COMPARING HISTORIC PRELIMINARY SPC TORNADO STORM REPORTS TO THE FINAL NUMBER OF VERIFIED TORNADOES

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ABSTRACT

Over the years, inconsistencies in reporting methods have caused issues with the reports submitted to Weather Forecasting Offices (WFOs) nationwide. WFOs use unfiltered reports to estimate the approximate number of tornadoes that occurred following a day on which tornadoes occurred. Due to the continuity issues with local storm reports, predicting the final number of tornadoes within 24 hours of a tornado day is challenging. Using data from the Storm Prediction Center's (SPC) severe storm database (2012-2024), the purpose of this study was to analyze the relationships between the SPC's preliminary storm reports and the confirmed tornado numbers to enhance tornado prediction estimates within a short period following a tornado day. Two statistically significant relationships were identified to predict a relatively accurate estimation for both daily and monthly final tornado counts.

1. INTRODUCTION

1.1 *Historical Trends of Tornado Reporting*

Historically, tornado reporting has been inefficient due to either the lack of reporting or issues with the organization (Verbout et al. 2006). The number of reported tornadoes in the early 2000s nearly doubled since the 1950s (Verbout et al. 2006). However, the tornado reporting process may vary depending on the National Weather Service (NWS) Weather Forecasting Office (WFO). For example, social media has become a popular way of reporting tornado events (Ripberger et al. 2014). In a 2012 case study, researchers found a significant relationship between issued tornado warnings and Twitter posts acknowledging tornado events. When more tornadic activity occurred, there was a notable increase in Twitter posts containing information about tornadoes. As the number of tornado-related tweets escalates and reaches a larger audience, the public becomes increasingly aware of the real-time threat the weather poses (Ripberger et al. 2014).

The Storm Prediction Center (SPC) can gather data through the analysis of social media posts to benefit the storm verification process. The primary role of the Local Storm Report (LSR) is to verify the occurrence of severe weather events based on the information provided to each NWS WFOs (Allen 2023). The SPC aggregates the LSRs from every NWS WFO and creates a preliminary storm reports database, which includes tornadoes. The data in the SPC's tornado database was previously submitted by a wide variety of people, including both trained and untrained individuals. The SPC plays a role in the National Centers for Environmental Prediction (NCEP), which provides forecasting services to the nation (NOAA/NWS 2025). However, because the SPC's database receives very diverse submissions, reports were prone to errors due to continuity issues (Verbout et al. 2006). This created a lack of consistency regarding whether both damage and wind speeds were considered in the reports.

More recent examples of tornado report processing methods include analyzing emergency calls,

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tree damage, or social media posts (M. Elliot, 2025, personal communication). Currently, the SPC does not have a way of providing the media with a relatively accurate estimation of how many tornadoes occurred following a “big tornado day”. Therefore, the goal of this project is to develop a methodology that will support the SPC in estimating the actual number of tornadoes that occurred on a tornado day. Having the ability to form a relatively accurate prediction of final tornado counts before the completion of storm damage surveys is crucial for the NWS, particularly for Emergency Managers (EMs). This way, the NWS may inform the media and general public of the estimated number of tornadoes within a shorter time period. Statistical analysis methods were used to identify any potential significant relationships between the unfiltered tornado reports and the final number of tornadoes from 2012 to 2024.

1.2 *Unfiltered and Filtered Reports*

Both unfiltered and filtered tornado storm reports are offered through the SPC tornado database. When evaluating storm reports, a specific criterion is used to enhance the accuracy of the actual number of reports. The unfiltered local storm reports refer to the total number of reports submitted to a WFO (NOAA/NWS Storm Prediction Center, 2025). Filtering occurs when the unfiltered reports are assessed according to a specific algorithm. If multiple tornado reports are submitted within less than five minutes and five miles of each other, they would be considered one report. Essentially, the unfiltered storm reports are run through this algorithm to minimize any potential duplicates that are close together (M. Elliot, personal communication). For this research project, we are using the unfiltered preliminary storm reports to compare to the final number of verified tornadoes.

1.3 *Big Tornado Days*

Defining a “big tornado day” is ambiguous. Depending on the research being conducted, specifying this phrase should be done arbitrarily and based on the project constituents (Verbout et al. 2006). This term has a wide variety of vague definitions associated with it, mainly because many explanations lack the consideration of quantifiable properties (Ćwik et al. 2021). One of the earliest mentions of a “tornado outbreak” was documented in the early 1950s, and since then, the phrase has been used flexibly depending on the user (Ćwik et al. 2021). It wasn’t until 1973 that a “tornado outbreak day” was defined considering both spatial and temporal factors, whereas previous definitions commonly considered only one of the two factors (Ćwik et al. 2021). Although it may sometimes contain a quantitatively specific definition, it may also be relatively vague. For this project, a “big tornado day” will generally refer to a day in which numerous tornadoes occur, enough that the public and media inquire to the NWS and SPC about the number of tornadoes that took place.

2. DATA AND METHODS

2.1 *Data*

Preliminary tornado storm reports are the severe weather reports submitted to WFOs during a severe weather event. In other words, the preliminary tornado counts are the estimated number of tornadoes before the completion of a storm survey following a severe weather event. As mentioned previously, WFOs have various methods for processing incoming storm reports. The final number of tornadoes is commonly verified through storm survey analyses. Post-Storm Data Acquisitions (PSDA) are performed through the NWS, which assesses any potential storm damage, such as debris, following a severe weather event and determines whether the damage was caused by straight-line winds or a tornado (NOAA/NWS 2023). These observations benefit the inference of storm intensity. The Damage Assessment Toolkit (DAT) is a Geographic Information System (GIS) application commonly used for tracking and collecting storm survey data, as well as for recording the geographic location of the storm (NOAA/NWS, 2023). Utilizing these tools and methods enhances the facilitation of the intensity and accuracy of a tornado event.

The data for this project is provided by the SPC’s severe storm reports database. We are using data from January 1, 2012, through December 31, 2024. In general, we looked at the total number of unfiltered preliminary tornado reports as well as the final count of verified tornadoes for each convective day within the thirteen-year range. We began the process by aggregating the data into multiple subsets. There were approximately 2,000 days in the dataset that consisted of both unfiltered and final tornadoes. For continuity, we removed any data that included “zero days”, or days with either zero unfiltered reports or zero final tornadoes. We then aggregated every tornado day into subsections by individual days and months.

2.2 *Analysis Methods*

Through the use of linear regression, we analyzed each relationship to look for any significant outliers. To analyze the changes in slope behavior throughout the regression, we used the Locally Estimated Scatter Plot Smoothing (LOESS) method and compared it to the 1-1 line. Using the results found from the regression of the upper 10% of tornado days, we applied our methodology to one of the biggest tornado days in the last 50 years to observe what a possible prediction might have been. Using this methodology helps to reveal how close the tornado prediction estimate would have been to the final number of verified tornadoes on this big tornado day, which benefits the verification of the data analysis process.

3. RESULTS

3.1 *Regression of Full Dataset*

Using the Ordinary Least Squares Regression method revealed that the majority of big tornado days, falling below the 1-1 line, receive more tornado reports than actual verified tornadoes. On big tornado days, it is common for long-track tornadoes to receive multiple reports for the same event, resulting in an overabundance of tornado storm reports.

On December 15, 2021, Figure 1 reveals that there were approximately 72 unfiltered tornado storm reports corresponding with 125 final verified tornadoes. This day is very unique, considering that it was a big tornado day, yet there were fewer unfiltered tornado reports than final verified tornadoes. This is very unusual for big tornado days, considering that on days such as these, the number of unfiltered tornado reports usually is far greater than the actual number of tornadoes that occurred. One possible reason for this is that not only was this a cold season event, but rather than being a day with a lot of supercells, storms on this day formed into a line of storms producing both tornadoes and widespread wind damage. Storm surveys after the fact could have determined that what was initially thought to be straight-line wind damage was actually the result of a tornado.

Another outlier occurred on April 28, 2014, where there were 153 reports and only 57 confirmed. Although this is generally common on a big tornado day, there is still quite a considerable overestimation in tornado storm reports.

3.2 *Outlier Effect on Slope*

To determine if major outlier days, such as December 15, 2021, had a significant impact on the slope, we removed this tornado day from the dataset and reran the regression. However, doing this did not cause any concerning changes to the slope. With the December 15 tornado day included in the data, the X variable of the regression was equal to approximately 0.65. When we removed this tornado day, the x variable remained 0.65. We concluded that the removal of this tornado day was not statistically significant to the overall slope. Since this did not have a substantial effect on the slope, this outlier day was not considered particularly concerning. Therefore, we decided to keep any significant outliers included in our datasets.

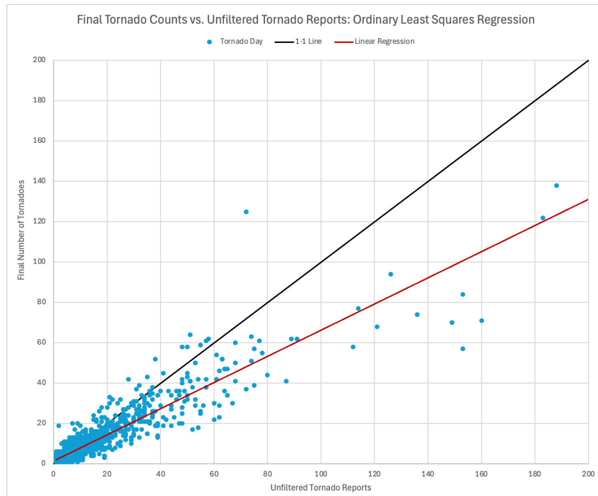

Figure 1*: The Ordinary Least Squares Regression of the Final Tornado Counts compared with the Unfiltered Tornado Reports, ranging from 0-200 (tornado) reports from 2012-2024. The equation of the line is y = 0.65x + 1.29*

3.3 *Regression of the upper 10% of Big Tornado Days*

In Figure 2, everything to the left of the vertical green line, where x = 23, represents the top 10% of the biggest tornado days. Everything to the left of the green line represents the lower 90% of ordinary tornado days. As you can see, most tornado days have fewer than 20 tornadoes. The slope of the orange line is presenting the regression of only the top 10% of the biggest tornado days. The slope of the line is 0.56, which is smaller compared to the slope of the regression of the full dataset. When considering smaller portions of the data with big tornado days, the slope shows a bit of a decrease. The reports and final tornado counts on the lower 90% of ordinary tornado days are normally closer in number compared to the top 10% of days.

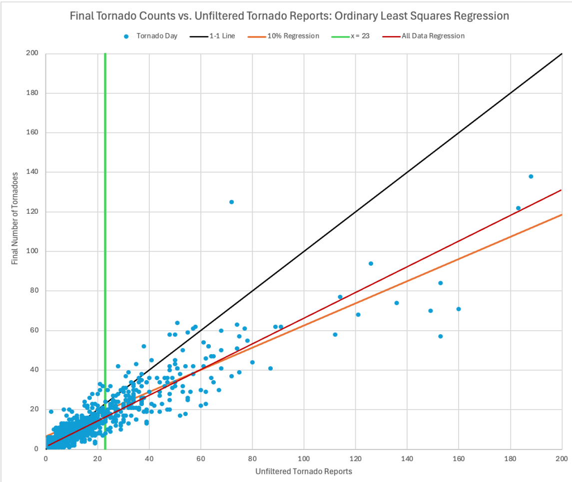

Figure 2*: Linear Regression of the upper 10% of tornado days is shown. The equation of the line is y = 0.65x + 6.50*

3.4 *Local Regression for the Average of Unfiltered Reports in 10% Increments*

Using Locally Estimated Scatter Plot Smoothing (LOESS), we wanted to analyze the changes in the slope of the regressions. By averaging the data in 10% increments, we can see the orange line begins to slope away from the 1-1 line, as the average number of unfiltered reports increases. Although we cannot see past the average of 45 unfiltered reports (because of the limitation of the dataset), we can assume that the slope will behave similarly as we move towards the end of the x-axis.

Figure 3*: LOESS Smoothing applied to the complete dataset in 10% increments, with the average of unfiltered reports as the x-axis and the average final tornado counts as the y-axis*

3.5 *Monthly Regression*

Figure 4 represents the regression of the combined monthly tornado totals. The most notable outlier occurs in April of 2014, with 270 unfiltered tornado reports and 129 verified tornadoes. The individual outlier day of April 28, 2014 (mentioned earlier), accounted for over half of the combined tornado reports for this month. If we recall the outlier of December 15, 2021, from the daily regression, we can see that December 2021 no longer appears to be a significant outlier when looking at the month as a whole. In fact, it falls almost perfectly on the 1-1 line of the monthly regression. It is also visually apparent that the majority of tornado days fall below the 1-1 line, once again revealing the weight that an overestimate in tornado storm reports holds over the overall regression compared to tornado days with an underestimate of reports.

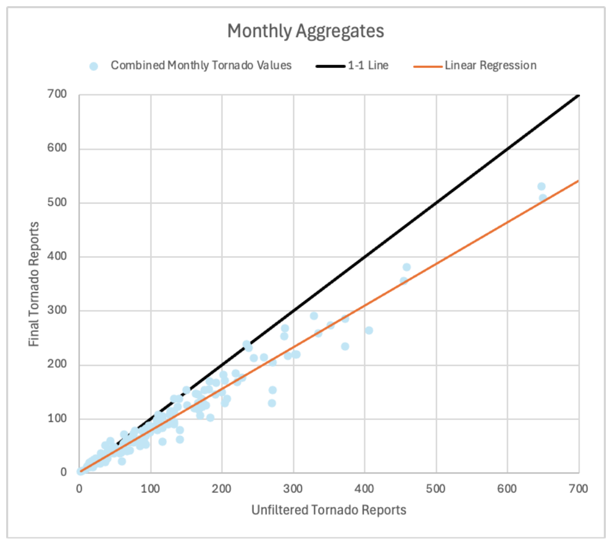

Figure 4*: Data of total tornado counts combined into monthly aggregates. The equation of the regression is y = 0.77x + 2.41*

The equation of the regression of this line is y = 0.77x + 2.41. This equation may be used to predict the final number of combined tornadoes for each individual month. Because of the small sample size, it is not realistic to perform a Local Regression on this subsection of the dataset. The fit of the Smoothing may be insufficient and inaccurate because of the limitations on the size of the data.

3.6 *Case Study: April 27, 2011*

Next, we will apply our methodology to the biggest tornado day within the past 50 years. On April 27, 2011, there were 292 preliminary tornado reports and 173 verified tornadoes. Immediately following this tornado day, the public, media, and even the White House were referring to the NWS, seeking a result of final tornado counts for this day. However, the NWS did not have a way of offering them an answer because storm damage surveys had not yet been completed, and it was too early to know the final verified numbers. It is important to note that 2011 is a date outside of the 13-year dataset that we have been analyzing, as well as the value of the 292 unfiltered reports. The largest value in the original dataset was equal to approximately 188 unfiltered reports, and the 292 preliminary reports substantially exceeds this maximum.

To see how the results would differ, we aggregated the data into three different sections. The equation of the regression of the lower 90% of ordinary tornado days is $y = 0.75x + 0.63$, with slope confidence ranging from 0.73 to 0.77. When applying the 292 preliminary reports, we received results ranging from 213 to 225, with an average of 220 reports. Next, we used the equation of the regression from the full dataset, with slope confidence ranging from 0.64 to 0.66, and received a range of results from 188 to 194 and an average of 191. Lastly, we applied the equation of the regression from the top 10% of big tornado days, with slope confidence ranging from 0.51 to 0.61, and received an average result of 170 final predicted tornadoes. This equation provided us with the result closest to the final verified numbers for April 27.

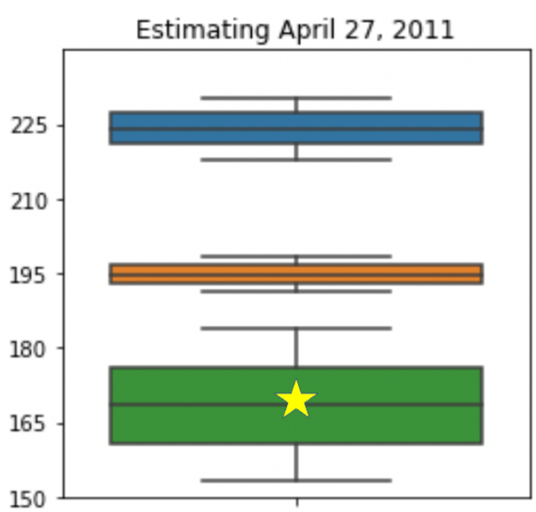

***Figure 5**: Displayed are the ranges of the slope confidence of each section. Blue represents the lower 90% of ordinary tornado days, orange represents the whole dataset, and green represents the upper 10% of big tornado days -the yellow star is located at 170 reports.*

4. DISCUSSION

The regression of the upper 10% of big tornado days offers an equation that the NWS might consider using when estimating the final number of tornadoes following a big tornado day. By doing so, EMs will have a way of communicating a relatively accurate estimate of the final number of verified tornadoes before storm surveys are complete. When faced with the question of "How many tornadoes occurred?" following a big tornado day, the NWS may now consider applying this methodology to identify an answer to this question with relative accuracy.

In addition, while predicting the number of total monthly tornado counts, the NWS may also consider using the equation offered from the regression of the combined monthly tornado totals. Because tornado verification may be tedious and a time-consuming process, using an equation to estimate monthly totals may be beneficial for both public communication and to additionally compare monthly totals from one year to another.

4.1 *Limitations*

The continuity issues with LSRs make it challenging to ensure the preliminary number of tornado counts is as accurate as possible. For example, the different report processing methods may strongly depend on the individual working on shift during the tornado events. (M. Elliott 2025, Personal Communication). Some WFO forecasters may process LSRs immediately, whereas others may not even end up sharing the report as an LSR, at least not until storm surveys are fully completed. In addition, the timing of the tornado events has an impact on whether or not a report is submitted as an LSR. For instance, if a tornado event occurs over the weekend or overnight, there may be a limit on staff numbers that may or may not affect how reports are received and processed. Improved storm reporting processes may benefit the consistency of LSRs throughout WFOs.

4.2 *Future Work*

For future research, it could be beneficial to look into how different geographic regions might have an effect on the slope of the regression of the tornado days reported in various locations throughout the nation. Depending on the outcome, different regions of the country might consider using a different equation to predict final tornado counts for both individual days and monthly totals. In addition, it may also be beneficial to look into wind and hail reports and perform similar statistical analysis methods to analyze any potential relationships that might exist.

5. CONCLUSION

In conclusion, inconsistent tornado reporting and processing methods make it difficult to predict final tornado counts. Due to this, the NWS has struggled to find a way to offer the public tornado prediction estimates following tornado events when faced with the question of "How many tornadoes actually occurred?". To find a way for EMs to create predictions not based on LSRs, this research discovered two methods to assist them in calculating predictions. Although there are limitations with efficient data availability, and despite the lack of research regarding geographical factors, the equations found using linear regression provide a way for the NWS to make predictions.

The next time that the NWS is faced with the question of "How many tornadoes occurred" following a big tornado day, they can consider using the equation found from the upper 10% of big tornado days to form a relatively accurate estimation of the final number of tornadoes based on the preliminary reports.

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