7B.3 **LEVELING THE FIELD FOR TORNADO REPORTS THROUGH TIME: INFLATION-ADJUSTMENT OF ANNUAL TORNADO REPORTS AND OBJECTIVE IDENTIFICATION OF EXTREME TORNADO REPORTS**

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1. Introduction

The concept of a tornado "outbreak" is one that has an intuitive appeal. Galway (1975) pointed out the large number of fatalities associated with "family outbreaks" (Pautz 1969), as well as the apparent ability of forecasters to forecast them with greater skill than other tornadoes. Galway (1977) gave an overview of the problems with previous definitions of outbreaks and focused on events with at least 10 tornadoes occurring in a confined space and time.

The increase in number of tornado reports over time opens the question of whether any arbitrary threshold for number of reports can hold for a lengthy period of time (Fig. 1). Since 1954, a linear regression fit to the number of annual tornado indicates an expected increase of about 13 tornado reports per year. Bruening et al. (2002) showed how such an approach to adjusting tornado reports for apparent inflation could be applied to looking at the progress of a tornado season through the year. (Whether a linear fit to the data is appropriate is open to question, although the impression of a large number of tornadoes in the early 1970s and a small number in the late 1980s fits with anecdotal evidence.) As a result, the mean expected number of annual tornado reports increased from 555 in 1954 to 856 in 1977 to 1183 in 2002. Clearly, interpretation of the importance of a single "big day" changes over that time. A 10-tornado day would have represented almost 2% of the expected number of tornadoes in 1954, but less than 1% today.

Another appealing approach to identifying outbreaks is to include information about the intensity of events. For instance, the occurrence a certain number of tornadoes at or above a threshold on the Fujita scale might be used as evidence for an outbreak. There is evidence to suggest that stronger tornadoes have been reported more consistently through time (Brooks and Doswell 2001), so that the problem of report inflation seen in Fig. 1 might not be so great. Caution must still be exercised, however. The threshold for inclusion that is used and the number of reports that would qualify are both arbitrary. In addition, the number of years over which the assumption of higher quality observations holds true is open to question. Finally, by applying a minimum threshold for the Fujita scale, the number of events on a day is necessarily limited. As a result, problems with damage assessment become critical. For instance, if four tornadoes at or above a threshold are required for identification as an outbreak, then a single classification error for an event in a small sample might lead to an incorrect classification.

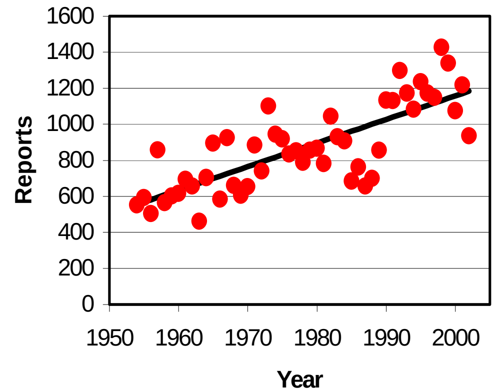

*Fig. 1: Annual reports of tornadoes from Storm Prediction Center data from 1954-2002. Black line is linear regression fit (Reports=-25035+13.1*Year).*

All of the questions involve the application of arbitrary thresholds. It is easy to define some cases for which any reasonable definition of outbreak should agree. For instance, any definition that didn't include the 1974 Superoutbreak would be ludicrous, and any definition that included a single F0 tornado in Oklahoma in May would be equally ludicrous. The problem, obviously, lies somewhere in between. Ideally, one would like to have a definition that identifies a number of cases where there would be little doubt in the classification, and minimizes the number of misclassification errors that are made, perhaps in comparison to some "expert" opinion. Nevertheless, the placement of the arbitrary thresholds will remain critical and how the thresholds are combined (e.g., 10 tornadoes of any intensity or at least 2 F2 tornadoes on a day, compared to 10 tornades of any intensity with at 2 F2 tornadoes.) In this paper, we examine the impacts of some of the decisions about where those thresholds are placed. We will start by ignoring the spatial and temporal constraints that Galway (1977) discussed. While those are important in meteorological discussion of convective outbreaks, as a first cut, we will ignore them for now, and focus on what might be considered "big days" from a national perspective, whether or not the tornadoes occur in a small window of space and time on a day. We will use the SPC convective day (1200 UTC-1200 UTC) as our time frame.

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Another way of considering the question is to reframe it in terms of the number of days per year, on average, that meet the criteria for a big day. If one wants to focus on a small number of the really big events, then perhaps having a definition that produces an average of one event per year would be desirable. If, on the other hand, one wants to look at the 10% biggest tornado days, given that tornadoes occur on the day, then a definition producing an average of 20 days per year would be more appropriate.

2. Days per year meeting thresholds

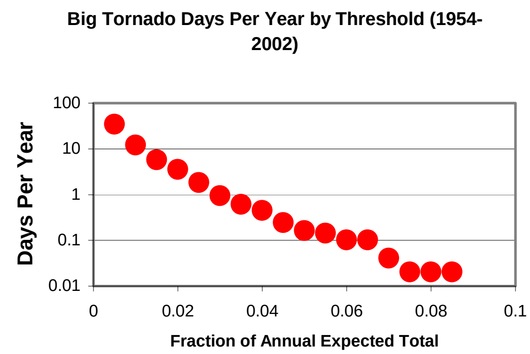
An important question to be answered is whether the data show any breakpoints that might be appropriate to use in defining thresholds. If, for instance, there were a large number of days with fewer than 5 tornadoes, no days with between 5 and 10 tornadoes, and a relatively big number with at least 10 tornadoes, then identifying outbreaks as having 10 or more tornadoes would be a natural outcome of looking at the data and that threshold would not be as arbitrary.

As the large increase in reports over the years suggests, application of a threshold of a fixed number of reports for any tornadoes over time is problematic. Instead, we will focus on whether days exceed a fraction of the expected value associated with the linear regresssion for a particular year (see Fig. 1). For example, we can count the number of days with more than 1% of the linear regression value. That leads to counting days with more than 5.5 tornadoes in 1954 and more than 11.8 days in 2003. No obvious break in the distribution exists until, perhaps, a threshold associated with events that occur once per decade is reached (Fig. 2a). (The 1974 outbreak had 17.5% of the expected annual total.) Obviously, restricting analysis to once per decadal or rarer events is a very strong constraint.

For thresholds using the F-scale, it may be appropriate to consider the number of events without regard to any long-term regression. Again, there's no obvious break in the distributions for counts of F1 or F2 and greater tornadoes per day (Figs. 2b and 2c) until perhaps the once per decade time scale. There is a suggestion that the distribution could be modelled using a mixed geometric distribution (Bruening et al. 2002), associated with a "common" process producing few tornadoes and a "rare" process producing many tornadoes. It's tempting to consider using the parameters of the mixed distribution as a basis for defining outbreaks, but a relatively wide range of parameters could fit the distribution reasonably well. As such, one would want the dataset to be very robust in order to put narrow bounds on the parameters. Given uncertainties in the assignment of F-scale values to particular tornadoes, this seems highly unlikely. As such, it is doubtful that such an exercise would be valuable.

In any event, the empirical distributions of Fig.2 provide a basis for placing thresholds depending on the number of events one wishes to have in a big day

a)



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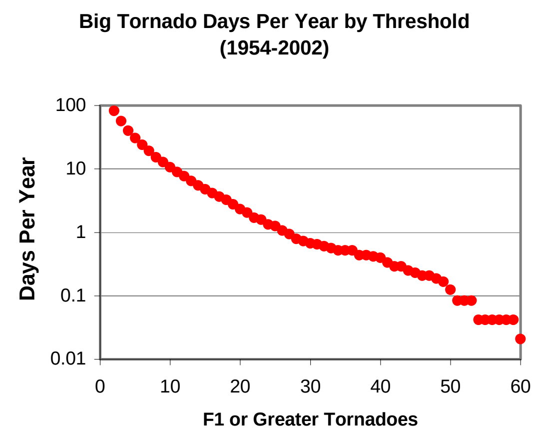

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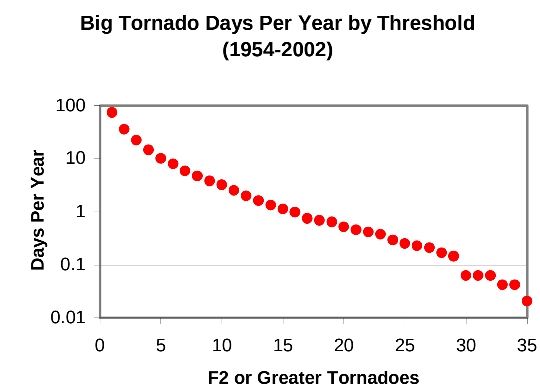

Fig. 2: Number of days per year exceeding thresholds for tornadoes per day for different damage classifications for 1954-2002. a) Any tornado, using threshold of fraction of annual expected number of tornadoes. b) Tornadoes of at least F1. c) Tornadoes of at least F2.

dataset. For instance, looking at an average of one event per year is equivalent to looking at days with at 3% of the expected annual tornadoes (in 2002, about 36) or 26 or more F1 or 15 or more F2 and greater tornadoes, if only one threshold is applied.

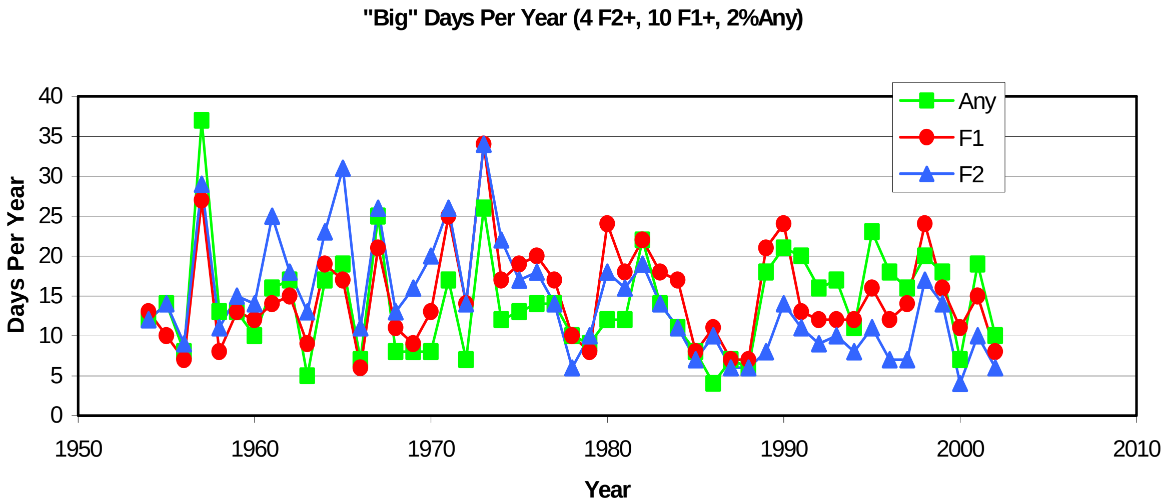

Fig. 3: Days per year exceeding "big day" thresholds of any tornado (green, threshold of 1.5% of expected annual value), F1 or greater tornado (red, 8 tornadoes), and F2 or greater tornado (blue, 4 tornadoes), for 1954-2002.

If arbitrary thresholds are chosen, time series of big days for each year can be generated (Fig. 3). The thresholds chosen here (1.5% of annual total for any tornado, 8 or more F1 or greater tornadoes, 4 or more F2 or greater tornadoes) produce, in the mean, 14-15 big days per year, roughly 8% of the days per with tornadoes. The "any tornado" and F1 tornado-based series track each other fairly well, but the F2-based series has a distinct break in the early-to-mid 1970s. From 1955-1972, there are more outbreaks identified by the F2 series than the F1 series for each year. From 1980-2002, the F1 series makes more identifications each year. The question of which time series is the source of the difference can be addressed by looking at the sorted distribution of big day identifications for the early and late part of the records. Looking at the first and last 19 years of the dataset, the two sorted distributions for F1-based big days are similar. The two biggest years are in the first part of the record, but beyond that, the two distributions are virtually indistinguishable (Fig. 4a). The picture for the F2-based big days is very different. The early part of the series has many more big days identified (Fig. 4b). The eight biggest years in the series are all in the first 19 years of the dataset and 16 of the values from the early record exceed 16 of the values from the late record. This is highly suggestive evidence that the F2+ record is what changed, but without accompanying changes in the F1+ record. Grazulis (1993) suggested that tornado damage was overrated in early part of the National Weather Service database (used here). Brooks and

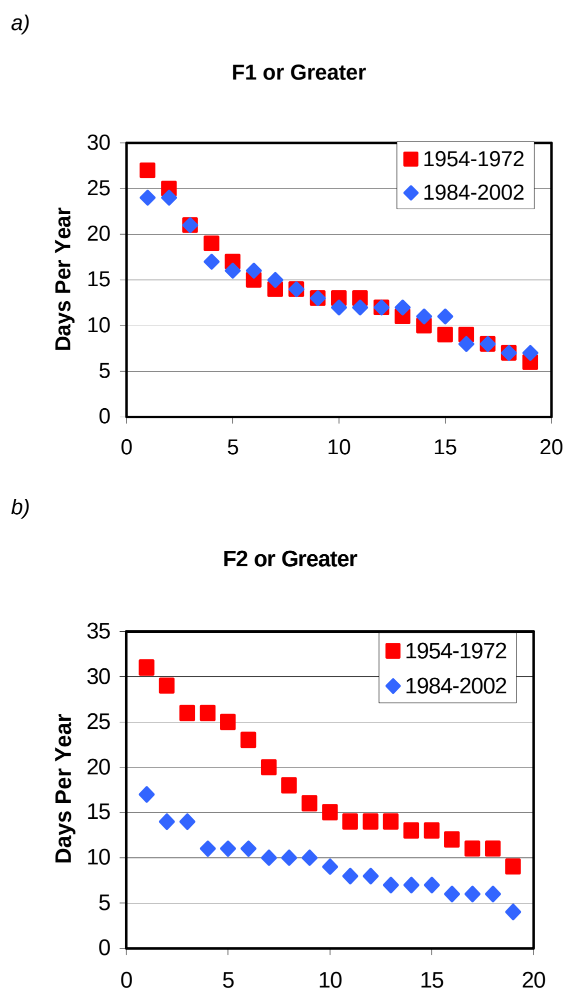

Fig. 4: Sorted distribution of number of days per year identified as big days from 1954-1972 (red) and 1984-2002 (blue). Leftmost item in each series is largest value of dataset and rightmost item is smallest value. a) F1 and greater tornadoes, using threshold of 8 tornadoes. b) F2 and greater tornadoes, using threshold of 4 tornadoes.

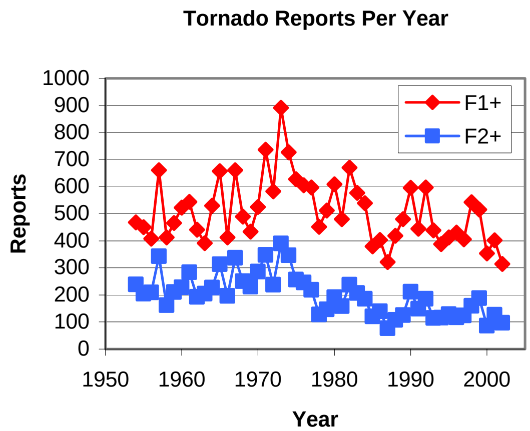

Fig. 5: Number of reported F1 and greater (red) and F2 and greater (blue) tornadoes by year from 1954 to 2002.

Craven (2002) and Brooks (2004) found objective support, although not proof, for the notion based on observations of environments associated with F2 and greater tornadoes and the length and width characteristics of reported tornadoes. Simply looking at the number of reported tornadoes of at least F1 and F2 ratings provides additional support that the change in F2 and greater tornadoes has been larger and occurs suddenly in the mid-1970s (Fig. 5.) A possible explanation of how the F2+ numbers could increase without the F1+ numbers increasing is that vast majority of the overall increase in tornado reports has been in those rated F0. The early part of the record (prior to the mid-1970s) contains reports of tornadoes that were overrated, compared to modern standards. The overrating problem was particularly acute for tornadoes for which evidence of damage was clear (i.e., greater than F0). As a result, tornadoes get "shifted" out of categories of F1 and greater to higher categories. The final distribution underestimates the true fraction of F1 tornadoes while overestimating the fraction of more damaging tornadoes.

Keeping in mind the arbitrary nature of any selected thresholds, calculation of the number of big days per year is an interesting exercise. As an example, using thresholds of 2% of the expected annual total tornado reports and 10 F1 or greater tornadoes, and identifying a day as "big" if it meets either criterion or both, 1957 and 1973 are identified as the years with the most big days on record, with 26 and 29, respectively (Fig. 6). There is still some hint of an increase in number of identified days over the length of the record, but it is not large. The years 1985-1988 are noteworthy in the period since 1980 for the absence of big days.

As mentioned earlier, we have made no effort to consider spatial and temporal constraints (other than looking at individual days) on the occurrence of tornadoes. Thus, we have looked at "big days", not necessarily outbreaks in the traditional sense. However, the relationship between the work here and an "objective" definition of outbreaks is transparent.

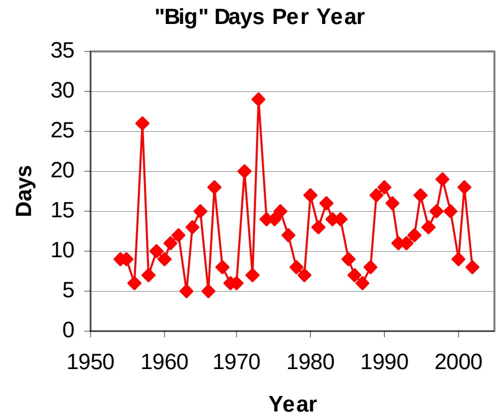

Fig. 6: Number of days per year identified as big tornado days from 1954-2002 using thresholds of 2% of expected annual number for any tornado and/or at least 10 F1 tornadoes.

Any definition of an outbreak would be inherently subjective, depending upon the needs of the user. Consideration of the rarity of events, however, can help provide guidance on the selection of thresholds.

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