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Article

Assigning lightning seasons to different regions in the United States

Elyse Hawkins and Chelsea Barreto
Summit High School, Summit, New Jersey

SUMMARY

Climate change is predicted to increase the frequency of severe thunderstorm events in coming years (1). Severe thunderstorms are often accompanied by lightning, which causes an average of 243 injuries and 27 deaths per year in the United States (US) alone (2). With these predicted increases in lightning events, it is important to understand and practice safety during severe thunderstorms. We examined severe thunderstorm data from the National Oceanic and Atmospheric (NOAA) database in seven states in the US (Colorado, Florida, Maine, Minnesota, New Jersey, Washington and West Virginia) to characterize lightning seasons over three years (2000, 2008, and 2017). We hypothesized that (i) the majority of severe thunderstorm events will occur in the summer months in all states examined for all years analyzed, (ii) climate change will cause an unusual number of severe thunderstorm events in winter months in all states, (iii) thundersnow would be observed in Colorado, and (iv.) there would be no difference in the number of severe thunderstorm events between states in any given year examined. We were able to classify lightning seasons in all states observed, with the most severe thunderstorm events occurring in May, June, July, and August. Colorado, New Jersey, Washington, and West Virginia were found to have severe thunderstorm events in the winter, which could be explained by increased winter storms due to climate change (1). Overall, it is important to quantify when lightning seasons occur to avoid lightning-related injuries or death.

INTRODUCTION

It is predicted that climate change will cause an increase in the frequency of lightning and severe thunderstorm events in coming years (1). This is due to increases in the global mean temperature, precipitation, and convective available potential energy (CAPE) that comes with climate change (1). Lightning frequency itself is predicted to increase by 12-15% for every 1°C of warming, projected to result in an increase of as much as 50% over the next century (1). With this predicted increase in lightning events in coming years, it is important to classify when lightning seasons may occur and what locations across the United States are most at risk. Lightning seasons can occur year-round in some locations in the US (2). However, defining a lightning season as when lightning strikes are most likely to occur can ensure safety precautions are put in place (2).

A lightning season is the time of the year when thunderstorms are most likely to develop and occur. There is an average of 243 injuries and 27 deaths per year due to lightning in the United States (3). Lightning injuries can occur when people are outdoors and are unaware of an incoming storm. Outdoor activities that pose a danger to lightning include outdoor sports such as golf (which involves metal poles that attract lightning strikes), swimming (especially in areas with flat, wide beaches), hiking (particularly at high elevations), soccer (on open fields), boating (in open ocean) and camping. Thundersnow can also cause lightning strikes during such sports as skiing and snowboarding (4). Lightning strikes can lead to serious injuries or death, whether they occur outdoors or indoors. With the predicted increase in lightning flashes due to climate change, storm-related injuries are also likely to increase (1).

According to the National Oceanic and Atmospheric Association (NOAA), severe thunderstorm events are a common late spring and summer occurrence in the United States, and they are defined as having winds of over 58 miles per hour, quarter-sized hail (24.26 mm in diameter), and frequent lightning (3). Other regions of the world experience severe thunderstorm events at different times. Globally, the most frequent lightning strikes occur in regions such as Lake Maracaibo, Venezuela; Kabare, Democratic Republic of Congo; and regions close to the equator that have large bodies of water that create near constant lightning storms (5). Uncommon events that occur during severe thunderstorms events include tornadoes, golf ball- to baseball-sized (1.68 to 2.875 inches in diameter) hail, downdrafts of wind (including more severe microbursts), and derechos (fast-moving windy thunderstorms) (3). Severe and large wildfires are known to produce their own weather effects, in some cases producing thunderstorms, and in certain conditions, generating a fire tornado (6). Volcanic eruptions can also produce lightning from clouds of volcanic ash. Lightning can even strike in an area with a clear sky 5-10 miles ahead of a severe thunderstorm (3). Lightning can also be produced from snow-bearing clouds; this is commonly referred to as thundersnow (2).Though very rare, thundersnow storms have been recorded in the Rocky Mountain Region as well as the

Great Lake Region (6). Since lightning can occur in multiple types of weather events, more awareness and caution should be taken to avoid injury during severe weather phenomena.

To date, there are no studies that quantitatively assign lightning seasons in the United States. Research on lightning is limited to lightning maps that show lighting frequency across the United States, which have been generated by NOAA and the National Lightning Detection Network. These nationwide organizations utilize resources for data collection such as lightning mapping arrays, which are sensors set up to track lightning through very high frequency (VHF) impulses (7). These sensors can detect the exact location of a lightning strike (7). Using the NOAA database, lighting seasons can be quantified by finding the average amount of severe thunderstorm events with lightning strikes for each month of the year every state in the US. Using these averages can help us determine the time of year when the most lightning strikes will occur in a given state. It is important to quantify when lightning seasons occur to avoid lightning-related injuries or death.

In this study, we examine the frequency of lightning in different regions in the US to assign lightning seasons using the parameters specified. We examined severe thunderstorm events in regions that had geographical importance or large populations. The seven states chosen were Colorado, Florida, Maine, Minnesota, New Jersey, Washington, and West Virginia. The purpose of examining severe thunderstorm events in different regions (Northeast, Southeast, Midwest, and Northwest) is to find specific patterns in the seasons (months) that have the most severe thunderstorm events, including the most frequent lightning events. We chose three different years to examine over a span of approximately two decades: 2000, 2008, and 2017. These years were chosen to look at how severe thunderstorm events have changed over a longer period of time, as well as how those changes relate to larger climate change patterns. We hypothesize that (i.) the majority of severe thunderstorm events would occur in the summer months in all states examined for the years 2000, 2008, and 2017; (ii.) climate change would cause unusually severe thunderstorm events in winter months in all states examined; (iii.) thundersnow would be observed in Colorado, as thundersnow is most common in that region; and (iv.) there would be no difference in the number of severe thunderstorm events between states in any given year examined.

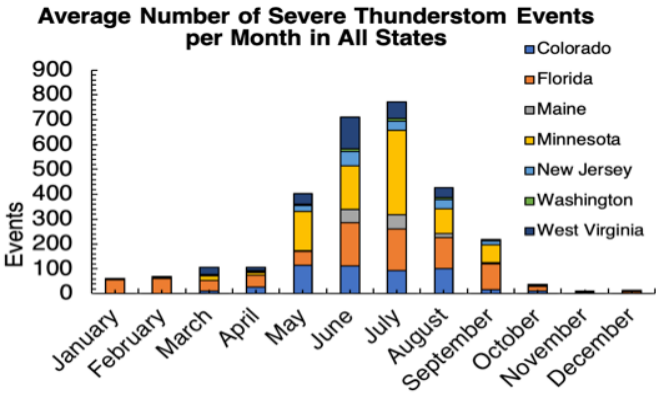

Figure 1. Summary of monthly severe storm events.

RESULTS

We collected data for seven states across the U.S: Colorado, Florida, Maine, Minnesota, New Jersey, Washington, and West Virginia. These states were chosen to represent a broad array of climates and geographical locations (**Figure 1**). For each of the seven states, severe thunderstorm events were recorded by month, and the averages were determined for the three years chosen (2000, 2008, and 2017). In all states, over 60% of the severe thunderstorm events occurred between May and August, with the summer months (June, July, and August) having the highest average severe thunderstorm events (**Table 1**). This was true for Colorado, Florida, Minnesota, Washington, and West Virginia. There was a significant difference between the monthly averages from each state over the years 2000, 2008, and 2017 (*p*-value=0.003, F=3.5) (**Table 2**).

Severe thunderstorm events occurred in winter months in Colorado, New Jersey, Washington, and Florida (**Figures 2-4**). Colorado observed three lightning related events in February of 2000 and 2008 (**Figure 2**). New Jersey received severe thunderstorm events in February of 2017 (seven total) and December of 2000 (two total), skewing the monthly average over the three years and reflected in the standard error bars (**Figure 4**). Washington also had tornadic events in winter months, specifically in January (one in 2008 and one in 2000), as well as five severe thunderstorm events not related to tornadic events (**Figure 4**). Florida received an average of 56.7 and 61 severe thunderstorm events

Table 1: Severe thunderstorm event monthly data for all states

Groups	*Sum*	*Average*	*Standard Error (SE)*	*% storms May-Aug*
Colorado	486.7	40.6	14.1	86.6
Florida	865.7	72.1	16.6	60.2
Maine	138.7	11.6	6.1	94.2
Minnesota	874.7	72.9	30.4	88.3
New Jersey	194.0	16.2	5.3	79.2
Washington	45.0	3.8	1.3	84.4
West Virginia	331.3	27.6	10.8	82.2

Table 2: One-way ANOVA table of monthly average data for all states across all three years (*p*-value = 0.003; F = 2.22)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	57377.3478	6	9562.8913	3.52972011	0.00386786	2.21881674
Within Groups	208612.186	77	2709.24917			
Total	265989.534	83				

respectively for January and February over the three years examined (**Figure 2**).

DISCUSSION

In this study, we classified lightning seasons in all states observed, with the most severe thunderstorm events occurring in May, June, July, and August. Colorado, New Jersey, Washington, and West Virginia were found to have severe thunderstorm events in the winter, which could be explained by increased winter storms due to climate change (1).

Lightning and thunderstorms occur in every state in the US. With climate change increasing the frequency of severe thunderstorms, it is important to quantify when lightning seasons occur to remain safe while outdoors (8). We hypothesized that the late spring and summer months (May, June, July, and August) would have the most frequently reported severe thunderstorm events in every US state due to the higher annual temperatures that occur in the Northern Hemisphere during these months. We also hypothesized that there would be severe thunderstorm events occurring in late fall or winter months that could be attributed to climate change, and that thundersnow events would occur in Colorado, where thundersnow storms have been previously reported (2).

Severe thunderstorm events seem to be most frequent during the months of May, June, July, and August. This is likely due to the convective available potential energy (CAPE), which is created in warmer climates (1). Since the late spring (May) and summer (June, July, and August) months are typically the warmest months of the year for all regions of the US, these months were expected to have the most frequent severe thunderstorm events. Though this was true, there were also reports of severe thunderstorms in winter months as well, which could be driven in part by climate change (1). Because Colorado has been known to have thundersnow, we wanted to examine whether thundersnow events would increase the severe thunderstorm event averages in winter months. Though we could not conclude that the severe thunderstorm events seen in the winter in Colorado were from thundersnow events, Colorado, New Jersey, Washington, and West Virginia all observed severe thunderstorm events in winter months. New Jersey received the largest number of severe thunderstorm events in winter months (December through February) with an

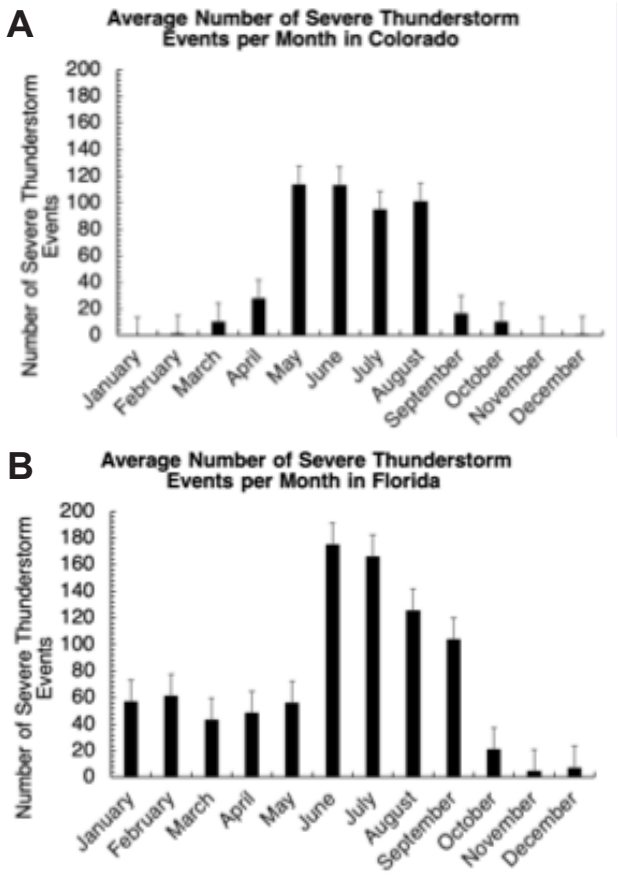

Figure 2. Severe thunderstorm events in Colorado and Florida. **(A)** Average number of severe thunderstorm events per month in Colorado. Mean of 40.56 storm events per month. Standard error of 14.1. **(B)** Average number of severe thunderstorm events per month in Florida. Mean of 72.139 reports per month. Standard error of 16.6.

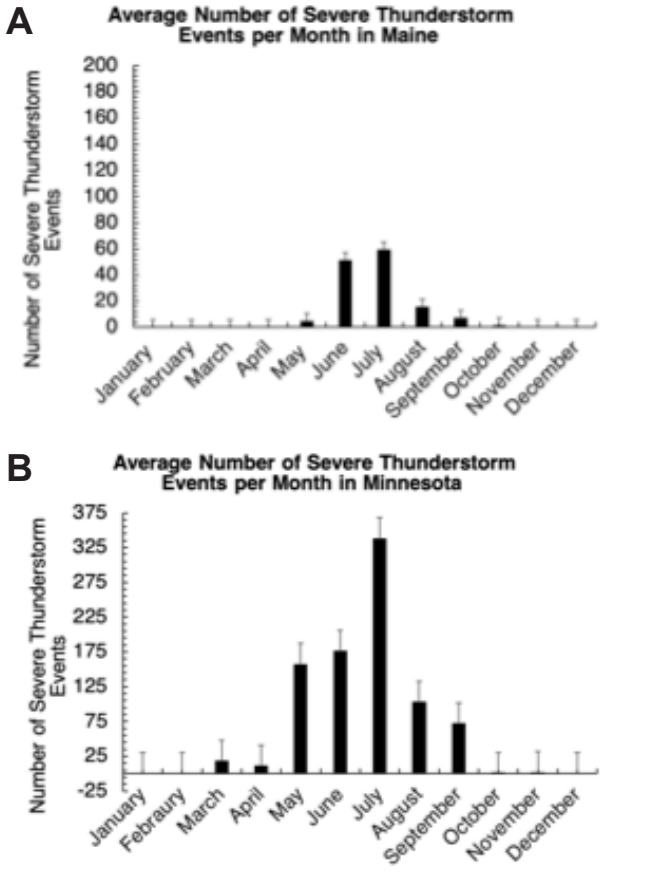

Figure 3. Severe thunderstorm events in Maine and Minnesota. **(A)** Average number of severe thunderstorm events per month in Maine. Mean of 11.55 reports per month. Standard error of 6.1. **(B)** Average number of severe thunderstorm events per Month in Minnesota. Mean of 72.89 reports per month. Standard Error of 30.4.

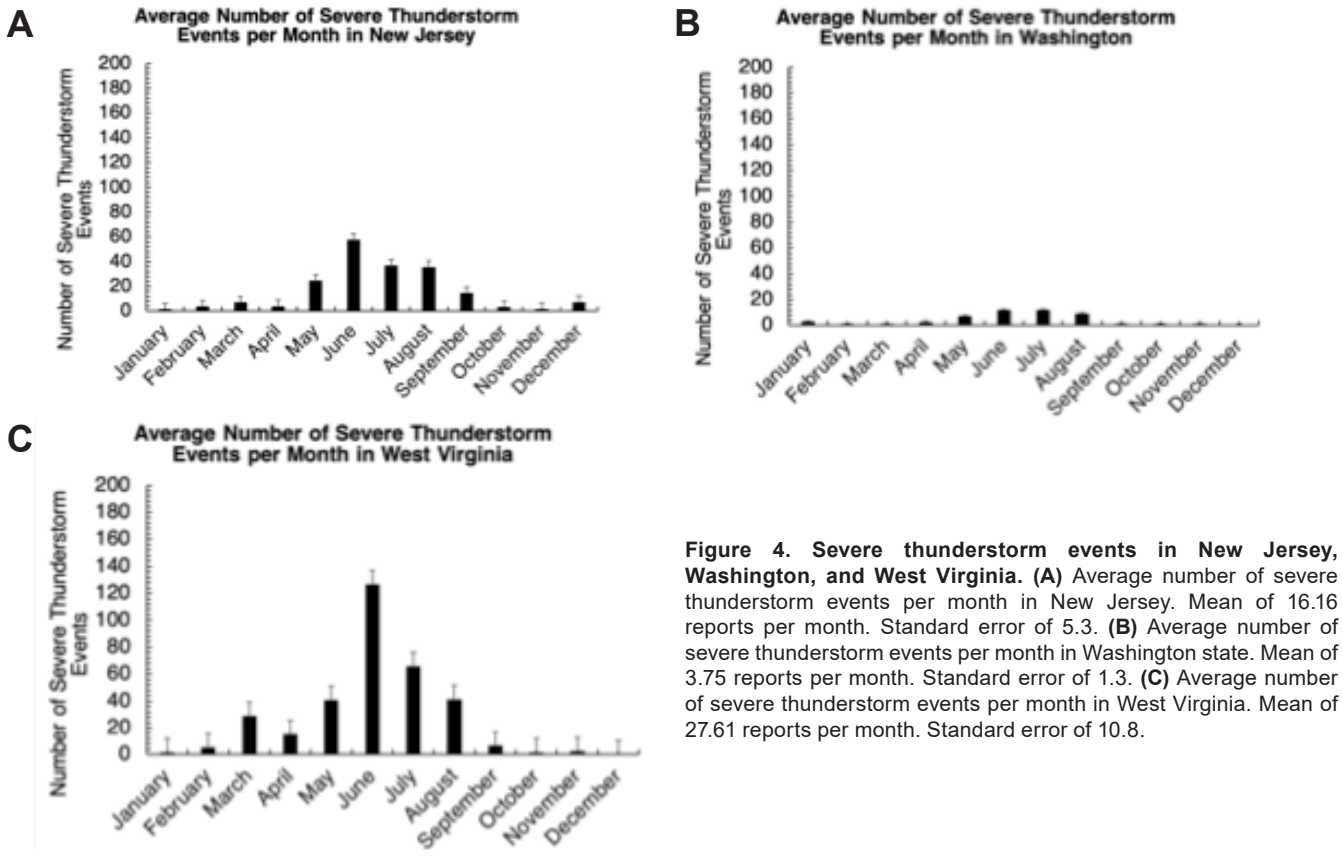

Figure 4. Severe thunderstorm events in New Jersey, Washington, and West Virginia. (A) Average number of severe thunderstorm events per month in New Jersey. Mean of 16.16 reports per month. Standard error of 5.3. **(B)** Average number of severe thunderstorm events per month in Washington state. Mean of 3.75 reports per month. Standard error of 1.3. **(C)** Average number of severe thunderstorm events per month in West Virginia. Mean of 27.61 reports per month. Standard error of 10.8.

average total of 11.33, although this is still much less than the summer months' average of 129.33. Washington's severe thunderstorm events in the winter were from tornadic events, which could also be driven by increased temperatures due to climate change (1).

Start and end dates to lightning seasons in each state varied, as was determined by data collected from the NOAA database. Colorado's lightning season was assigned from May to August; these months had the highest average severe thunderstorm events, most likely due to the number of tornadoes seen in the late spring. As Colorado falls partially into the Plains region of the US, it is more prone to tornadoes than most states, which can explain the late spring severe thunderstorm events (9).

Florida's lightning season was assigned from June to September. Florida was moderately active with severe thunderstorm events for almost every month of the year except the late fall and early winter months (October, November, and December). The most active months in Florida were June, July, August, and September. The amount of severe thunderstorm events in September can be explained by Florida's propensity to get hit by tropical storms and hurricanes during early fall, which were counted as severe thunderstorm "related" events (6). The activeness of storms throughout most of the year in Florida can be explained by the subtropical environment of the state, which allows for high to moderate temperatures throughout every season (6).

Maine's lightning season was assigned from June to July. Its relative inactivity as compared to other states can be explained by its geographical location, since it is one of the northernmost states in the US. (7). Therefore, its winters are longer and summers are briefer (7).

Minnesota's lightning season was assigned from May to September. Minnesota had the highest reported number of severe thunderstorm events, with a monthly average of 337.67 for July (over all three years). Given that Florida is known as the "Lightning Capital of the U.S," it is surprising that Minnesota surpassed Florida during a peak lightning month. Minnesota is very active because of its Northern position and extremely cold weather; it is also situated in the prairie biome that gathers moisture from the many lakes in the state (8).

New Jersey's lighting season was assigned from June to August. New Jersey was a relatively inactive state, with the most active months including June, July, and August. This can be explained by its temperate climate and rolling hills, which make it hard for severe weather phenomena such as tornadoes to strongly form (10).

Washington's lighting season was assigned from June to July. Washington had less severe thunderstorm events than New Jersey, making it the least active state of the states examined; June and July were its most active months. Washington's inactivity can be explained by its

temperate climate and geographical location, lying within the Cascade Mountain range. Its temperature remains fairly cool throughout the majority of the year, ranging from the low 40s °F to the mid-60s °F (11).

Lastly, West Virginia was a moderately active state, with its lightning season ranging from May to August. Its activity can be explained by its location (Southeast), which receives greater temperatures than New Jersey, Maine, Minnesota, Colorado, and Washington. This is because of the state's proximity to the equator, allowing the warmer temperatures to form the cumulus clouds that create thunderstorms (1). West Virginia also borders the Midwestern states that receive severe weather due to their climate (12).

Overall, the monthly severe thunderstorm event averages (across all years) from all seven states were significantly different from each other, as revealed by a one-way ANOVA. This rejects our hypothesis that there would be no difference between the monthly averages of all seven states. This was most likely due to their differing geographic locations and importance.

Lightning safety continues to remain a concern, as severe thunderstorm events are likely to increase in coming years due to climate change (1). In this study, we assigned lightning seasons to seven states in the US, all of which differ in geography and climate. Future studies will continue to assign lighting seasons to the remaining states. Repeating this collection over many years recorded in the NOAA database could also make up for any variation in the data, given that only three years were looked at. Lighting seasons could potentially vary with a larger sample size. We also plan to look at countries with similar climates and topography to understand how lightning seasons may differ from the US. With global change comes changing weather. Understanding how lightning seasons are changing over time could help us educate the public and prevent lightning-related injuries or death.

MATERIALS AND METHODS

Collecting Data

The data presented in the study was collected from the NOAA Storm Events Database. Data collected from the database consisted of severe thunderstorm events such as thunderstorm with wind and hail, tornados, funnel clouds, lightning, hurricanes, tropical storms, and tornadic waterspouts. We collected data for three years (2017, 2008, and 2000) for each of the following states: Colorado, Florida, Maine, Minnesota, New Jersey, Washington, and West Virginia, and categorized them by county and month of the year. The years 2017, 2008, and 2008 were chosen as a representative sampling of the past two decades. Climates differed greatly between the chosen states, representing the following biomes: temperate deciduous forest (New Jersey, West Virginia, Maine, parts of Florida, parts of Minnesota), coniferous forest (Washington, parts of Florida), prairie grassland (parts of Minnesota, parts of Florida), savannah (parts of Florida), and alpine tundra (Colorado).

Determining Lightning Seasons

The total number of severe thunderstorm events for each state was collected and broken down by month and year. We determined the mean severe thunderstorm events per month (over years selected) by calculating the sum of severe thunderstorm events for each month (in each year) and dividing the total by three (for the three years examined). A histogram was created to depict the average number of severe thunderstorm events over the three years by month. The average number of severe thunderstorm events for each state was used to determine lightning seasons.

Statistical Analyses

We assessed the counties of each state to determine the highest average annual severe thunderstorm events over the three years chosen. A one-way ANOVA was performed on the severe thunderstorm data from all seven states (an average per month). For statistical analysis, we applied a *p*-value of 0.05 as the threshold for significance. Data analyses were performed using Google Sheets. We also calculated the percentage of average severe thunderstorm events that occurred in May, June, July, and August, the months that we hypothesized would have the most events.

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