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The Occurrence of Severe Weather Outbreaks into November and December with Respect to a Retreating 850 Millibar -5°C Line

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ABSTRACT

Making use of historical reports of severe weather, the months of November and December were reanalyzed using multiple definitions of severe weather outbreaks and how to classify them. Over one hundred different dates over more than 60 years were examined to look for a trend in the number of reported severe weather events; tornadoes, strong damaging winds, and hail, and their severity. These were then compared to their corresponding 850 millibar (mb) temperature maps to identify the location of the -5°C line and its association with the outbreak area.

The individual severe weather events; tornadoes, hail, strong damaging winds, were all looked at independently and overlap was looked at, and a strong tornado outbreak took precedence as the outbreak of the day. This reasoning was used in prior research that took outbreak criteria the same way and outlined that a date where tornado reports made up a certain percentage, then that day was used for tornado outbreak research. Categories were used in favor of percentages in this research.

Early results are mixed in their outcomes showing variability in the nature of severe weather. These results are not just mixed in number, but it varies by the intensity and even the type of event that occurred. These early results, despite variability, suggest a positive correlation between the retreating -5°C line and outbreaks. The implications of the research outline new scenarios and concerns for climate studies and the impact of warming on the planet.

1. Introduction

Historically, the months of November and December are the last month of meteorological autumn and first in meteorological winter respectively, months that climatologically are colder and according to the SPC, minimally active for severe weather (See Appendix A). However, according to Martin 2015 and NCEP Reanalysis of the 850 mb temperature field, these months are warming up compared to where the average temperatures were even in the 1980s. The SPC reports have also indicated a plausible increase in
the number of reports in these two months, even dating back to as recently as 1990.

The occurrence of the warming of the 850 mb pressure level was confirmed in Martin 2015 where it was analyzed during the winter months of December through February. In those months, the areal extent of five different temperature lines were taken and averaged over the time period of 1948 and 2014 to look for the trend, which, was found to be declining. Due to Martin 2015 not outlining 850 mb temperatures for November, the NCEP Reanalysis was used. The NCEP Reanalysis is a modernized data source that takes historical reports from radiosonde and upper air data and creates graphs and charts for meteorological variables to be used in research. The research conducted in this paper used 850 mb 30 year averages and monthly averages from 1990-2015 for the months of November and December. For purposes of severe weather, the extent of cold air is important to not interfere with convection, and thus, looking at the retreat of the -5°C line with respect to the expansion of severe weather outbreaks was analyzed.

The outbreaks were determined and analyzed with research from Edwards et. al. 2004 and 2005, and Schneider et. al. 2004, all of which studied how to classify tornado outbreaks. The Edwards et. al. papers would be used exclusively for strong damaging wind and large hail outbreak analysis. Once all analysis tools were in place, the data from the SPC was truncated to just include the months of November and December and then days that fit the criteria outlined in the definitions papers were independently analyzed. Tornado outbreak days were categorized according to Schneider et. al. 2004 and the non-tornadic severe weather outbreaks were analyzed by Edwards et. al. 2004/2005.

For this research, the cutoff values or minima established by Edwards et. al. 2004 (Table 1) were too stringent, and thus a new method was established to expand upon the number of outbreaks to more than three. Schneider et. al. 2004 took a different approach. Rather than taking eight individual members, just take the number of significant and violent tornadoes and base an outbreak on those values (Table 2). Using Schneider et. al. 2004, increased the number of outbreaks from three to forty-two, and of those, thirty-five were found to be the most significant outbreak of the day, using Edwards et. al. 2004 definitions on biases, and were included in analysis.

The trends and correlations are done once the analyzed data is compiled and then run through regressions to create trend lines. These trend lines are then compared to the change and trends of the 30 and 66 year averages. The particulars are further outlined in this paper; Section 2 will be a description and background into the methodology used for analysis, as well as the data sources used in the analysis. In Section 3, the trend lines and statistical analysis of the data is covered and compared to the Martin 2015 and NCEP averages. The 4th section will look at an analysis of how the -5°C line has evolved from 1990 to 2015 and how severe weather outbreaks correlate to the evolution of the -5°C line. This research is summarized in section 5, and
suggestions for future work are discussed there as well.

With strong evidence of atmospheric warming outlined in Martin 2015, a logical study in how this evidence could change the global weather is to look at severe weather, and in particular, tornadoes, hail, and strong damaging winds, commonplace events in the United States.

2. Data and Methods

The storm report data itself is archival from the SPC and National Severe Storms Forecasting Center (NSSCF) [SPC predecessor] where it was condensed from the reports sent into NWS Offices into a useable master list. The reports have been reviewed multiple times and are still subject to edits, making the SPC Storm Reports accurate and useable for this research. The papers used in the research of this topic to classify severe and tornado outbreaks work for both before and after the time period and the main reason for the limitation is the storm report data as considered in the National Research Center 2012 Review of Modernization and Associated Restructuring (MAR).

While this research has SPC and 850 mb temperature data from 1950 on, the focus of this research will be focused on the most recent twenty five years [1990-2015], as prior to the widespread installation of the WSR-88D Doppler Radars at NWS Offices, and the modernization of how reporting and damage assessments were done by NWS Employees, detection and reporting of tornadoes and severe thunderstorm events [strong damaging winds and large hail] was not as strictly standardized and the error of untrained spotter reports skewing the data is too great to risk. While the same risk still exists in the aforementioned modern period, NWS modernization and continued updating helped and continues to help mitigate these issues to a high degree. While storm report data prior to 1990 was still used, much of the statistical analysis and trend line data will be focused on the 1990-2015 period due to the aforementioned issues.

Numerous research projects attempted to define what a tornado outbreak is. Edwards et. al. 2004 outlined the full ‘O’ equation (Equation 1) that took eight variables, set a minima (Table 1) for each that must be met to qualify to then be run through the ‘O’ equation (Equation 1).

\[ O = \Sigma [O_g = \frac{(D - M_g)}{S_g} \ast W_g] \]

**Equation 1: The ‘O’ Equation**

O = Total Outbreak Value
O_g = Normalized Outbreak Value
D= Daily Value for the member
M_g = Mean of “top 50” members
S_g = Standard Deviation of “top 50” members
W_g = Weighting factor for the member

For the ‘O’ Equation to return a positive result, the value of ‘O’ must exceed 0 (zero) with severe outbreaks resulting in far higher values, such as the April 3-4 1974, which yielded a score of 9.79 on the ‘O’ Index. The ‘O’ equation was not used to analyze tornadoes because the cutoff values limited the number of outbreaks to three, whereas Schneider analysis produced 42 outbreaks.

As precluded to earlier, tornadoes are
not the only type of severe weather, strong damaging winds and large hail are also types of severe weather defined by NWS. To classify non-tornadic severe weather outbreaks, Edwards et. al. 2004 and 2005 were used with the ‘SO’ equation, which, much like the ‘O’ equation, uses the total number, the mean of

<table>
<thead>
<tr>
<th></th>
<th>Number Tor.</th>
<th>Number Violent</th>
<th>Number SigTor</th>
<th>DPI</th>
<th>Path Length</th>
<th>Deaths</th>
<th>Number Killers</th>
<th># 80+km Tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutoff Value</td>
<td>37</td>
<td>2</td>
<td>13</td>
<td>131</td>
<td>349</td>
<td>8</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Rank at Cutoff</td>
<td>50</td>
<td>48</td>
<td>52</td>
<td>51</td>
<td>53</td>
<td>49</td>
<td>59</td>
<td>82</td>
</tr>
<tr>
<td>Mean</td>
<td>26.9</td>
<td>1.14</td>
<td>9.6</td>
<td>145</td>
<td>319</td>
<td>9.09</td>
<td>2.05</td>
<td>0.61</td>
</tr>
<tr>
<td>Std Dev</td>
<td>18.8</td>
<td>2.57</td>
<td>9.5</td>
<td>258</td>
<td>358</td>
<td>26.6</td>
<td>3.93</td>
<td>0.92</td>
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<tr>
<td>Weight</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Members of, Cutoff Values and Weighting Factors for the eight members, of the ‘O’ Equation (Edwards et. al. 2004)

(1)Number of tornadoes, (2) Violent (EF/F 4 or stronger) Tornadoes, (3) Significant (EF/F 2 or stronger) Tornadoes, (4) Damage Potential Index (Tor Length* Tor Width)(EF/F Value+1), (5) Path Length summed up of all tornadoes for the day, (6) Deaths caused by tornadoes, (7) Number of Tornadoes resulting in Deaths, (8) Tornadoes with a path length of 80 km (~50 miles) or longer

<table>
<thead>
<tr>
<th></th>
<th>Range of Tornado Counts by Outbreak Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cat. 1</td>
</tr>
<tr>
<td>F2–F5 (initial)</td>
<td>2 – 5</td>
</tr>
<tr>
<td>F3–F5</td>
<td>0 – 2</td>
</tr>
<tr>
<td>F4–F5</td>
<td>0 – 1</td>
</tr>
</tbody>
</table>

Table 2: Outbreak Categories and their Criteria according to Schneider et. al. 2004

For this study, the modified values were used in conjunction with the ranges of EF/F 3 to EF/F 5 as well as EF/F 4 to EF/F 5
events were looked at independently of each other, so a day that may have had fifty combined hail and wind events was not studied, whereas a day with more than fifty wind, but less than fifty hail was and it would be examined as a non-tornadic wind severe weather outbreak. Hail was viewed in the same way, and between the two, sixty-nine unique days were examined in the entire data set (1950-2015) (Table 3). Combined with the thirty five tornado days yields exactly one hundred days to study, of those one hundred, eighty-one are within the 1990-2015 time period, giving validity that this time period is in fact the appropriate time period not only with NWS MAR, but also with the number of days that can be studied being more than eighty percent of the total days that were considered.

<table>
<thead>
<tr>
<th>Type</th>
<th>1950-2015</th>
<th>1990-2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tornado</td>
<td>35</td>
<td>23</td>
</tr>
<tr>
<td>Wind</td>
<td>52</td>
<td>46</td>
</tr>
<tr>
<td>Hail</td>
<td>17</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 3: Total Outbreak Days by Type and time period

3. Results and Discussion

The results of the analysis showed a divide in how severe weather trends change over time. The results are shown in Figures 1a-c, and 2a, b, tornadoes, wind, and hail in that order, with the first set of figures being the unfiltered results, which include data sets prior to 1990, and the second set contains the concatenated data that spans the MAR years and newer reports. Looking at the total extent of the research, the trend for the number of tornadoes is rising, at approximately .6045 tornado per outbreak per year. The wind reports show a somewhat opposite trend, as the number of reports is declining ever so slightly from 1975 to 2015, decreasing at a rate of .0628 reports per outbreak per year. Hail had a completely different graph than either tornadoes or winds, showing a sinusoidal graph, indicating that a linear trend line would not be a statistically accurate fit for this data set. However, this is the entirety of the data set that is being analyzed, not the focus area of 1990 to 2015.

While the entirety of the data set is viable data, the focus on the MAR and newer years will give a better representation of how severe weather is evolving as the atmosphere continues to warm. Looking again at the trend lines for tornadoes and wind, they both continue their trends, but their rates are flipped as the rate of increase for tornadoes drops to +.1 tornado per outbreak per year, while the decrease in the wind line shows more rapid decrease to -.6258 wind report per outbreak per year. Hail, again, had no discernable linear trend, thus, it was discounted for use in this research at this point. Wind though, has an issue; there are several extreme outlier events that skew the data to the early years of the study. Figure 3 is modified removing the five days that are about one hundred reports more than surrounding days. Those days included are November 11, 1995, November 10, 1998, November 9, 2000, November 6, 2005, and December 21, 2013. Each had more than two hundred fifty reports and thus skewing the results of the other forty plus events. Looking again at the data for the 1990 to 2015 period, the line now shows an increasing trend in the
number of total number of severe wind reports per outbreak, and the number of significant reports, or reports of 65 knots or greater wind speeds, concurs with the total trend over the time period indicating that

**Tornado Outbreak Days with Schneider 2004 Definitions**

![Tornado Outbreak Days with Schneider 2004 Definitions](image)

**Severe Wind Outbreaks with Modified Edwards 2004 Basis**

![Severe Wind Outbreaks with Modified Edwards 2004 Basis](image)
Figures 1a, 1b, 1c: Analyzed Tornado, Hail and Wind Outbreaks for 1950-2015

All data comes from the SPC Historical Storm Reports files. Tornado data is categorized according to Schneider et. al. 2004 having the three different members to categorize outbreaks (See Table 2). The wind data is mixed as many wind reports did not have a wind speed associated with them, and thus, it was prudent to show how many reports went into the average wind speed value showing that it was not necessarily an average for the majority of the wind reports. For hail reports, the NWS and SPC classified severe hail as hail of ¾ of an inch or greater until 2010 when that number changed to 1 inch, but the SPC keeps tabs on all reports of hail that still exceed that pre-2010 value. To keep the study consistent, all reports are analyzed and counted towards outbreak criteria. (Included is the regression equation for the total values and how they change with time.)

The outbreaks are increasing in scale and are becoming slightly more intense with the passage of time.

Now, the same could be said about tornadoes, but, the already small number of days for tornadoes relative to wind shows that outlier events may be more commonplace than the study leads on to. For this study, these days will be kept for all analysis on tornadoes. Concerning tornadoes again, while the total number of tornadoes was increasing with time, albeit slowly, the intensity of these tornadoes was on average, decreasing, shown by the decrease in the total number of violent (EF/4, EF/F 5) tornadoes, at .0456 EF/F 4+ per outbreak per year.
Figures 2a and 2b: Tornado and Wind Outbreaks with MAR Years as the start
Similar to Figures 1a, 1b, and 1c, but without hail and having truncated the data to only 1990 through 2015 or the start of MAR to the date of most recent SPC data year.
Overall though, the trends are supporting more tornado and strong damaging wind outbreak days, while also supporting more events on outbreak days. However, the intensity is mixed as studies for winds indicated a very slight trend of increasing events greater than 65 knots, .0253 reports per outbreak per year, but tornadoes had a slight decrease in intensity as the number of events classifying as EF/F 4 or greater has dropped by .0456 EF/F4+ per outbreak per year.

The issue though with looking at tornado intensity is that intensity derives from the damage assessment and post storm surveys. Tornadoes are unpredictable and while a multitude of small tornadoes may impact populated areas, the larger and more violent events often remain over rural areas skewing their intensity rating much lower than it really was. While important to look at, the intensity of tornadoes is subject to change. Even with the Edwards et. al. ‘O’ equation, there is great dependence on intensity with requirements for EF/F 2 or greater, as well as EF/F 4 or greater, and the Damage Potential Index, requires the EF/F rating to calculate it as well.

However, the intensity information will stay. Due to the fact that the likelihood of intensity changing in tornadoes is relatively small, yet still possible, it does need to be included as part of how severe weather

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**Figure 3: Wind Outbreaks minus Outliers**

This chart shows the average of wind events without the influences of five dates that, between them, had more than twenty five percent of the total reports for the outbreak days studied (1617 of 5788 total reports).
outbreaks have evolved over the studied time period. Since, how the intensity of the outbreaks changes is just as important as the number of the severe weather events. Thus, based on observed data and its analysis, a trend exists, showing a correlation between the -5°C line retreating, and the increasing frequency and spread of severe weather outbreaks.

One corollary to this finding comes from the very paper that helped to prove this, Schneider et. al. 2004, in which, the research conducted leads to proving a “second tornado season,” which so happens to be October and November, the early part of the time of year investigated in this research. This means that, should the findings of the work in this paper hold true, that Schneider et. al. 2004 findings collaborated with the results of this paper, show that the initial time of year of the second season and the frequency of the tornado days in the second season are increasing.

The importance of the findings is stated as thus; this is another tangible piece of evidence to the impacts that are brought upon by not only a warming atmosphere but warming on a planetary scale. The potential for more devastation from meteorological events is increasing into parts of the year where devastation from tornadoes and strong damaging winds is not as commonplace as it is in April through June.

This could also have impacts on meteorological forecast models as models written over the course of years where a large scale severe weather event in November or December may not have the proper closure equations to handle late season severe weather events. While unlikely to be influenced, it has yet to be determined if the changing atmosphere and the changing severe weather scenario has an impact upon the global models that view this time of the year as more subdued thermodynamically as diabatic heating is reduced and the amount of daytime heating is reduced due to less incident solar radiation to generate daytime heating. Again, as more information becomes available, it will become apparent if the changes in severe weather in the final months of a calendar year have any effect on the forecasting models, and while unlikely, it does propose a topic for discussion on how the atmosphere and severe weather changes will impact the accuracy of forecast models.

4. Analyzing the -5°C Contraction

A thirty year average and 66 year compound were used to compare the expansion and contraction of the -5°C line in order to look for a pattern or significant departure from the mean temperature lines. November does not have a Martin 2015 average of the -5°C line and thus, only the NCEP 30 year average will be used to analyze November changes. December will still use both Martin 2015 and NCEP data for analysis as the NCEP data is 30 years, 1981 to 2010, whereas Martin 2015 used 66 years of data; 1948 to 2014 (Figures 4, 5). Each average will be compared to the monthly averages of 1990 to 2015 to show how the -5°C line has evolved over the last 25 years with respect to the 30 year and 66 year averages and compounds. Specific
years will be further analyzed for their occurrences of more than two severe weather outbreaks in one of the two months, in order to determine correlations between the -5°C line and severe weather outbreaks.

Figure 4: NCEP 850 mb Temperature Map: November Average
This map is the NCEP November average with the yellow to green line being the extent of the -5°C line averaged from 1981 to 2010.

Figure 5: NCEP 850 mb December 30 year Average Temperature Map and Martin 2015 66 year -5°C Line Map
The first map is the NCEP December average with the yellow to green line being the extent of the -5°C line averaged from 1981 to 2010. The second is the Martin 2015 66 year conglomerate of the full Northern Hemispheric 850 mb -5°C line. The two maps are used as reference to how the -5°C line is expected to behave during these months. Since Martin 2015 only focused on meteorological winter, (December through February), there is not a 66 year line map of the -5°C line for the month of November. Figure 6 shows the even year (1990-2014) averages in the -5°C line for November, and Figure 7 will model even year December averages for 1990-2014 (Appendices B and C will have all 25 year averages for November and December respectively).
Using only the even years leaves gaps in which a clearer trend would be visualized. It does correlate well with years where multiple events occurred, 1994, 2004, 2006, all three show the -5°C line north of Lake Superior, or where the average has the southernmost point of the average. The year of 2014 is an anomalous reading, as it was the impact of two weeks where a strong winter storm brought January like conditions to many cities and in particular, Buffalo, NY saw its historic lake effect snow events, which is why 2014 seems to be breaking the trend of receding -5°C lines.
December shows better trends with the extent of the -5°C line, showing how it fluctuates more on the retreat for the entirety of the 25 year range (1990-2015), and that years where the line is greater than normal are fewer than the number of years where the line was further north than normal. Even in 2014, when the November was much colder than normal, December followed the trends outlined in Martin 2015 that the -5°C line was retreating north. The importance of the map trends helps to support the correlation that severe weather is in fact becoming more widespread in November and December.

5. Concluding Remarks and Future Research Opportunities

Research done supports the proposed hypothesis that the contraction of the -5°C line correlates to more severe weather outbreaks occurring in November and December. While hail outbreaks proved to be non-supportive of the hypothesis, further analysis of hail outbreaks could yield a better comparison to the areal extent of the -5°C line into the United States and show that while looking at tornadoes and severe wind is grounds for solid research, that hail was the key to the comparison. That being said, this first round of research opens up a door for future research into the topic of late season severe weather.

The research conducted opened many doors to further research into numerous areas. During the course of research into this topic, a chance graph in Edwards et. al. 2005 supported the decreasing trend in the intensity of tornadoes, indicating a downward trend in average DPI for tornadoes. This coupled with the data from Martin 2015, showing that winters are not getting as cold as they once did, could lead to more research into temperature trends and their impacts on severe weather in the United States. There is a case that can be made for a better classification method of non-tornadic severe weather outbreaks akin to Schneider et. al. 2004’s tornado outbreak classification by category. Further, looking more in depth at this research with respect to analysis of different levels of the atmosphere such as 500 mb or looking if there is a cyclic pattern that exists that is being amplified by atmospheric warming. The foundation has been made for the further research with the observed correlation that severe weather is becoming more common into November and December as the atmosphere continues to warm.

6. Acknowledgements

A special thank you to Dr. Martin of UW-Madison and Roger Edwards of the SPC for providing me with supplementary information that helped make this research possible. Furthermore, many thanks to Rod Donavon and Dr. Gallus for helping guide this research to its conclusion.
7. References


8. Appendix A: Severe Climatology

The SPC Severe Weather Climatology for selected dates from November 1st through December 31st.

The importance of this climatology study is that it shows very little in terms of potential
for severe weather (shaded area is ~1%) and it is decreasing in size as the season progresses. Furthermore, many of the outbreaks that occur occur outside of the shaded area, like the Ohio River Valley or Western Great Plains. Thus, the SPC Climatology reports (1982-2011) verify the integrity of the research by showing that severe weather is not routinely expected during these months of the year.

9. Appendix B: Complete November Averages
10. Appendix C: Complete December Averages