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THE MONTH-TO-MONTH CONSISTENCY IN THE OCCURRENCE RATES OF TORNADOES AND SEVERE THUNDERSTORMS

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1. INTRODUCTION

Much has been said about the continuing increase in the number of reported tornadoes over the United States (e.g., Schaefer, et. al., 2002). During the 51 years of data (1950-2001) that were in the Storm Prediction Center (SPC) tornado database when this paper was being written, the number of tornadoes has been increasing at an annual rate of about 16 tornadoes per year (Fig. 1). However, these changes are not linear. There are marked discontinuities in the time series. It is likely that the general increasing trend is a product of changes in American society rather than in the actual tornado climatology (Schaefer and Brooks, 2000). For instance, cellular phones, which are commonplace now but were unknown in the 1950's, make it much more likely that people will report tornadoes that they observe while they are traveling.

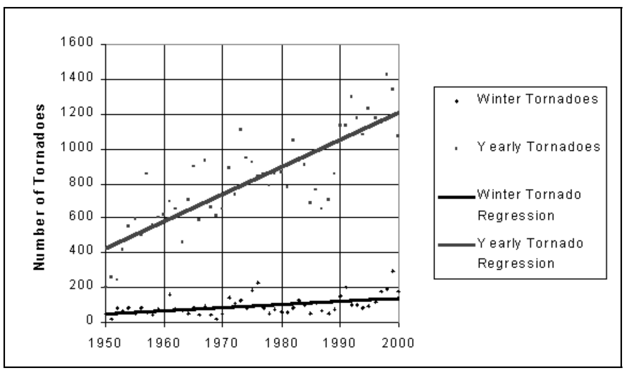

Figure 1. The annual number of tornadoes - top line - and the number of "winter" (January, February, and March) tornadoes - bottom line - per year. Dots give data points, and lines represent fit by linear regression.

Similarly, there is a marked variation in the number of tornadoes reported in any given month. As can be seen by a "box and whiskers" plot (Fig. 2), a "typical" tornado month is as much a mathematical artifice as a physical quantity. For instance, while the median (or typical) number of tornadoes for June is 147, the total reported during that month has varied from as few as 28 (in 1950) to as many as 399 (in 1992).

The box and whiskers plot not only shows an annual tornado cycle with a peak occurrence rate in May, but it also shows a November increase in the 75%, 90% and maximum points suggesting the presence of a weak secondary maximum. Also, if all months received the median number of tornadoes, only 76 tornadoes would be reported during the first three months (called "Winter" in this report). This is less than the number of tornadoes that are expected during any one individual month from April through July. The median values fall off rapidly during the last half of the year, and the last three months of the year have median tornado counts even lower than those of the first three months of the year.

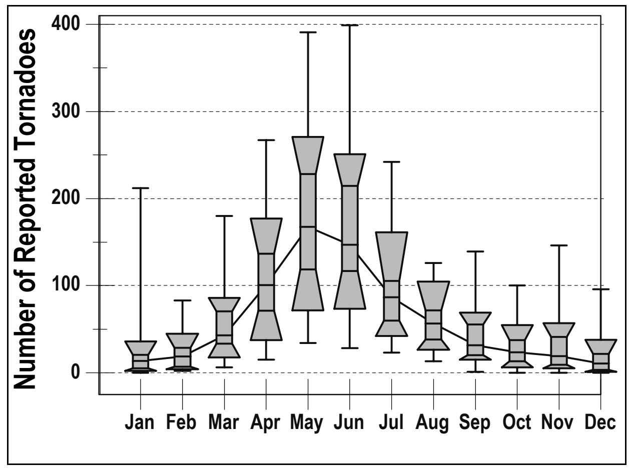

Figure 2. Box and Whiskers plot of the monthly number of tornadoes. The 7 horizontal lines of each icon mark the minimum, the 10% point, the 25% point, the 50% point (median), the 75% point, the 90% point, and the maximum. The median values are connected by a line.

2. RELATIONSHIP OF WINTER TORNADOES TO THE YEAR'S TOTAL TORNADO COUNT

There is a high degree of variation in the monthly tornado counts. Because of this, it is very unusual for the first three months of the year all to have "sub-normal" tornado activity. In only seven of the 51 years of record (14%) has the number of tornadoes reported in each of the three winter months been less than the median value of each individual winter month. The last time this happened was in 1984, when the number of tornadoes reported in a year was only about two thirds of what it is today.

However, that is exactly what the preliminary data for the year 2002 indicated happened. In January, the SPC received reports of only eight tornadoes. (The January median count is 14.) This was followed by a February in which only two tornadoes were reported in the contiguous United States. (The February median is 19 tornadoes.) The 2002 winter ended with a March in which there were only 30 reported tornadoes. (The March median is 43.) Thus during the first three months

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of the year, only 40 tornadoes were reported. For comparison, the average for the three preceding years (1999 - 2001) was 175 reported tornadoes.

Because of the low tornado count during the 2002 winter months, the SPC received numerous inquires as to what the small number of winter reports boded for the remainder of the year. It is tempting to simply note that the number of tornadoes that occurred over a given period of each year with the year's final tornado count has a correlation coefficient of 0.62 (Fig. 3). However, there are problems with this. Since the number of tornadoes reported each year and the number of winter tornado reports are both generally increasing (Fig. 1), the computed correlation includes the joint dependence on year. Another problem is the 290 winter tornadoes recorded during 1999. This is 62 more winter tornadoes than during the second-most tornado prone winter. This outlier was a result of 95 tornadoes that were reported over Arkansas, Tennessee, and other parts of the "mid-South" during outbreaks on January 17 and January 22, 1999. Since 1999 also had the second highest annual tornado count on record (1,342 tornadoes – the record was 1,424 in 1998), two tornado outbreaks dominate the statistics and force the correlation.

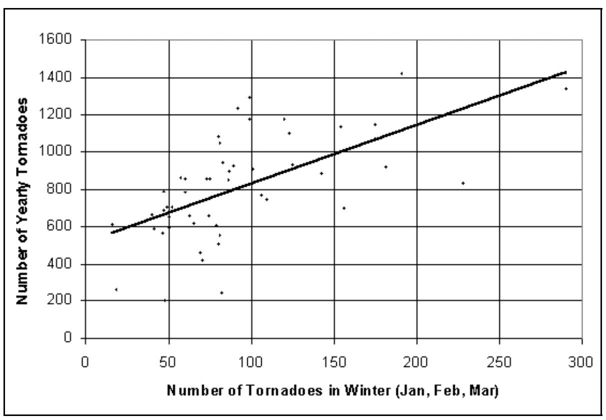

Figure 3. Scatter diagram relating the number of tornadoes reported during the winter months to the total tornado count during the year. Data points for the years 1950 - 2000 are indicated by dots, and a linear regression line is plotted.

To address these problems, the total and seasonal tornado counts are detrended by subtracting the values obtained via least-squares regression from the appropriate tornado counts for each year. The correlations are then recomputed ignoring the data from 1999. The resulting scatter diagram (Fig. 4) shows that there is considerably less functional dependence between the detrended tornado counts than there was with the observed values. After the data are detrended and the outlier year (1999) is omitted, the correlation coefficient between winter tornadoes and total tornadoes is only 0.41. Preprocessing the data reduced the apparent correlation coefficient by 34%.

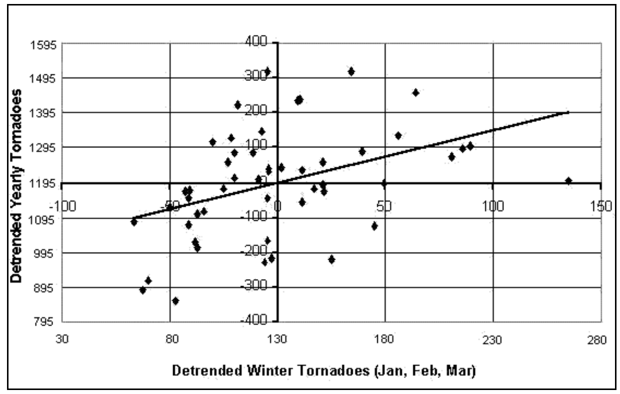

Figure 4. Scatter diagram relating the number of tornadoes reported during the winter months to the total tornado count during the year. -- Both the number of winter tornadoes, and the total number of tornadoes have been detrended using the regression lines shown in figure 1. Data from 1999 was not used in the calculations. For display purposes, the labels are computed as number of tornadoes predicted by the regression for the year 2000. Data points are indicated by dots, and a linear regression line is plotted.

Using a "Fischer's z" transformation (James and James, 1959), it can be shown that the magnitude of the correlation coefficient computed over a 50-member sample must be at least 0.48 before it is possible to reject, at a 99% confidence level, the hypothesis that the correlation is actually zero. Thus, since the sample correlation coefficient is 0.41, there is no statistical significance in the correlation between the number of tornadoes that occur during the winter months and the number that occur during the entire year. Heuristically, the clustering of the data points in Fig. 4 is indicative of the weakness in the correlation between winter tornadoes and the total number of tornadoes reported during the year. The total number of tornadoes during the year cannot be estimated from the number of winter tornadoes reported.

3. THE RELATIONSHIP OF THE NUMBER OF TORNADOES DURING OTHER TIME PERIODS TO THE YEAR'S TOTAL TORNADO COUNT

The relationship between the number of tornadoes observed during the winter and the total number of tornadoes is further explored by considering the relationship between tornado occurrences during January and February and the total number of observed tornadoes (Fig. 5). Once again, the data has been detrended, and 1999 has not been considered. The scatter diagram consists of a large group of points clustered around the origin distinctly separated from a group of three points that are farther out along the x-axis. During the three years represented by these points, there were over 55 more tornadoes than normal during January and February and, not surprisingly, the total number of tornadoes observed during those years was also greater than normal. However, when there were less than 25 more tornadoes than normal during

January and February, no apparent relationship existed between a year's total number of tornadoes and the number it receives during January and February. Even with the highly correlated three point cluster, the sample correlation coefficient was only 0.45, which is statistically insignificant at the 99% confidence level. Unless there is an extreme number of January and February tornadoes, the total number of tornadoes during the year cannot be estimated from what happens during first two months of the year.

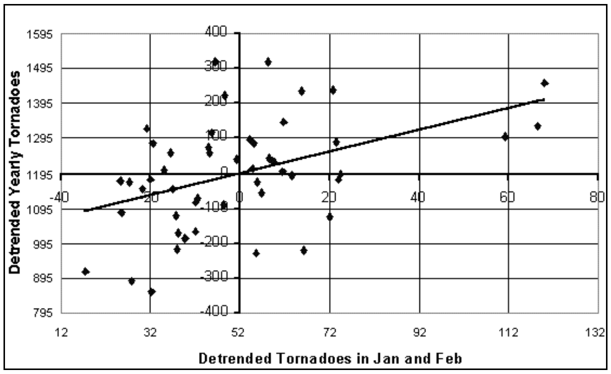

Figure 5. Scatter diagram relating January and February tornadoes to the total number of tornadoes observed during the year. -- Legend as in Fig. 4.

While no significant correlation exists between either the number of tornadoes observed in January and February, or tornadoes that occur during the winter months, and the yearly total, a significant correlation is found when tornadoes during the first four months of the year are considered. The correlation coefficient between the number of tornadoes observed from January through April and those observed during the entire year is 0.63. This is well above the 0.48 value necessary for statistical significance at the 99% level.

The scatter diagram (Fig. 6) relating January through April tornadoes to annual tornadoes (detrended, and without 1999) indicates this correlation. In Fig. 6, the data points are generally clustered about the regression line rather than around the origin, as was the case in Fig. 4, for the winter data. From this, it can be said that the number of tornadoes reported by the first of May is a strong indicator of how the annual tornado count will compare to "normal."

4. TORNADO DAY COMPUTATIONS

It is frequently argued that because of the many inaccuracies and biases inherent in the collection of tornado occurrence data, the "tornado day" is a better statistic than the number of reported tornadoes. [See Court (1970) for a detailed discussion of this topic.] From a climatological point of view, the idea of counting tornado days rather than individual tornadoes is appealing because it essentially entails a diagnosis of the occurrence of mesoscale features that are conducive to the development of tornadic storms rather than the identification of cloud scale features that determine the occurrence of individual tornadoes.

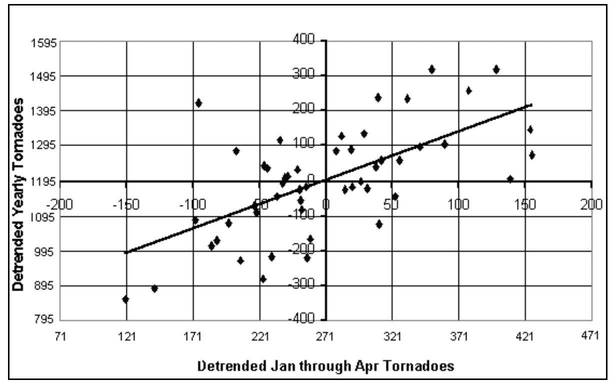

Figure 6. Scatter diagram relating tornadoes observed from January through April to the total number of tornadoes observed during the year. -- Legend as in Fig. 4.

To see how the tornado day approach would affect the conclusions of this study, the analysis is redone counting the number of days on which tornadoes occurred rather than the number of tornadoes. The most immediately obvious feature is the annual (or monthly) number of tornado days has a numerical upper bound as well as a lower one. There simply cannot be more than 366 tornado days a year. Because of this, variations between months are smaller for tornado days than for tornadoes. Also, the temporal increase in the number of tornado days (Fig. 7) is only 1 day per year as compared to the increase of 16 tornadoes per year.

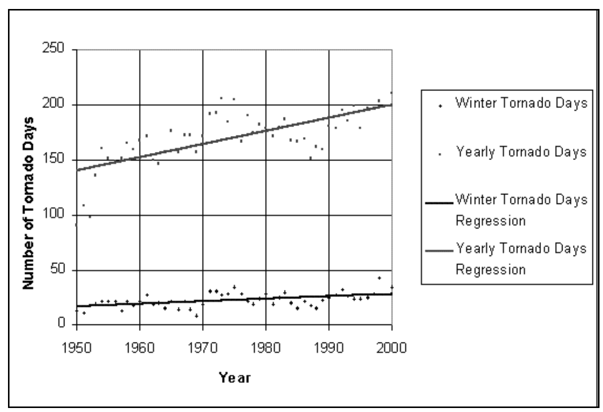

Figure 7. The annual number of tornado days - top line - and the number of "winter" tornado days (January, February, and March) tornadoes - bottom line - per year. Dots give data points, and lines represent fit by linear regression.

After the data are detrended and 1999 is omitted, the sample correlation coefficient is 0.58. This is much larger than the 0.48 needed for significance at the 99% level. Changing consideration from tornadoes to tornado days has a large impact on the results. The scatter diagram of winter tornado days versus annual tornado days (Fig 8) shows that the individual data points cluster around the regression line. The number of days on which tornadoes occur during the winter is indicative of the number of days on which there will be tornadoes during the year. This reflects that "winter" months contain 25% of the total days in the year, and that over the 51 years considered, tornadoes occurred on 25% of winter days (1163 winter tornado days in the 51 years).

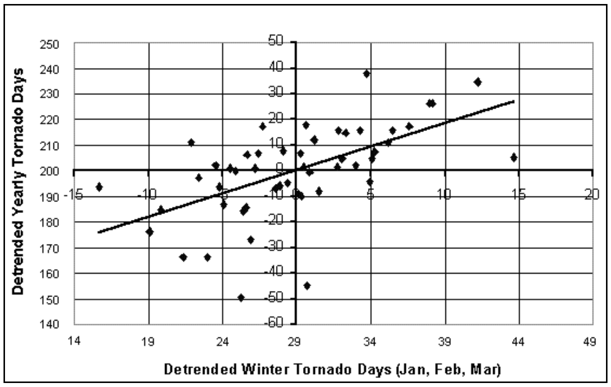

Figure 8. Scatter diagram relating the number of tornado days during the winter months to the total number of tornado days during the year. -- Legend as in Fig. 4.

When tornado days during the months of January and February are correlated with the annual number of tornado days, the sample correlation coefficient is 0.37, making this correlation statistically insignificant. The scatter diagram in Fig. 9 (detrended data, ignoring 1999) shows the points generally clustered around the origin. However, at the wings of the distribution, when there are many more/many fewer tornado days than normal in January and February, the final number of tornado days will be above/below normal.

When tornado days during the first four months of the year (January through April) are correlated to the annual number of tornado days, the sample correlation coefficient is 0.71, well above the threshold for statistical significance.

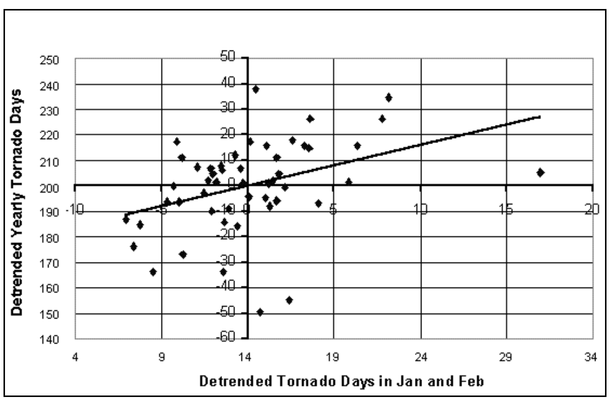

Figure 9. Scatter diagram relating the number of tornado days during January and February to the total number of tornado days during the year. -- Legend as in Fig. 4.

5. CONCLUSIONS

The number of tornadoes reported during the winter months (January through March) cannot be used as an indicator of the number of tornadoes that will occur during the current calendar year. However, there is a significant correlation between the number of tornadoes reported during the period January through April and the total number of tornadoes reported during the year. Thus, one can be relatively safe in saying whether a year will have above or below normal tornado activity by early May.

When tornado days rather than tornadoes are considered, a slightly different picture emerges. The question changes to “How many days will there be tornadoes this year?” Because of the limit on the number of possible tornado days in a year, one can be reasonably confident in giving an above or below normal type answer by early April.

Of course, these are crude estimates. Since the tornadoes that occur during the January through March period are also included in the annual count, there are clearly questions as to the independence of the variables. But changing what fields are correlated also changes the basic question being answered.

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