TORNADO AND SEVERE THUNDERSTORM DAMAGE

Harold E. Brooks
NOAA/National Severe Storms Laboratory
Norman, Oklahoma, USA

ISSUES IN REPORT DATABASES

The historical records of the occurrence of and losses from severe thunderstorms and tornadoes present significant challenges in attempting to establish trends, if they exist. Very few countries collect data on events as an activity of the national meteorological service. Within those that do, spatial and temporal differences in reporting procedures or effort mean that consistency is rarely achieved (e.g., Doswell et al. 2005). It is likely that the highest-quality dataset of significant length is the tornado dataset of the United States, which began in the early 1950s. Even these data have serious problems with consistency (Brooks 2004; Verbout et al. 2006) (e.g., Fig. 1). Even though the vast majority of the increase has been in the weakest tornadoes (Brooks and Doswell 2001b), serious inhomogeneities exist even when consideration is restricted to the strongest tornadoes, which have typically been viewed as being better reported (Fig. 2). Recent and planned policy changes within the US National Weather Service may add even more problems to the interpretation of the record.

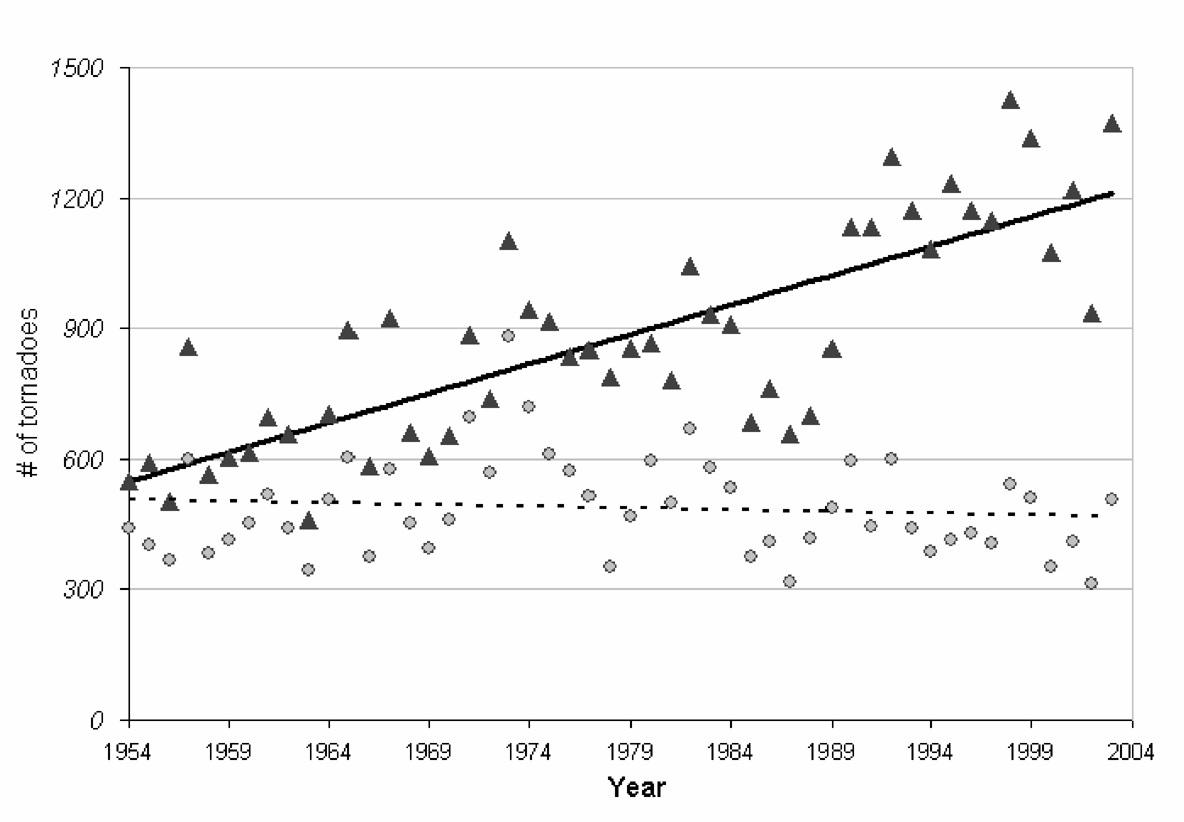

Fig. 1: 1954-2003 annual tornado reports in US. Total (black triangles), and tornadoes rated F1 or higher (gray circles). Linear regression fits to time series in solid and broken lines, respectively. (From Verbout et al. 2006).

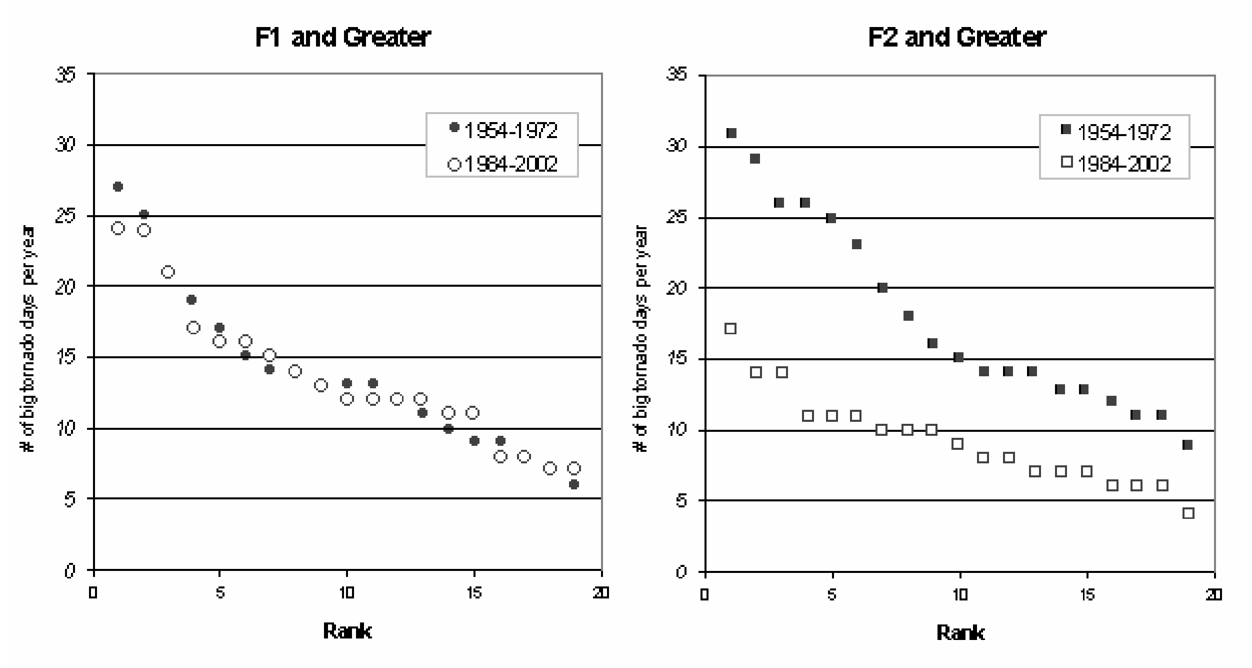

Fig. 2: The ranked distribution of number of days per year exceeding threshold for "big tornado days," as defined by Verbout et al. (2006). F1 and greater series (left) and the F2 and greater series (right). The early portion of the dataset (1954-1972) is denoted by black points; the later portion of the dataset (1984-2002) is represented by open points. The leftmost point in each series is the greatest value and decreases to the right. (From Verbout et al. 2006).

The number of tornadoes reported per year has increased by about 13 per year, or roughly 1% of the current number of reports. Fundamentally, it is effectively impossible to determine whether any changes have occurred in the actual meteorological events from the official observed records in the US. Relatively large physical changes (say, 20% in the period of record) *could* have happened, but would be difficult to detect in the background of reporting issues. There is a profound break in the reported number of strong tornadoes (at least F2 on the Fujita scale, going from F0 to F5) in the mid-1970s, as shown in Fig. 2. Brooks (2004) also showed that the reported path length and width information has undergone large changes, seemingly independent of official policy alterations. It is possible to smooth the report data to produce a distribution of tornado occurrence that may be a reasonable estimate of "truth" (Brooks et al. 2003a), but that smoothing is likely to make the estimate sufficiently resistant so that real changes would be masked. In related work, Dotzek et al. (2003, 2005) and Feuerstein et al. (2005) have shown that the distribution of tornadoes by intensity is similar over much of the world by fitting statistical distributions to reports. Although different environmental regimes can be distinguished (e.g., the US vs. the United Kingdom), the quality of the fit at the most intense end of the spectrum, which represents the rarest events, means that detecting changes in the distribution by intensity of the strongest tornadoes will be difficult at best, unless those distributions are very different.

ENVIRONMENTAL CHANGES

An alternative approach to the question of changes in meteorological events is to look for possible changes in environmental parameters favorable for severe thunderstorms. Brooks et al. (2003b) followed techniques from forecasting research and developed relationships between large-scale environmental conditions and severe thunderstorms and tornadoes, using global reanalysis data. Recently, the work has been expanded to look at a longer period of record around the globe. Interannual variability on a global scale in the frequency of favorable severe thunderstorm environments has been large, with no discernable trend. Regionally, there have been changes, although the question of the quality of the reanalysis representation requires caution to be applied to the interpretation. The eastern US showed a decrease from the late 1950s to the early 1970s, followed by a slow increase through the 1990s

(Fig. 3a). For the same size region including the high-frequency severe thunderstorm areas of southern Brazil and northern Argentina, there has been a decrease though the period of record (Fig. 3b).

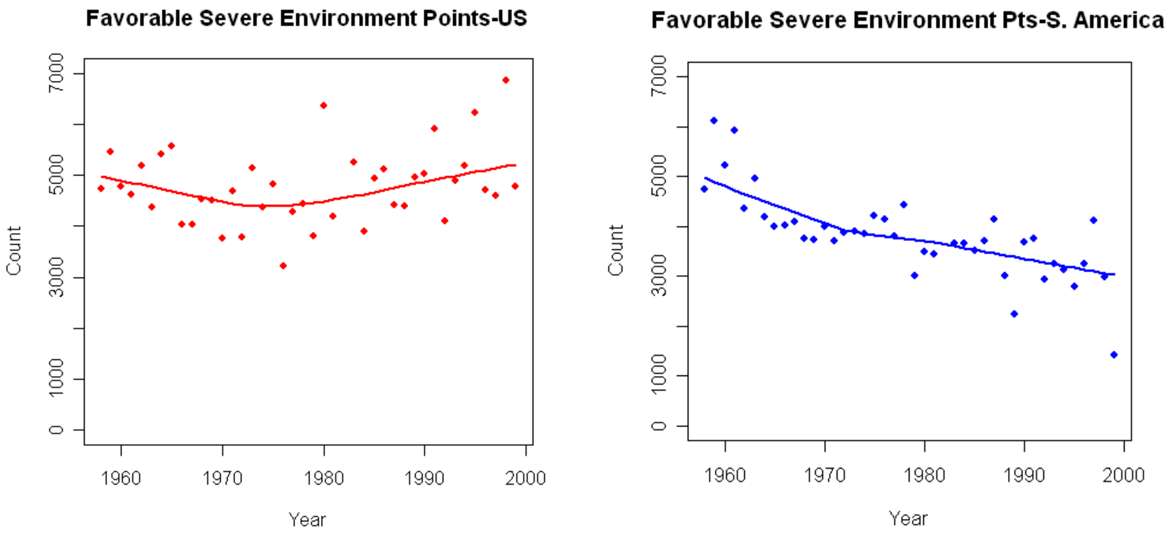

Fig. 3: Counts of 6-hourly periods at individual gridpoints with favorable environments for severe thunderstorms in the US, east of the Rockies (left) and South America (right).

The inflection point in 1973 in the US record is consistent with an inflection point in the number of reports of 3-inch (7.5 cm) diameter and larger hail per year. The reanalysis suggests an increase of 0.8% per year in the number of favorable environments in the region, whereas the reports have increased by 6%. If we take the reanalysis as an estimate of the real changes, a step to be taken with a grain of salt, it implies that the environmental changes have accounted for about 13% of the total changes in reports. It is interesting to note, perhaps, that the reanalysis trend in the US qualitatively resembles the US surface temperature record. Observations of events in South America are insufficient to corroborate the trend seen in the reanalysis.

DAMAGE AMOUNTS

The question of changes in the property damage caused by severe thunderstorms is a separate issue. The difficulties encountered in the report databases seem minor compared to those in the damage databases. Again, the systematic collection of data is a serious issue. Looking at historical descriptions of damage in national meteorological services, it is not always apparent whether damages that are reported are insured losses or total losses. Also, for some storms, no monetary estimate may be given. In other cases, the estimates that get recorded may be preliminary. For example, in some sources, the 1975 Omaha, Nebraska tornado is listed as the biggest-damage tornado, in inflation-adjusted dollars, in US history, based on a statement made the next day by the mayor of the city that there might be $750 billion in damage, an estimate that turned out to be high by a factor of three. Nevertheless, the original estimate made it into some “official” records and still appears in some lists of the damage.

Another issue is that severe thunderstorm damage tends to be relatively isolated (in space), but occurs relatively frequently. Where and when storms occur can dramatically affect the amount of damage, even for the exact same meteorological event. An urban area may suffer little property damage from a widespread fall of 1 cm diameter hail, while a vineyard or grain crop at certain times of the year might be devastated. Hail of 5 cm diameter might cause vast amounts of damage in an urban environment, especially to vehicles, while, if it occurs before crops have emerged from the ground in spring, it might have little impact in a rural location.

Brooks and Doswell (2001a) looked at the record of property losses from the most damaging tornadoes in the US from

1890-1999 and adjusted the losses for inflation and national wealth. [1] They found that, by including the wealth adjustment, there was no tendency for changes in the most damaging tornadoes in recent years, with a return period of about 10 years for a billion dollar tornado. As possible support for the notion of using wealth adjustment, Beatty (2002) took the most damaging tornado from the Brooks and Doswell study, the Saint Louis tornado from 1896 and put its damage path on the current area to estimate property damage. His estimate was about 10% smaller than the approximately $3 billion estimate from Brooks and Doswell based on national wealth adjustment.

As part of preparing for this workshop, I've built a simple model of the damage process. The model consists of two parts-tornado description and damage associated with the tornado. For the first part, I start with the mean number and standard deviation of annual reported tornadoes based on the linear regression from Verbout et al. (2006), roughly 1200 and 150, respectively. For each simulated year, a count of tornadoes is drawn from the distribution. Each tornado is then assigned a Fujita scale rating, drawing randomly from the empirical distribution of tornadoes by intensity for 1995-2004. A damage amount is assigned to each tornado. The damage amount for each F-scale is assumed to be exponential and has an absolute lower bound. The maximum damage is capped at $6 billion, in order to avoid rare, but extremely large values that might bias the results. As a first guess, the lower bound of F5's damage was $100 million, with a 10% probability of exceeding $1 billion. The lower bound for each successively smaller F-scale was an order of magnitude smaller. The 10% probability was taken as an order of magnitude above the lower bound. (I've done some exploration with the various shapes of the distributions and bounds, but the results of the study are qualitatively similar.)

The distribution of annual damage from this model is log-normal, roughly similar to the observed annual reported damage. The mean of the distribution is roughly $400 million per year and the return period for a single billion-dollar tornado is approximately a decade, in keeping with the observed record. The annual damage is, in effect, controlled by the damage associated with a small number of tornadoes, almost exclusively from the F3 and stronger tornadoes.

I explored the effects of changing the annual number of tornadoes and the distribution of intensity, looking for statistically significant differences in the distribution of annual damage. Increasing the mean number of tornadoes by less than 30% (more than two standard deviations) failed to produce statistically significant differences from the control simulation. Similarly, increasing the number of the most damaging tornadoes (F4 and F5) by 50% was necessary to get significant differences or to make the return period for billion-dollar tornadoes much shorter than a decade. These results aren't surprising, given that the damage is concentrated in a small number of rare events. Thus, large changes are needed to give a high probability of generating damaging tornadoes. As a result, it seems unlikely that damage amounts will provide a clear indication of changes, even with reasonably large physical changes.

CONCLUDING THOUGHTS

Problems in the reporting databases mean that it is extremely unlikely that climate change will be detectable in severe thunderstorm and tornado reports, even if there is a physical effect. Estimation of changes in the frequency of favorable environments may be more useful. There is no evidence to date to suggest that changes in damage are related to anything other than changes in wealth in the US. Given inflation on the order of 3% per year and a real GDP growth rate of 3.5%, reflecting the trends of the last half century, we would expect unadjusted damages to double every 10-11 years. From the adjusted damage work of Brooks and Doswell (2001a), there has been one year (1953) with 5 of the 30 most damaging tornadoes in US history. Thus, even a year with multiple events would not be evidence of changes.

It is of fundamental importance for future work to develop systems that collect data on the events and their effects in a systematic, consistent way. In the absence of databases of at least reasonable quality, it is extremely difficult to say much of substance.

---

[1] As of the middle of April 2006, no tornadoes have occurred that would have been included in the top 30 in terms of adjusted-damage in the US.

REFERENCES

Beatty, K. A., 2002: What would be the monetary loss if the 1896 St. Louis/East St. Louis tornado happened today? *Preprints*, 21st Conference on Severe Local Storms. Amer. Meteorol. Soc., San Antonio, Texas, 247-250.

Brooks, H. E., and C. A. Doswell III, 2001a: Normalized damage from major tornadoes in the United States: 1890 1999. *Wea. Forecasting*, 16,168-176.

Brooks, H. E., and C. A. Doswell III, 2001b: Some aspects of the international climatology of tornadoes by damage classification. *Atmos. Res.*, **56**, 191-201.

Brooks, H. E., and C. A. Doswell III, 2002: Deaths in the 3 May 1999 Oklahoma City tornado from a historical perspective. *Wea. Forecasting*, **17**, 354-361.

Brooks, H. E., C. A. Doswell III, and M. P. Kay, 2003a: Climatological estimates of local daily tornado probability. *Wea. Forecasting*, **18**, 626-640.

Brooks, H. E., J. W. Lee, and J. P. Craven, 2003b: The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmos. Res.*, **67-68**, 73-94.

Brooks, H. E., 2004: On the relationship of tornado path length and width to intensity. *Wea. Forecasting*, **19**, 310-319.

Doswell, C. A. III, H. E. Brooks, and M. P. Kay, 2005: Climatological estimates of daily local nontornadic severe thunderstorm probability for the United States. *Wea. Forecasting*, **20**, 577-595.

Dotzek, N., J. Grieser, and H. E. Brooks, 2003: Statistical modeling of tornado intensity distributions. *Atmos. Res.*, **67-68**, 163-187.

Dotzek, N., M. V. Kurgansky, J. Grieser, B. Feuerstein, and P. Névir, 2005: Observational evidence for exponential tornado intensity distributions over specific kinetic energy. *Geophys. Res. Lett.*, **32**, L24813, doi:10.1029/2005GL024583.

Feuerstein, B., N. Dotzek, and J. Grieser, 2005: Assessing a tornado climatology from global tornado intensity distributions. *J. Climate*, **18**, 585-596.

Verbout, S. M., H. E. Brooks, L. M. Leslie, and D. M. Schultz, 2006: Evolution of the US tornado database: 1954-2003. *Wea. Forecasting*, **21**, 86-93.