Estimating the Distribution of Severe Thunderstorms and Their Environments Around the World

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1 Reporting of severe thunderstorms

Severe thunderstorms pose a significant challenge for development of reasonably accurate climatologies. They are rare events at any particular location and, in general, their reporting depends upon the presence of a system designed to collect data and an observer at the location of the event. Brooks and Doswell (2001) discussed some of the problems with particular regard to the tornado reporting problem. A lack of uniformity in standards for data collection between different countries and changes through time in the way data are collected makes comparisons across space and time very difficult. Attention to collecting reports can be seen clearly in a comparison of tornado reports from France and Germany (Paul 2001, Dotzek 2001) in the 19th and 20th Centuries (Fig. 1). There's no meteorological reason to believe that tornadoes in those two countries should follow dramatically different trends, but the annually-averaged numbers are anticorrelated, even prior to the large increase in German reports after World War II. The presence of interested individuals in Germany (e.g., Alfred Wegener during WW I, Johannes Letzmann in the 1930s and Nikolai Dotzek in the 1990s) lead to spikes in the number of reported events.

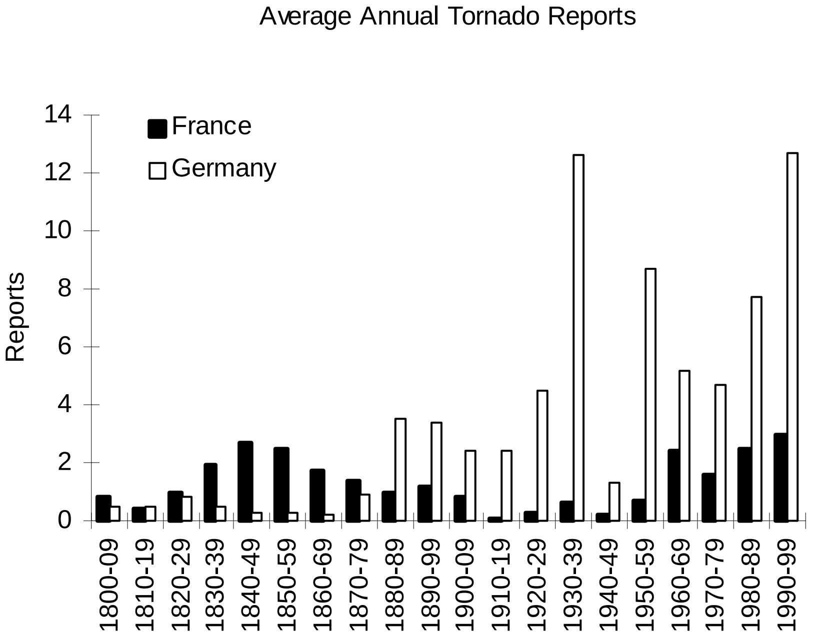

Fig 1: Reported tornadoes in France (black bars) and Germany (white bars) per year by decade.

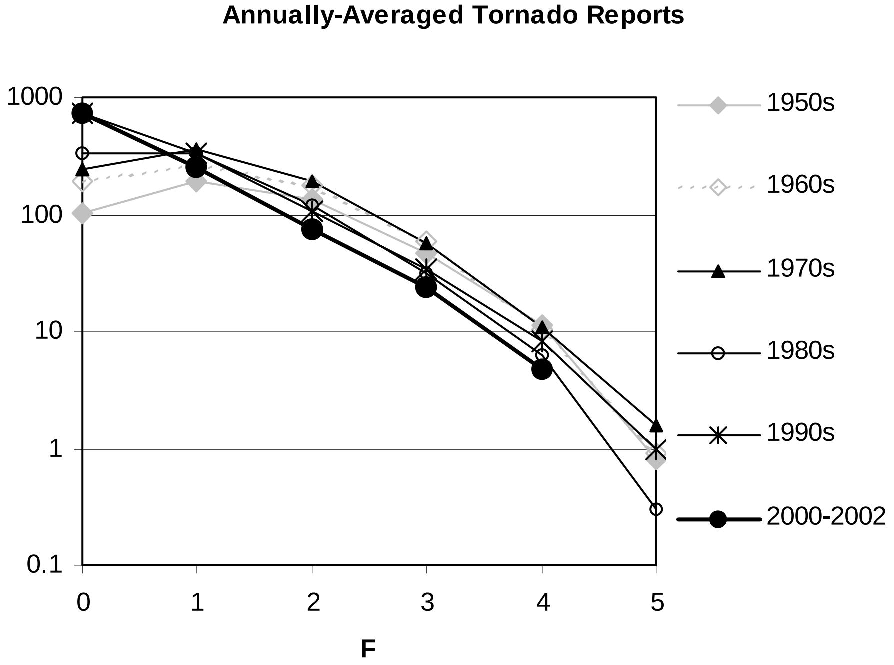

Fig. 2: Average number of tornado reports in United States per year by F-scale for each decade. Note logarithmic scale for reports. The F-scale estimates tornado damage intensity and goes from F0 (weakest) to F5 (strongest).

It might be argued that part of the problem with the French and German records is that it is not part of the responsibilities of the national meteorological services in those countries to collect reports systematically. Indeed, only three countries (the United States, Canada, and Australia) have demonstrated a long-term commitment to relatively systematic report collection. However, there are still problems even when resources are put into addressing the problem. In the United States, an average of 600 tornadoes per year are in the official database the 1950s, while approximately 1200 have been reported per year in the last decade. The increase has been entirely in the weakest tornadoes (F0) (Fig. 2). Long-term trends in the annual total of F1 and more damaging tornadoes are small, at best. If that was the only problem in the database, adjustments could be made easily, such as not considering the F0 tornadoes. However, changes in reported path size (Brooks 2004) and other evidence from consideration of the environmental conditions in which storms form (Brooks and Craven 2002) suggests that tornadoes in the 1950s through 1970s are likely to be overrated in their damage. This adds complications to the challenge of interpreting trends in the data.

2 Environmental conditions

A possible solution to some of the problems is to use meteorological covariates (Brown and Murphy 1996) to estimate the occurrence of events. Covariates are variables that are measured consistently in space and time and have some relationship to the event of interest. In effect, the challenge of estimating occurrence of the weather event of interest is transformed from solving the poor quality of observations to developing a reasonable relationship between a well-observed variable and the event we are actually interested in.

In the severe weather community, there is a long tradition of studies of so-called “proximity soundings”, rawinsonde launches taken near to severe weather events in space and time, to try to determine the relationship between large-scale environmental variables and severe weather occurrence (e.g., Fawbush and Miller 1952, Rasmussen and Blanchard 1998, Hanstrum et al., 2002) A goal on many of these studies was to find a small set of parameters that could discriminate between different kinds of weather of interest, say between severe and non-severe thunderstorm environments or tornadic and non-tornadic environments.

Proximity sounding analyses are naturally related to the concept of meteorological covariates. If a relationship can be established between variables associated with the soundings and severe weather occurrence in regions where the reporting of severe weather is reasonably good, it might be possible to apply those relationships to soundings taken in other locations where the severe weather reporting is not as good and estimate the likely occurrence of severe weather. For instance, if a particular combination of convective available potential energy (CAPE) and vertical shear of the tropospheric horizontal winds is associated with severe thunderstorms more often than another combination, then the frequent occurrence of the former combination at some other location would imply that severe thunderstorms are likely to be frequent at the second location.

A problem with the use of proximity soundings is that radiosonde launches are not made as frequently in time or space as we would like. To get around that, Brooks et al. (2003) used data from the National Center for Atmospheric Research/National Centers for Environmental Prediction (NCAR/NCEP) “reanalysis” of the atmosphere (Kalnay et al. 1996) in order to make synthetic radiosonde data. The reanalysis acts like an analysis cycle of a global numerical weather prediction model. The NCAR/NCEP reanalysis has data every six hours on a spectral grid with effective spacing of slightly finer than 2 x 2 degrees latitude and longitude going back to 1 June 1957. Brooks et al. (2003) looked at every other grid point over non-ice-covered land from 1997-1999. It is hoped to present additional results of a longer analysis at the conference. Lee (2002) carried out extensive analyses to compare the reanalysis soundings and collocated observed radiosonde values. He found that, for most convectively important parameters, the reanalysis matched the radiosondes fairly well. For parameters that didn’t depend on sharp vertical gradients, linear correlation coefficients were typically on the order of 0.6-0.8 comparing the reanalysis to unsmoothed observed data. Parameters requiring sharp vertical gradients (e.g., strength of capping inversions) did not mimic reality as closely.

Using the reanalysis data, Brooks et al. developed relationships between environmental conditions and the occurrence of so-called significant severe thunderstorms (those producing at least an F2 or stronger tornado, 5-cm diameter hail, and/or 120 km/h wind gusts) over the eastern United States from 1997 to 1999. Significant severe thunderstorms were focused on because previous analyses had shown that discriminating between “lesser” severe thunderstorms and non-severe storms was extremely difficult. They then applied those relationships to the rest of the globe, using the time of day in the reanalysis nearest late afternoon (in an effort to consider the time nearest the maximum potential instability). Given that severe thunderstorms were estimated to occur, a second set of relationships was developed to discriminate between the tornadic and non-tornadic soundings. The primary predictors for discriminating between severe and non-severe environmental conditions were the convective available potential energy (CAPE), the magnitude of the difference in the winds between the surface layer and 6 km (representing the vertical shear of the horizontal winds), and the lapse rate in the layer between 2 and 4 km above ground level. The tornadic discriminators included the height above the ground of the lifting condensation level for a parcel mixed over the lowest 100 hPa of the atmosphere (Craven et al. 2002), the wind shear over the lowest 1 km, and the station elevation. Details of the procedure are given in Brooks et al. (2003).

Many of the results of the estimation of severe thunderstorm are not surprising. Areas downstream (east) of mountainous terrain or deserts and poleward of sources of warm, moist air tend to have high estimated frequency of severe thunderstorm occurrence (Fig. 3). [Note that the pattern is what is critical in consideration of the results in Fig. 3. The absolute magnitude is not that important as the analysis ignores issues such as initiation of thunderstorms. As a result, it is a measure of where storms are likely to be severe, *if* storms occur.] The Great Plains of North America, southeastern Brazil through northern Argentina, the region near the Himalayas, and central and extreme southeastern Africa are regions of particularly high occurrence. Coastal Australia (except for south-central Australia) and southern Europe are secondary maxima.

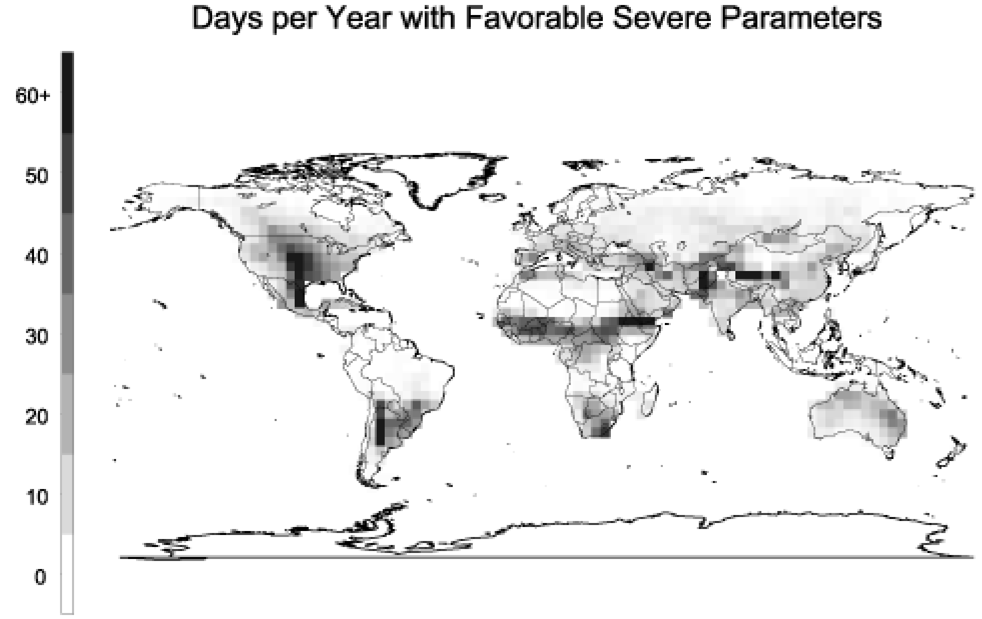

Fig. 3: Estimated number of days per year with conditions favorable for the production of significant severe thunderstorms (F2 or stronger tornado, 5-cm diameter hail, and/or 120 km/h wind gusts), based on NCAR/NCEP reanalysis data from 1997-9.

The analysis for tornadic environments looks similar to that of severe thunderstorms, with the notable absence of the central African maximum (Fig. 4). It is important to note that the North American maximum is displaced somewhat to the east of the observed maximum of significant tornado occurrence. Work in progress suggest that observed soundings associated with tornado are more likely to be associated with low lifted condensation level heights and high low-level shear, while isolated significant tornadoes don't have as extreme of values of those parameters, suggesting a need for additional development work in the tornadic/non-torandic discrimination.

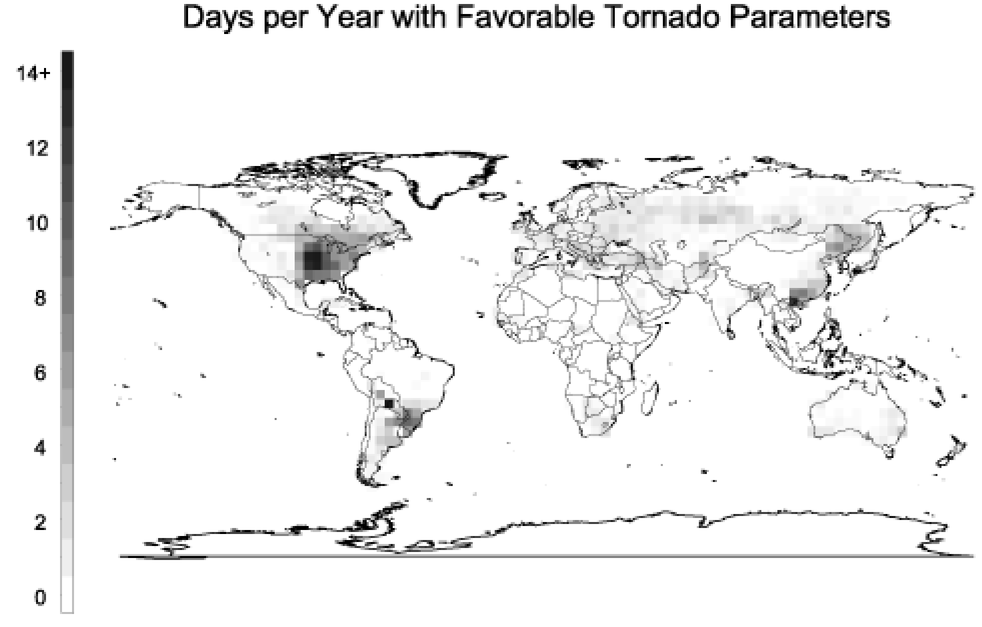

Fig. 4: Same as Fig. 3 except for F2 or stronger tornadoes.

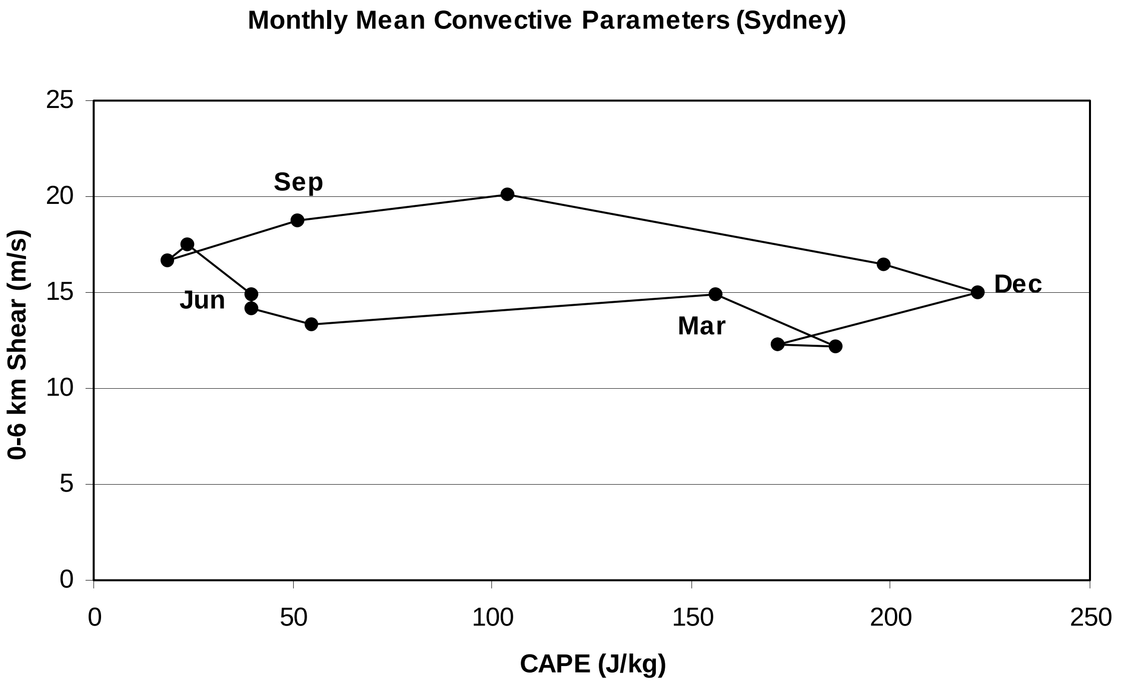

Fig. 5: Monthly mean values of convective available potential energy (CAPE) in J/kg and 0-6 km shear (m/s) for grid point near Sydney, New South Wales, from NCAR/NCEP reanalysis for 06 UTC from 1997-9.

The reanalysis also provides the opportunity to investigate convective parameters over a broad range of time and space. This is particularly useful for locations or times when soundings aren't launched. As an example, the annual cycle of monthly mean CAPE and deep shear for Sydney, New South Wales has been calculated for 06 UTC (Fig. 5). The annual cycle moves in a generally clockwise direction on the figure, with the highest (lowest) instability in December (July/August) and higher values of deep shear in austral spring than in austral autumn.

3 Discussion

Severe thunderstorms occur wherever the right ingredients come together. Storms in different places aren't different because of where on the globe they form, but rather because of the different environments which occur there. For example, the Rocky Mountains are a tremendous source of potentially unstable mid-tropospheric air in the Great Plains of the United States. If similar lapse rates can be produced in other locations, the storms that form there will have tremendous instability, *ceteris paribus*. The fundamental effect of the Rockies is that they make those high lapse rates more likely in the Great Plains than almost anywhere else. An important lesson of the use of environmental conditions to analyze thunderstorms is that knowledge about what kinds of storms form in different environments can be transferred to other locations for use when similar environments occur. Different regions of the planet may get different kinds of storms because the frequency of favorable environmental conditions is different, but the atmosphere doesn't "care" where it is. That said, consideration of conditions, and the associated storms, in different locales can help meteorologists focus on what they *really* know about how the atmosphere behaves as opposed to what they know because of some limited sample in a small area. If, for example, our understanding of the environmental conditions associated with the development of strong and violent tornadoes is limited because there is a set of environmental conditions that rarely occur in the Plains of the United States, but that is supportive of tornadoes, that implies that our physical understanding of tornadogenesis is limited.

Estimations of the distribution of severe thunderstorms based on meteorological covariates and observations of environmental conditions are a matter of expediency. They are necessary because of the poor quality of reporting databases and, at the same time, are limited by that poor quality. Improvements in reports can help in both the direct estimation of events, but also in development of relationships based on covariates. There is no substitute for improvement in data quality. At a minimum, national meteorological services need to collect data on all kinds of severe weather events (kind of phenomenon, intensity) with time and space specific information on the occurrence and effects of the events. It is important for the meteorological services to take this responsibility because of the long-term continuity they can provide for data collection. Even though the current data quality is insufficient for many purposes, any efforts to improve that situation for the future need to be supported. It may take many years to get sufficient quantities of quality reports to make direct estimation of event occurrence, but even relatively short records can be exploited in the development of covariate relationships. The identification of environmental conditions associated with severe thunderstorms can be useful both for operational forecasting and for climatological purposes. Given that environments that are potentially supportive of severe thunderstorms and tornadoes are observed more regularly than the events themselves, it is likely that the environmental observations may prove more useful in efforts to identify potential effects of global climate change, both in the historical record and in global climate model simulations (Intergovernmental Panel on Climate Change 2002).

4 References

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

_____, and J. P. Craven, 2002: A database of proximity soundings for significant severe thunderstorms, 1957-1993. *Preprints*, 21st Conference on Severe Local Storms, San Antonio, Texas, American Meteorological Society, 639-642.

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

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

Brown, B. G., and A. H. Murphy, 1996: Verification of aircraft icing forecasts: The use of standard measures and meteorological covariates. *Preprints*, 13th Conf. Probability and Statistics in the Atmospheric Sciences, San Francisco, California, USA, Amer. Meteorol. Soc., 251-252.

Craven, J. P., R. E. Jewell, and H. E. Brooks, 2002: Comparison between observed convective cloud-base heights and lifting condensation level for two different lifted parcels. *Wea. Forecasting*, **17**, 885-890.

Dotzek, N., 2001: Tornadoes in Germany. *Atmos. Res.*, **56**, 233-252.

Hanstrum, B. N., G. A. Mills, A. I. Watson, J. P. Monteverdi, and C. A. Doswell III, 2002: The cool-season tornadoes of California and southern Australia. *Wea. Forecasting*, **17**, 705–722.

Intergovernmental Panel on Climate Change, 2002: *Workshop Report, IPCC Workshop on Changes in Extreme Weather and Climate Events*, Beijing, China, 107 pp.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteorol. Soc.*, **77**, 437-472.

Lee, J. W., 2002: Tornado proximity soundings from the NCEP/NCAR reanalysis data. M. S. Thesis, University of Oklahoma, 61 pp.

Paul, F., 2001: A developing inventory of tornadoes in France. *Atmos. Res.*, **56**, 269-280.

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148–1164.