DISCLAIMER

Savannah River National Laboratory®

A U.S. DEPARTMENT OF ENERGY NATIONAL LAB • SAVANNAH RIVER SITE • AIKEN, SC • USA

Exploring the Early Lightning Notification of an Electric Field Mill at the Savannah River Site

Stephen Noble[1], Stephen W. Weinbeck[1], Alyssa Bagby[2]

[1]Atmospheric Technologies Group, Savannah River National Laboratory, Aiken, SC

[2]University of South Carolina, Columbia, SC

June 2025

SRNL-STI-2025-00525, Revision 0

srnl.gov

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2025-00525
Revision 0

Keywords: Lightning safety, electric field, lightning notification

Retention: 75 Years

Tracking Number: 10708

Exploring the Early Lightning Notification of an Electric Field Mill at the Savannah River Site

Stephen Noble[1], Stephen W. Weinbeck[1], and Alyssa Bagby[2]

[1]Atmospheric Technologies Group, Savannah River National Laboratory, Aiken, SC

[2]University of South Carolina, Columbia, SC

June 2025

Savannah River National Laboratory is operated by Battelle Savannah River Alliance for the U.S. Department of Energy under Contract No. 89303321CEM000080

Reviews and Approvals

AUTHORS:

STEPHEN NOBLE (Affiliate) Digitally signed by STEPHEN NOBLE (Affiliate)
Date: 2025.08.26 10:21:15 -04'00'

Stephen Noble, Atmospheric Technologies Group Date

STEPHEN WEINBECK (Affiliate) Digitally signed by STEPHEN WEINBECK (Affiliate)
Date: 2025.08.26 10:50:34 -04'00'

Stephen W. Weinbeck, Atmospheric Technologies Group Date

On behalf of Alyssa Bagby

Steven R. Chiswell

Digitally signed by STEVEN CHISWELL (Affiliate)
Date: 2025.08.26 10:59:52 -04'00'

Alyssa Bagby, University of South Carolina Date

TECHNICAL REVIEWERS:

ARELIS RIVERA-GIBOYEAUX (Affiliate) Digitally signed by ARELIS RIVERA-GIBOYEAUX (Affiliate)
Date: 2025.08.26 11:28:59 -04'00'

Arelis Rivera-Giboyeaux, Atmospheric Technologies Group Date

APPROVAL:

STEVEN CHISWELL (Affiliate) Digitally signed by STEVEN CHISWELL (Affiliate)
Date: 2025.08.26 11:38:18 -04'00'

Steven R. Chiswell, Atmospheric Technologies Group/Manager Date

Preface or Acknowledgements

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI). This work was produced by Battelle Savannah River Alliance, LLC under Contract No. 89303321CEM000080 with the U.S. Department of Energy.

Executive Summary

At the Savannah River Site (SRS), employees receive automated broadcast notification about lightning only after three strikes have already occurred near the site boundary. To increase employee safety, it is preferential to give employees lead time before lightning strikes occur. We compared measurements from an on-site electric field mill to lightning detection data from the National Lightning Detection Network and the Geostationary Lightning Mapper. Using a difference threshold, we determined that the electric field mill provided a lead time greater than 6 minutes for 95% of lightning events from 2009-2020, with an average lead time of 56 minutes. Detection of events were limited to a 7-mile radius around the field mill. We also identified that the field mill threshold generated many false detections not clearly identified. False detections and detections from only precipitation can be reduced by using a second threshold without creating too many missed detections (Type II errors). The two thresholds used together provide the best information about rapidly changing electric fields and aid in advanced detection necessary to improve the lightning warning system used at SRS.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

SRNL	Savannah River National Laboratory
NLDN	National Lightning Detection Network
GLM	Geostationary Lightning Mapper
SRS	Savannah River Site
KP07	Kabela and Parker 2007
EFM	Electric Field Mill
tA	Threshold A
tB	Threshold B
tC	Threshold C
tD	Threshold D
CG	Cloud-to-Ground lightning
CC	Cloud-to-Cloud lightning
IC	Intracloud lightning

1.0 Introduction

Lightning strikes pose a threat to people exposed outdoors, such as at large outdoor work sites or recreational areas. Lightning detection data, such as the National Lightning Detection Network (NLDN; Cummins et al. 1998) or the Geostationary Lightning Mapper (GLM; Goodman et al. 2013), detect when lightning has occurred. This information is sufficient to provide alerts for incoming storms (Leinonen et al. 2022).

Workers at the Savannah River Site (SRS), in western South Carolina, work around electrically conductive materials in open areas, making lightning strikes a major safety concern. Current SRS safety procedures issue notifications for lightning after three (3) lightning strikes are detected, via the NLDN, within the 803 square kilometer area of the SRS site boundary (plus a surrounding buffer area). Lightning notifications are initiated through automated paging system directly to remote workers and emails to site control room operators who then issue verbal public address announcements. The system can provide notification to the SRS community within about 2 minutes after the third strike.

This legacy method has proven adequate over the years, but several concerns have arisen. First is the potential for employees to be struck prior to notification (i.e., by the first, second or third strike from a developing storm), or while in the process of seeking cover. When storm(s) develops directly over the worksite, since the existing lightning data detection methods do not provide lead-time, only detection post facto, no time is provided for exposed workers to seek cover. Additionally, the legacy method has no clear criteria for releasing workers back to work once the storms have moved off.

Electric field mills provide information about electric field variations created by developing convective storms or convective storms moving within range (Sabu et al. 2017; Wilson and Cummins 2021; Yamashita et al. 2022). Strong updrafts in areas of the cloud with temperatures below freezing, where both ice and super-cooled water droplets are present, act to separate electrical charges, strengthening the electric fields which precede a discharge via lightning (Workman and Reynolds 1949; MacGorman and Rust 1998). These processes could occur directly over the electric field mill for detection or alternately be detected as the convective storm moves within range. With current improvements in sensing and communications, rapid changes detected by electric field mills could provide more timely alerts for on-site workers.

Initial research was conducted at the Savannah River Site in 2007 by Kabela and Parker (2007, hereinafter KP07). The current study uses the same electric field mill and the NLDN as in KP07 but adds the GLM as a secondary lightning detection method to improve the accuracy of the data through detection of cloud-to-cloud and intracloud strikes that are not provided in the NLDN data purchased by SRS. KP07 applied three thresholds to the electric field mill data to signal the notification of possible lightning. The first was based on the rapid change of the electric field where the difference of the maximum and minimum electric field was greater than 500 V/m over a 15-minute period. This was an indication of developing or incoming convection. The others were if the mean electric field went below 0 V/m or -600 V/m. These thresholds were likely chosen because an approaching or building storm would generate a negative electric field as seen by the field mill prior to a lightning strike. The mean lead time for the three thresholds were 77.3 minutes for the greater than 500 V/m, 81.5 minutes for average electric field below 0 (zero) V/m and 44.4 minutes for the average electric field being less than -600 V/m (KP07).

This study addresses two main questions about electric field mill use and possible risks (errors). First, does historical field data indicate a consistent reliable lead time warning for lightning strikes? Second, what errors exist in using threshold values of the electric field for lightning detection? To answer these questions, we examine these same thresholds but use a slightly different approach to their implementation in the research. The comparison between the two projects and the two methods can be used to identify improvements in lightning detection and predicting systems.

2.0 Data and Methods

This study utilizes data collected from a Mission Instruments EFS 1000 Series Electric Field Mill (EFM) located at the Savannah River National Laboratory (SRNL) in A-Area near the northwest edge of SRS (Fig. 1). The optimal minimum range of the EFM, as per Mission Instruments, is a 7-mile (11.27 km) radius where the EFM can detect rapidly changing electric field conditions within this minimal detectable range. Beyond that range, some influence on the electric field is to be expected but limited. KP07 looks at the EFM influence from across the entire SRS as to identify the capabilities of extending the range compared to the need to add additional EFMs.

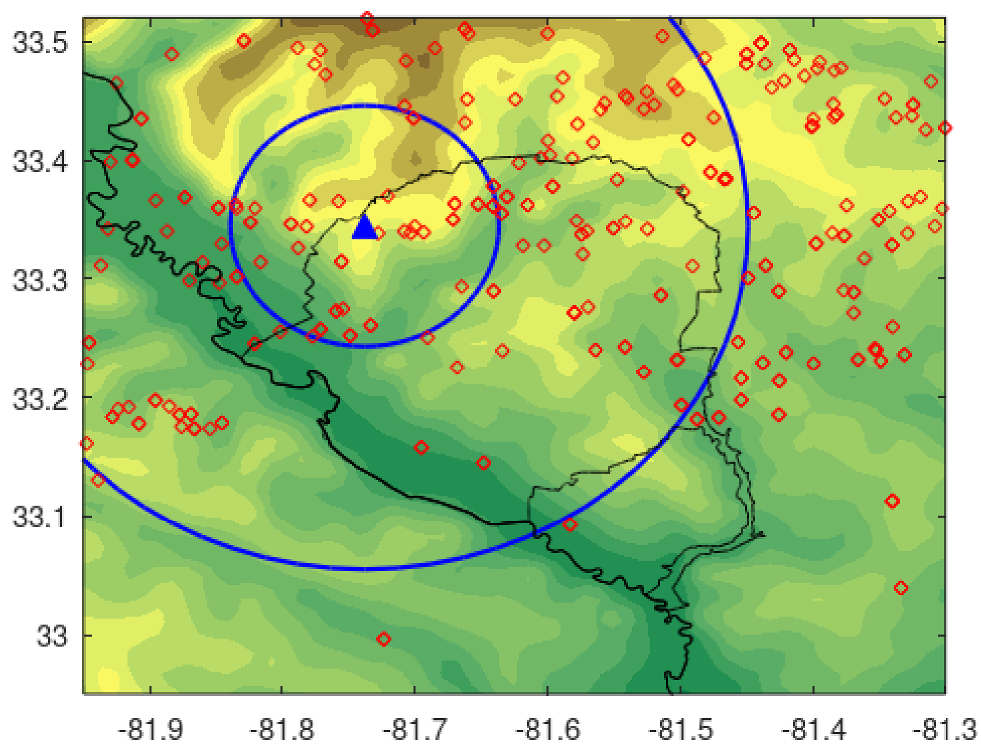

Figure 1. Map of cloud-to-ground lightning strikes on 6/20/2019 near the Savannah River Site. The NLDN strikes are red diamonds. The site is the thinner black outline. The thick black line is the state line between Georgia and South Carolina. The blue triangle symbol is the location of the Electric Field Mill, and the inner blue ring is the 7-mile radius around the Electric Field Mill while the outer ring is the 20-mile radius around the Electric Field Mill. From Bagby and Noble 2022.

The datalogger that records the EFM data samples the EFM at 10 Hz and calculates mean, maximum and minimum electric field values every 15 minutes, which are written to a relational database. The period of data used for this study is from 2009 to 2020. Because we are using this record to identify risk of lightning based on changes to the electric field and we are limited to how the data was previously recorded, we selected four thresholds that can be determined using the recorded data to indicate risk. The first three are derived from KP07. Threshold A (tA) is when the difference between the maximum and minimum is greater than 500 V/m. Threshold B (tB) is when the mean is less than 0 V/m. Threshold C (tC) is when the mean is less than -600 V/m. The final threshold, D, (tD) we derived from the minimum detection alarms setting for the Mission Instruments alarm/display/control unit (ALB101). This value (-450 V/m) is the smallest set point limit for that unit, i.e., the unit alarms when the value of the electric field is less than -450 V/m. This threshold was selected to test using minimum values as thresholds rather than means as used by KP07.

The primary lightning detection used for verification in this study is the NLDN provided with the SRNL contract with Vaisala. The contract provides only detection information on cloud-to-ground (CG) lightning strikes which is transferred to the site via the SRNL NOAAPort satellite dish and archived. The main limitation with this NLDN data is that only CG strikes are detected. The archive provides time and location for each strike in a long-term data set (2009-2020) that will be used for comparison with the EFM. Distances from each strike to the EFM were calculated to identify the strikes that were within the 7-mile range. Additionally, we selected strikes that were within 20 miles (32.19 km) as that range covered the majority of the SRS area (Fig. 1) similar to KP07.

GLM data was used as a secondary identification of lightning to detect cloud-to-cloud (CC), and intracloud (IC) lightning. Located on a geostationary satellite, it detects photons in the near infrared from lightning flashes. We used the GLM flashes (weighted mean flash centroid) as opposed to events or groups to limit the amount of data processing for our study and as a secondary identification. For our study, the exact location of the lightning or how far it travels from cloud to cloud is not important but only the presence of lighting in the area. Thus, the GLM flashes even at 10km resolution are sufficient to determine if lightning occurred in the vicinity of SRS that was not detected by the NLDN CG lightning detection. As an optical sensor, the GLM could have some limitations during daylight hours, but a direct comparison of the two detection methods is beyond the scope of this work.

2.1 Detection lead times

Understanding the lead time provided by the EFM is key in implementing a strategy for using it to protect workers. In other words, this research aims to derive how far in advanced the EFM threshold is met before a strike occurs. We identified all the CG strikes in the NLDN from 2009 to 2020 within a 7-mile radius of the EFM (inner blue circle in Fig. 1). Strikes that were clustered in time were marked as an event. Then we compared the time of the event to the EFM tA and tC data (KP07). To calculate lead times for potential lightning strikes, we compared data from the NLDN to the EFM for each 15-minute time interval for each NLDN lightning event from 2009 to 2020 (Bagby and Noble 2022). For the EFM data, we selected a detection threshold based on the difference between the maximum and minimum field values for each time interval (KP07). If the difference was greater than 500 V/m, then the atmospheric electric field is changing rapidly, indicating conditions for a potential lightning event.

To calculate the lead time of the EFM, we identified the first 15-minute time period that tA or tC was met prior to the first strike of each lightning event. Fig. 2 demonstrates this process with an example as demonstrated in Bagby and Noble (2022). For the specific lightning event shown, the NLDN detected the first lightning strike at 18:40 UTC. However, EFM measurements indicate an exceedance of the tA beginning at 17:45 UTC, which persisted until the end of the lightning event. This specific lightning event had an estimated 55-minute lead time from the first EFM detection to the first CG strike detected by the NLDN.

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.

Figure 2. Depiction of lead time determinations. Here the strike occurred at 18:40 UTC and the example fields from the Electric Field mill are shown at 15-minute time intervals: 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. The threshold (tA) is met at 17:45 UTC. From Bagby and Noble 2022.

2.2 False detections

Use of these thresholds in the electric field can indicate the potential for lightning. However, these thresholds can also be triggered even when no CG strikes occur. To understand these false detections, we used data from the NLDN, GLM, EFM, and on-site precipitation measurements for 2019 and 2020 lightning events. In other words, here, instead of first identifying lightning events, we identify the threshold events from the EFM data and identify whether or not there was lightning potential. We were limited to 2019 and 2020 because the GLM measurements began to provide operational data starting in 2018.

We first identified all time periods when tA was met in the EFM data. Potential events were separated by periods of at least an hour when tA was not met. We then matched each event to times when lightning activity (CG, CC, or IC) was detected in the NLDN and GLM data within 7 miles and 20 miles, separately. If either source detected lightning within the time intervals of tA, then the tA event detection was deemed successful. Next, we compared the remaining tA events to precipitation data from five locations at SRS that were also measured in the same 15-minute intervals. Falling precipitation is formed in clouds through the same processes that generate charge separations and the potential for lightning. Thus, the building electric field creates the potential for lightning. However, as the precipitation falls, it carries the charge to the surface which can reduce the buildup of the electric field, and a strike will not always occur. For the purposes of this study, because rain is the discharge but the potential for lightning existed, tA coinciding with 'rain only' is not considered a detection error. The remaining tA events were determined to be false detections as no lightning or precipitation occurred. In other words, we determined no valid reason linked to atmospheric convective processes for reaching tA in our study.

KP07 utilized several different thresholds to develop their lightning threat levels. We applied tB, tC and tD as secondary thresholds in conjunction with tA to better discriminate when lightning is occurring.

3.0 Results and Discussion

3.1 Detection Lead Times

In the 12-year data set, there were a total of 634 lightning events containing 20,421 lightning strikes within the 7-mile radius of the EFM (Bagby and Noble 2022). The tA criteria led to an average lead time of 55.8 minutes, whereas KP07 had a 77.3-minute average lead time for their 26 lightning events. As seen in Fig. 3, we found that 95% of these lightning events had a lead time of 6 minutes to over 165 minutes. These lead times would allow timely warnings to be sent to employees about the potential lightning risk before any lightning occurs. An example of one of the longest lead times of 700 minutes before a CG strike was observed in 2020 when Hurricane Sally made landfall. The remaining 5% of lightning events were ones in which tA was met 0 minutes to 5 minutes before the initial strike, insufficient lead time to warn employees; tA occurred after the initial strike; or lightning occurred without tA being met. For example, on 23 July 2011 a single strike from the NLDN was recorded ~11 km from the EFM however, tA was not met within 10 hours before or after the strike.

To better determine the coverage across SRS, we tried to identify lead times for lightning within the 20-mile radius. By expanding the lightning detection distance, the EFM was not able to provide sufficient lead time consistently. Thus, for coverage across the entire SRS, it would be necessary to add additional field mills. When using tC, a large majority of lead times were too short, negative or did not occur to provide alerts for lightning events. To reach a mean of -600 V/m over a 15-minute period, the electric field values would have to remain negative for a long time, which may be why tC did not perform as well.

It is important to note that the EFM provides more rapid sampling for real time detection, but we were only able to record data every 15 minutes for the long-term data record due to limitations in the data loggers available at the time of installation. Data recorded at shorter intervals (i.e., 1-minute) would likely provide greater lead times. With higher frequency data, using a threshold based on the minimum value of the electric field might provide better lead time.

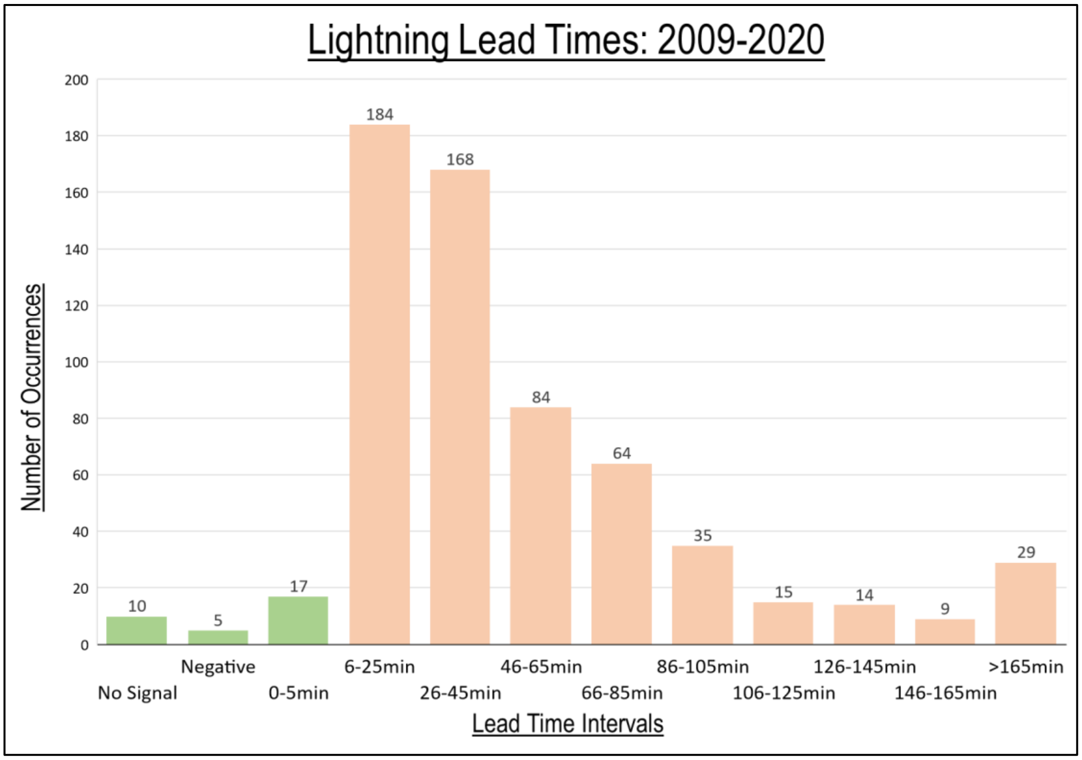

Figure 3. Number of times each lead time interval occurred for lightning events between 2009-2020. These are based on the appearance of the detection threshold occurring within a specified amount of time around the first confirmed lightning strike for each lightning event. 95% of the occurrences (peach 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 Bagby and Noble 2022.

3.2 False Detections

For the two-year period, false detections using only tA comprised 50% (437) of the EFM detections (Table 1). This amount greatly exceeded EFM detections when lightning was within the 7-mile radius (123, or 14%), when lightning was within 20 miles (62 events, or 7%), and during precipitation only events, 250 & 29%. This high number of false detections could be related to using a gap of an hour to separate detections. Nevertheless, adding a secondary threshold drastically reduces the false detections and somewhat reduces detections for only precipitation. By including tB 264 false detections and 79 rain only detections are removed. Including tC to tA removes 428 false detections and 156 rain only detections. However, these two additional thresholds also remove a few actual strike detections in the 7-mile radius: 1 detection for tB and 6 detections for tC. However, the one detection in the 7-mile radius in tB was a strike only detected by the GLM and not the NLDN, which therefore was not CG and could have been outside the 7-mile range due to the resolution of the GLM (see Table A 1). The 5 additional detections removed by tC creates a Type II error where lightning occurs with no indication. Again, this could be from using the mean value of the electric field over the 15-minutes as rapidly moving storms might not reach this threshold before a strike. As mentioned above, the tC threshold presented difficulties in establishing lead times. Thus, while tC eliminates many false detections, it introduces additional errors.

Table 1. Numbers of events for False Detections, Rain Only, lightning within 20-miles, and lightning within 7-miles. Includes the threshold of maximum and minimum difference in electric field greater than 500 V/m (tA) and combinations with other thresholds: 15-minute mean less than 0 V/m (tB), 15-minute mean less than -600 V/m (tC), and minimum less than -450 V/m (tD).

	Diff>500 (tA)	Diff>500 (tA) & mean<0 (tB)	Diff>500 (tA) & mean<-600 (tC)	Diff>500 (tA) & min<-450 (tD)
False Detection	437	173	9	158
Rain Only	250	171	94	176
Strike 20mi	62	47	27	47
Strike 7mi	123	122	117	122

The best additional detection threshold is tD. When applied with tA, tD removes more false detections than tA with tB (279 compared to 264) and only loses one strike detection within the 7-mile radius (the same strike only detected by the GLM mentioned previously). It does not remove as many false detections as tA with tC (279 compared to 428) but also does not suffer from the extra missed lightning strike detections within the 7-mile radius (Type II error). With additional testing, there could conceivably be a limiting threshold where the minimum electric field could be used in place of tD to further reduce the false detections without hindering the lightning threat detection, but this research only focused on previously described thresholds. Again, tD may also be better with higher frequency data than the other previously used thresholds.

The different detection cases were counted by month to describe the variability in detections during the year (Fig. 4). False detections were higher in June through October and in December and January. The increase in the presence of in-cloud ice and frequent frontal passages in December and January could account for some of these false detections as rain only detections were also high in the colder months of December to February. June through October false detections could be due to cumulus clouds creating updrafts sufficient for charge separation but not sufficient to trigger lightning, at least within 20 miles of the EFM. This could be due to the convection in the cloud not developing enough ice to separate the charge in the cloud or limiting the precipitation development. This is supported by the lower number of rain only events in many of these months. Detections triggered by precipitation only is a clear indicator of clouds and charging. These detections are most prevalent in the cooler months, September through April. In May through August, the southeastern United State experiences warm season convection that often triggers thunderstorms. Therefore, in these months, these thresholds detections are most frequently linked to actual lightning strikes nearby the electric field mill.

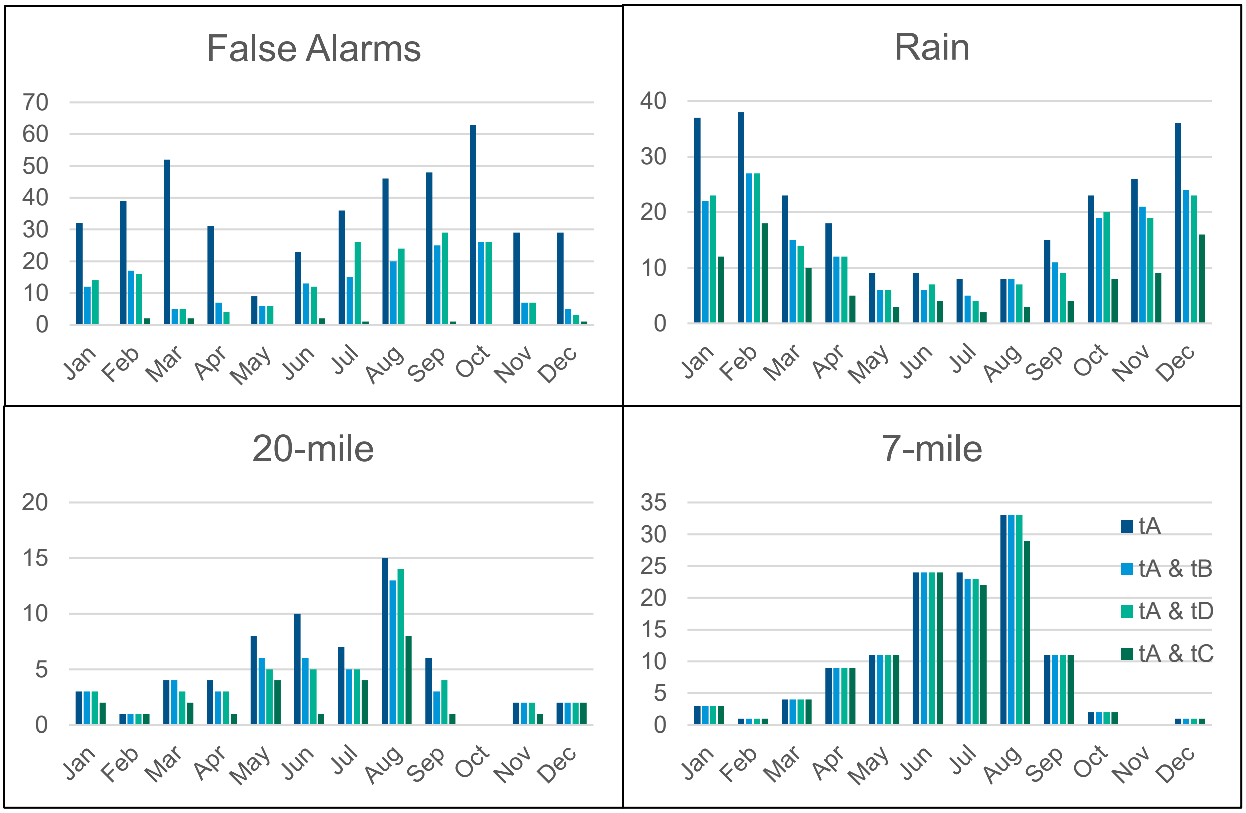

Figure 4. Monthly detection counts for 2019-2020. Clockwise from the top left: false detections, rain only detection, detections of lightning at a 20-mile radius, detections of lightning at a 7-mile radius. Different colors show the different combination of electric field thresholds: tA (dark blue); tA and tB (light blue); tA and tC (light green); and tA and tD (dark green).

For this study, the GLM provided a secondary detection method to identify CC or IC strikes not detected by the NLDN. The lower resolution of the GLM (10 km compared to 1 km for the NLDN) provides an added uncertainty to the location. But as most lightning travels horizontally as well as vertically, this resolution is sufficient to determine these CC or IC strikes near the electric field mill. For the single tA, the GLM strikes accounted for 32 of the lightning strikes within the 7-mile radius detected by the EFM. Most of these detections (25) contained NLDN strikes within a 20-mile radius of the EFM while 7 detections were only attributed to the GLM. The GLM strikes also accounted for 17 lightning detections within 20-mile radius that were not indicated by the NLDN. This secondary use of the GLM indicated the presence of CC or IC lightning that would have been identified by the EFM when using these thresholds for the electric field. However, only a total of 24 detections out of 185 occurred that were attributable to CC or IC lightning from the GLM.

4.0 Conclusions

Using 12-years of electric field mill data recorded at 15-minute intervals, we investigated electric field characteristics that could lead to advanced notification of lightning strikes. The primary detection threshold was met when the difference between the maximum and minimum electric field was greater than 500 V/m, which represents a rapidly changing environment conducive to separating electrical charges. This provided viable lead time of at least 6 minutes 95% of the time for a 7-mile radius area, with an average lead time of 56 minutes. However, this threshold also generated a false detection rate of 50%. False detections seemed to be related to times of the year with likely shallow convective or less convective clouds that contain ice particles, but this requires further research.

We applied additional complementary detection thresholds to reduce the number of false detections. The additional threshold of the 15-minute mean <-600 V/m drastically reduced false detections but also failed to detect lightning events and did not provide sufficient lead time before strikes. However, using a threshold based on the minimum electric field rather than a mean electric field provides an intermediate result that reduces false detections while still successfully detecting lightning strikes. The addition of the GLM provided verification of cloud-to-cloud data that the NLDN did not provide in previous studies (KP07) but only accounted for 13% of the EFM detection of lightning. Electric field mills provide a viable solution for an early lightning notification system. Further testing of thresholds or comparisons with cloud information could provide additional reductions to false detections.

Overall, this research provided an in-depth look at long term electric field mill data at SRS. The general outcome provides guidance for the Savannah River Site use of these field mills. Additional field mills placed on site will be needed to provide the best coverage based on the 7-mile radius best statistics. The addition of the GLM provided verification of cloud-to-cloud data that the NLDN did not provide in previous studies (KP07) but only accounted for 13% of the EFM detection of lightning. More research based on seasonality and the presence of non-precipitating clouds is needed to further identify reasons for false detections. Future work could also consider the use of the electric field mill to determine when it is safe to return to work.

5.0 Recommendations, Path Forward or Future Work

This study provides guidance for the ATG potential use of these field mills. Based on the analysis presented above, the following changes have been made to the SRNL field mill data. The averaging time was decreased from 15-minutes to 1-minute to improve temporal resolution which will presumably improve lead time and limit false detections.

Additional field mills could be placed on site will be needed to provide coverage based on the 7-mile radius best statistics. More research based on the cloud fractions, or the height of the cloud base could further identify reasons for false detections. Additionally, future work should also consider the use of the electric field mill to determine when it is safe to return to work after electrical storms.

References

Bagby, A., and Noble, S., 2022: Lightning strike prediction at the Savannah River Site. https://doi.org/10.2172/1878527

Cummins, K. L., M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, 1998: A Combined TOA/MDF Technology Upgrade of the U.S. National Lightning Detection Network, *J. Geophys. Res.*, **103**(D8), 9035– 9044. doi:10.1029/98JD00153.

Goodman, S. J, R. J. Blakeslee, W. J. Koshak, D. Mach, J. Bailey, D. Buechler, L. Carey, C. Schultz, M. Bateman, E. McCaul, and G. Stano, 2013: The GOES-R Geostationary Lightning Mapper (GLM). *Atmospheric Research*, **125-126**, 34-49. https://doi.org/10.1016/j.atmosres.2013.01.006

Kabela, E. D. and M. J. Parker, 2007: Lightning Detection at the Savannah River Site. Washington Savannah River Company, Aiken, South Carolina.

Leinonen, J., U. Hamann, U. Germann, and J. R. Mecikalski, 2022: Nowcasting thunderstorm hazards using machine learning: the impact of data sources on performance. *Nat. Hazards Earth Syst. Sci.*, **22**, 577–597. https://doi.org/10.5194/nhess-22-577-2022

MacGorman, D. R., and W. D. Rust, 1998: *The Electrical Nature of Storms*. Oxford University Press, 422 pp.

Randerson, D. and W. Schalk, 2006: Investigation of Range-Applicable Lightning Detection Systems. National Oceanic and Atmospheric Administration, Air Resources Laboratory, Silver Spring, Maryland.

Sabu, S., S. Srichitra, N. E. Joby and B. Premlet, 2017: Electric field characteristics during a thunderstorm: A review of characteristics of electric field prior to lightning strike. 2017 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Kollam, India, pp. 1-6. doi:10.1109/SPICES.2017.8091357

Wilson J. G. and K. L. Cummins, 2021: Thunderstorm and fair-weather quasi-static electric fields over land and ocean. *Atmospheric Research*, **257**, 105618. https://doi.org/10.1016/j.atmosres.2021.105618

Yamashita, K., H. Fujisaka, H. Iwasaki, K. Kanno, and M. Hayakawa, 2022: A New Electric Field Mill Network to Estimate Temporal Variation of Simplified Charge Model in an Isolated Thundercloud. *Sensors (Basel)*, **22**(5):1884. doi: 10.3390/s22051884

Workman, E. J., and S. E. Reynold, 1949: Electrical Activity as Related to Thunderstorm Cell Growth. *Bulletin of the American Meteorological Society*, **30**(4), 142–44. http://www.jstor.org/stable/26258148

Appendix A. Expanded Table of Events

A.1 Expanded Table of Events

Table 1 is further broken down into additional components of individual lightning detection methods in Table A 1. This further adds to the understanding for use in further optimization of the thresholds. Of note, addition tB or tD only removes a single lightning strike within 7-miles of the EFM that was only detected by the GLM. Thus, it was not CG and could actually be out of range due to the resolution of the GLM. Adding tC, however, removes events for lightning detected by the NLDN and GLM which creates a false negative scenario that could be costly. Here an additional threshold is added using a minimum less than -1000 V/m that demonstrates further optimization by not including any CG false negative but further reduces false detections (false positives) beyond tD. This threshold was only a test with no justification for including this value.

Table A 1. Expansion of Table 1. Numbers of events for False Detections, Rain Only, lightning within 20-miles for both the NLDN and GLM, lightning with only the GLM within 20-miles, lightning within 7-miles for both the NLDN and GLM, lightning with the NLDN within 7-miles and the GLM within 20-miles, and lightning with the GLM within 7-miles and the NLDN within 20-miles. Includes the threshold of maximum and minimum difference in electric field greater than 500 V/m (tA) and combinations with other thresholds: 15-minute mean less than 0 V/m (tB), 15-minute mean less than -600 V/m (tC), minimum less than -450 V/m (tD), and minimum less than -1000 V/m (additional threshold).

	Diff>500 (tA)	Diff>500 (tA) & mean<0 (tB)	Diff>500 (tA) & mean<-600 (tC)	Diff>500 (tA) & min<-450 (tD)	Diff>500 (tA) & min<-1000
False Detection	437	173	9	158	34
Rain Only	250	171	94	176	123
Both 20mi	45	34	21	33	25
GLM only 20mi	17	13	6	15	9
Both 7mi	86	86	84	86	86
GLM only 7mi	7	6	6	6	6
NLDN 7mi & GLM 20mi	5	5	5	5	5
GLM 7mi & NLDN 20mi	25	25	22	25	23