

# The 2014 Upgrade to the Lightning Warning Circles Used by 45th Weather Squadron

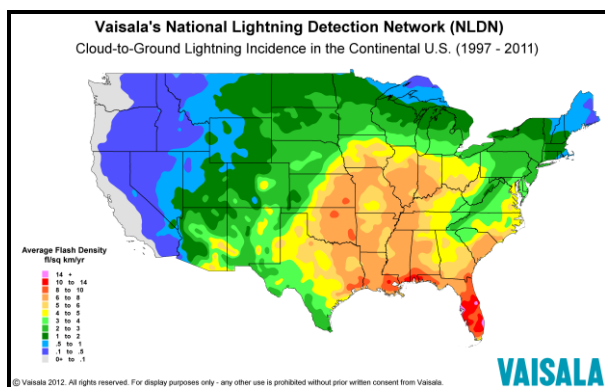
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## 1. Introduction

The 45th Weather Squadron (45 WS) is the U.S. Air Force unit that provides weather support to America's space program at Cape Canaveral Air Force Station (CCAFS) and National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC). The weather requirements of the space program are very stringent (Harms et al., 1999). In addition, the weather in east central Florida is very complex. This is especially true of summer thunderstorms and associated hazards. Central Florida is 'Lightning Alley', the area of highest lightning activity in the U.S. and shown in Figure-1 (Holle et al., 2016). The 45 WS uses a dense network of various weather sensors to meet the space program requirements in this environment (Roeder et al., 2003).



**Figure-1.** Average annual cloud-to-ground lightning flash density for the CONUS (1997-2011). CCAFS/KSC is located in central Florida, the area of highest lightning activity.

The lightning watches and warnings are among the most important services provided by 45 WS. These watches and warnings

provide lightning safety for over 25,000 personnel and protection for over \$20 billion of facilities. An average of over 2,500 lightning watches and warnings are issued each year. A lightning watch is issued for a lightning warning circle(s) when lightning is expected with a desired lead-time of 30 min. A lightning warning is issued when lightning is imminent or occurring within any of the lightning warning circles. The lightning warning circles do not provide lightning safety throughout the entire circle—a safety buffer of several miles is included to protect against nearby thunderstorms throwing a longer flash towards the area being protected (Figure-2). The inner area being protected is a small area at the center of the lightning warning circle.



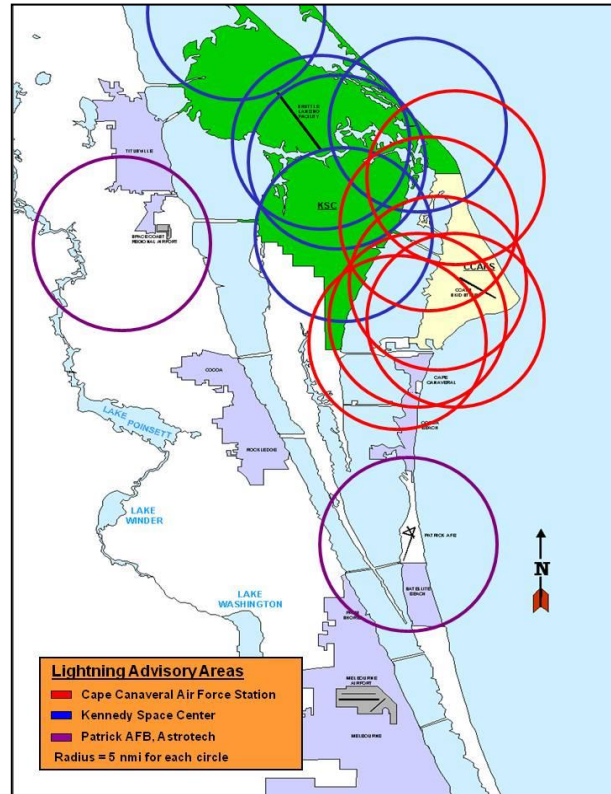
**Figure-2.** An example of some of the 45 WS lightning warning circles. The yellow outer rings define the lightning warning circles. The green inner rings define the area being protected. The distance between the green and yellow ring is several miles of safety buffer required to provide good lightning safety for the inner area.

A new set of lightning warning circles was implemented in May 2014. The main goal was to optimize the new lightning warning circles to:

- streamline the lightning warning process so the forecasters can spend more time predicting the lightning rather than managing the warning process
- reduce the areal overlap of many of the warning circles to better match the state of the art in precision lightning prediction
- increase, or at least maintain, the previous level of lightning safety
- minimize increased over-warning and any other impact on operations

## 2. Previous Lightning Warning Circles

The previous lightning warning process used by 45 WS consisted of a thirteen circles with radii of 5 nmi centered on key facilities on CCAFS/KSC, Patrick AFB, and other nearby facilities (Weems et al., 2001). The previous lightning warning circles are shown in Figure-3. There is considerable overlap of ten of the lightning warning circles on CCAFS/KSC. The median distance to the nearest circle for the ten overlapping CCAFS/KSC circles was 2.71 nmi. Issuing lightning warnings with that precision for these individual circles is at or beyond the state of the art in lightning forecasting. The high frequency of lightning and large impact on operations led to frequent phone calls asking when the lightning warnings would be cancelled. These phone calls took time from the forecasters monitoring the weather and deciding to cancel the lightning warnings. These problems were being compounded as more organizations requested additional lightning warning circles for their locations. A new set of lightning warning circles was developed to improve the 45 WS lightning warning process and was implemented in May 2014. The number of highly overlapping circles on CCAFS/KSC was reduced from ten to seven and the median distance to the nearest circle was increased from 2.71 nmi to 3.39 nmi, an improvement of 30.0% and 25.2%, respectively.



**Figure-3.** The previous 13 lightning warning circles used by 45 WS. Each has a radius of 5 nmi. Most of the circles on CCAFS/KSC have a large amount of areal overlap, which leads to a large amount of temporal overlap in lightning warnings issued by 45 WS.

## 3. New Lightning Warning Circles

The 45 WS redesigned the lightning warning circles to streamline the lightning warning process. The three main goals were to: 1) allow the forecasters to spend more time forecasting the lightning rather than managing the process, 2) reduce the areal overlap in many of the circles, and 3) increase or maintain safety while minimizing increased over-warning. In addition, some opportunities for other improvements were recognized: more precise centering of the lightning warning circles, improved names of the circles, and educating CCFAS/KSC personnel better on the lightning warning circles.

### *3.1 Research in Designing the new Lightning Warning Circles*

The 45 WS had attempted to design a new set of lightning warning circles intermittently for over 20 years but was unsuccessful in finding a satisfactory solution until 2014. These efforts focused on combining the preexisting adjacent pairs of circles into combined warning areas. The first step in designing the new process was documenting the anecdotal impression that many pairs of the lightning warning circles were frequently issued together and thus were effectively single lightning warning areas. This work began with a preliminary analysis under the Air Force Academy Cadet Summer Research Program (Bowman, 2010). This analysis confirmed that there was considerable temporal overlap between some of the CCAFS/KSC lightning warning circles. This led to a more in-depth study by the Naval Postgraduate School to refine the amount of temporal overlap in issued warnings and perform an operational analysis to optimize the design of the lightning warning circles (Ceschini, 2014). This study showed that the temporal overlap in adjacent pairs of the 45 WS lightning warnings varied from 73% to 94%. The operational analysis showed that no improvement was possible with the current 5 nmi lightning warning circles.

The 45 WS finally realized the key limiting factor was using only 5 nmi radii for the lightning warning circles. While previous studies had showed 5 nmi provided a good balance between safety and operational impact, those studies implicitly assumed a single location was being protected. When multiple locations are being protected, combining nearby locations into a single warning area and increasing the radius of the lightning warning circle may offer a better solution. Although a slightly larger radius would be needed to provide the same level of safety and would lead to slight over-warning, there would be fewer warning areas. This could better match the state of the art in forecasting lightning since the distance between the circles would be larger. This would also require less time of the forecasters

in managing the warning process, allowing more time to decide to cancel the warnings. Thus the net effect could be improved overall operations for multiple locations requiring lightning warnings, even if individual warning areas have some over-warning.

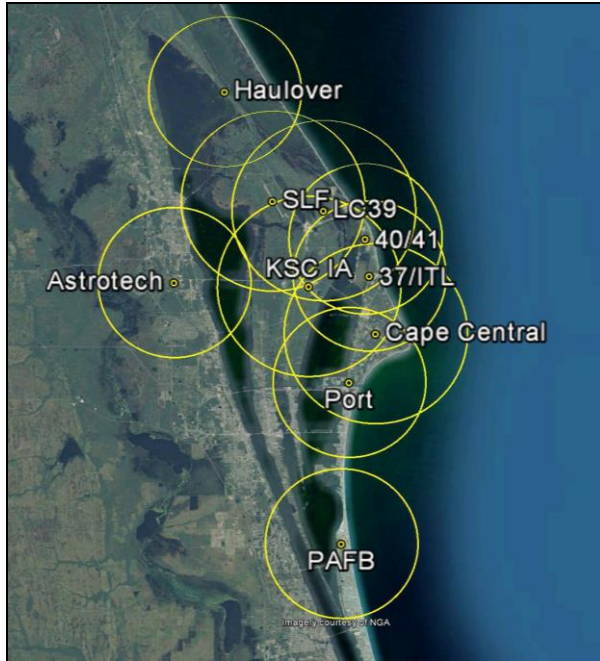
### *3.2 The New Lightning Warning Circles*

The new 45 WS lightning warning circles converted the previous thirteen 5 nmi lightning warning circles into ten circles with radii of either 5 nmi or 6 nmi. A 5 nmi radius is used if one small location is being protected. A 6 nmi radius if several close locations are, or one large location are, being protected. If facilities to receive lightning warnings are more than 1.5 nmi apart, they receive separate warning circles since a single 6 nmi circle cannot provide the desired 4.5 nmi safety buffer to the closest lightning without a warning being issued. When multiple facilities are incorporated into a single warning circle, the average latitude/longitude of all the facilities is used as the center of the circle. This minimizes the new over-warning that would result from the new larger circle.

The new lightning warning circles were implemented in May 2014. The most important improvement was that the seven circles with considerable areal and temporal overlap in issued warnings were reduced to five circles. The new lightning warning circles are shown in Figure-4. An overall comparison with the previous lightning warning circles is in Table-1. A summary of the changes for the individual warning areas is in Table-2 at the end of the paper, after the references.

#### *3.2.1 4.5 nmi Safety Buffer*

Another improvement was changing the distance from protected locations to the nearest edge of the lightning warning circle. Under the previous lightning warning circles, the nearest edge of the lightning warning circles was 5 nmi. Under the new warning circles, the closest distance remains 5 nmi when single locations are being protected. However, when multiple locations are being



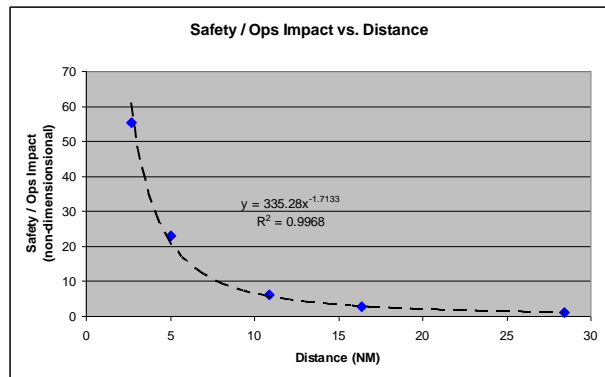
**Figure-4.** The new 10 lightning warning circles used by 45 WS. A radius of 5 nmi is used if one small facility is being protected. A 6 nmi radius is used if several facilities or one facility of large area is being protected.

**Table-1**

Comparison of the new and previous lightning warning circles. Items shaded in green indicate an advantage over the other design.

| Parameter   | New        | Previous |
|---|------------|----------|
| Total number of circles   | 10         | 13       |
| Number of circles with considerable overlap on CCAFS/KSC                  | 7          | 10       |
| Percent improvement in number of overlapping circles                      | 30%        | N/A      |
| Radii of circles  | 5 or 6 nmi | 5 nmi    |
| Average distance to nearest circle for overlapping circles on CCAFS/KSC   | 3.39 nmi   | 2.71 nmi |
| Percent improvement in distance to nearest circle for overlapping circles | 25.1%      | N/A      |

protected, the closest distance is 4.5 nmi. This maintains nearly the same level of safety based on research by Parsons (2000) and McNamara (2002) and adapted for 45 WS use by Roeder (2008) by creating a combined safety/operational impact metric and plotting it as a function of distance. This metric divides the probability of lightning striking within the distance divided by the distance squared representing the increased likelihood of a warning being issued. Since 45 WS issues warnings based on the edge of the lightning field, allowing for a typical lightning field radius of 5 nmi shows that a 4 nmi to 5 nmi standoff distance represents the best balance between safety and operational impact (Figure-5).



**Figure-5.** A combined lightning risk/operational impact metric vs. distance (Roeder, 2008). Allowing for a typical lightning field radius of 5 nmi, the best balance between safety and operational impact is a lightning warning of 4 to 5 nmi (9 to 10 nmi in the figure).

For the new 45 WS lightning warnings, 4.5 nmi was chosen as the closest allowable distance to lightning without issuing a warning. This helps reduce the over-warning that will occur with circles larger than the previous 5 nmi circles. For example, in 6 nmi circles, the 4.5 nmi threshold reduces the over-warning by 17.4% that would have resulted if 6.5 nmi circles had been chosen to provide the same level of safety of the 5 nmi circles.



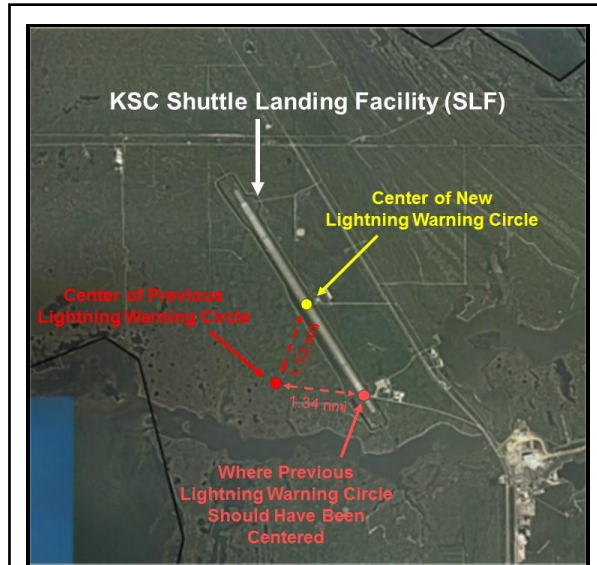
A second factor is that the 45 WS issues lightning warnings based on total lightning, including lightning aloft. Lightning aloft provides an average of 4.2 min of additional lead-time as compared to using just cloud-to-ground lightning (Forbes and Hoffert, 1999). The use of total lightning in 45 WS warnings is supported by the local lightning detection systems used by 45 WS (Roeder and Saul, 2017) (Roeder, 2010).

A third factor to consider is that the 4.5 nmi standoff distance is effectively that used by many Air Force Bases. Consider the standard 5 nmi lightning warning circle centered on the runway at an Air Force Base. The runway would typically be about a mile long, so workers at either end of the runway would have a standoff distance as low as 4.5 nmi from some lightning. While the 5 nmi standoff distance is a frequently used standard in lightning safety, many organizations using it have the same issue of treating an area being protected as a point so that most of the area actually receives less than the 5 nmi safety buffer.

### 3.2.2 More Precise Locations of the Circles

Another benefit of the new lightning warning circles is improved location of the warning circles. Under the previous system, the circles were located only to the closest  $0.01^\circ$  of latitude and longitude. This was an artifact of accuracy of the weather system displays in use over 20 years ago. However, that precision can lead to up to a 0.80 nmi error in the location of the center of the circles at the latitude of CCAFS/KSC. The new circles are located to the nearest  $0.00001^\circ$  of latitude and longitude, or a location error of up to only 0.0008 nmi (4.9 feet).

An example of the benefit of more locations of the lightning warning circles is shown in Figure-6. The previous lightning warning circle for the Shuttle Landing Facility (SLF) was supposed to be located near the southeast side of the runway, but it was mislocated by 1.34 nmi. This is larger than the 0.8 nmi that can be attributed to the limited precision of the previous lat/lon, so some other error must have been involved. In



a) Center of previous circle was supposed to be near the southeast side of the Shuttle Landing Facility (SLF) but was mislocated by 1.34 nmi. The center was also moved 0.91 nmi to the center of the SLF for more efficient lightning warnings for the entire runway.



b) The previous and new lightning circle for the Shuttle Landing Facility. In addition to moving the center to the middle of the SLF and locating it more precisely, the new circle uses a radius of 6 nmi to provide at least a 4.5 nmi safety buffer from the nearest lightning.

**Figure-6.** The previous and new lightning warning circles for the Shuttle Landing Facility on KSC.

addition to a more precise location, the new circle was relocated to the center of the SLF and its radius was expanded to 6 nmi so that everywhere on the SLF receives a safety buffer of at least 4.5 nmi to the nearest lightning. This was especially important given changes to operations since the end of the Space Shuttle program. Previously, most of the outside work was at the Shuttle Mate/Demate Facility at the southeast end of the SLF. Now operations occur all over the runway, such as Morpheus vertical launch and landing testbed operations just off the northwest side of the runway (<https://morpheuslander.jsc.nasa.gov/>).

### 3.2.3 Improved Names of the Circles

Another benefit of the new lightning warning circles is improved naming. This enhances communication during the warning process. Previously, when a lightning watch or warning was issued for a circle protecting multiple facilities all those facilities would be listed. That would lose valuable seconds in notifying the personnel and risk miscommunication if the users missed hearing their specific facility in the list. Under the new process, each circle has a simple name, which allows faster and clearer communication. The circle names were chosen to be meaningful to the users, e.g. 'Cape Central' clearly conveys the center of Cape Canaveral Air Force Station, which helps users remember which lightning warning circle applies to them.

The 'LC39' circle was a good example of customer custom-tailored support. This circle includes Launch Complex 39A, Launch Complex 39B, and the Vehicle Assembly Building (VAB). To some of the 45 WS members designing the new circles, 'LC39' does not clearly convey including the VAB. However, to the KSC workers involved, they think of the VAB as dedicated to supporting Launch Complexes 39A/B, and so to the workers LC39 includes the VAB. Since the goal is to ease use by the customers, and since 'LC39' is shorter than if 'and VAB' were added, that is the name chosen for that lightning warning circle.

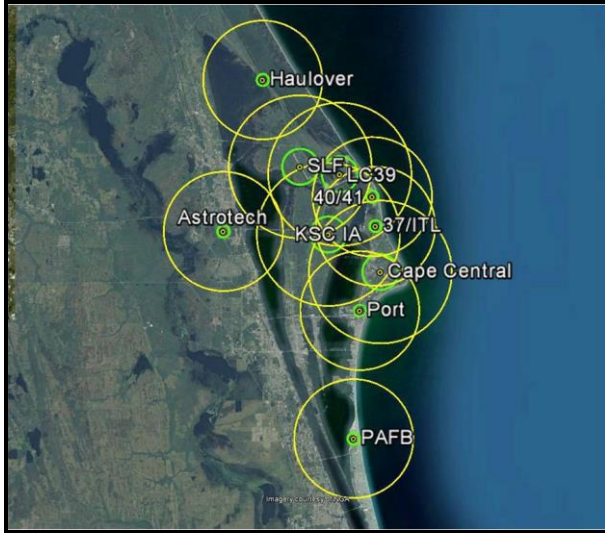
### 3.3 Customer Coordination and Education

Extensive coordination was required with the launch customers, facility managers, 45th Space Wing Safety, KSC Safety, and the KSC Weather Office before implementing the new lightning warning circles. Likewise, extensive training was required for the personnel at CCAFS, KSC, and PAFB. A multimedia approach was used including briefings, posters, mass e-mail, websites, newsletter articles, and newspaper articles. A website application was developed that told which lightning warning circle should be used by every building on CCAFS/KSC. However, that tool was disabled since it contributed to the confusion rather than helping answer as to which lightning circle should be used.

One persistent problem is the perception that the entire lightning warning circle is protected (Figure-7). However, only a small area for a single small facility is protected for the 5 nmi circle or a somewhat larger area for several close small facilities or a single large facility for the 6 nmi circles. Many of the CCAFS/ KSC personnel did not realize that most of the lightning warning circle is to provide a standoff distance as a safety buffer. For example, consider a person outside at the inner edge of a warning circle with lightning just outside the circle adjacent to that person. A warning would correctly not be issued since the lightning is outside the circle, yet the lightning is only a fraction of a mile from the person, which is obviously unsafe.

## 4. Future Work

Although the new lightning warning circles provided significant improvement over the previous circles, further improvement is still possible. For example, one desired improvement under the new circles was not achieved. The 45 WS wanted to combine the two 5 nmi lightning warning circles at Launch Pads 40/41 and Launch Pad 36/37/Integrate Test Launch Facility into one lightning 6 nmi warning area. However, the launch customers at Launch Pad 40 and 41 were concerned there would be too much



**Figure-7.** The new lightning warning circles showing the area within each circle that receives good lightning protection (inner green circles) and the safety buffers (outer yellow circles). Note that the inner protected areas do not cover all of CCAFS/KSC.

increased over-warning and would not accept the change. However, at least the two previous warning circles were relocated for more exact positioning and the Launch Pad 36/37/ITL was relocated slightly for better safety. The 45 WS is working with the Air Force Academy to use real-world total lightning observations to simulate what the warning times would be under the current and proposed lightning warning areas. Once the expected over-warning is determined, that information will be used to try to combine the 40/41 and 36/37/ITL circles.

A second possible improvement would be to further refine the current lightning circles. Although we overcame the paradigm of having lightning warning circles of only 5 nmi radii, we still wanted only two standard size circles, 5 nmi and 6 nmi. As a result, some of the new circles aren't perfect or there are opportunities for improvement. For example, it was discovered after implementation that the Launch Pad 40/41 inner area doesn't quite touch those launch pads, being a tiny fraction of mile too small. Another example, is the new LC-39 circle. Although it covers all three of its intended facilities, an increase of

radius of only about 0.3 nmi would allow the addition of two new facilities with a large number of personnel to be fully covered by the lightning warning inner area. Those two new facilities are the Operations Support Building-1 and Operations Support Building-2. The original lightning warning circles were designed to provide lightning safety for areas with significant outdoor operations, not general lightning safety to personnel. Perhaps that approach should be reconsidered in situations like this where a small change to the circles would include areas with large numbers of mostly indoor workers. In retrospect, it might be better to use the 4.5 nmi safety buffer as the standard and design the lightning warning circles accordingly, allowing the size of the full circles to vary as needed while always providing at least a 4.5 nmi stand-off distance for all the facilities being protected.

A third possible improvement would be to provide lightning warnings that protect all areas and all facilities on CCAFS/KSC. The current process provides lightning warnings only for 18 key facilities that have considerable personnel working outdoors or are very sensitive to lightning. While the lightning warning circles cover all of CCAFS/KSC, this is for the entire circle, not the inner area being protected. The small inner areas being protected do not cover all of CCAFS/KSC. Unfortunately, this results in large areas of CCAFS/KSC not being protected by lightning warnings (Figure-8). The 45 WS and KSC are pursuing approaches to change from the current facility-centric lightning warnings to a user-centric approach. The 45 WS total lightning sensors (Roeder and Saul, 2017) will be used as part of an automated process to provide lightning warnings anywhere on CCAFS/KSC. Outdoor workers will have smart phones that use GPS to continually determine their location. These locations will be used by a central workstation along with the 45 WS total lightning sensors to notify the outdoor workers via the smart phones whenever lightning is occurring within 5 nmi of their location. When no total lightning has been detected within





**Figure-8.** The areas on CCAFS/KSC receiving and not receiving good lightning safety by the lightning warning circles, inside and outside the green circles, respectively.

5 nmi of the workers for about 20 min, a warning cancellation will be sent to the workers via the smart phones. Just as the 5 nmi distance has been determined by studies of lightning strike distance distributions, the 20 min period is set by studies of probabilities of more lightning versus time since previous lightning was observed (Preston and Fuelberg, 2015). The 45 WS has submitted a grant proposal to the Test Resource Management Center to develop and test a prototype of this process and is awaiting approval of that grant. KSC is also developing a prototype for testing. One important question to be answered is how the automated warnings perform as compared to the human warnings for the current facility-centric lightning warnings. It may be that the forecaster adds enough value-added to the process to continue these warnings for those key facilities and adjusting parts of the automated process such as storm motion. In that case, the automated user-centric/smart phone process will be used for outdoor workers not protected by the current

warnings. Eventually, a similar process for lightning watches may be developed. The automated prediction of lightning may combine continuity of motion of current total lightning, radar based prediction, and perhaps the satellite/radar prediction method developed by Mecikalski et al. (2015), which is being tested in central Florida.

Finally, 45 WS and KSC are exploring if the standoff distance safety buffer in the 5 nmi and 6 nmi can be reduced safely. The current radii are based on studies of cloud-to-ground lightning strike distances. These studies implicitly assume the standoff distances are from the point of origin of the lightning or the center of the thunderstorm (Roeder, 2008). However, the 45 WS lightning warning process is based on the edge of the lightning field—this typically includes a few miles to the lightning’s origin or thunderstorm center. Therefore, the 45 WS standoff distances should be based on the distribution of strike distances outside of preexisting lightning fields. Since such studies have not been done previously, the 45 WS and KSC have begun this research. The Applied Meteorology Unit (Madura et al., 2011) has been tasked to do this study. Since the operational impact of the lightning warning circles is proportional to the area of the circle and thus scales as the square of the radius, even a relatively small reduction in the size of the warning circle can yield a large reduction in lost work time. For example, if the standoff distance can be reduced 1 nmi, the operational gain would be 36% and 31% for the 5 nmi and 6 nmi circles, respectively. The 45 WS is conducting a similar study using a different analysis method. Even though this may be duplication of effort, this is being done since lightning warnings are extremely important to personnel safety and resource protection at CCAFS/KSC. Before making important changes to such a vital process, independent confirmation of the research results is desired. If two independent and different analyses yield the same conclusion, CCAFS/KSC can be that much more confident in implementing the change.



## 5. Summary

The lightning warning circles used by 45 WS were significantly improved in May 2014. There were several benefits from the new lightning warning circles and only one main disadvantage of the new lightning warning process.

### BENEFITS:

- the lightning warning process was streamlined so the forecasters can spend more time predicting the lightning rather than managing the warning process
- the areal overlap of many of the warning circles on CCAFS/KSC was reduced to better match the state of the art in precision lightning prediction
- the previous level of lightning safety was increased or at least maintained
- increased over-warning was minimized

### DISADVANTAGES:

- a small increase in over-warning, which was likely offset by the benefits listed above

The previous thirteen warning circles with radii of 5 nmi were reduced to ten circles of radii 5 nmi or 6 nmi depending if one or several facilities were being protected, respectively. Thus safety was improved for several of the circles. The lightning warning circles with considerable areal overlap and temporal overlap in issued warnings were reduced from ten to seven circles, a 30% improvement. Under the previous set, some adjacent circles were so close that the separation was at or beyond the state of art in lightning forecasting. Because of their proximity, adjacent circles had lightning warnings issued simultaneously up to 94% of the time and so were essentially a single warning area. The median distance to the nearest circle for all the overlapping circles on CCAFS/KSC was increased from 2.71 nmi to 3.39 nmi, a 25.1% improvement. By reducing the number of warning areas, the 45 WS streamlined their lightning warning process,

allowing the forecasters more time to analyze the weather and consider cancelling lightning warnings. In addition, the lightning warning circles were located more precisely, eliminating location errors up to 0.80 nmi. Finally, the names of the warning circles were changed for clearer communication. Overall, the lightning warning service provided by 45 WS to the launch customers and personnel at CCAFS/KSC, Patrick AFB, and other facilities was significantly improved.

## 6. Acknowledgements

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**Table-2**

Summary of the changes by individual warning circles. Rows with the same color shading represent key facilities that are protected under the same lightning warning circle. Rows that are unshaded (white) are lightning warning circles that contain only one key facility.

| KEY FACILITIES              | SUMMARY OF CHANGES   |
|-----------------------------|--|
| Launch Pad 17A              | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.20 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |
| Launch Pad 17B              | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.20 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |
| CCAFS Industrial Area       | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.20 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |
| Eastern Processing Facility | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.20 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |
| Fuel Storage Area 1         | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.20 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |
| Munitions Storage Area 3    | Name Of Circle: changed to 'Cape Central'<br>Circle Center: moved to average lat/lon of the six key facilities:<br>LC17A, LC17B, Cape IA, EPF, FSA1, and MSA3<br>(1.80 nmi from previous LC17 lightning warning circle)<br>Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to six facilities |

*Table-2 continued on next two pages*

Table-2 continued

|                                       |   |
|---------------------------------------|---|
| <p>Launch Pad 40</p>                  | <p>Name Of Circle: unchanged, still LC40/41<br/>           Circle Center: moved slightly to center lat/lon of 40/41<br/>           (0.47 nmi from previous 40/41 lightning warning circle)<br/>           (previous lat/lon precision only 0.01°, which led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           Circle Size: unchanged at 5 nmi</p>      |
| <p>Launch Pad 41</p>                  | <p>Name Of Circle: unchanged, still LC40/41<br/>           Circle Center: moved slightly to center lat/lon of 40/41<br/>           (0.47 nmi from previous 40/41 lightning warning circle)<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           Circle Size: unchanged at 5 nmi</p> |
| <p>Launch Pad 37</p>                  | <p>Name Of Circle: unchanged, still LC37/ITL<br/>           Circle Center: moved to center of LC37, plus offset 0.5 nmi toward ITL to provide some safety there<br/>           (1.50 nmi from previous 40/41 lightning warning circle)<br/>           Circle Size: unchanged at 5 nmi</p>   |
| <p>Integrate Test Launch Facility</p> | <p>Name Of Circle: unchanged, still LC37/ITL<br/>           Circle Center: moved to center of LC37, but offset 0.5 nmi toward ITL to provide some safety there<br/>           Circle Size: unchanged at 5 nmi</p>   |
| <p>Port</p>                           | <p>Name Of Circle: unchanged, still 'Port'<br/>           Circle Center: moved slightly to center of facility<br/>           (0.64 nmi from previous LC17 lightning warning circle)<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           Circle Size: unchanged, still 5 nmi</p>    |
| <p>Launch Pad 39A</p>                 | <p>Name Of Circle: unchanged, still LC39<br/>           Circle Center: moved to average lat/lon of the three key facilities:<br/>           LC39A, LC39B, VAB<br/>           (1.60 nmi from previous LC39 lightning warning circle)<br/>           Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to three facilities</p>  |
| <p>Launch Pad 39B</p>                 | <p>Name Of Circle: unchanged, still LC39<br/>           Circle Center: moved to average lat/lon of the three key facilities:<br/>           LC39A, LC39B, VAB<br/>           (1.60 nmi from previous LC39 lightning warning circle)<br/>           Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to three facilities</p>  |
| <p>Vehicle Assembly Building</p>      | <p>Name Of Circle: changed to LC39<br/>           Circle Center: moved to average lat/lon of the three key facilities:<br/>           LC39A, LC39B, VAB<br/>           (1.60 nmi from previous LC39 lightning warning circle)<br/>           Circle Size: increased to 6 nmi from 5 nmi to provide enough safety to three facilities</p>  |

Table-2 continued on next page



Table-2 continued

|                                 |  |
|---------------------------------|--|
| <p>Shuttle Landing Facility</p> | <p>Name Of Circle: unchanged, still SLF<br/>           Circle Center: moved to center of facility<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           (0.91 nmi from previous SLF lightning warning circle)<br/>           Circle Size: increased to 6 nmi from 5 nmi to provide safety across entire facility, including northwest and southeast ends)</p> |
| <p>KSC Industrial Area</p>      | <p>Name Of Circle: unchanged, still KSC IA<br/>           Circle Center: not moved, still at center of the area<br/>           (though now located with lat/lon precision 0.0001°)<br/>           Circle Size: increased to 6 nmi from 5 nmi to provide safety across all the facilities in the area, including west and east ends</p>   |
| <p>Haulover Bridge</p>          | <p>Name Of Circle: unchanged, still Haulover Bridge<br/>           Circle Center: moved to center of facility<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           (0.28 nmi from previous SLF lightning warning circle)<br/>           Circle Size: unchanged, still 5 nmi</p>  |
| <p>Patrick AFB</p>              | <p>Name Of Circle: unchanged, still PAFB<br/>           Circle Center: moved to center of facility<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           Circle Size: unchanged, still 5 nmi</p>  |
| <p>Astrotech</p>                | <p>Name Of Circle: unchanged, still Astrotech<br/>           Circle Center: moved to center of facility<br/>           (previous latitude/longitude precision only 0.01°, led to a slight offset from true center. New lat/lon precision 0.0001°)<br/>           (0.08 nmi from previous SLF lightning warning circle)</p>   |

*end of table*