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# Lightning strike prediction at the Savannah River Site

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ABSTRACT:

At the Savannah River Site, employees receive warnings about lightning only after three strikes have already occurred near the site. In order to increase employee safety, it is preferential to warn employees of a lightning threat much sooner. We used data from an on-site Electric Field Mill to measure values of the atmospheric electric charge. We also used lightning detection data from the National Lightning Detection Network and the Geostationary Lightning Mapper. By comparing the data of each, we can determine how long before or after a lightning strike did the Electric Field Mill first measure within our lightning detection threshold. If the detection threshold occurs before the strike does, this provides a lead time for knowing about lightning risks before they happen. Our findings conclude that 95% of lightning strikes have a lead time in the electric field where we can predict the lightning before it occurs and warn employees of the potential lightning threat. However, our lightning detection threshold

can occur even without lightning or precipitation. Finding how these false lightning alarms affect our data is necessary to improving the lightning warning system.

# I. INTRODUCTION

Currently, at the Savannah River Site, employees receive lightning warnings after three confirmed lightning strikes within the site boundary plus a surrounding buffer area. This means that before employees can even know of a lightning threat, it could already be upon them. With many people working outside and in/around conductive materials, lightning strikes are a big safety concern. Being able to predict potential lightning events and warn employees of the risks before they happen would increase employee safety and awareness.

Lightning is something in which there are many unknowns involved. For our purposes, we will be looking at three types of lightning strikes.[1] Cloud-to-ground lightning is the type that threatens employee safety from striking materials on the Earth's surface. Cloud-to-cloud lightning and inter-cloud lightning both stay in the atmosphere within clouds, they can still affect our data, but bring little to no threat.

For our study we used three main devices. The first is the National Lightning Detection Network (NLDN) which detects only cloud-to-ground lightning strikes from a ground-based network.[2] The second is the Geostationary Lightning Mapper (GLM) which detects cloud-to-ground, cloud-to-cloud, and inter-cloud lightning.[2] It is located on a geostationary satellite, focused on the eastern hemisphere disk, and measures lightning from detecting optical emissions of lightning flashes from Earth. Both the NLDN and GLM detect lightning strikes once they occur and give measurements, for our purposes, of the time, date, and position of each lightning strike. The final device we used is an EFS 1000 Series Electric Field Mill that is located at the Savannah River Site.[3] The Electric Field Mill measures the atmosphere's electric charge in Volts per meter (V/m) at 10 Hz but is recorded in 15-minute intervals. It gives the measurements of the average, maximum, and minimum field values for each time interval. It also measures within a minimum 7-mile radius, which we found to give the best measurements of data. Figure 1 shows the site boundary lines as well as the 7-mile radius and another 20-mile radius for comparison to see the large width of the Savannah River Site.

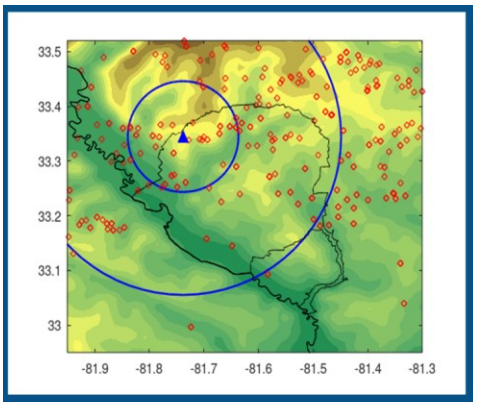


FIG. 1. Map of cloud-to-ground lightning strikes (red symbols) confirmed by the NLDN on 6/20/2019 near the Savannah River Site (thin black outline) The thick black line is the state line between Georgia and South Carolina. The blue triangle symbol is the location of the Electric Field Mill, and the inner blue ring is the 7-mile radius of the Electric Field Mill while the outer ring is the 20-mile radius of the Electric Field Mill.

This project expands on initial research that was conducted at the Savannah River Site in 2007 by Parker and Kabela.[4] We used the same Electric Field Mill and the NLDN but added another lightning detection device, the GLM, to improve the accuracy of the data by being able to detect multiple types of lightning. Also, we used a similar lightning detection threshold that they used in their research as we found it to provide the best results. From this, we calculated lead time values for lightning predictions and identified the times that false alarms occurred in the data, i.e., signals for lightning that never occurs. We can compare between the two projects and the two methods used to determine how much we have improved with detecting and predicting lightning events.

## II. METHODS

### A. Lead time values

To calculate lead times for potential lightning strikes, we compared data from the NLDN to the Electric Field Mill for each 15-minute time interval for each lightning event between 2009 to 2020. As stated, since the NLDN shows the time, date, and position of cloud-to-ground lightning strikes, we can compare that data to data from the Electric Field Mill, of the same time and date, within the 7-mile radius.

Our detection threshold was based on the difference between the maximum and minimum field values for each time interval. If the difference was over 500V/m, then that means the atmosphereic electric field is changing rapidly, creating conditions for a potential lightning event. In the Electric Field Mill data, we identified where the lightning strike detection threshold occurred continuously before and after the time frame of a confirmed lightning event from the NLDN data.

Figure 2 is an example of this process. For the specific lightning event shown, the NLDN data detected the first lightning strike at 18:40 UTC. However, we can see that measurements over the detection threshold in the Electric Field Mill first appeared at 17:45 UTC and stayed from the initial occurrence of lightning to the end of the lightning event. This means this specific lightning event has a 55-minute lead time, for detecting there may be lightning, between the first measurement above the detection threshold and the time in which the lightning event started.

First NLDN confirmed lightning strike was at 18:40 UTC.

| Timestamp (UTC) | Average (V/m) | Maximum (V/m) | Minimum (V/m) | Difference (V/m) |
|---|---|---|---|---|
| 8/1/2019 17:45 | -94.3 | 229.3 | -838 | 1067.3 |
| 8/1/2019 18:00 | -112.8 | 330.5 | -1341 | 1671.5 |
| 8/1/2019 18:15 | -1615 | 1217 | -5274 | 6491 |
| 8/1/2019 18:30 | -4502 | 7999 | -7999 | 15998 |
| 8/1/2019 18:45 | -7999 | -252.2 | -7999 | 7746.8 |
| 8/1/2019 19:00 | -7999 | -5696 | -7999 | 2303 |
| 8/1/2019 19:15 | -5796 | -3668 | -7999 | 4331 |
| 8/1/2019 19:30 | -1097 | -223.9 | -3864 | 3640.1 |
| 8/1/2019 19:45 | -272.4 | -26.98 | -909 | 882.02 |

Over 500V/m difference detection threshold first detected within 17:45 UTC time interval.

FIG. 2. Example of data from the Electric Field Mill at 15-minute time intervals. Each category is the time and date in UTC, the average electric field values in V/m, the maximum electric field values in V/m, the minimum electric field values in V/m, and the difference between the maximum and minimum field values in V/m.

B. False alarms

While the Electric Field Mill measuring over the 500V/m detection threshold is an indication of lightning, this threshold also appears even when there is no lightning occurrence. In order to better understand these false detections, we used data from the NLDN, GLM, Electric Field Mill, and on-site precipitation measurements for 2019 and 2020 lightning events. We were limited to these years as the GLM data started in mid-2018 and it was necessary to use this data to account for cloud-to-cloud and inter-cloud lightning events.

We first sorted through the Electric Field Mill data to only include the time intervals that detected over the 500V/m threshold. Then, we matched those time intervals to the times of lightning occurrences from the NLDN and GLM data. If either detected lightning within the time intervals measuring over the threshold, then the threshold occurrence was caused by lightning, either cloud-to-ground, cloud-to-cloud, inter-cloud. Next, we looked at the remaining time intervals where the over 500V/m detection threshold occurred without lightning and compared them to precipitation data from five locations at SRS that were also measured in the same 15-minute intervals. We looked at this data because precipitation is related to convection in the atmosphere and this movement creates fluctuations of the electric charges that could be measured over the detection threshold. Finally, the only time intervals left were false alarms that contained no lightning nor precipitation yet an occurrence measuring over the lightning detection threshold.

## III. RESULTS

After doing research to measure lead time values, between the years 2009 to 2020, there were a total of 634 lightning events containing 20,421 lightning strikes within the 7-mile radius of the Electric Field Mill. As seen in Figure 3, we found that 95% of these lightning events have a lead time from 6-minutes to over 165-minutes. These are lead times that we can, in a timely manner, detect and send warnings to employees about the upcoming potential lighting risks before any lightning can even occur. The remaining 5% of lightning events are ones in which the detection threshold occurs within 0-minutes to 5-minutes before the initial strike which is too soon before the strike to detect and send out warnings to employees, the detection threshold occurs after the initial strike, or the detection threshold does not appear even with the occurrence of lightning.

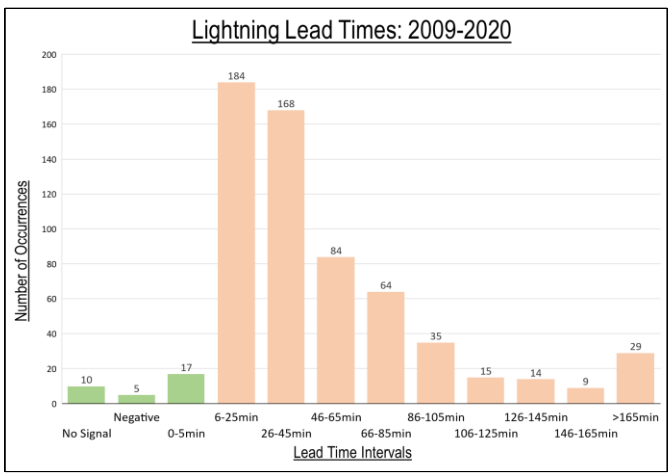


FIG. 3. Number of times each lead time interval occurred for lightning events between 2009-2020. These are based on the appearance of the detection threshold occurring within a specified amount of time around the first confirmed lightning strike for each lightning event. 95% of the occurrences (peach coloring) have a lead time from 6-minutes and higher that can be used to warn employees of a potential lightning threat. 5% of the occurrences (green coloring) do not have a viable lead time for warning employees.

From the false alarm findings, 40% / 43% of the appearances of the detection threshold being over 500V/m are from lightning, either cloud-to-ground, cloud-to-cloud, or inter-cloud as detected by the NLDN and the GLM. This left nearly two-thirds of the detection threshold appearances to be caused by events other than lightning. We then looked at on-site precipitation rates and found that 26% / 34% of the time, the detection threshold is caused by precipitation without lightning. Finally, the remaining 34% / 23% is the false alarm rate. These rates can be seen in Figure 4.

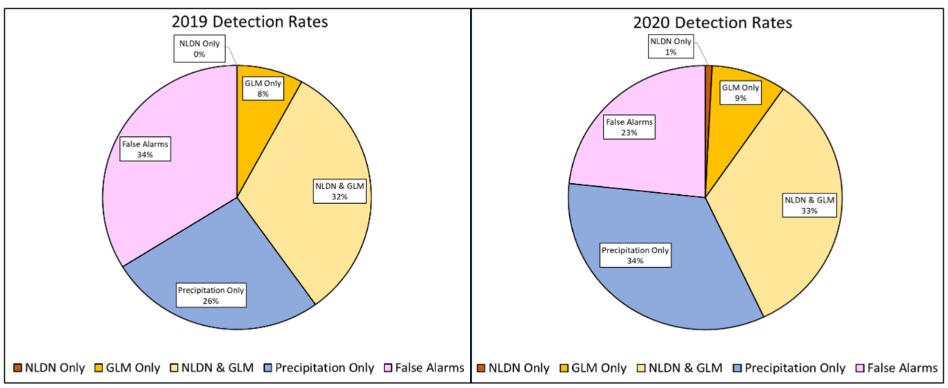


FIG. 4. Detection rates for 2019 and 2020 showing the percentages for the number of times the lightning detection threshold is caused by lightning detected from the NLDN (red), GLM (gold), or both (beige), caused by precipitation (blue), or if the appearances are false alarms (pink).

Currently, we do not know the reasons for false alarm detections. It could be an error with the Electric Field Mill, however, that is unlikely. There are millions of data points from the Electric Field Mill and the appearances of false alarms are very small in comparison. There is also no consistent pattern for these false alarm detections. We were not able to determine any possible causes of false alarms within our time frame to complete this project, however, further research will help to determine causes behind them.

## IV. CONCLUSIONS

From these results, we can compare between our data now and the data from Parker and Kabela.[4] Originally, their data set only consisted of a few months of Electric Field Mill data in which they used only 26 days of cloud-to-ground lightning occurrences for their research. Also, at that time, the GLM was not yet created, so they only used NLDN data to account for lightning. This means it was likely that their false alarm rate contained cloud-to-cloud or inter-cloud lightning strikes that were mistaken to be false alarms. Currently, we used Electric Field Mill data over a 12-year period containing 606 days of lightning occurrences. Also, we used both GLM and NLDN data to account for each lightning type that would have affected our data to not have misplaced false alarm detections. On average, using the 500V/m detection threshold, the research by Parker and Kabela had a 77.3-minute average lead time for their 26 lightning days. Our current data had an average 55.8-minute lead time from 606 lightning days. Also, they calculated a 19.4% false alarm rate. Their rate also includes data of possible cloud-to-cloud and inter-cloud lightning as well as other two detection thresholds which lowered the percent of false alarms compared to our data with only one detection threshold. We calculated false alarm rates for two separate years which gave us the percentages of 23% and 34% false alarm rates. From these results, we can see that the data from the current research is the most accurate with more lightning detection devices used and a longer time frame used. However, the data also seems to be a bit worse for lightning detection, with lower average lead times and more false alarms. The different ways in which this project can still be improved in the future are described below.

## V. FUTURE WORK

In order to increase employee safety and predict lightning as accurately as possible, we have created future ways to fix the problems identified by this project and how to create more accurate results from lightning data.

First, we want to improve the lightning alert system. Currently, the Savannah River Site waits to warn employees of a lightning threat until after three, confirmed, near site lightning strikes. Based on our research, we plan to have the system warn employees of potential lightning and then warn them of confirmed lightning. Any time the detection threshold is measured, we can send out a lightning risk announcement to employees that will warn them of potential lightning. After one, confirmed, near/on site lightning strike we will then send employees a lightning threat announcement to tell them that there is a lightning occurrence and to stay at or get to a safe place. Based on this double warning system, we hope to increase employee safety and awareness while also allowing them to not miss work if there is an occurrence of a false alarm.

Second, we need to find more or better detection thresholds. At the beginning of this project, we used two thresholds that were previously found by Parker and Kabela[4], the difference between the maximum and minimum values being over 500V/m and the average field values being below -600V/m. From our research, we found that the first threshold was useful over the full data set. However, we found that the second threshold gave a large majority of lead times that were unusable for lightning warnings. Although we only used one good detection threshold within the time frame we had, there could be more thresholds that would provide good lead times while also reducing the number of false alarms.

Third, we need to reduce the time intervals for the Electric Field Mill from 15-minute to 1-minute intervals. By having more frequent measurements of the atmosphere's electric field, we can have improved lead times, send out faster warnings for potential lightning, and hopefully reduce the false alarm rate.

Fourth, we hope to find if there are any other physical factors that could be causing false alarms to be measured, whether that be something related to clouds, wind, or other meteorological events. From future research, we could have more time to find factors involved with the change of the atmosphere’s electric field that would explain the cause(s) of false alarms.

Finally, we found that the optimal Electric Field Mill detection range is within its 7-mile radius. With the placement of two more Electric Field Mills on-site we could have near complete coverage of the atmospheric electric field over the Savannah River Site. This increased measurement accuracy will improve lead times for the purpose of improving SRS lightning warnings and employee safety from lightning strikes.

## VI. ACKNOWLEDGEMENTS

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## VII. REFERENCES:


1. N. NSSL.
2. N. NSSL.
3. M. I. Co., (2006).
4. M. J. P. E. D. Kabela, 2007.