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Influence of Topography on Convective Patterns across the Greater Capital Region of New York

Honors College Undergraduate Research Thesis

(8 May 2016)

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ABSTRACT

The greater Albany region is unique in regards to its terrain. The various mountain ranges and river valleys play a significant role in convective patterns due to modification of flow. The purpose of this research is to compare the days of convection, both severe and non-severe, to the large scale flow pattern. Lightning data from the National Lightning Detection Network was used to analyze the role terrain plays in organizing convection and the associated lightning. The greater Capital Region was divided into 0.1° grid boxes, and the number of total lightning strikes (both cloud-to-cloud and cloud-to-ground) was recorded within that box for each convective day. The days were then analyzed to find the flow directions using the Climate Forecast System Reanalysis (CFSR). After analysis these events were predominantly in the westerly and southwesterly synoptic-flow regimes. The results show that the flow direction does have an influence on the preferred locations of lightning and convection in the greater Capital Region of New York.

1. Introduction

While any kind of convective activity is not necessarily uncommon in the greater Capital Region of New York, it still poses forecasting challenges to local meteorologists. When convection occurs, whether it is severe or non-severe, it can cause a multitude of problems. The Storm Prediction Center defines a severe thunderstorm as a storm either producing a tornado, hail greater than 2.5 cm in diameter, or wind gusts greater than 26 m s^{-1} (SPC). The Northeast in general has a greater population density compared to the rest of the United States, so any thunderstorms that occur will already have a greater impact on society. Strong winds can cause downed trees and long-lasting power outages. Heavy precipitation can cause flash flooding, wash out major roadways and sweep away vehicles. Severe storms can have hail or spawn tornados, which can damage property, injure people and even cause fatalities. It is essential for forecasters to gain a better understanding of how convection is formed and sustained, especially in the Northeast.

Atmospheric scientists have often discussed that there is a potential relationship between terrain and the distribution of convection in the greater Capital Region. Major topographical features include the Adirondack Mountains, Catskill Mountains, Green Mountains, and Berkshire Mountains (Figure 1). Other important features are the east-west oriented Mohawk Valley and the north-south oriented Hudson Valley. Taking these features into consideration, different wind directions can result in upslope or downslope flow, which can either enhance or suppress convection. Upslope occurs when air is forced up the windward side of a mountain. This upward vertical motion may invigorate convection. Downslope, on the other hand, is when air descends on the leeward side of a mountain, which may hinder convection.

Previous studies have addressed the influence of terrain on tornadogenesis, but there are few studies that deal with the forecasting issues surrounding terrain influences on convection (Bosart et al. 2006, Lapenta 2005). One particular project was conducted by Wasula et al. (2002), hereafter W02, which focused on severe weather distribution and the potential influence of terrain features. Severe storm reports were aggregated and compared to locations of cloud-to-ground lightning strikes. Since population bias can be a factor in locations of severe storm reports, a population correction was applied to the data. These severe weather days were then stratified by 700-hPa flow and organized into northwesterly and southwesterly flow regimes. Results from this work showed a maximum lightning density just east of Albany associated with a northwesterly flow regime and a maximum lightning density in the southern Hudson Valley associated with a southwesterly flow regime (Figure 2). This study primarily expands on the research conducted by W02 using total lightning.

2. Data and Methodology

a. Data

Archived lightning data for this study was obtained from the National Lightning Detection Network (NLDN; Cummins, 2009). As of 2014, new sensors allow for the total lightning to be accounted for, which includes both cloud-to-ground (CG) and cloud-to-cloud (CC). Since CG lightning is only a small fraction of the total lightning, this new data may show different results from W02. Unlike W02, which only used days of severe weather, days of any type of convection is used in this study. The convective seasons of 2014 and 2015 are used for this study (May 1-August 31), since that is the beginning of the availability of the total lightning data from the NLDN network. Terrain maps were obtained from the local Albany, NY National

Weather Service Office. Archived gridded wind data was obtained from the Climate Forecast System Reanalysis (CFSR; Saha, 2010).

b. Methodology

The region of interest used in this research was defined from 41.5° to 44.5°N and 72.0° to 76.0°W (Figure 3), which approximately covers the greater Capital Region and surrounding terrain. This region was then divided into a 0.1° grid. All days in the 2014 and 2015 convective seasons (May 1–August 31) were filtered for convectively active days, which are defined as days with more than one lightning strike within the domain. All strikes occurring in each of these boxes were tallied.

To determine the wind pattern across the domain, 700-hPa wind was used. This pressure level represents the flow just above the highest elevation. Although it is understood that wind direction can change over the course of the day, only wind from 1800 UTC was used in this study because that tends to be around peak time for convection. The wind was then averaged over the domain in order to have one direction associated with each day. Once an angle was determined, it was then organized into eight categories (northerly, northeasterly, easterly, etc.), or a 45° range for each wind direction. For example, a northerly wind had a range from 337.5° to 22.5°, and a southerly wind had a range from 157.5° to 202.5°. The definitions of northwesterly and southwesterly wind slightly differ between this study and W02. In W02, a southwesterly wind had a larger angle range, from 180°-250° and a northwesterly wind ranged from 290°-360°. All convective days were then binned into these eight directions to determine which directions were the most convectively active. Composite average lightning density plots were created by averaging each grid box location for all days with the same average wind direction category.

These plots were only created for the top three most convectively active directions, which will then be compared to the findings of W02 to determine if there is a connection between topography and convective patterns using the total lightning data.

3. Results

Figure 4 shows a comparison of the total number of convective days for each wind direction. There were no convective days for the easterly and southeasterly wind directions and only one convective day for the northeasterly wind. Both southerly and northerly wind directions had five convective days each; for the northerly wind directions, all of those days had a westerly component (337.5° to 360°/0°). The greatest number of convective days is for the westerly direction, followed by the southwesterly and northwesterly wind directions. However, the results are slightly different for the average number of lightning strikes for each wind direction (Figure 5). Although the top three wind directions remained the same, the southwesterly wind direction had a greater daily average number of lightning strikes, followed by the westerly and northwesterly wind directions. This could likely be attributed to more instability in the atmosphere with a southwesterly wind.

a. Northwesterly Flow Regime

The northwesterly flow regime had a total of 27 convective days and an average of 3131 lightning strikes per day. In order to effectively locate patterns in convection for this wind direction, an average density composite plot was created (Figure 6). Regions where there is darker red are areas with a higher number of lightning strikes, and regions of white are those with no lightning strikes. By comparing this plot to Figure 1, one can clearly see some terrain influences on convective activity. There appears to be an isolated spike of 33 lightning strikes over the Litchfield Hills. Considering that there was only 27 days of convection associated with this wind direction, it is possible that this spike could be attributed to a single convective day. The primary maximum appears to be in the eastern part of Albany County into Rensselaer County. This region of enhanced convection may be due to upslope on the windward side of the Taconic Ridge. It is also possible that the westerly component of the northwesterly flow was channeled down the Mohawk Valley and the northerly component was channeled down the Hudson Valley, initiating convection at the convergence zone of these terrain features, whence the convection propagates southeast. The location of the minimum appears to be at the triple point of Warren County, Saratoga County, and Hamilton County. This minimum may be due to downslope from the Adirondacks. Other secondary maxima include Otsego County, which is may be due to upslope from the Catskill Mountains, and Addison County in Vermont, which is may be due to upslope from the Green Mountains. There is an additional maximum in Hampshire County, Massachusetts, which may also be due to very localized terrain effects. A secondary minimum for this flow regime is located in both Orange County and Windsor County. This may be due to downslope from the Green Mountains.

b. Westerly Flow Regime

The westerly flow regime had the 58 convectively active days, the highest number out of all wind directions. The average number of lightning strikes per day for this wind direction was 5169. An average density composite plot was also created for this wind direction (Figure 7). There is a clear primary maximum at the triple point of Albany, Saratoga and Rensselaer Counties. It is much stronger than the primary maximum associated with northwesterly flow.

This maximum may be due to the channeling of flow down the Mohawk Valley, which then becomes upslope flow as it reaches the Taconic Ridge. There is a secondary maximum to its south, which may be linked to the aforementioned maximum, although the reason for the gap between the two is unclear. The location that appears to have the lowest values is the border between Saratoga County and Warren County, which may be attributed to downslope from the Adirondacks, similar to the northwesterly flow regime. Another maximum is on the leeward side of the Green Mountains in Windham County. Since the Berkshires and the Green Mountains are north-south oriented, all locations just east of highest ridge tops have the potential for downslope flow, which may weaken convection and cause a lightning strike minimum. The secondary minima in these locations are consistent with the effects of downslope. Additional areas where downslope might be contributing to a lightning strike minimum are the southwestern part of Albany County, Greene County, Sullivan County and Schoharie County.

c. Southwesterly Flow Regime

The southwesterly flow regime was the second most convectively active direction with 45 days of convection. However, this wind direction surpassed all other directions in average lightning strikes with 10509 strikes per day. The composite plot for this wind direction is shown in Figure 8. While the northwesterly flow had more defined minima and the westerly flow the most defined maxima and minima, the southwesterly flow tends to be associated with more lightning on average across the domain. The primary maximum appears to be in the southern Hudson Valley in Dutchess County. This may be attributed to the southerly component of the surface wind being channeled up the Hudson Valley. There is another maximum along the Mohawk Valley, perhaps associated with upslope along the southern tier of the Adirondacks.

There does not appear to be a pronounced single minimum but one location with a lower density is in Greene County, although the reasoning behind this minimum is unclear. One possible issue could be a lack of sensors in the higher peaks in the mountains, causing a lack of data. Other regions where the lightning density are lower are co-located with the peaks of the mountains. These locations seem to follow a similar pattern as well, where there is a potential for sparse data.

d. Comparison

W02 compared convective patterns associated with northwesterly winds and southwesterly winds. In order to effectively compare the results from this research to those from W02, figure 9 shows a difference plot between southwesterly and northwesterly flows. Regions of red are locations where convection associated with southwesterly flow is favored. Regions of blue are locations where convection associated with northwesterly flow is favored. This figure illustrates that lightning strikes just east of Albany are slightly preferred with northwesterly flow, which is consistent with the findings of W02. There is also a clear maximum in the southern Hudson Valley associated with southwesterly flow, which is also consistent with W02.

While the locations of these maxima appear to be consistent with W02, there is some discrepancy with the lightning gradients between these two projects. The CG strike density in northwesterly flow in W02 has a much steeper lightning gradient than this current research, which is likely due to differences in the definition of a northwesterly flow and a differing amount of lightning data (CG versus CG and CC). There is no defined westerly wind in W02, rather it is divided and added to both the southwesterly and northwesterly flow, which could affect the comparison between both studies. Another reason for differences in gradients is the fact that

W02 only incorporates severe weather days, which eliminates any days of non-severe weather and general convection.

4. Conclusions/Discussion

There appears to be a terrain influence on convective patterns in the greater Capital Region of New York. Southwesterly, westerly and northwesterly wind directions were the most convectively active. Westerly wind had the most number of convective days, whereas days with a southwesterly wind had a greater average daily number of lightning strikes. Both CC and CG lightning was used in this study, which allows for a much larger sample size of lightning per year than W02. Although the total lightning was used in this study, the results remain consistent with W02. The location of the lightning maximum in both studies for the northwesterly wind direction was just east of Albany County. The location of the lightning maximum in both studies for the southwesterly wind direction was south of Albany County in the Hudson Valley. Regions with the highest concentrations of lightning strikes were associated with regions of inferred upslope and regions with the lowest concentrations of lightning strikes were associated with regions of inferred downslope.

Although this research hints at the possibility of terrain influences on convective patterns, there is still more work to be done in the future. Because total lightning from the NLDN has only been available since 2014, a larger sample size and more convective events are needed in order adequately link terrain to convective patterns. Association between lighting maxima and terrain could also be assessed by determining areas of upslope flow in the data. A better comparison between the different wind directions can be achieved by normalizing the lightning using the 90th percentile. The comparison between climatological wind direction histograms and Figure 4 could also be added in future work. Like W02, severe weather reports can also be incorporated in future work, as it will help distinguish between storm severity. However, if storm reports are to be included in future work, then a population bias correction needs to be included as well. With the population constantly increasing with each passing year, accurate convection forecasts are needed now more than ever.

5. Acknowledgements

I would like to thank the University at Albany’s Honors College for giving me this opportunity to conduct research as an undergraduate. I have definitely grown and learned a lot through this experience. I would also like to thank my research advisor Professor Brian Tang, who has guided me through this project and supported me through my senior year. Thank you Tomer Burg and Dylan Card for helping me with my Python scripts when they decided not to run properly. Lastly, I would like to thank the DAES for giving me the best undergraduate education I could have ever wanted.

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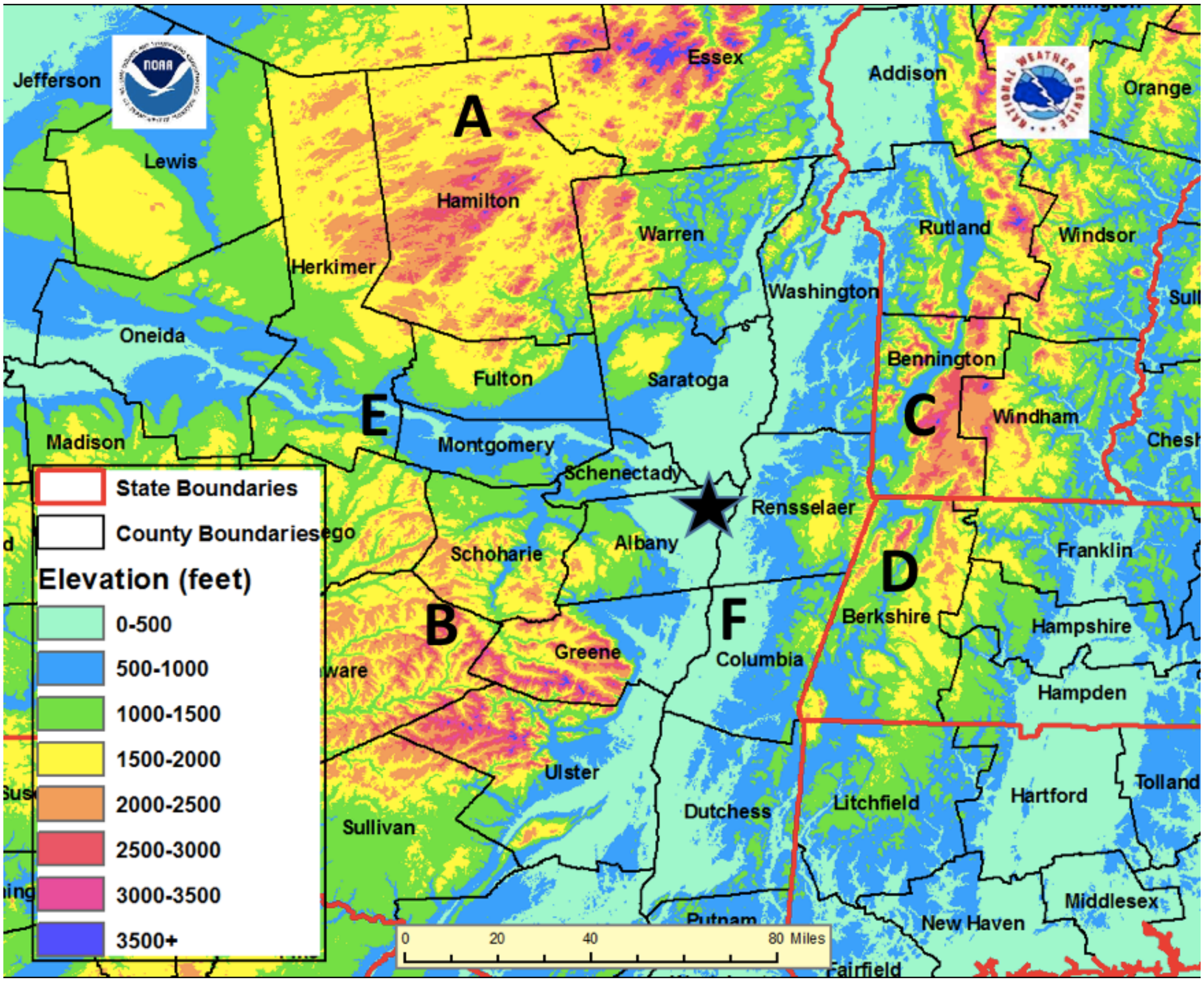

Figure 1: Terrain map of greater Capital Region. A=Adirondack Mountains, B=Catskill Mountains, C=Green Mountains, D=Berkshires, E=Mohawk Valley, F=Hudson Valley.

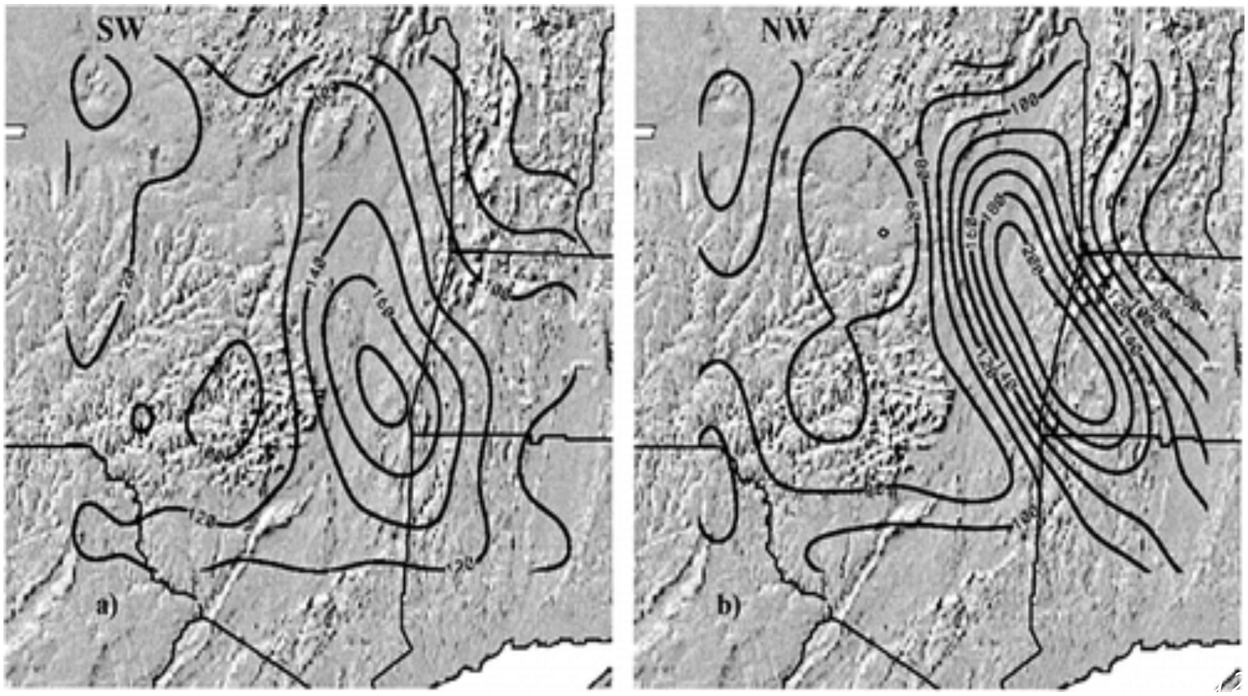

Figure 2: Contoured CG lightning strikes per severe weather day for southwesterly flow (a) and northwesterly flow (b) from Wasula et al. (2002).

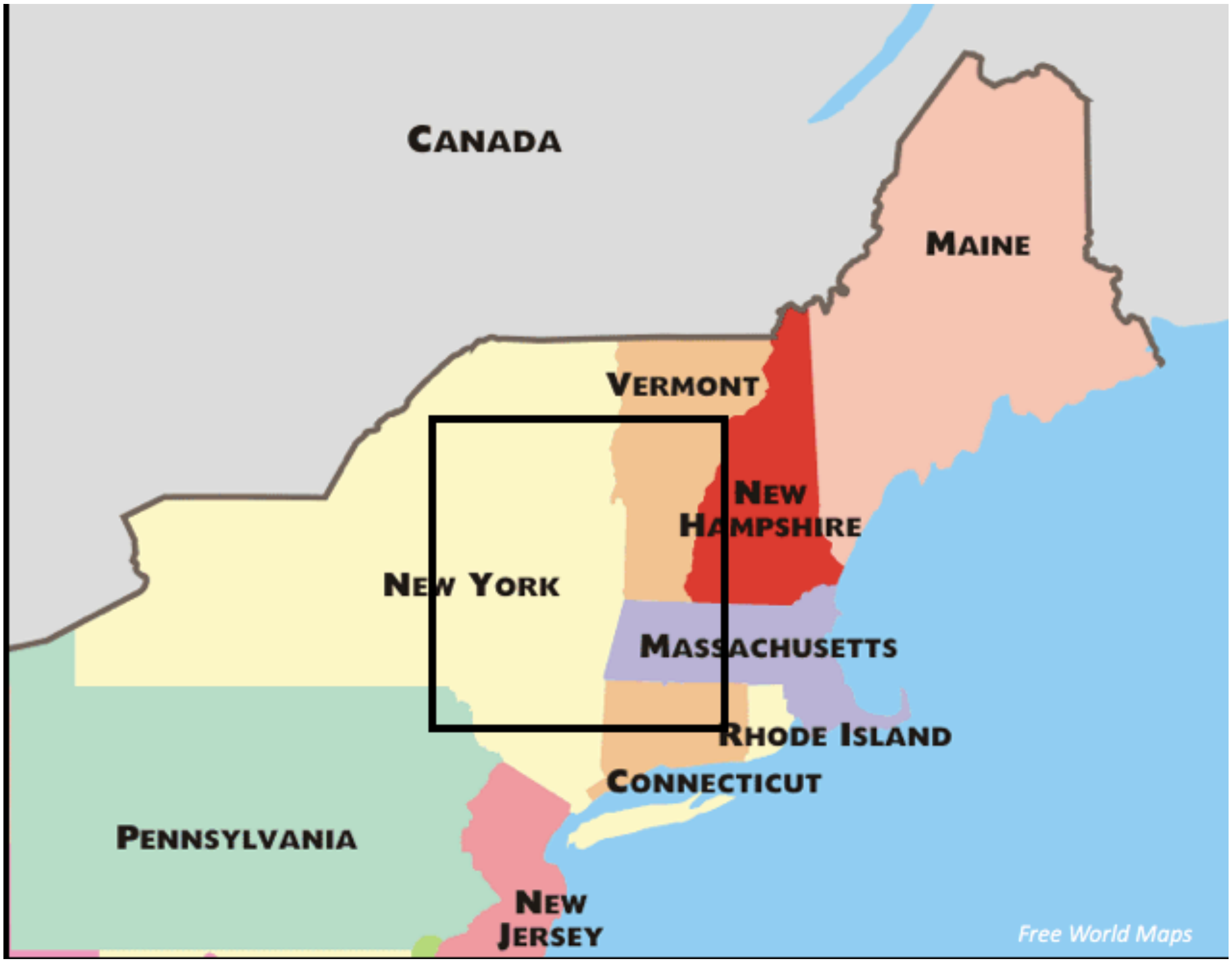

Figure 3: Political map of northeast outlining region of interest for this study.

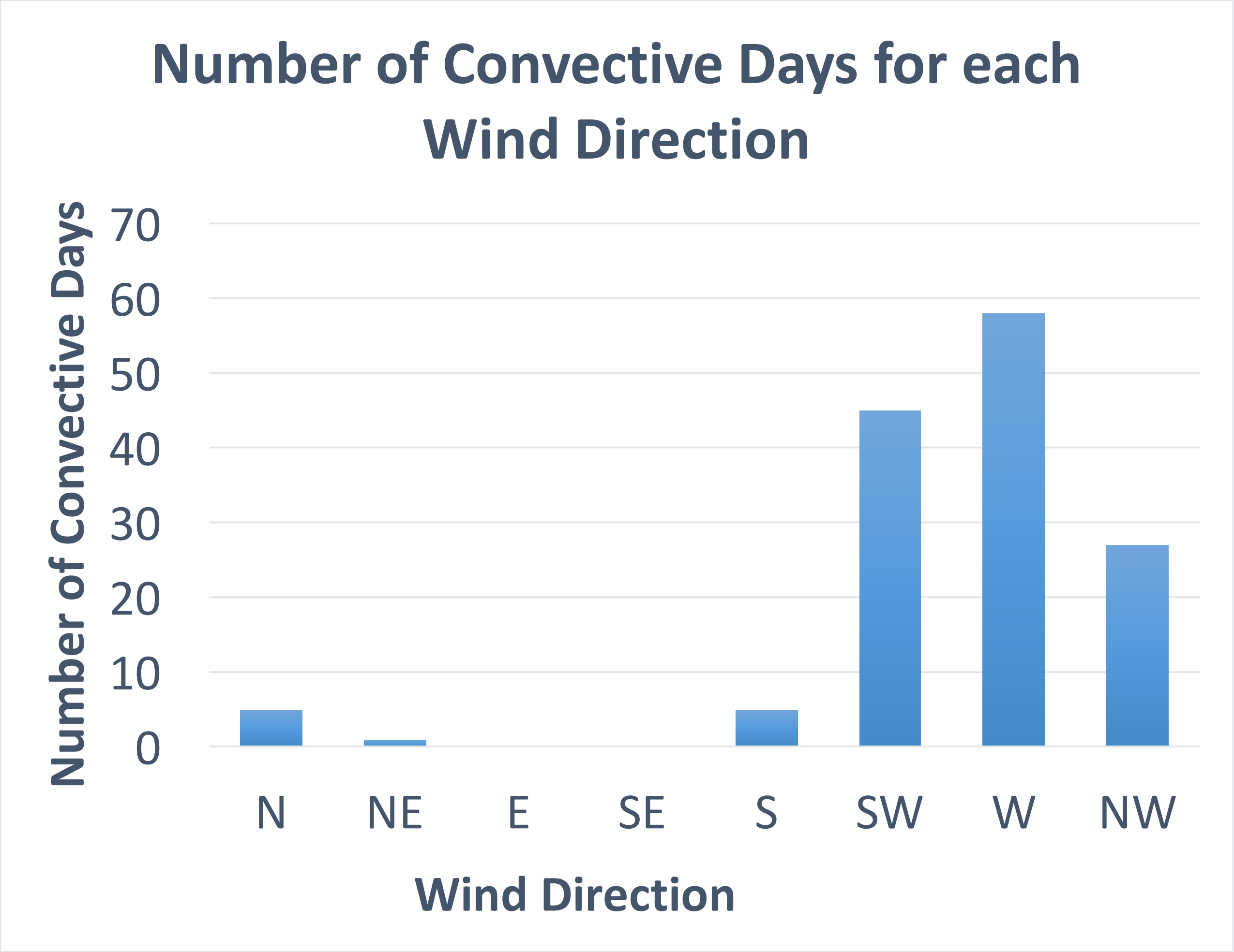

Figure 4: Number of convective days for each wind direction category.

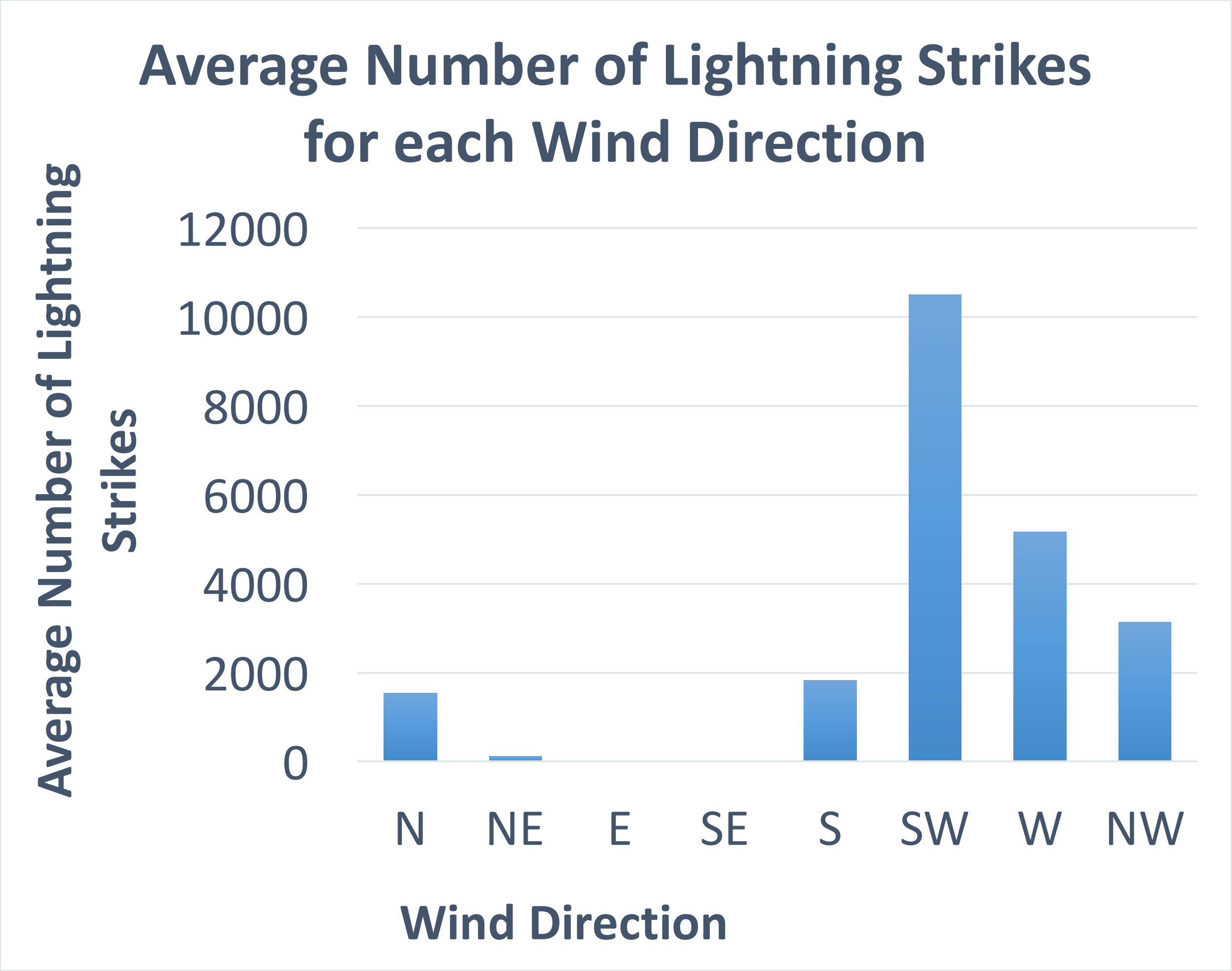

Figure 5: Average number of lightning strikes per day for each wind direction category.

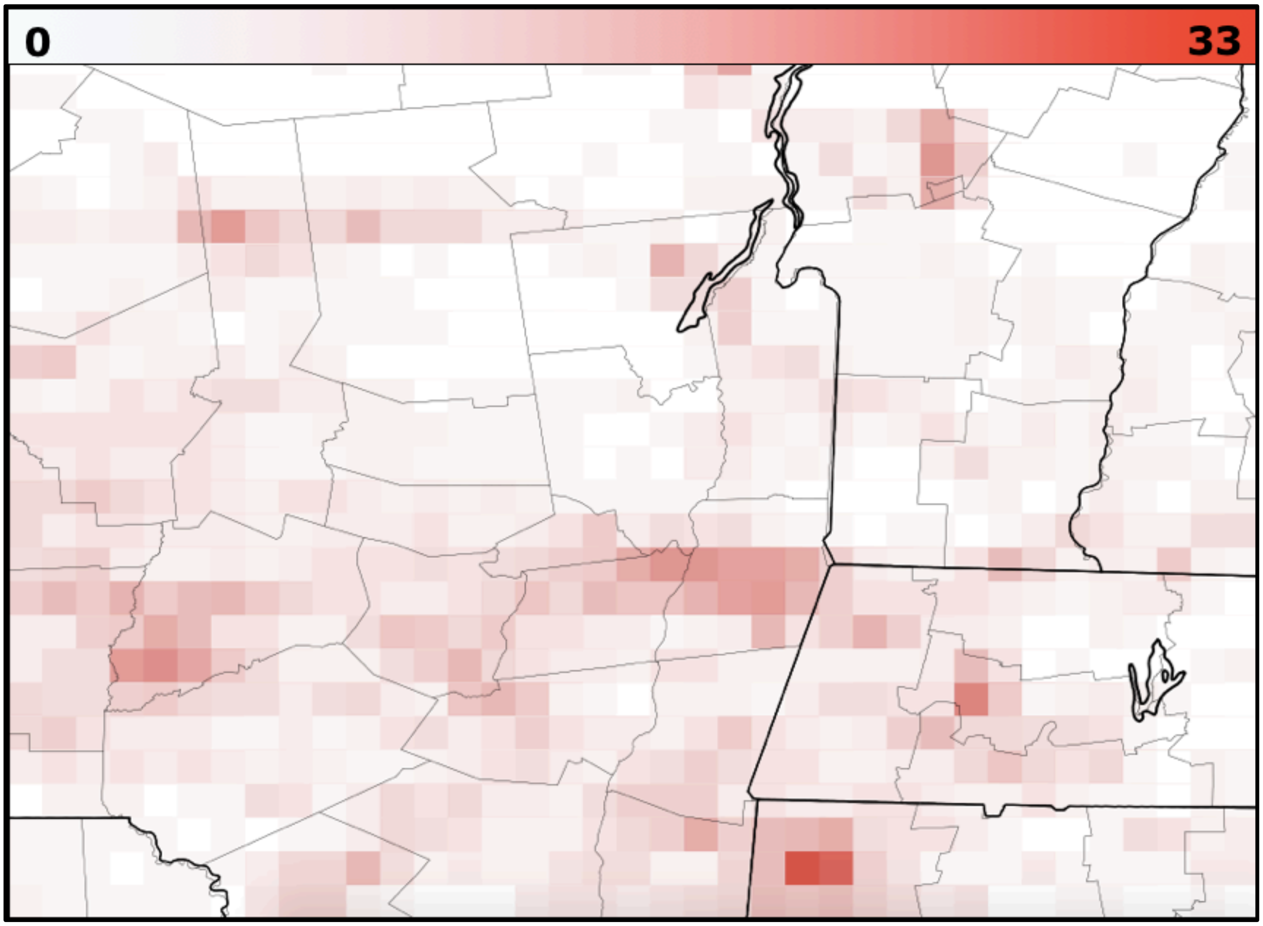

Figure 6: Composite lightning strike density for convective days with 700-hPa northwesterly flow in units of lightning strikes per 64 km^2 (8 km grid spacing).

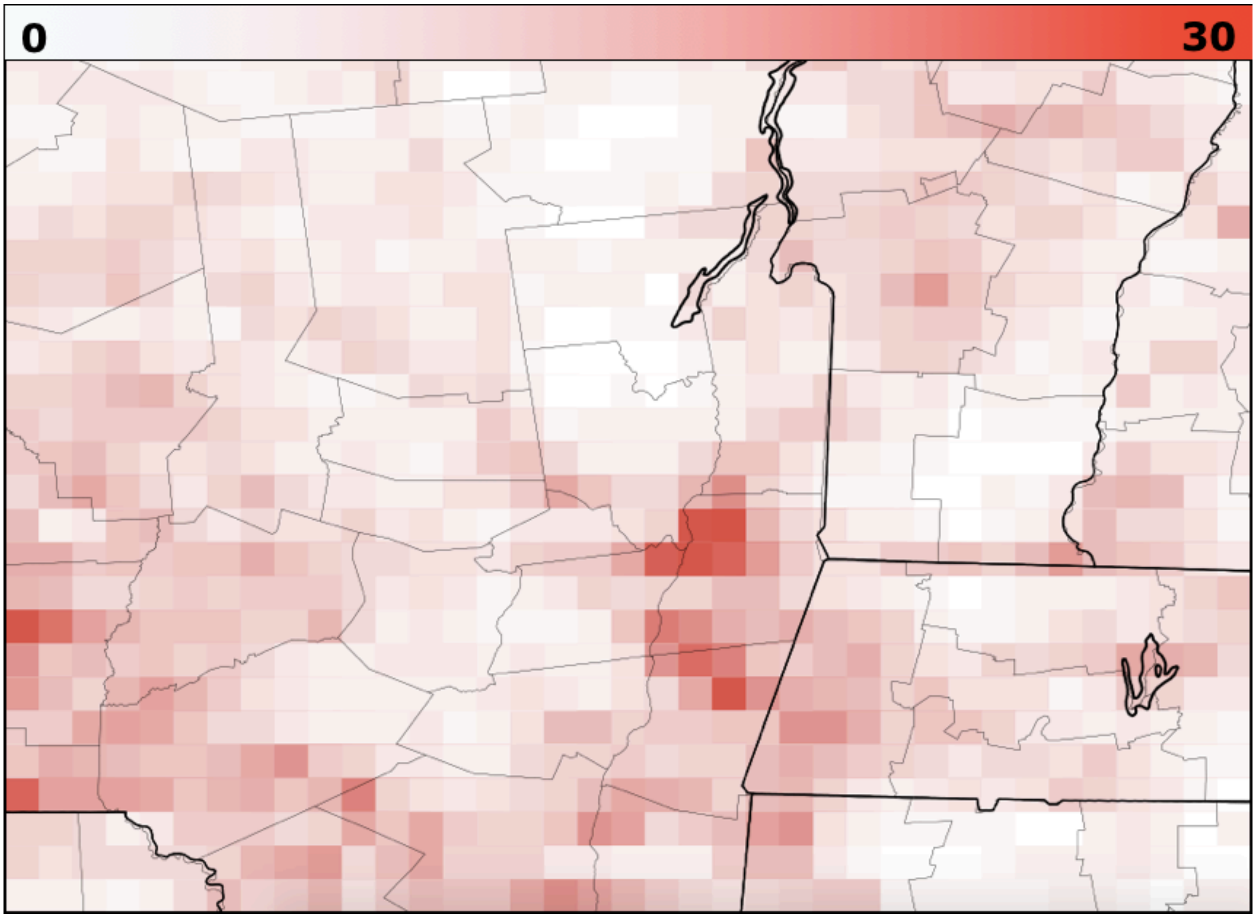

Figure 7: Composite lightning strike density for convective days with 700-hPa westerly flow in units of lightning strikes per 64 km^2 (8 km grid spacing).

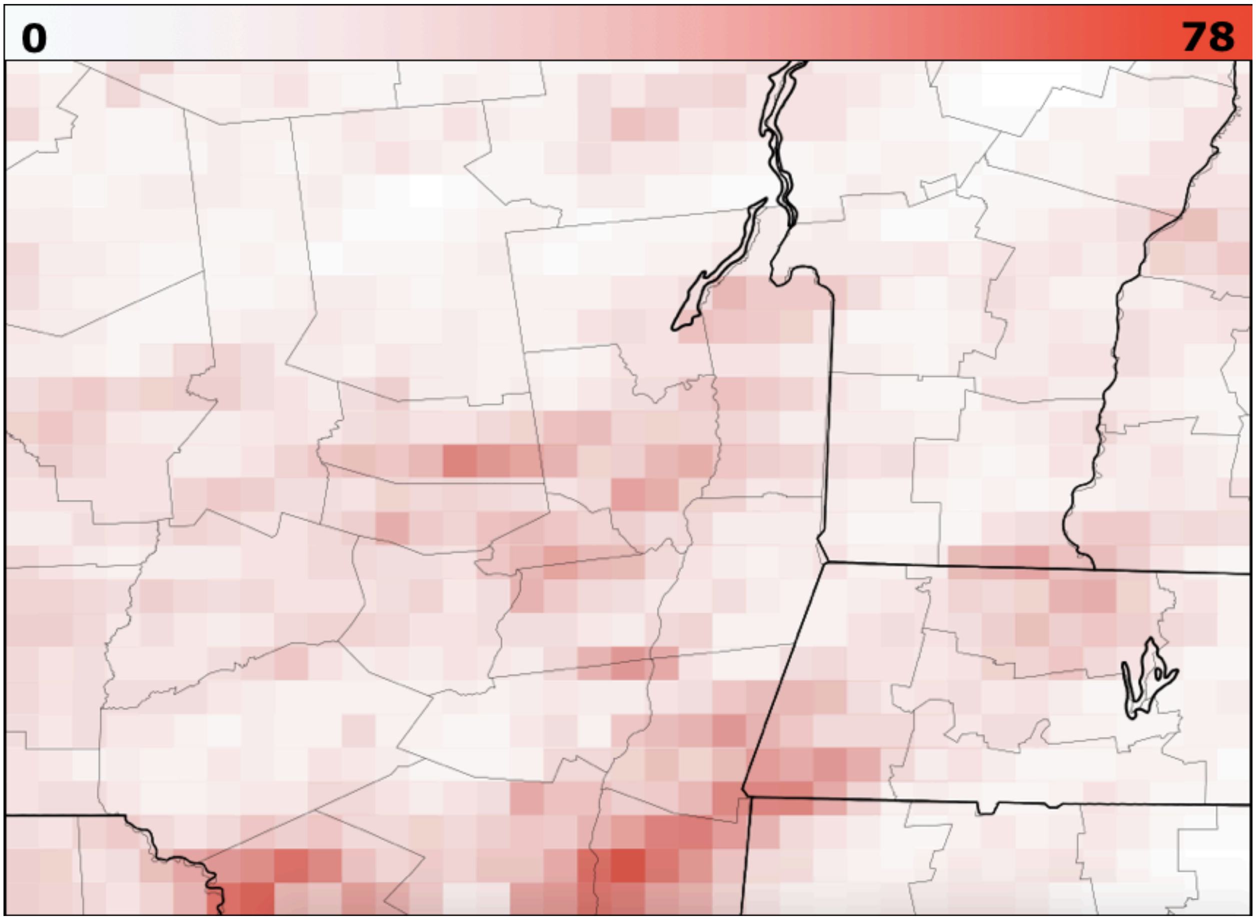

Figure 8: Composite lightning strike density for convective days with 700-hPa southwesterly flow in units of lightning strikes per 64 km^2 (8 km grid spacing).

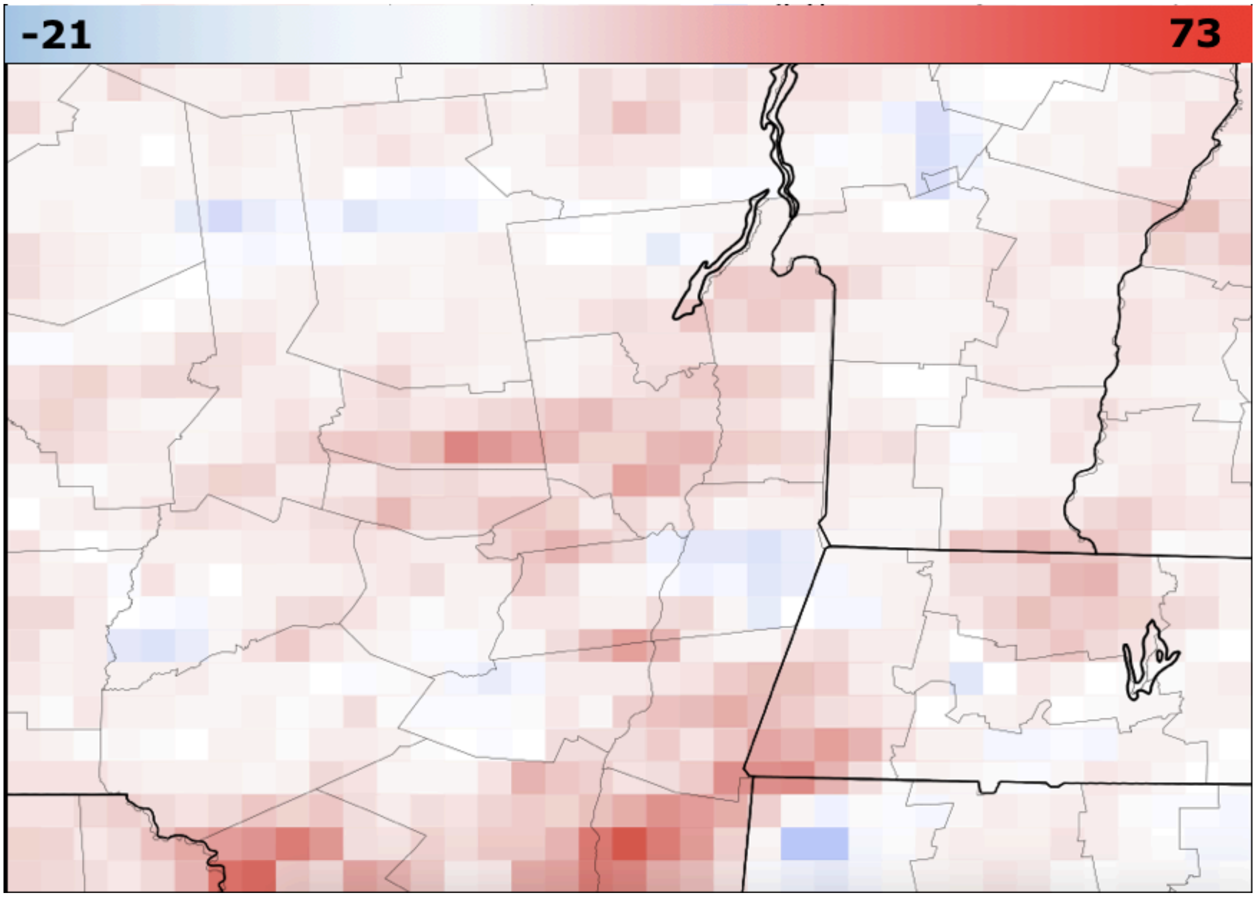

Figure 9: Composite lightning strike density difference between 700-hPa southwesterly and northwesterly flows in units of lightning strikes per 64 km^2 (8 km grid spacing).