps leading to distributions approaching those seen in the 1975-1999 era.

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