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USING TOTAL LIGHTNING OBSERVATIONS TO ENHANCE LIGHTNING SAFETY

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1. INTRODUCTION

Severe weather is most typically associated with phenomena such as floods, tornadoes, hurricanes, and hail by the public. These garner much of the media attention as they are large, longer lasting, and can affect large swaths of society at one time. However, while less discussed publicly, lightning is a serious threat from any thunderstorm, although it is far more isolated on a case by case basis. Figure 1 (from Orville et al. 2008) shows that while lighting is greatest in the southeastern United States, nearly every part of the country can experience lightning. According to Holle et al. (1992) and Curran et al. (2000), lightning is the second leading cause of weather related fatalities, behind flooding.

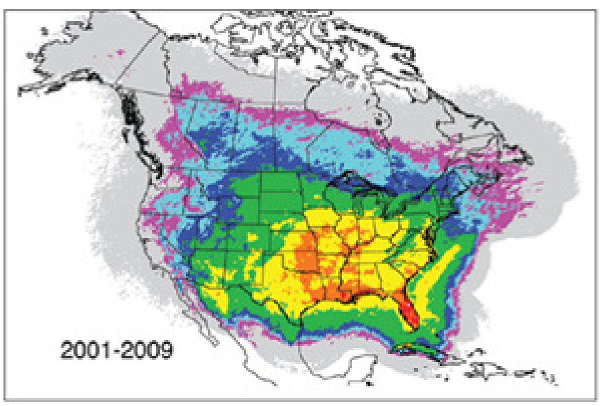

Figure 1: Mean annual average cloud-to-ground strike density for North America from 2001-2009. (From Orville et al. 2011)

Based on the dangers of lightning and our incomplete understanding of its formation, there have been a wide array of studies on the topic (e.g., Uman 1987; Orville 1994; Jameson et al. 1996; Lopez and Aubagnac 1997; MacGorman and Filliaggi 1997; Carey and Rutledge 1998). Utilizing radar data has played a prominent role in studying lightning with attempts to correlate precipitation particles to lightning occurrence (Jameson et al. 1996; Lopez and Aubagnac 1997; and Carey and Rutledge 1998) as well as using radar parameters to detect lightning producing storms (Larsen and Stansbury 1974; Marshall and Radhakant 1978; Buechler and Goodman 1990; Michimoto 1990; and MacGorman and Filiaggi 1997). Research by Holle et al. (1992) found that the majority of lightning casualties occur during the initiation and cessation of storms, where the threat of lightning is less obvious. This has led to studies attempting to create lightning forecasts (Shafer and Fuelberg 2008; McCaul et al. 2009), lightning nowcasts (Vincent et al. 2003; Wolf 2006) as well as lightning cessation (Hinson 1997; Holmes 2000; Stano et al. 2010). Furthermore, the National Weather Service (NWS) already works to convey the threat that lightning poses through special weather statements and wording in severe thunderstorm warnings. The public sector has seen a great deal of attention spent on lightning safety within the past 20 years. This is seen with efforts to improve education about lightning and the wide array of safety policies that are now in place for major outdoor events.

Much of the progress can be attributed to using the observations available from the National Lightning Detection Network (Cummins et al. 1998; 1999 – NLDN). This national network provides continuous observations across the country. However, the vast majority of NLDN observations are of cloud-to-ground strike locations, while the majority of lightning is, in fact, intra-cloud lightning (Boccippio et al. 2001), which the NLDN cannot observe. The ratio can vary across the country. Today, we do have the ability to observe both intra-cloud and cloud-to-ground lightning through the use of lightning mapping arrays (Rison et al. 1999; Krehbiel et al. 2000; Wiens et al. 2005; Goodman et al. 2005; Krehbiel 2008 – LMAs). The combination of both lightning types, called total lightning, provides new avenues of research for expanding our understanding of

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lightning and how this knowledge can be applied to lightning safety.

This paper will discuss the pros and cons of lightning mapping arrays and provide a few examples of how their observations can enhance lightning safety. Furthermore, this will lead to a brief discussion about the Geostationary Lightning Mapper (Christian et al. 1992; 2006 – GLM) that will be launched aboard GOES-R. Lastly, another important point of this paper is to provide information about total lightning to a wider circle of meteorologists who may not have the opportunity to participate in lightning-centric conferences or sessions.

2. TOTAL LIGHTNING OBSERVATION NETWORKS

There are several networks across the country that observe total lightning (e.g. Koshak et al. 2004; Goodman et al. 2005; Krehbiel 2008; MacGorman et al. 2008). NASA's Short-term Prediction Research and Transition (SPoRT) center (Darden et al. 2002; Goodman et al., 2004; http://weather.msfc.nasa.gov/sport/) works with its partners to transition data from three networks to collaborating National Weather Service offices. Each network consists of 8-12 sensors working in concert. The sensors observe electromagnetic pulses in the very high frequency (VHF) spectrum, such as 76-82 MHz. For a network to observe a flash, the flash must be seen by at least six sensors. The observations are processed using the time of arrival at each sensor to triangulate the azimuthal and elevation location of each individual source, or stepped leader, that makes up a full lightning flash. For SPoRT's real-time products, a gridded lightning density product is generated every two minutes.

The big advantage of the LMAs versus the NLDN network is the ability to observe intra-cloud flashes. This allows forecasters to gain improved situational awareness of storms as the amount of total lightning is related to the updraft strength of the thunderstorm. This connection between lightning and updraft evolution was first show in Workman and Reynolds (1949), where the amount of lightning produced was closely tied to the updraft evolution and the appearance of an ice phase. Later Vonnegut (1963), Williams (1985), and Boccippio (2002) demonstrated that the relationship between storm depth and the amount of lightning produced was non-linear, indicationg that storms with strong updrafts have a greater potential to produce more lightning. Furthermore, Carey and Rutledge (1996; 2000) and Pertersen et al. (2005) provide evidence linking precipitation ice mass to lightning occurrence, while Deierling (2006) linked the ice mass and updraft to lightning occurrence. Combined, these studies present a strong correlation between the microphysical and dynamical development of a thunderstorm to lightning activity. A very rapid increase in total lightning in a short period of time, called a lightning jump, serves as a precursor to a given thunderstorm about to become severe (Schultz et al. 2009; Gatlin and Goodman 2010 – Figure 2). Typically, there is little trend in cloud-to-ground only lightning leading to the formation of a tornado (blue line). Conversely, the total lightning trend is very obvious ahead of the tornado (red line).

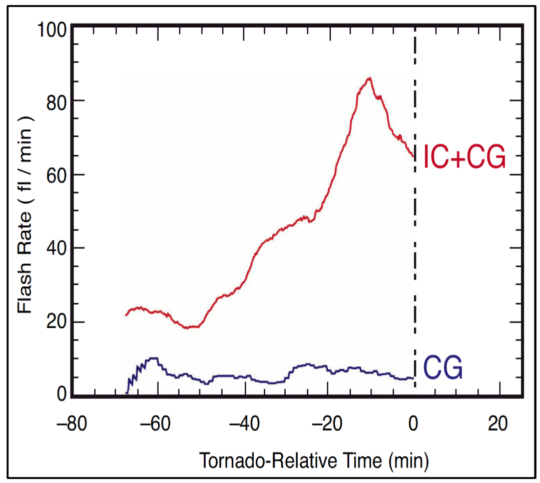

Figure 2: Trends in total lightning (red) and cloud-to-ground (blue) lightning ahead of a tornado touchdown. The rapid increase in total lightning illustrates a lightning jump.

Another way to view this difference is in Figure 3. This shows the lightning observed for 31 summertime thunderstorms in central Florida. The red bars are a plot of all of the cloud-to-ground strikes observed. The blue bars show all of the total lightning flashes observed. It can be seen that the total lightning observations provide more information about the amount of lightning in each storm than the NLDN only observations. This is particularly evident in two storms (13 and 23). Here neither storm had an observed cloud-to-ground strike. However, both were electrically active and in the case of storm 23, it was the most active of all 31 storms.

In addition to more available data, total lightning provides spatial extent information that is not available with NLDN observations. NLDN observes the point where a cloud-to-ground strike reaches the ground. Conversely, since ground-based total lightning networks observe the individual stepped leaders of all flashes, these networks observe the entire lightning channel and not just its termination point. Figure 4 illustrates this. The NLDN observations in the lower left show an electrically active storm. However, the total lightning observations show that lightning extends far beyond the point locations observed by NLDN and in some cases beyond the regions of higher radar reflectivity. From a lightning safety perspective, the basic display shown in Figure 4 can be expanded as shown in Figure 5. Here, the grid display of total lightning plots the maximum lightning value in each grid box for the past 30 minutes. Therefore, the max density display shows where all lightning has occurred within 30 minutes. This can be tied directly to the 30-30 rule that states that individuals should remain indoors for 30 minutes after the last lightning flash.

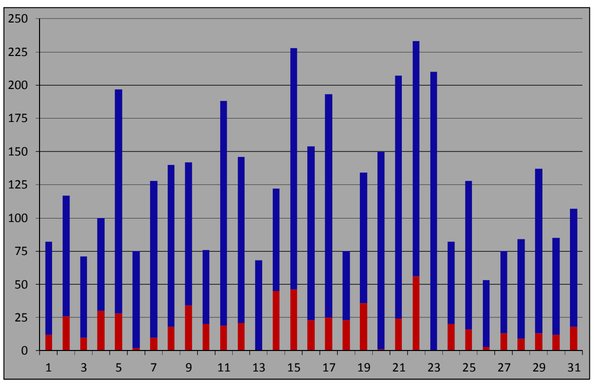

Figure 3: A comparison of cloud-to-ground strikes (red) versus intra-cloud flashes (blue) for 31 thunderstorms in Central Florida. Note the differences in magnitude.

The major drawback to the various LMA networks is that they are short-ranged. The networks usually have a range radius of no more than 240 km. Furthermore, the networks' detection efficiency will drop off with range, which is due to a combination of both the sensor configuration and the curvature of the Earth. This means that while the additional data available from total lightning is incredibly valuable (Bridenstine et al. 2005; Goodman et al. 2005; Demetriades et al. 2008; Nadler et al. 2009; Darden et al. 2010; Stano et al. 2011), these data can only impact a small portion of the country. The following operational examples are taken from real-time events using the ground-based data.

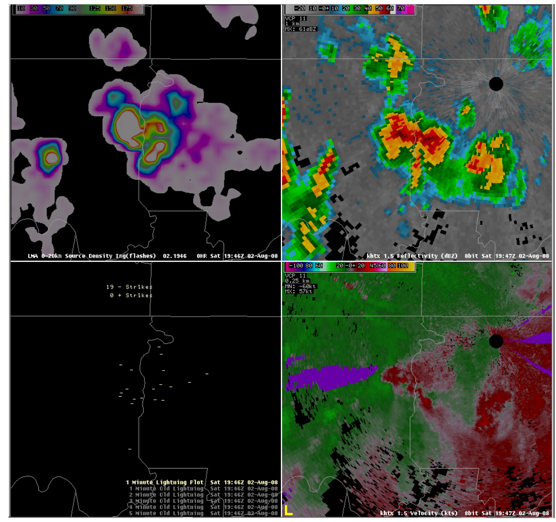

Figure 4: A four-panel display of total lightning (upper left), NLDN cloud-to-ground strike locations (lower left), radar reflectivity (upper right), and storm relative velocity (lower right). The image is in the x-y plane. Note the expanded spatial information from the total lightning.

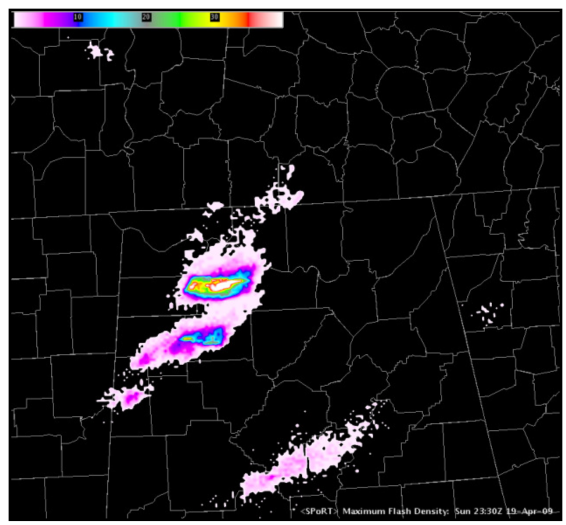

Figure 5: The maximum flash density product developed by NASA SPoRT. This displays the maximum amount of lightning in each grid space for a 30 min period. This provides a visual of where the lightning threat is most likely and provides awareness on how far lightning can reach.

3. OPERATIONAL EXAMPLES FOR LIGHTNING SAFETY

3.1 Airport Weather Warning

The first example comes from the Huntsville, Alabama National Weather Service office on 21 January 2010. The pre-storm environment indicated the potential for thunderstorms during the evening hours and thus the threat for lightning. The 1700 UTC sounding from Redstone Arsenal (not shown) indicated deep layer shear and helicity and CAPE values sufficient for mesocyclones. Furthermore, a dry slot and cold pool aloft existed leading to a steep mid-level lapse rate of 6.9℃ / km. Low top convection then developed across northern Alabama.

This particular event starts at 2200 UTC (Figure 6). Here several distinct cells are observed by radar, including a cell already over the Huntsville airport (highlighted by the range rings). Figure 6 also shows the observed cloud-to-ground (CG) lightning strikes from the NLDN (currently none) and total lightning from the North Alabama Lightning Mapping Array (Koshak et al. 2004; Goodman et al. 2005 – NALMA). With the current lightning observations, no storm is producing CG strikes. However, the cell to the southwest of the airport indicates that lightning is already occurring in this cell.

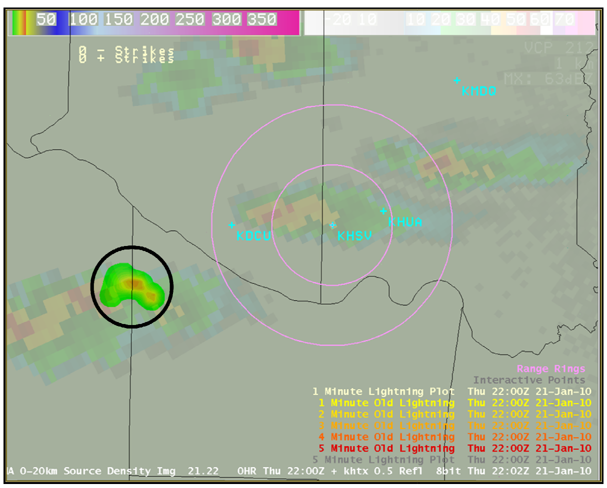

Figure 6: Radar reflectivity (background) and NALMA total lightning (circled in black) from a storm approaching the Huntsville International Airport at 2200 UTC on 21 January 2010. The pink circles are range rings of 8 and 16 km from the airport.

Two minutes later at 2202 UTCT (Figure 7), there is still no CG strikes observed by the NLDN, while the NALMA continues to show lightning activity. With the general motion of the cell to the northeast, towards the airport, the Huntsville office issued an airport weather warning. This warning is designed to alert the airport to the imminent threat of a CG strike within 8 and 16 km of the airport (range rings). In addition, note the small area of lightning detected within 16 km just east of the airport. This would trigger a warning as well.

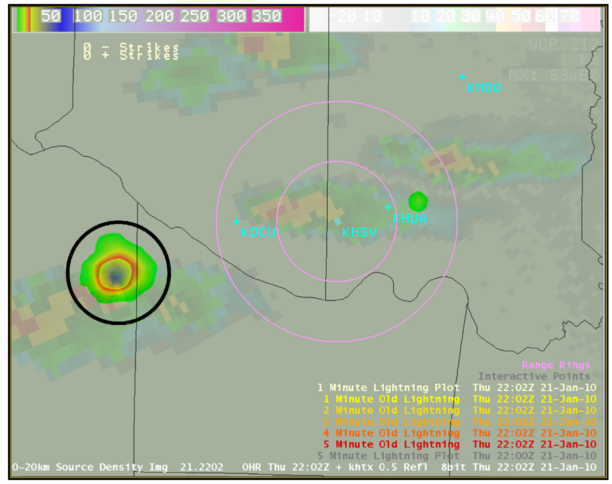

Figure 7: Same as Figure 6 but for 2202 UTC.

Figure 8 occurs at 2206 UTC and here the NALMA continues to observe lightning. Additionally, the NLDN observes the first CG strikes at 2205 UTC, giving the NALMA a 5 minute lead time on the first CG strike. This immediately highlights a primary strength of total lightning over CG only detection networks. The NALMA gave the forecasters an additional 5 minutes of lead time for the airport weather warning. Furthermore, the NALMA observations show the spatial extent of the lightning activity versus the NLDN's point location.

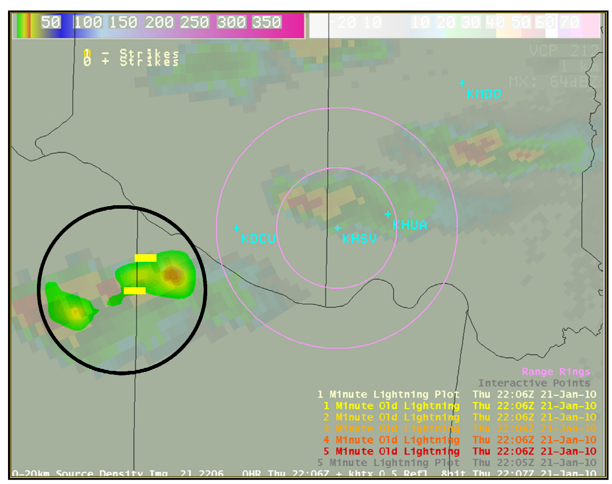

Figure 8: Same as Figure 6, but for 2206 UTC. Note the two cloud-to-ground strikes (yellow dashes)

Finally, we skip ahead to 2232 UTC (Figure 9). Here the storm cell has finally moved over the Huntsville airport. At this point, the NLDN observes the first CG strike within 16 km of the Huntsville airport, verifying the airport weather warning. The lead time for the warning was 30 minutes, giving airport personnel plenty of time to move indoors. Furthermore, the NALMA observations show that intra-cloud lightning is occurring directly over the airport. This clearly indicates that the potential for a cloud-to-ground strike is imminent here as well, and eventually did occur at 2244 UTC (not shown). These results are consistent with previous studies (Williams et al. 1989; MacGorman and Rust 1998; Stano et al. 2010; MacGorman et al. 2011).

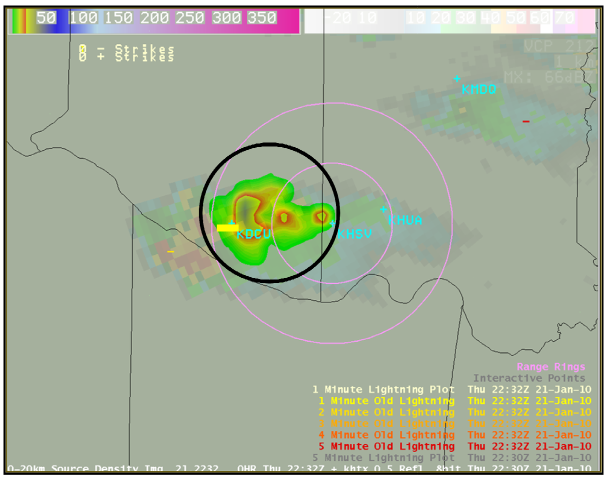

Figure 9: Same as Figure 6 but for 2232 UTC.

3.2 Flash Extent Awareness

A second example that shows some of the unique total lightning capabilities comes from the Melbourne, Florida forecast office. This event comes from a typical sea breeze day in central Florida on 16 August 2010. We will first look at radar reflectivity from Melbourne at 1849 UTC (Figure 10). The sea breeze was progressing inland from the east moving into the Orlando metropolitan and Orlando International Airport regions. From the reflectivity signature, there are several strong updraft cores, providing plenty of charging in this region.

We move forward in time to 1914 UTC with a GOES visible satellite image (Figure 11) taken 25 minutes after the original reflectivity observation (Figure 10). The region of interest has been circled. What is important to note is that in the visible imagery several towering cumulus clouds are observed with anvil clouds being advected to the west. This corresponds well to what has been observed in the radar reflectivity at 1849. Next, at 1923 UTC (Figure 12), we return to the radar reflectivity. Unlike in Figure 10, the reflectivity in the circled region of interest has significantly decreased, particularly in the central part near downtown Orlando. From a reflectivity only perspective, it would appear that the threat of lightning is diminishing. However, the visible satellite image (Figure 11) indicates that the region is covered by a large anvil cloud. This anvil could potentially retain charge.

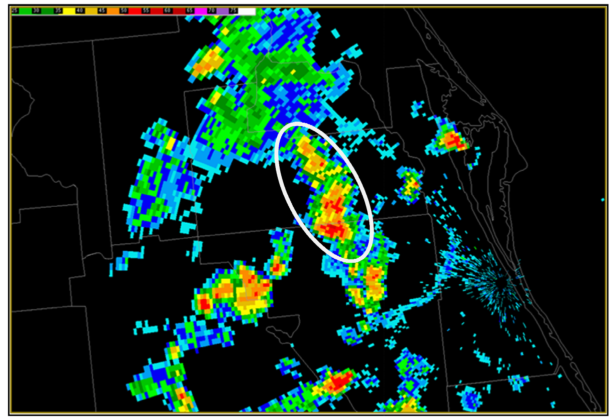

Figure 10: Radar reflectivity from Melbourne, FL on 16 August 2010 at 1849 UTC. The area of interest is circled.

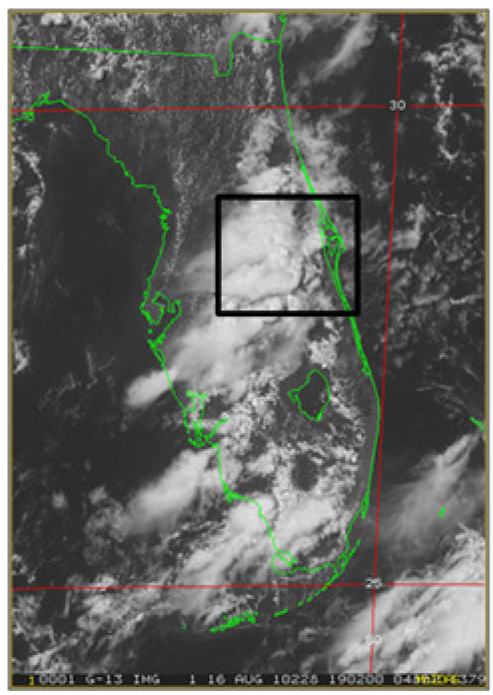

Figure 11: GOES visible satellite image taken at 1914 UTC. The region shown in Figure 10 is outlined in the black box here.

Figure 13 shows that while the radar reflectivity may have decreased, the anvil clouds indeed retained the charge that was produced by the earlier convection at 1849 UTC (Figure 10). Figure 13 shows a single lightning flash that originated in the southern area of interest near the Orlando International Airport, as observed by the Kennedy Space Center's Lightning Detection and Ranging Network (LDAR) at the same time as Figure 12. This flash proceeded north over downtown Orlando and then arced westward towards Apopka and Winter Garden. In total, the flash traveled over 40 km and the majority of the flash occurred in an extremely weak reflectivity region (over Orlando) or where there was no radar reflectivity (Apopka/Winter Garden). No cloud-to-ground strikes were associated with this flash, but the potential existed.

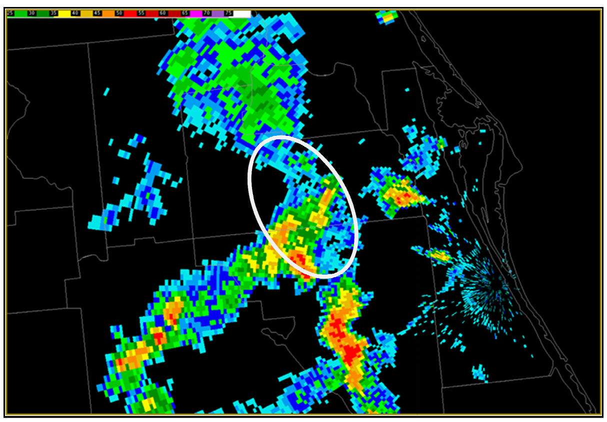

Figure 12: Same as Figure 10 but at 1923 UTC.

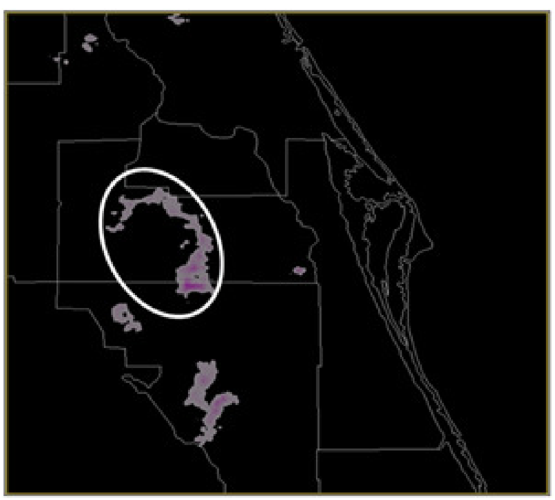

Figure 13: Total lightning observations from the Kennedy Space Center's Lightning Detection and Ranging Network at 1923 UTC on 16 August 2010. The large flash that extended over Orlando, FL is circled in white.

The purpose of this example was to demonstrate that total lightning networks provide a clear picture of the spatial extent of a lightning flash. This is useful for training and public awareness. Although the rain has stopped, the threat of lightning may continue to persist. This is a valuable tool for public safety individuals to show to the public in support of why the 30-30 rule is important. Just because conditions look clear does not mean that lightning is no longer a threat. This is particularly important as shown in this example as the storm that generated the flash was tens of kilometers away from its termination point. While extremely long-ranged flashes are not the norm, examples like this are vital to raise awareness of the potential threat.

4. THE FUTURE OF TOTAL LIGHTNING

While limited in range, the ground-based LMA networks are being used to prepare for the future GOES-R GLM instrument. Once launched, the GLM will be able to provide nearly hemispheric coverage of total lightning (Figure 14) with greater than 90% detection efficiency for both the day and night. Unlike the ground-based LMAs that observe the VHF sources of lightning, the GLM will detect the optical flashes of light.

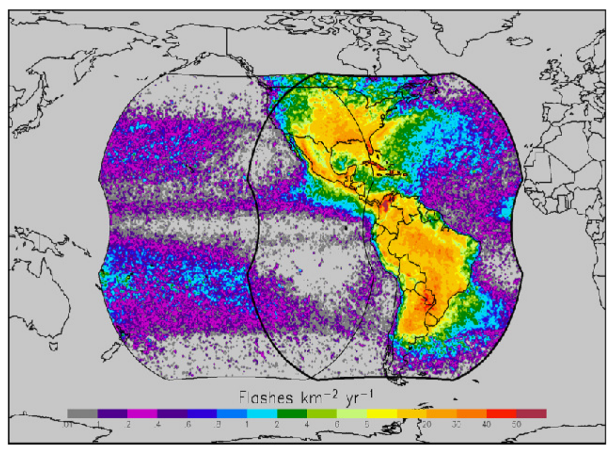

Figure 14: A total lightning density map derived from observations covering 1995-2005 from the Optical Transient Detector and Lightning Imaging Sensor. The two fields of view correspond to the future Geostationary Lightning Mapper fields of view aboard GOES-East and West. (Image courtesy of the NASA LIS Science Team, Huntsville, AL.)

This means that the GLM will observe lightning differently from the LMA networks, but the overall concepts of how to use total lightning will be similar. The other major difference is that the GLM will have an 8 km resolution whereas the LMAs provide their products at 1 or 2 km resolution. SPoRT, collaborating with the GOES-R Proving Ground and the Hazardous Weather

Testbed is involved in helping prepare forecasters for the GLM by producing a demonstration product, the pseudo geostationary lightning mapper (Stano et al. 2012 - PGLM), based on observations from the ground-based networks. This effort aims to better integrate the future GLM data into operations, which also includes how it can assist with lightning safety, and to train forecasters in the use of total lightning. Operational examples using the PGLM in the Hazardous Weather Testbed's Spring Program (Kain et al. 2003) are discussed in Stano et al. (2012).

5. SUMMARY

The purpose of this write-up is two-fold. First, discussions for using lightning in forecast operations are typically limited to lightning specific conferences or sessions or in the discussions of future instrumentation, such as GOES-R. This paper aims to present background information and operational examples of total lightning to a wider audience. The second aspect of this paper is to focus on how total lightning can enhance current lightning safety practices.

Total lightning, as observed by ground-based lightning mapping arrays or the future geostationary lightning mapper (GLM) on GOES-R, is the combination of both cloud-to-ground and intra-cloud lightning. The most well known lightning observation network in use now is the National Lightning Detection Network (NLDN). The NLDN only observes cloud-to-ground flashes. Total lightning provides several benefits over cloud-to-ground only observations. Total lightning, namely the intra-cloud component, usually precedes the first cloud-to-ground strike in a thunderstorm by 5-10 minutes. Some longer lead times exist as do storms that initiate with a cloud-to-ground strike. However, for many cases, the first observations of total lightning will provide a heads-up that a cloud-to-ground strike is imminent. This was illustrated in section 3.1.

Furthermore, total lightning observations do not provide a single point location for a lightning strike. Total lightning observes the full spatial extent of a lightning flash. Most often lightning occurs within a few kilometers of the core of a storm. It is this region where the majority of charging occurs that results in a lightning flash. However, lightning flashes are not confined to just the core of the storm. They can extend for many tens of kilometers into the stratiform region behind a line of storms or within a thunderstorm's anvil (e.g. anvil crawlers). Also, flashes can discharge from one storm core into regions previously charged for earlier storms cores, as shown in Figures 10-13. Where these flashes occur, the threat for a cloud-to-ground strike exists. Having this spatial information provides forecasters and emergency managers greater awareness of where lightning is occurring as well as the fact that lightning is not confined only to regions where there is strong radar reflectivity. This can be further used in training to individuals to help explain why the lightning safety rule is to remain indoors for 30 minutes after a flash is seen or thunder is heard as a flash may not initiate directly overhead.

The primary drawback to total lightning observations is that the majority of observations are taken by ground-based lightning mapping arrays that have a very limited range. This is usually no more than a 240 km radius. This has been part of the reasoning for the development of the geostationary lightning mapper (GLM) that will eventually launch aboard GOES-R in the coming years. The NASA SPoRT program, in concert with its National Weather Service partner offices have been working to develop ways to incorporate ground-based total lightning in forecast operations and use this knowledge to prepare for the availability of GLM data. Although the resolution will be on the order of 8 km, the GLM will provide a huge field of view (Figure 14) and will be a valuable tool to continue to improve lightning safety activities.

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