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Improved Real-Time Lightning Trend Products

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1. INTRODUCTION

NASA's Short-term Prediction Research and Transition (SPoRT) program (Goodman et al. 2004) (http://weather.msfc.nasa.gov/sport/) seeks to accelerate the infusion of NASA Earth science observations, data assimilation, and modeling research into weather forecast operations and decision-making at the regional and local level. The program is executed in concert with other government, university, and private sector partners. The primary focus is on the regional scale and emphasizes forecast improvements on a time scale of 0-24 hours. The SPoRT program has facilitated the use of real-time NASA data and products to address critical forecast issues at a number of partner National Weather Service (NWS) Weather Forecast Offices (WFOs) and private weather entities, primarily in the southeast United States. Numerous techniques have been developed to transform satellite observations into useful parameters that better describe changing weather conditions (Darden et al. 2002).

A core effort of SPoRT is the infusion of total lightning data into real-time operations. The main emphasis has been with the North Alabama Lightning Mapping Array (Goodman et al. 2005 – NALMA). The NALMA, centered in Huntsville, Alabama has been operational since 2001 and was first transitioned to WFO Huntsville in 2003. Since then, SPoRT has provided NALMA data to the surrounding WFOs of Birmingham, Morristown, and Nashville. The utility of these data have been documented by Bridenstine et al. (2005), Goodman et al. (2005), and more recently by Darden et al. (2010). Additionally, SPoRT is coordinating with WFO Melbourne, Florida to transition the Kennedy Space Center's Lightning Detection and Ranging (LDAR) network to that office.

The term total lightning acknowledges the fact that these networks can observe both the cloud-to-ground and intra-cloud lightning flashes within a given thunderstorm. The ability to observe both the cloud-to-ground and intra-cloud lightning in a storm grants these networks several advantages over the well known National Lightning Detection Network (Cummins et al. 1998; 1999; 2006 – NALMA) that can only observe the cloud-to-ground (CG) strike.

First, intra-cloud component of a storm is typically much greater than its cloud-to-ground component (Boccippio et al. 2001). This allows the total lightning networks to observe all of the lightning activity in a storm. This has led to the NALMA's primary use of monitoring the intensity of thunderstorms. Investigations by the Huntsville WFO and other offices with these data (Sharp 2005) show a clear correlation between the time rate of change of total lightning and trends in the intensity and severity of the parent convective cell. Storms that may become severe usually exhibit a very rapid increase in lightning activity, known as a lightning jump (Schultz et al. 2009; Gatlin and Goodman 2010). An example of a lightning jump is shown in Figure 1. The use of lightning jumps to diagnose severe weather operationally has been documented by SPoRT collaborators (Nadler et al. 2009; Darden et al. 2010).

In addition, the NALMA and other total lightning networks observe the full spatial extent of a flash and not just a single point where a flash strikes the ground as observed by the NLDN. As a CG strike can reach the ground many kilometers from where it originated in the storm (reference), these observations allow forecasters to easily determine where electrical activity is occurring. Also, the intra-cloud lightning flashes typically precede the first CG strikes in a storm by several minutes (MacGorman et al. 1989; Williams et al. 1989; Stano et al. 2010a). Combined with the spatial extent, these two features can greatly enhance lightning safety. The major drawback to the

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NALMA and similar networks is their small operational domains.

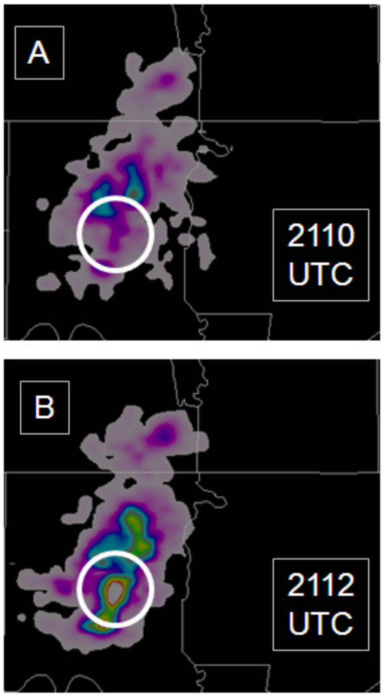

Figure 1: An example of what a lightning jump looks like in AWIPS. The source density count at 2110 UTC (A) is approximately 30 sources. However, two minutes later, at 2112 UTC (B), the source density value has rapidly increased to over 260 sources for the same region shown within the ring.

Feedback from forecasters (Demetriades et al. 2008; Nadler et al. 2009) has indicated that total lightning data has been most useful in moderate severe weather events, where the radar signature is inconclusive or not updating fast enough. In these situations, total lightning has been able to provide enhanced situational awareness and confidence to issue severe weather warnings. However, the process of utilizing lightning jumps in real-time is a subjective one. Each forecaster makes a judgment call to decide if the rapid increase in lightning activity is truly a lightning jump. The situation is further hampered by the fact that the total lightning networks do loose detection efficiency with range. While this is not a major problem, a storm moving rapidly into or out of the network's domain can falsely appear to be intensifying or weakening. Researchers at the University of Alabama in Huntsville (UAH) are attempting to address this by creating the lightning jump algorithm (Schultz et al. 2009). Until this becomes operational, SPoRT is working to develop new visualizations or displays of total lightning data to assist forecasters who need to make a quick decision on a particular storm. This effort is investigating ways to provide additional data to the forecasters within the confines of their current decision support system; AWIPS. The following sections discuss these efforts.

2. Current Efforts

a. SCAN

An early effort was to duplicate efforts by developers at the Meteorological Development Laboratory (MDL) in Washington D.C. The System for Convection Analysis and Nowcasting (Filiaggi 2006 – SCAN) within the NWS' own decision support system was used. MDL created software that took data from the Washington D.C. Lightning Mapping Array and imported these data into SCAN. The result was a system that could track individual storm cells and plot a time series trend of lightning activity. A sample image using code from MDL and NALMA data is shown in Figure 2.

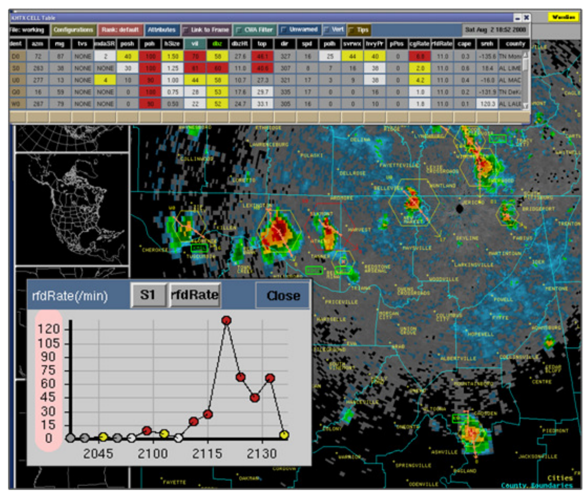

Figure 2: An example of SCAN being used with the NALMA observations and radar reflectivity from Hytop, Alabama. Each storm cell, as defined by SCAN has a hexagon drawn about it and the table provides additional information. The line graph shows the trend in NALMA source densities with a lightning jump for the central storm in the red hexagon.

This was considered a very powerful capability and SPoRT coordinated with MDL to apply the same capability to the NALMA data. The approach using SCAN also addressed a key forecaster request of being able to see how the lightning activity had changed with time for a particular storm cell. Unfortunately, while powerful, the SCAN approach had two major drawbacks. First, it was difficult to implement.

Since the lightning tracking component was not part of the baseline AWIPS system, the periodic software updates to AWIPS itself would cause the changes to SCAN to be broken. This reduced the reliability of the data. Secondly, discussions with forecasters indicated that while SCAN did address the concern of showing the time series of lightning activity, it was not the most efficient use of resources during a severe weather event. The SCAN software could be slow and opens in a separate window and cannot have other meteorological data, beyond radar, overlaid. Additionally, the time series could only be plotted for one cell at a time. These limitations meant that forecasters would be less likely to use the SCAN approach during a real-time severe weather event.

The SCAN approach is still the best option, at this time, to provide a real-time trend product, compared to any other display technique. However, its utility in a rapidly evolving real-time event is more limited.

b. Rate of Change Product

The SCAN technique attempts to address the issue of providing a visualization of the real-time trend of lightning activity by creating a product partially external to the forecaster's native decision support tool, AWIPS. Seeing the limitations faced by this product, SPoRT discussed options with our NWS partners to determine other ways to display these data.

One approach has been to create variant total lightning products. The most commonly used product is the source density product. See Figure 1 for an example. Source densities refer to the raw total lightning observations detecting the individual stepped leaders of a flash. This results in a single flash being composed of dozens to hundreds of individual sources. The source density product is therefore a measure of the number of stepped leaders in a given volume, but one can generally assume that more sources indicate more flashes. Depending on the network discussed, the source density product may be a 1 x 1 or 2 x 2 km product at 1 or 2 min temporal resolution. The NALMA (Figure 1) is 2 x 2 km every 2 min.

SPoRT has attempted to convey different information using the same lightning data, by creating different total lightning products. One of these is the rate of change (ROC) product. This product borrows heavily from the research done by the UAH researchers with their lightning jump algorithm. The algorithm utilizes a storm cell tracker to match lightning activity to a given storm. From there a baseline storm flash rate is derived. Next, the current flash rate is compared to this baseline and its standard deviation from this baseline is calculated. As long as the flash rate reaches a certain threshold and the current flash rate is at least two standard deviations above the baseline, a lightning jump is said to have occurred (Schultz et al. 2009). The UAH results have been robust, but the main issue is the development of a robust cell tracking algorithm.

The ROC product attempts to fill the gap, for now, between the current source density product and the upcoming lightning jump algorithm. Instead of focusing on tracking storms cells, the ROC monitors each individual grid point. In essence, the ROC aims for an Eulerian perspective versus the lightning jump algorithm's Lagrangian perspective. The advantage is that the ROC does not require and computationally costly storm cell tracker.

An example of the ROC product is shown in (Figure 3) and comes from 19 April 2009. The ROC, much like the UAH lightning jump algorithm, monitors the previous 10 min of lightning activity to create a baseline value for each grid point, which is then compared to the current, 2 min flash rate. The actual output shows a gridded product that is color coded to the standard deviation value from the baseline. Warmer colors indicate standard deviations of above 2 sigma, signifying a lightning jump in a particular grid box, whereas colder colors signify negative standard deviations, indicating rapidly weakening locations.

Unfortunately, the simplicity of the ROC product also is its greatest liability. The ROC example shown is based on the NALMA's 2 km resolution. Over the course of 12 minutes (ten to calculate the baseline value and 2 for the current flash rate value) a single storm may traverse multiple grid boxes. The result is that the ROC is picking up on the movement of a storm and the change in lightning activity based on the storm's movement. This results in most of the highest ROC values, indicating a jump, to be in the direction of movement of the storms. There is a corresponding minimum of values behind the maximum as the storms move out of a particular grid box. The problem is further exaggerated when data from the KSC LDAR, which is used at a 1 km resolution, is used. The

ROC performs better for slower moving storms, but it is clear that this method is not viable for real-time operations and clearly emphasizes the need for the UAH algorithm.

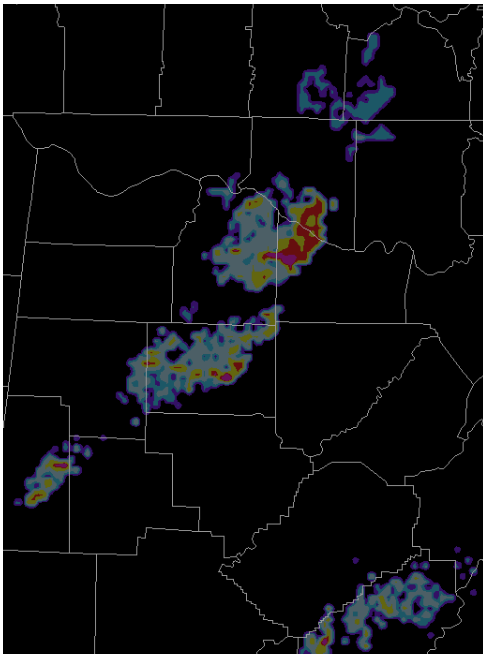

Figure 3: An example of the rate of change product in AWIPS from 19 April 2009. Each grid cell is plotted as a standard deviation from a baseline flash rate for that grid cell using data from 2322-2330 UTC. Warm colors indicate 2 (yellow) or ≥ 3 (red) sigma deviations above the baseline. Cool colors indicate -2 (dark blue) and ≤ -3 (purple) sigma deviations below the baseline. The light blue indicates no significant change. Not that most of the large, positive deviations occur along the leading edge of the storms, along their direction of movement.

c. Maximum Density Product

The two previously described products held a great deal of promise, but where not viable products for real-time operations. With this in mind, SPoRT and our WFO partners discussed what other alternatives may exist. The goal for the new product is to make it available within AWIPS, provide "at a glance" information, and provide more details than using a source or flash density product alone. The next product developed that fits this is this is the maximum density product.

The maximum density product can be derived from either a source or flash density and uses the spatial and temporal resolution of those products. The maximum density plots the greatest flash or source density value at each grid point using any time frame requested. For this presentation, two times were chosen; 10 and 30 min. This product is updated every 2 min (for the NALMA) by dropping the earliest file in the series and adding the most recent 2 minutes (for the NALMA) of observations.

The two times selected for this presentation had specific importance. The first, using 10 min (Figure 4A) is intended to capture a single lightning jump for each cluster of storms. SPoRT's training for total lightning uses 10 minutes as the period of time for a rapid increase in lightning activity to be considered a lightning jump. Lightning activity over a longer time period would indicate a gradually strengthening storm and one that is not necessarily becoming severe. Additionally, storms may cycle in intensity. Using a 10 min timeframe for the maximum density prevents a previous, large value at a grid point from masking the start of a new lightning jump. The second time used, 30 min (Figure 4B), is intended to capture the lifecycle of an individual cell as it moves across each grid box. Note how in Figure 4B, the 30 min product shows regions of increased lightning activity to the west of each cell cluster, indicating these cells had intensified, weakened, and were intensifying again. While a 30 minute timeframe will mask individual lightning jumps, particularly for stationary storms, the product tends to create what appears to be a track of lightning activity. Seeing this spatial trend as a storm moves has resulted in this product also being called the density track product.

The two time periods capture different aspects of a storm's lifecycle as it moves across the grid, but the general interpretation is similar. By itself, the maximum density product can give a history of lightning activity for various storm regions over time. Both time periods show how intense the lightning activity has been. Additionally, the maximum density product works well as a lightning safety tool. Instead of showing just a two minute snapshot of lightning activity, like the NALMA source density product, the maximum density retains the observations for all lightning activity in the domain for the specified period of time. In particular, the 30 min product ties in well with the current rule of thumb for lightning safety, stating that individuals should remain indoors for 30 min after the last flash. Potentially, the 30 min maximum density product could be evolved into a simple lightning safety tool as it shows where all lightning has been occurring throughout the domain.

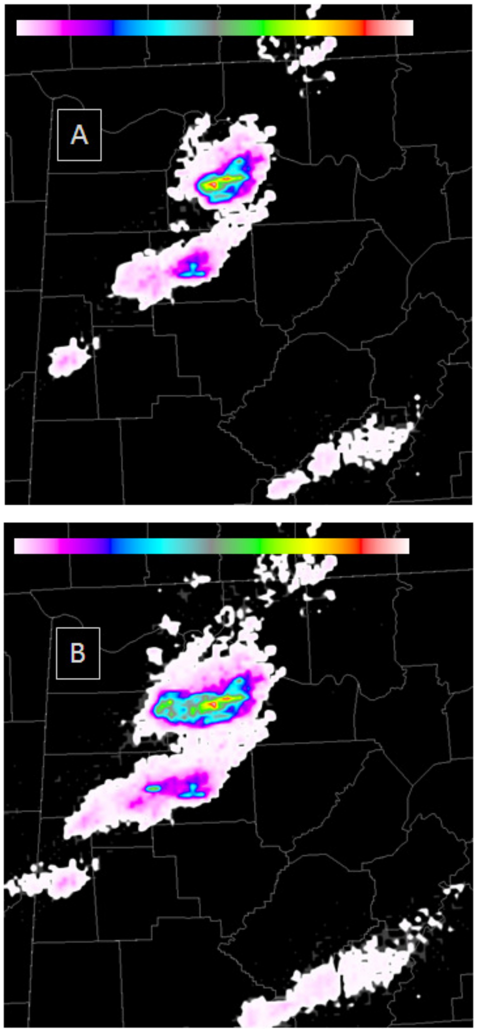

Figure 4: An example of the maximum source density product in AWIPS II use composite times of (A) 10 min and (B) 30 min on 19 April 2009. Note the greater spatial extent in the 30 min version and the ability to see the change of lightning activity with time from individual, strong cells.

Another use for the maximum density product is in concert with the source density product. Within AWIPS, forecasters can either overlay the current 2 min source density (for the NALMA) on the maximum density product or separately in different windows (Figure 5), such as a four panel plot. Our example uses the 30 min maximum density. When done, forecasters can quickly visualize the current lightning activity level and compare it with a history of the storm's maximum activity, at least in a grid box sense.

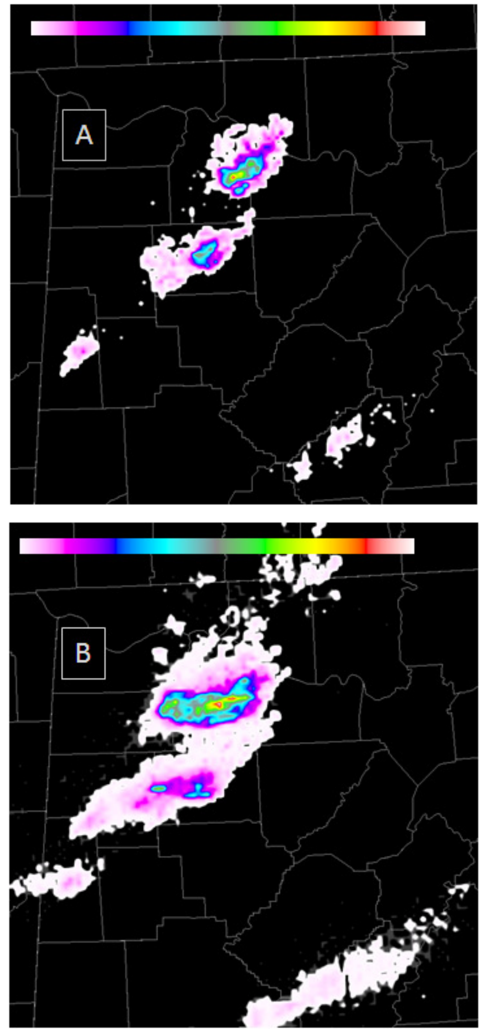

Figure 5: An AWIPS II comparison between (A) the instantaneous source density values at 2332 UTC versus the 30 min maximum source density values ending at 2330 UTC on 19 April 2009.

The result is that a forecaster does not have to mentally reconstruct the lighting levels by constantly looping the source density product, nor do they need to open a program external to AWIPS. A forecaster can therefore, at a glance, see where the current source density values have increased compared to the previous 10 or 30 min of maximum values. However, there is an added benefit. In addition to spotting locations where the lightning activity is rapidly increasing, the combination of the source density and maximum density products allow forecasters to monitor storms that are maintaining significant levels of lightning activity as well as noting which locations may be experiencing a reduction in lightning activity. These regions of reduction may inform forecasters that this particular region is losing strength and the threat of severe weather is diminishing.

This can be applied to our example in Figure 5, where there are 3 main clusters of storms in a line stretching from the west central portion of the domain to the north central. A fourth cluster is in the southeast. Comparing the 2 min source densities (Figure 5A) to the 30 min maximum source density (Figure 5B), the southeastern cluster of storms show no major changes. Here, lightning remains active, but as of 2332 UTC, the lightning activity remains at a steady state. The same can be said for the small cluster on the southwestern portion of the line of storms in the domain. In the middle cluster, the 30 min density track shows lightning activity from nearly the Alabama-Mississippi border to the current location at 2332 UTC in the source density product. The maximum source density also shows that the cluster did have a large increase to the west and then dissipated before increasing to a maximum value of 30-40 sources. However, the source density product at 2332 UTC shows that the middle cluster has ramped up to 60-70 sources for the same region. This is a clear indication that these cells are intensifying and may be ready to become severe. Lastly, the northernmost cluster can be seen to have maintained maximum values 60-120 sources over a wide region for the past 30 minutes, although the storms have intensified to nearly 200 sources recently. The source density product (Figure 5A) shows that the intensity of the main cell is still near 200 sources, indicating that this storm has maintained its intensity and is still severe (based on the NWS' previous observations of this storm in conjunction with the lightning data). Also, immediately south of the maximum value in the northern cluster, a secondary cell appears to be forming that that barely visible in the maximum density product, but clearly visible in the source density product.

3. Summary and Future SPoRT Actions

At this point, SPoRT has qualitatively investigated three separate methods to address forecaster feedback for the need of better insight into the trend of lightning activity within a storm. These include an update to the SCAN software, developed by the Meteorological Development Laboratory (MDL), a grid-based flash rate of change product (ROC), as well as a grid-based maximum source or flash density product. The investigation was informal as SPoRT coordinated with our partners at the Huntsville, Alabama WFO to look for ways to address this issue.

SCAN was the first method investigated and comes very close to providing the information that forecasters need. By including MDL's upgrades, the SCAN algorithm can track individual cells and then plot a time series of lightning activity for each storm cell (Figure 2). Unfortunately, SCAN is an external addition to the baseline AWIPS software. As a result, forecasters must load new windows when they wish to run SCAN, which can be a time consuming process. Additionally, these external windows do not allow an overlay of other observations. The most success with this product has been seen with the Sterling, Virginia WFO. SPoRT will continue to work to implement this and look for additional ways to improve this product.

The second product, ROC (Figure 3), was not found suitable for real-time application. The ROC was a "what if" case of applying the University of Alabama in Huntville's (UAH) lightning jump algorithm methodology to a grid-based product. This is a major departure from the UAH method that tracks individual storm cells. As a result, ROC observes lightning activity from an Eulerian perspective, versus the Lagrangian perspective from UAH. The ROC suffered from the small grid spacing used by the various ground-based total lightning networks. Even a slow moving storm could affect multiple grid boxes during the 12 minute window used to calculate the current flash rate's standard deviation from the grid box's baseline value. This resulted in false lightning jumps being registered as a storm moved across multiple grid boxes, particularly for fast moving storms. The results show that the UAH approach will clearly be the preferred method in the future. SPoRT will be involved to assist the UAH researchers transition their results to the operational AWIPS setting.

The last product investigated was the maximum density (Figure 4A/B), which could use either source or flash densities. Like the other two products, the maximum density is an attempt to create a new AWIPS visualization of total lightning data that may provide more information than the basic source or flash density alone. The maximum density does work well in conjunction with the existing total lightning density products. When combined, the current 2 min source density (Figure 5A/B) with either the 10 or 30 min maximum density lets forecasters see how the current lightning activity compares to the previous activity in a region. Aside from the ROC, this work used source densities as the primary quantity to track. However, the activities discussed with this paper are just as viable with a flash density-based product (or mandatory in the case of the ROC). Additionally, a forecaster can use this combination to not only decide if a region is experiencing a lightning jump but also maintaining its strength or decreasing in activity. This particular product may also be valuable as a lightning safety tool, showing the spatial extent of all lightning for the previous 10, 30, or other user selected period of time. This product's utility, both for severe weather and lightning safety, will be investigated further.

This informal evaluation brought up another topic of discussion. Ground-based total lightning data are currently only used in a column total source or flash density product. The three-dimensional nature of the observations is not used. This is not due to a lack of effort by forecasters, but due to a lack of efficient visualization the data. Currently, ground-based total lightning data are provided in AWIPS as gridded products with multiple levels of data. However, due to time constraints, only the total column density values are used as it takes too much time to load individual levels to investigate a storm. Studies, including Ushio et al. (2003) have observed vertical lightning development within storms, indicating that the three-dimensional component may be important to interrogating storms. While a full three-dimensional visualization in AWIPS is unlikely, it may be possible to create a product that displays how quickly lightning activity is progressing vertically.

The discussion on the three-dimensional data ultimately brings the conversation to the topic of AWIPS II (Tuell et al. 2009). This will be the next generation of decision support system used by the National Weather Service. SPoRT is already involved in understanding how AWIPS II operates and developing plug-ins for the system (Stano et al. 2010b). Currently, SPoRT has developed a plug-in for the existing visualization of total lightning data, which can already be applied to the rate of change or maximum density products. However, this merely replicates what is available in the existing AWIPS framework. AWIPS II should provide more flexibility in terms of how the data are imported and how they can be displayed. Once example is that an advanced version of SCAN is being developed, which may be a powerful tool. Additionally, SPoRT will investigate better ways to display total lightning data, which may result in the ability to investigate total lighting in a three-dimensional sense.

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