

Lightning Detection at the Savannah River Site (U)

Washington Savannah River Company
Savannah River Site
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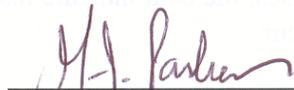
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Executive Summary

Worker safety at the Department of Energy's Savannah River Site (SRS) is the top priority of site management. Remote worker safety is one of the more challenging aspects of worker safety at SRS. Due to the size of the site, 310 square miles, getting timely hazardous weather warnings to remote workers is critical for optimal safety. Lightning presents one of the largest weather related hazards to remote workers.

Lightning can strike with little or no warning, making detection crucial for safety. The Savannah River National Laboratory (SRNL) monitors changes to the electric field of the atmosphere atop a building near the northern edge of the SRS. Data from the electric field sensor were correlated with actual lightning strikes over the 2006 and 2007 lightning seasons. In most cases, the data indicate that ample warning time can be provided before lightning strikes occur.

Also proposed herein is the installation and implementation of two additional electric field mill sensors to be installed near the K- and H-Area meteorological towers. (Parker and Addis [1993] provide a complete description of the meteorological monitoring program at SRS.)

Background

Lightning Basics and Electric Field

Lightning kills an average of 80 people per year, many of whom had little or no warning before thunderstorms capable of producing lightning were present (National Severe Storms Laboratory 2007). The National Severe Storms Laboratory (NSSL) points out that sometimes lightning flashes can simply "come out of the blue" (Figure 1), and have been documented to travel upwards of 25 miles from thunderstorms. This illustrates the need for advanced warning of lightning strikes.

Golde (1977) alludes to the fact that warning time, based on visual observation, for lightning will normally be less than 30 minutes if a storm is first hinted to be 15 km (9.3 miles) away with a forward motion of 30 km hr⁻¹ (18.6 mi hr⁻¹). Lead time of typical warning systems are thus not adequate, due to the fact that forward motion can be greater than 72 km hr⁻¹ (45 mi hr⁻¹).

The Earth's electric field is one way to measure the changing conditions of the atmosphere, and changes in the electric field can provide warning of a potentially dangerous situation. During clear days, a "fair weather" electric field is present where values of average electric field (V m⁻¹) tend to be slightly positive (from 50 to 200 V m⁻¹). This value can be modified slightly due to effects such as dust, smoke, etc. (Mission Instruments Company 2006).

When thunderstorms begin to form, a negative electric charge begins to build on Earth's surface in response to a positive charge building at the base of overhead clouds/thunderstorms. Separation of negative and positive charges occurs with the bottom of the thunderstorm exhibiting a net positive charge, while the surface exhibits a net negative charge (Figure 1). An actual lightning strike begins with a visually undetected downward-moving traveling spark called the stepped leader (Uman 1970). Once this leader is within tens to hundreds of meters above ground, the electric field between the leader from the cloud and the ground becomes large enough to produce electrical breakdown. The electrical breakdown involves one or more upward moving connectors from either the ground or elevated objects such as towers, buildings, or trees. Once the downward and upward propagating leads touch, the circuit is completed as a visible lightning strike; a process that can take as little as 0.5 milliseconds (5×10^{-4} seconds) (Uman 1970; Uman and Rakov 2002).

A strong electric field indicates that the situation is conducive to the formation of lightning. Measurement from electric field mill gives only an idea as to the likelihood of lightning occurring, and is not a guarantee.

Data and Methods

Savannah River Site Lightning Detection

Electric field data for 2006 and 2007 was collected from a Mission Instruments EFS 1001 Electric Field Mill Sensor (Mission Instruments, Co, Jacksonville, OR). Data is sampled every second and average and stored every 15 minutes. Variables stored include average electric field ($V m^{-1}$), maximum electric field ($V m^{-1}$), and minimum electric field ($V m^{-1}$). A description of the electric field mill and its components can be found on the Mission Instruments website at <http://www.missioninstruments.com>.

Typically due to the relatively large spatial coverage of thunderstorms, the electric field does not show much variation over short distances, which is why the EFS 1001 has a minimum operating range of 7 miles. Figure 2 illustrates a map of the Savannah River Site, site rain gages, and meteorology towers. The circle on the map represents a 7 mile radius in which the EFS 1001 would operate. The upper left hand corner of the figure is the current EFS 1001 installed by SRNL.

Data Analysis

Data from the electric field mill sensor was used to look for patterns when lightning strikes occurred, as well as when "false alarms" took place. A threshold was then formulated to devise a lightning detection warning system for SRS. Confirmation of a lightning strike came from archived lightning data from the National Lightning Detection Network (NLDN, Vaisala GAI, Inc., Tucson, AZ), corroborated against radar data. Lightning data was used from June 1, 2006 to September 30, 2007.

An initial test from June 1, 2006 to December 31, 2006 concluded that twenty-six days were found to have confirmed lightning strikes at SRS. There were four days where conditions were favorable for lightning strikes, however, no strikes were confirmed. Three quantities were found to be good indicators of a lightning strike occurring. The first is the difference between the minimum and maximum electric field. When the differences between these two fields exceeded 500 V m^{-1} , lightning struck within approximately 45 minutes 88.5% of the time (23 out of 26), while the other three times this quantity did not provide a warning.

The second quantity used in the analysis was the mean (15 minute) value of the average electric field. When this fell below -600 V m^{-1} , lightning occurred within approximately 15 minutes 81% of the time (21 out of 26), while the rest of the time there was no warning. The last was observing when the minimum electric field fell below zero. Of the 26 days observed, this quantity provided a warning 92% of the time (24 out of 26), while the other two times gave no indication that lightning was imminent.

Results and Conclusions

Upon completion of the analysis portion of this study, a lightning warning system has been designed for possible use at SRS. Twenty-six days were chosen in this study when an electric field mill sensor determined conditions were conducive for lightning to occur and lightning strike data confirmed a strike on site. For days were chosen as example days when conditions were conducive for lightning, however lightning data did not show a lightning strike. One limitation of the lightning data, however, is it only accounts for cloud-to-ground (CG) lightning and not cloud-to-cloud (CC) lightning. Therefore, CC lightning may have occurred thus corroborating the electric field data.

Based on this analysis, a system for timely lightning warnings has been created based on relative "risk". Risk categories "low", "moderate", and "high" are represented by the colors "green", "yellow", and "red" and are denoted as "Normal Conditions", "Watch", and "Warning". A category "green" means that conditions are not favorable for lightning within the vicinity of the site. (However, field workers should still monitor the sky for rapidly changing conditions.)

The next category is "yellow". This implies that the electric field sensor indicates the risk that lightning may occur. Persons outside should be especially cautious and be aware of changing weather conditions. Also, conditions are possibly becoming dangerous with lightning either occurring or soon to occur. Workers need to prepare to take shelter.

Lastly, a category "red" indicates that the electric field is within the high risk category. Conditions are very dangerous and those working outside should seek shelter. Category "yellow" will remain in effect for one hour after the field drops below the threshold to trigger a watch, unless a warning precedes the watch. If a watch proceeds a warning, the watch will remain in effect for 30 minutes after the warning is terminated. A warning will always remain in effect for 30 minutes after field drop below the threshold to trigger a warning. This concept was adopted and modified from suggestions by Gratz and Noble

(2006) in which they suggest an all-clear signal be sounded 30 minutes after thunder is last heard for patrons of National Collegiate Athletic Association (NCAA) football games in the event of inclement weather. This ensures that conditions have improved, and it is safe to re-enter the stadium. The same can be said at SRS where the 30 minute rule ensures conditions have improved and safe working conditions can resume. Results from the use of this new warning system for the entire SRS is shown in Figure 3 and Figure 4.

Of the 26 days when lightning did occur, one day was in category “green” when lightning did occur (4% of the time), three days were in a “yellow” (12%), and 21 days were in a “red” (80%) (Table 1). Warning lead time, time of first strike on site, and warning color category at the time of strike are summarized in Table 2. Of the 4 days when conditions were favorable for lightning with no recordable strikes on site, all 4 attained category red status at some point during the day. Also on these 4 days, rain occurred (with a few embedded thunderstorms) at the time when the red category would have been issued.

The new warning system was tested on the June 1, 2006 to September 30, 2007 data set to determine its effectiveness. Lightning strikes were divided up into those that occurred within the 7 mile operating range of the electric mill at SRNL and those that occurred more than 7 miles away but were also within the SRS boundary. Summary statistics are found in Figure 5. In all, 253 warnings would have been issued over the 15 month period. Forty-nine of those warnings (19.4%) yielded “false alarms” where a warning was issued but no lightning strike was recorded on site and no rain was seen on radar with embedded thunderstorms. Warnings were issued with rain, embedded thunderstorms, and no lightning strikes 110 times (43.5%). Twenty-two times (8.7%), a warning was issued when a lightning strike hit only within the 7 mile operating radius, 21 times (8.3%) a warning outside of the 7 mile radius but within SRS, and 48 times (19.7%) a warning was issued when a lightning strike bit both within a 7 mile radius of SRNL and outside of 7 miles but within the SRS boundary.

This proposed lightning warning system would have yielded an 80.6% success rate with only a 19.4% failure rate for the entire SRS. Watch and warning lead time was also calculated from occurrences where the warning system was a success. Eighty-one cases from lightning strikes within 7 miles of SRNL and 84 cases of lightning strikes from greater than 7 miles from SRNL and still on site were used. Statistics for watch and warning lead time are shown in Table 3 with supplemental statistics shown in Table 4. Results shown in Table 3 indicate an average watch time at less than 7 miles from SRNL to be around one hour with a standard deviation close to one and a half hours; watch lead time for an onsite strike greater than 7 miles from SRNL to be approximately one hour and ten minutes with a standard deviation of one hour and 40 minutes. Average warning times were as follows: 31 minutes for less than 7 miles from SRNL with a standard deviation of 48 minutes; 44 minutes for an on site strike more than 7 miles from SRNL with a standard deviation of 56 minutes.

A median time was calculated for the two watch and warning sets. Overall, when the proposed lightning warning system was successful, it provided a watch time of 40 minutes with a warning time of 15 minutes to locations within 7 miles of SRNL, respectively.

Outside of 7 miles from SRNL and still on site, the warning system provided at watch within 40 minutes and a warning within 23 minutes of a strike.

As can be seen in Figure 2, the seven-mile radius for the electric field sensor operated by SRNL only covers a portion of the SRS. Obviously, the effectiveness of detecting lightning activity beyond the seven-mile radius is in question up to 20% of the time. However, if sensors were placed at K- and H-Areas, lead time may be increased for both SRNL and the rest of the site due to better spatial coverage. Also, missed strikes (strikes where no watch or warning was issued) could be lessened with the addition of two more sensors.

The last statistic to take note of pertains to the number of strikes where only a watch was issued, or only a warning was issued, or where both were issued when a lightning strike occurred (Table 4). Of the 87 strikes less than 7 miles from SRNL, 16 (18%) had only a watch issued at the time of strike, 23 (26%) had only a warning issued at time of strike, and the remaining 48 (55%) had both a watch and a warning issued before the strike. Similar statistics are found with strikes more than 7 miles from SRNL (88 total, 16 [18%] with watch only, 21 [24%] with warning only, and 51 [58%] with both a watch and a warning).

Recommendations

In order to maximize the capabilities of a lightning detection warning system for SRS, it is recommended that two additional EFS 1001 electric field mill sensors be purchased and placed in K- and H-Areas, to compliment the sensor already in place at SRNL. Figure 6 illustrates the increased lightning detection coverage with the addition of two new sensors. The current system, with its 81% success rate, is considered marginally successful. A success rate of at least 90% is desirable in order to consider the lightning warning system adequate for operational use. It is likely that the addition of two electric field sensors would meet or surpass the 90% detection goal.

The position of the current field mill sensor at SRNL covers approximately one-third of SRS. With the addition of two field mill sensors at K- and H-Areas, approximately 90% of SRS would be covered to detect changes in the atmospheric electric field. This would provide the site with ample warning in cases of inclement weather. It should be noted that the electric field mill sensors at K- and H-Areas can be easily incorporated into the existing SRNL meteorological data acquisition system.

References

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Tables

Category	Frequency
Green	1
Yellow	3
Red	22

Table 1: Frequency of lightning strikes under category green, yellow, and red.

Date	Time of Strike (EST)	Lead Time Diff > 500 ($V m^{-1}$)	Lead Time Ave Field < -600 ($V m^{-1}$)	Lead Time Ave Below Zero ($V m^{-1}$)	Category at Lightning Strike
6/2	4:25 PM	105 min	75 min	105 min	Red
6/12	8:35 PM	135 min	75 min	120 min	Red
6/13	6:40 PM	90 min	75 min	155 min	Red
6/25	12:15 PM	75 min	45 min	60 min	Red
6/26	12:30 PM	60 min	45 min	45 min	Red
6/28	3:00 PM	30 min	none	none	Yellow
7/15	4:40 PM	90 min	75 min	75 min	Red
7/21	3:55 PM	45 min	none	45 min	Red
7/22	4:05 PM	60 min	45 min	60 min	Red
7/23	10:25 PM	none	none	30 min	Yellow
7/24	5:15 PM	60 min	15 min	60 min	Red
7/29	4:40 PM	105 min	90 min	90 min	Red
8/4	5:20 PM	none	none	45 min	Yellow
8/5	5:50 PM	45 min	30 min	105 min	Red
8/7	2:00 PM	60 min	45 min	45 min	Red
8/8	2:50 PM	120 min	30 min	75 min	Red
8/9	3:30 PM	45 min	30 min	330 min	Red
8/10	7:10 AM	75 min	60 min	60 min	Red
8/12	5:30 PM	180 min	15 min	75 min	Red
8/21	5:30 PM	60 min	none	60 min	Red
8/22	4:40 PM	75 min	15 min	150 min	Red
8/23	1:20 PM	none	none	none	Green
8/24	3:55 PM	120 min	90 min	60 min	Red
9/4	2:20 PM	165 min	150 min	60 min	Red
9/5	2:20 PM	60 min	45 min	60 min	Red
10/12	12:05 AM	150 min	105 min	150 min	Red
Average Lead Time		77.3 min	44.4 min	81.5 min	

Table 2: Time of first lightning strike, detection lead time for each field, and warning category at the time of first strike.

	Lead Time (minutes)		
	Average	Std. Dev.	Median
Watch Issued for Strike <7 miles from SRNL	60.8	91.3	40.0
Warning Issued for Strike < miles from SRNL	30.9	48.1	15.0
Watch Issued for Strike >7 miles from SRNL and on site	74.4	103.1	40.0
Warning Issued for Strike >7 miles from SRNL and on site	44.4	56.3	22.5

Table 3: Lead time (in minutes) for watches and warnings issued before lightning strikes less than 7 miles from SRNL and those greater than 7 miles from SRNL but still on site.

		Strike <7 miles from SRNL	Strike >7 miles from SRNL and on site
Occurrences	Watch Only	16	16
	Warning Only	23	21
	Both Watch and Warning	48	51
Rate of Occurrence (%)	Watch Only	18.4	18.2
	Warning Only	26.4	23.9
	Both Watch and Warning	55.2	58.0

Table 4: Statistics for occurrences and rate of occurrence for lightning strikes with only a watch issued, only a warning issued, and both a watch and warning issued before the strike occurred.

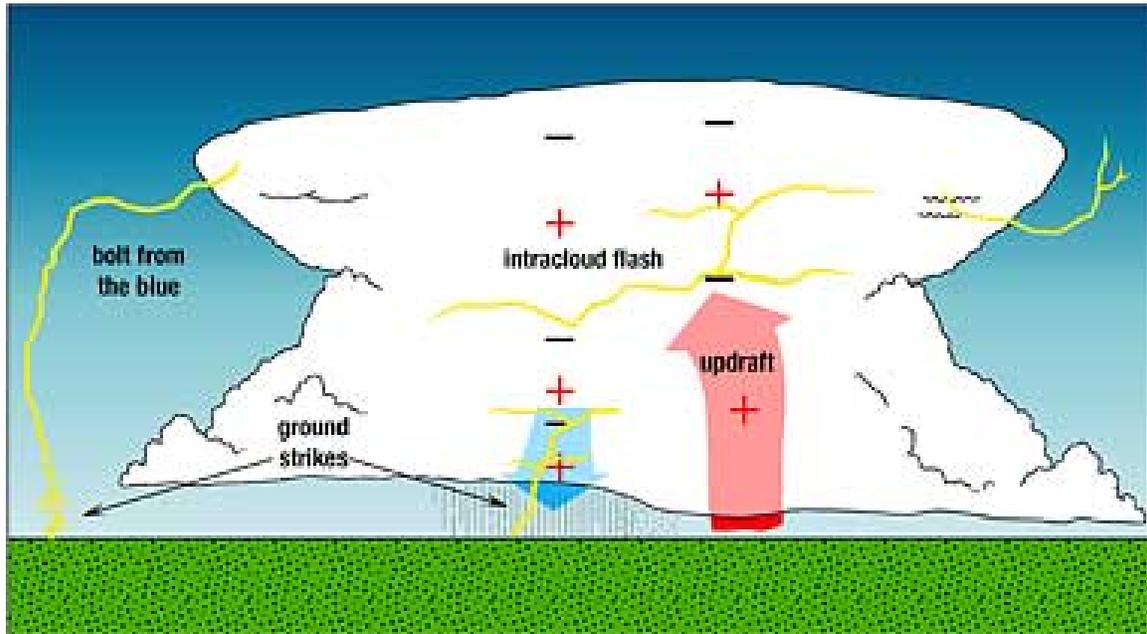
Figures

Figure 1: Schematic of charge separation in a thunderstorm (Source: NOAA/National Severe Storms Laboratory, Norman, OK).

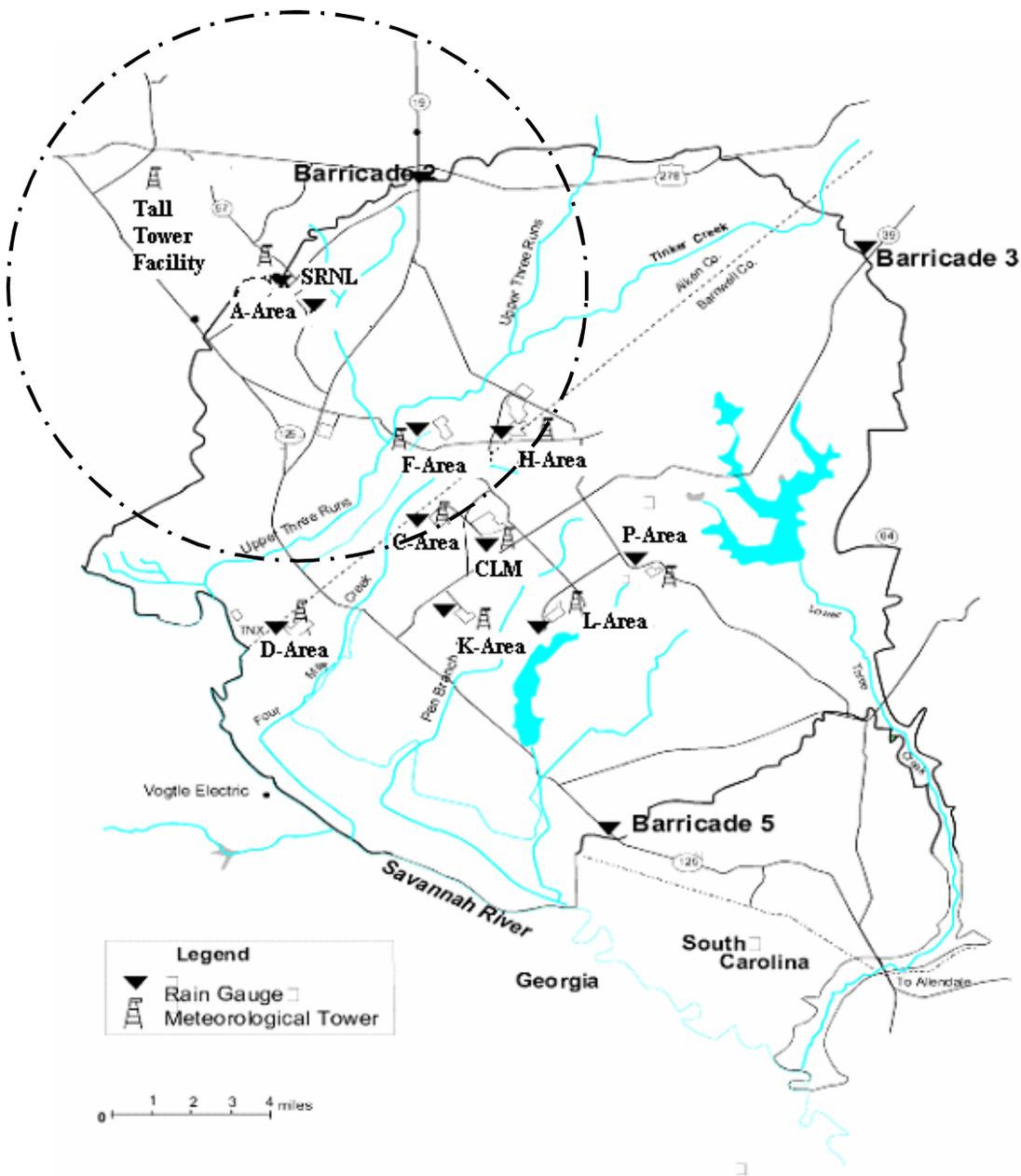


Figure 2: Savannah River Site map with locations of rain gages and meteorological towers. The circle represents the 7 miles range of the electric field mill sensor at SRNL.

The screenshot shows the Atmospheric Technologies Center website. The header includes the SRNL logo and the center's name. A navigation menu is at the top. A left sidebar contains various service links. The main content area is divided into three sections: 'CURRENT CONDITIONS AT SRS', 'REGIONAL RADAR', and 'CONDITIONS AND FORECASTS AROUND THE U.S.A.'. The 'CURRENT CONDITIONS AT SRS' section features a table of ground level observations from ATG's Central Climatology station near N-Area, updated on 03/14/2007 at 4:15 PM. The 'REGIONAL RADAR' section shows a radar map of the Savannah River area. The 'CONDITIONS AND FORECASTS AROUND THE U.S.A.' section includes a dropdown menu for selecting locations. At the bottom, a lightning warning level indicator shows three colored circles (green, yellow, red) with the text 'Current Lightning Warning Level is: GREEN'.

SRNL
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About the Atmospheric Technologies Group (ATG)

CURRENT CONDITIONS AT SRS

Ground level Observations
from ATG's Central
Climatology station near N-Area

Updated 03/14/2007 4:15 PM

Temperature	77 ° F
Dew Point	51 ° F
Rel Humidity	40%
Wind Direction	214° (SW)
Wind Speed	4.6 mph
Max Wind Gust	8.2 mph
Estimated WBGT	69.6°
Heat Stress Index	"None"
Pressure	1008.6 mb

[SRS Forecast](#)

REGIONAL RADAR

CONDITIONS AND FORECASTS AROUND THE U.S.A.

Augusta/Aiken
Albuquerque/Sandia-Los Alamos
Amarillo/Pantex
Asheville

Current Lightning Warning Level is:

GREEN

Figure 3: Atmospheric Technologies Group website with the proposed new lightning warning system on display. This figure illustrates the look of the website under a category “green” warning.

The screenshot shows the Atmospheric Technologies Group website interface. On the left is a navigation menu with links for Current Observations, Radar, ATC Forecasts, Regional/National Weather, Climate Data, Miscellaneous, and About the Atmospheric Technologies Group (ATG). The main content area is divided into three sections: 'CURRENT CONDITIONS AT SRS', 'REGIONAL RADAR', and 'CONDITIONS AND FORECASTS AROUND THE U.S.A.'. The 'CURRENT CONDITIONS AT SRS' section displays ground level observations from ATG's Central Climatology station near N-Area, updated on 03/15/2007 at 7:45 AM. A table lists the following data: Temperature (56 ° F), Dew Point (53 ° F), Rel Humidity (90%), Wind Direction (182° (S)), Wind Speed (2.1 mph), Max Wind Gust (3.8 mph), and Pressure (1006.7 mb). Below this table is a link for 'SRS Forecast'. The 'REGIONAL RADAR' section features a radar map of the region with various cities labeled. The 'CONDITIONS AND FORECASTS AROUND THE U.S.A.' section includes a dropdown menu with city options: Augusta/Aiken, Albuquerque/Sandia-Los Alamos, Amarillo/Pantex, and Asheville. At the bottom of the page, a lightning warning level indicator is shown as a vertical column of three circles: green at the top, yellow in the middle, and red at the bottom. To the right of these circles, the text reads 'Current Lightning Warning Level is:' followed by the word 'RED' in large red letters.

Figure 4: Atmospheric Technologies Group website with the proposed new lightning warning system on display. This figure illustrates the look of the website under a category “red” warning.

80.6% Lightning Detection Success Rate with 19.4% False Alarm Rate

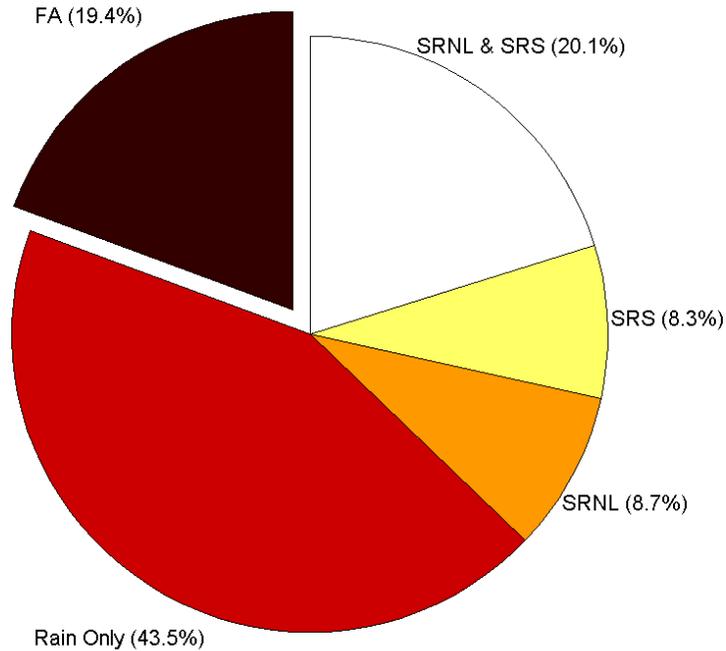


Figure 5: Pie chart with rate of occurrence for false alarms and warnings. “Rain Only” indicates a warning where only rain and embedded thunderstorms occurred, “SRNL” indicates a warning where a lightning strike occurred less than 7 miles from SRNL and nowhere else on site. “SRS” indicates a warning where a lightning strike occurred greater than 7 miles from SRNL but struck within the site boundary. “SRNL & SRS” represents a warning where lightning strikes occurred both within 7 miles of SRNL and greater than 7 miles from SRNL and within the site boundary. Lastly, “FA” indicates the occurrence of false alarms where a warning was issued but no lightning strike or rain with embedded thunderstorms were detected.

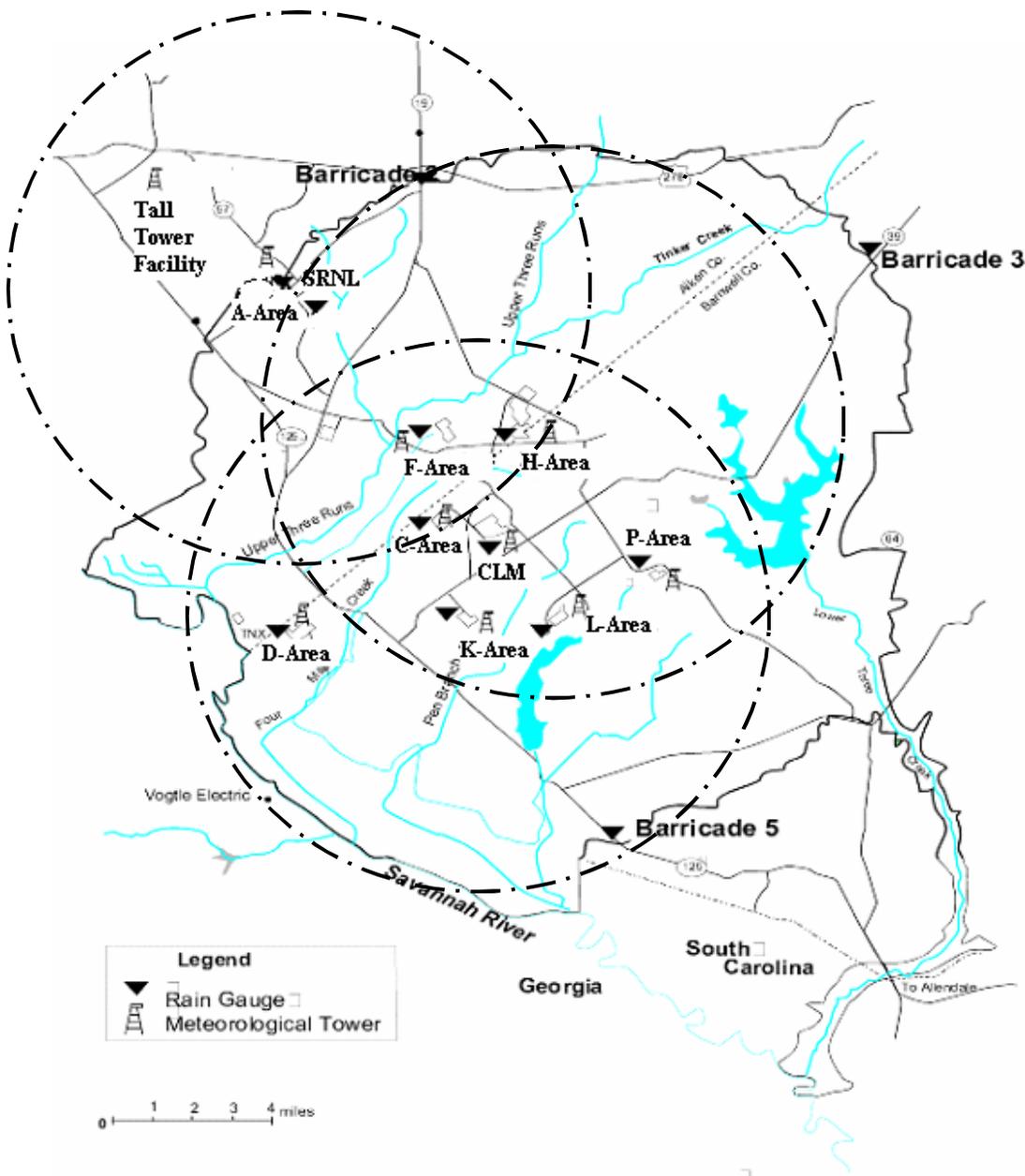


Figure 6: Savannah River Site map with locations of rain gages and meteorological towers. The circles represents the 7 miles range of the electric field mill sensors at SRNL as well as the two proposed sensor sites at K- and H-Areas.