Preparations for Integrating Space-Based Total Lightning Observations Into Forecast Operations

Geoffrey T. Stano[1], Kevin K. Fuell[2], and Andrew L. Molthan[3]

NASA Short-term Prediction Research and Transition (SPoRT) Center

[1]ENSCO, Inc., [2]University of Alabama in Huntsville, and [3]NASA Marshall Space Flight Center

Huntsville, Alabama, United States

ABSTRACT

NASA's Short-term Prediction Research and Transition (SPoRT) Center has been a leader in collaborating with the United States National Weather Service (NWS) offices to integrate ground-based total lightning (intra-cloud and cloud-to-ground) observations into the real-time operational environment. For much of these collaborations, the emphasis has been on training, dissemination of data to the NWS AWIPS system, and focusing on the utility of these data in the warning decision support process. A shift away from this paradigm has occurred more recently for several reasons. For one, SPoRT's collaborations have expanded to new partners, including emergency managers and the aviation community. Additionally, and most importantly, is the impending launch of the GOES-R Geostationary Lightning Mapper (GLM). This has led to collaborative efforts to focus on additional forecast needs, new data displays, develop training for GLM uses based on the lessons learned from ground-based lightning mapping arrays, and ways to better relate total lightning data to other meteorological parameters.

This presentation will focus on these efforts to prepare the operational end user community for GLM with an eye towards sharing lessons learned as EUMETSAT prepares for the Meteosat Third Generation Lightning Imager. This will focus on both software and training needs. In particular, SPoRT has worked closely with the Meteorological Development Laboratory to create the total lightning tracking tool. This software allows for NWS forecasters to manually track storms of interest and display a time series trend of observations. This tool also has been expanded to work on any gridded data set allowing for easy visual comparisons of multiple parameters in addition to total lightning. A new web display has been developed for the ground-based observations that can be easily extended to satellite observations. This paves the way for new collaborations outside of the NWS, both domestically and internationally, as the web display will be functional on PCs and mobile devices. Furthermore, SPoRT has helped developed the software plug-in to visualize GLM data. Examples using the official GLM proxy product will be used to provide a glimpse as to what real-time GLM and likely MTG-LI data will be in the near future.

1. Introduction

NASA's Short-term Prediction Research and Transition (SPoRT; Darden et al. 2002; Goodman et al. 2004; Jedlovec 2013) Center is part of the Marshall Space Flight Center in Huntsville, Alabama in the United States. SPoRT's mission is to transition unique NASA and NOAA observations and research capabilities to the operational weather community. The primary emphasis is on short-term weather forecasts on the regional and local scale.

Started in 2002, SPoRT collaborates with a number of weather forecast offices and national centers across the United States. The collaborative activities demonstrate the capabilities of experimental products for weather applications and societal benefit. SPoRT works in a testbed environment that allows it to rapidly prototype capabilities in operations for evaluation. Additionally, in the case of the GOES-R and JPSS proving grounds (Goodman et al. 2012), these efforts serve to prepare forecasters for these new missions.

SPoRT's success and its role in the proving ground is due to a successful paradigm of collaboration with our end users (Figure 1). The paradigm is focuses on an end-to-end transition of developing a product, providing it in

Corresponding Author: Dr. Geoffrey T. Stano
NASA SPoRT, ENSCO, Inc.
320 Sparkman Dr., Huntsville, AL 35805 Unites States
E-mail: geoffrey.stano@nasa.gov

the user's display system, providing training and assessment. Throughout the process, SPoRT includes end users in development in order to maintain a focus on the operational utility of the experimental products. The success of the program has been with a paradigm (Fig. 1) that emphasizes close collaborations with end users. This allows for identification of forecast problems and potential solutions, the development of training, transitioning products into the user's display system, and conducting assessments of the potential solution.

One effort that has been a core activity for SPoRT since 2003 is the demonstration of total lightning (cloud-to-ground and intra-cloud) observations from ground-based lightning mapping arrays (Rison et al. 1999; Koshak et al. 2004) in operations. Through coordination with our operational partners, SPoRT has developed training that is based on feedback from assessments of total lightning data usage. SPoRT's collaborations with our end users have demonstrated the utility of total lightning for severe weather warning decision support, situational awareness, lightning safety, and aviation applications (Bridenstine et al. 2005; Goodman et al. 2005; Demetriades et al. 2008; Nadler et al. 2009; Stano et al. 2010a, 2014; MacGorman et al. 2011; Stano 2012; White et al. 2012). These demonstrations have been supported by 11 ground-based lightning mapping arrays (Fig. 2) with local forecast offices, national centers, and emergency managers.

Figure 3 highlights several key features of total lightning observations. Unlike more well-known ground-based lightning observations systems such as the National Lightning Detection Network, Global Lightning Detection, World Wide Lightning Location Network, or Earth Networks the lightning mapping arrays have superior detection efficiency of intra-cloud lightning, albeit within a small region of the network (e.g., a 240 km radius). Also, the total lightning observations provide the spatial extent of lightning and not a single point observation.

Physically, total lightning activity is driven by the strength and volume of the updraft in the mixed phase region of a storm (staring around -10°C). A stronger and deeper updraft will generate more lightning (Lhermitte and Krehbiel 1979; Tessendorf et al. 2005; Kuhlman et al. 2006; Deierling et al. 2008) and this effect is non-linear. As a result, total lightning observations can serve as a proxy for the intensity of the storm's updraft and allow for the monitoring of convective development. In extreme cases a rapid increase, or lightning jump (Gatlin and Goodman 2010; Schultz et al. 2009, 2011), can indicate the potential for severe weather (e.g., > 2.5 cm hail, > 26 ms^{-1} winds, or a tornado).

Since 2009, SPoRT has led training efforts for the Geostationary Lightning Mapper (GLM; Christian et al. 1989, 1992; Christian 2006; Goodman et al. 2013) in the GOES-R Proving Ground with the pseudo-geostationary lightning mapper (PGLM; Stano et al. 2010b, 2011, 2012, 2014) demonstration product. Although an imperfect representation of what the GLM will observe, this real-time product has provided the means to demonstrate GLM capabilities (i.e., 8 km flash rate trends) and to start the iterative training process to prepare for the GLM. Figure 4 (slide 4) shows an example of the PGLM during an evaluation of this product at the Hazardous Weather Testbed (Kuhlman et al. 2010; Stano et al. 2012).

Additionally, SPoRT has worked with Marshall Space Flight Center's lightning group to use the GLM proxy for training for the United States' National Weather Service. Unlike the PGLM, the GLM proxy attempts to create a transformation function between ground-based lightning mapping array data and the TRMM-Lightning Imaging Sensor (Christian et al. 1999). The effort is designed to convert the ground-based observations (in the very high frequency spectrum) to the near-infrared view of GLM. This is only available for a few specific cases, but these data are invaluable for demonstrating the GLM products that will be available after launch.

This manuscript summarizes the presentation made for the 2016 EUMETSAT conference outlining NASA SPoRT's efforts to prepare the Unites States forecaster community for the GOES-R GLM. This will include a demonstration from the training that has been developed as well as a brief discussion on lessons learned so far and the potential for collaboration with EUMETSAT with the preparations to launch the Meteosat Third Generation Lightning Imager. Appendix A provides the links for additional information on NASA SPoRT, GOES-R, and the GLM.

2. Preparations for the Geostationary Lightning Mapper

NASA SPoRT personnel have continued to play a leading role in the GOES-R Proving

Ground particularly with the Geostationary Lightning Mapper. At the time of the 2016 EUMETSAT conference, the launch of GOES-R was just over a month away. To prepare the forecaster community, SPoRT has been involved with the two foundational training modules for the GLM; one as a subject matter expert and the other as the primary developer. The imagery presented here comes from NASA SPoRT's GLM training module focusing on the visualization of the GLM in operations.

This training is intended to provide a basic understanding of what the GLM is and how it will be visualized operationally. Once launched, SPoRT will focus on new modules that directly address the operational applications of the GLM. Given the similarities between the GLM and EUMETSAT's Lightning Imager, much of the material presented here can be used to help support user preparedness efforts for EUMETSAT.

An important step in the training is to demonstrate what GLM observations will look like in the National Weather Service's display system; the Advanced Weather Interactive Processing System (AWIPS). This is the utility of the GLM proxy as it provides observations of events, groups, and flashes derived from a ground-based LMA. The advantage of the proxy over the TRMM-Lightning Imaging Sensor is that the proxy can be used to monitor a storm over its entire life cycle as oppose to the 90 s overpass view from TRMM.

This requires a brief discussion of the GLM observations. This manuscript provides a brief discussion. A full description of the GLM and its standard observations are available in Goodman et al. (2013).

The most basic GLM observation is the event (Fig. 5) and shown with radar reflectivity. An event represents any illuminated pixel during a 2 ms window. These are identified brightening of the pixel compared to the background. This comparison to a background allows for GLM to observe lightning during the daytime. A note about figure 5 should be made. The GLM observations will be provided with no more than 20 s latency. The demonstration shown here shows a one minute summation of the GLM observations.

Following events are the derived groups (Fig. 5). The groups are clusters of events based on temporal and spatial criteria. The location of the groups are weighted by the radiance power of the associated events. The groups are equivalent to the return strokes observed by other ground-based lightning detection networks.

Lastly, groups are clustered based on temporal and spatial criteria into flashes (Fig. 5). Like the groups, the flashes are weighted by the radiance power of the associated groups. The current GLM flash has one difference from the events and groups. Unlike the events and groups, the GLM flash only shows the centroid of the flash. This means that the spatial extent information that is available in the events and groups is not currently available. This is an operation issue that SPoRT is recommending to be changed for GLM.

Figure 6 provides an alternative way to view how the GLM events, groups, and flashes come together. In this example, there is only one flash observed. The image shows that the single flash is composed of two groups and five events. In addition to showing how multiple events are combined into groups and then a single flash, it also shows how the radiance weighting can slightly shift the location of the observations.

As mentioned previously, using the GLM proxy allows for investigated a case for training that is not possible with the short "snapshot" of data from the TRMM-Lightning Imaging Sensor. This is demonstrated in Figs. 7-10 highlighting a tornadic event that occurred in northern Alabama in the southeastern United States on March 2, 2012. The initial display is similar to figure 6 and shows GLM proxy events, groups, and flashes along with the corresponding radar reflectivity. The yellow rings highlight an area of interest.

At 1430 UTC (Fig. 7), a broken line of storms is moving from west to east across northern Alabama. The environment is conducive to severe weather, but no severe weather has been reported at this time. The reflectivity is strong (>50 dBZ) in numerous locations. With no other information a warning forecaster would likely need to spend time on most of these locations to determine if there is a potential for severe weather. The GLM proxy offers a little insight. Unlike the reflectivity, the GLM events, groups, and flashes are concentrated on storms on the southwestern and northeastern ends of the line. This is indicating that while the reflectivity may be similar across the entire line, the convection is strongest in these two locations. The forecaster must remain aware of the situation across the entire line of storms, the GLM proxy helps focus the forecaster's attention on where the storms may be more dangerous.

Four minutes later at 1434 UTC (Fig. 8), the radar reflectivity has not yet updated. However, the same cannot be said for the GLM proxy. Lightning observations can be observed throughout the line. The events and groups also show the spatial extent of the lightning and how the lightning is extending beyond the main convective cores. The increase in lightning activity immediately highlights that the storms throughout the line are likely intensifying. Another feature that stands out is the lightning activity in the central part of the line, circled in yellow. Here there is a local maximum in the events and groups that are combined into two flashes. This is far short of a lightning jump, but it suggests that the central part of the line of storms may be intensifying more rapidly than the rest of the line. It is not a strong observation, but the warning forecaster may choose to focus attention on this part of the line of storms.

The greatest change is observed thirteen minutes later at 1447 UTC (Fig. 9). Here, all three GLM proxy observations show an increase in activity in the central part of the line. The corresponding radar reflectivity also increases to nearly 60 dBZ. The greatest GLM proxy values are directly associated with the strongest storm core. The increase, while likely not strong enough to be an official lightning jump clearly indicates that this section of the line is continuing to intensify and is the most likely candidate to generate severe weather. Furthermore, the spatial extent of the events and groups indicate that the threat of lightning extends several tens of kilometers away from the main convective cells in the line. This storm would continue to intensify and eventually produced an EF-3 tornado.

Another way to visualize this event is with the tracking meteogram tool (Fig. 10) that was developed for the National Weather Service by the Meteorological Development Laboratory and NASA SPoRT. This tool allows forecasters to manually select storm cells of interest to track and to receive time series plots of the gridded fields of interest. The tracking tool for the GLM proxy shows a steady increase in lightning activity as the storms develop and intensify. Meanwhile, the radar reflectivity plots shows a minor increase, but a limited trend in the observations overall.

3. Future Work

The previous section provides a small demonstration of the work NASA SPoRT is conducting to support user readiness of the Geostationary Lightning Mapper (GLM) as part of the GOES-R Proving Ground. This initial effort is designed to prepare the Unites States forecaster community for the GLM, understand its basic capabilities, and to contrast its abilities with currently available ground-based lightning detection systems. This is only the first step in SPoRT's activities.

NASA SPoRT is continuing to work with its NOAA partners to prepare the visualizations of GLM observations for the user community. This is primarily for the National Weather Service's AWIPS system, but also includes ongoing web-based visualization tools for other end users such as community emergency managers. Part of this effort includes recommending changes to how the GLM data will be visualized once the instrument is operational. The first is to ensure that the data can be viewed as an accumulation or summation of data over a 1-2 minute period. Previous work has indicated that showing the GLM observations in their native 20 s increments may not be possible in AWIPS and makes it very difficult to identify trends in the lightning data for both severe weather decision support and lightning safety. Also, SPoRT is recommending that the event data be used to change the current flash product from a single, flash centroid point to a flash extent density that allows forecasters to observe both where the greatest number of flashes are occurring and the spatial extent of the flashes observed.

Following the foundational training NASA SPoRT will be developing an applications library of GLM cases for operational training on the GLM. This will be based on concepts derived from the ground-based lightning mapping arrays, which have served as the de facto demonstration product for the GLM with the NASA SPoRT pseudo-geostationary lightning mapper product. This effort will demonstrate to forecasters operational cases where GLM data have been used, highlight situations where GLM data may not be as readily viable (e.g., high shear, low CAPE environments), and show the wide array of forecast scenarios the GLM can provide support to (e.g., severe weather decision support, lightning safety, aviation forecasting, etc.).

Some of the cases for this applications library will come from an operational assessment of the GLM that will be led by NASA SPoRT. SPoRT will draw on the collaborations it has built with end users using the ground-based lightning mapping arrays to focus on an initial assessment of how forecasters will use GLM data in operations. This will occur during the summer and fall of 2017 after the GLM instrument has gone through its calibration and validation phase. The effort will identify cases to use in training as well as identify concepts that need additional training in order for the forecasters to best utilize GLM observations.

Lastly, with the launch of GLM provides an opportunity for collaboration. NASA SPoRT is leading the effort for developing the training to prepare the United States forecaster community. This training will support a variety of end users from local forecast offices, emergency managers, to aviation weather forecasters. This diversity in applications provides a wide range of expertise to share with international partners as other satellite-based lightning observations are launched, such as EUMETSAT's Meteosat Third Generation Lightning Imager. The work by the international community offers an opportunity to share experiences in both training an applications development.

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Appendix A – Supplemental Information Links

NASA SPoRT web page:
http://weather.msfc.nasa.gov/sport/

NASA SPoRT training web page:
http://weather.msfc.nasa.gov/sport/training/

Wide World of SPoRT Blog:
https://nasasport.wordpress.com

GOES-R web page:
http://www.goes-r.gov/

The Geostationary Lightning Mapper:
http://www.goes-r.gov/spacesegment/glm.html

Images

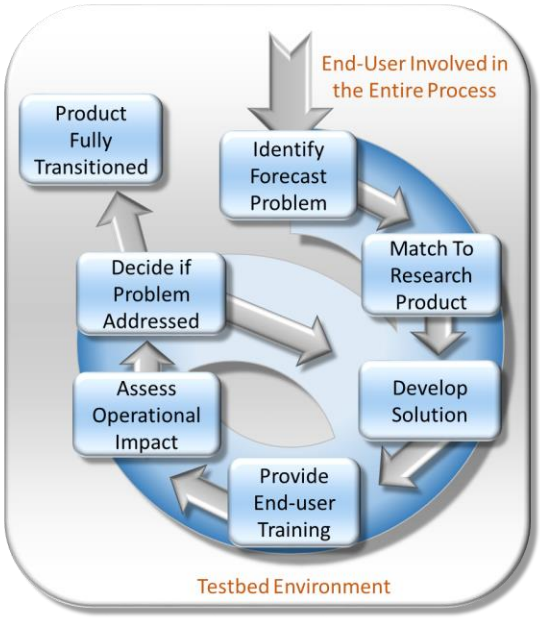

Figure 1: The NASA SPoRT research to operations paradigm. This demonstrates SPoRT's efforts to incorporate the end user throughout out the process to identify a solution to a forecast issue, develop training, perform assessments, and determine if the forecast issue has been properly addressed.

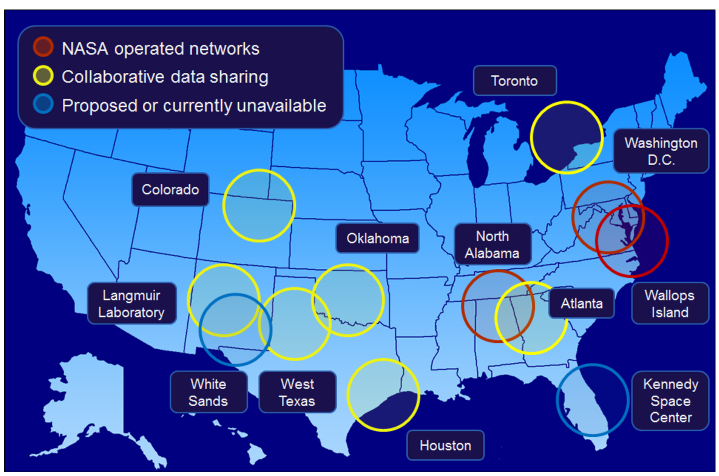

Figure 2: This image shows all of the ground-based lightning mapping arrays that NASA SPoRT is or is working to obtain data from to demonstrate with our operational partners. The rings show the approximate range of each of the networks.

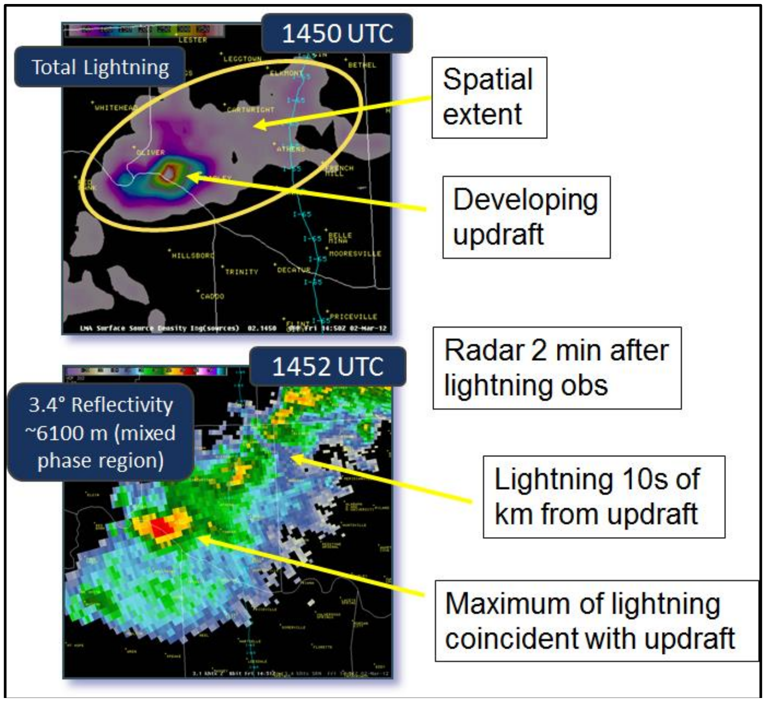

Figure 3: This figure shows several unique features of total lightning observations that will be available from the Geostationary Lightning Mapper. Total lightning observations can provide information on the spatial extent of lightning as well as serve as a proxy for the strength and intensity of a storm updraft in the mixed-phase region of the storm.

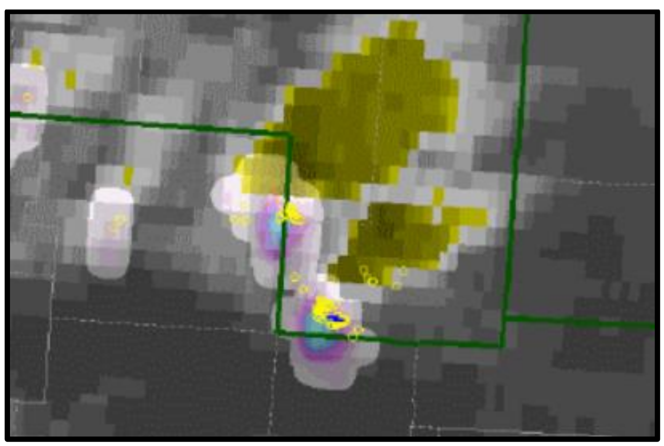

Figure 4: An example of the NASA SPoRT pseudo-geostationary lightning mapper with 8 km resolution (multi-colored shading) along with the GOES-14 infrared (background), and Earth Networks intra-cloud and cloud-to-ground flash points during the 2015 Hazardous Weather Testbed.

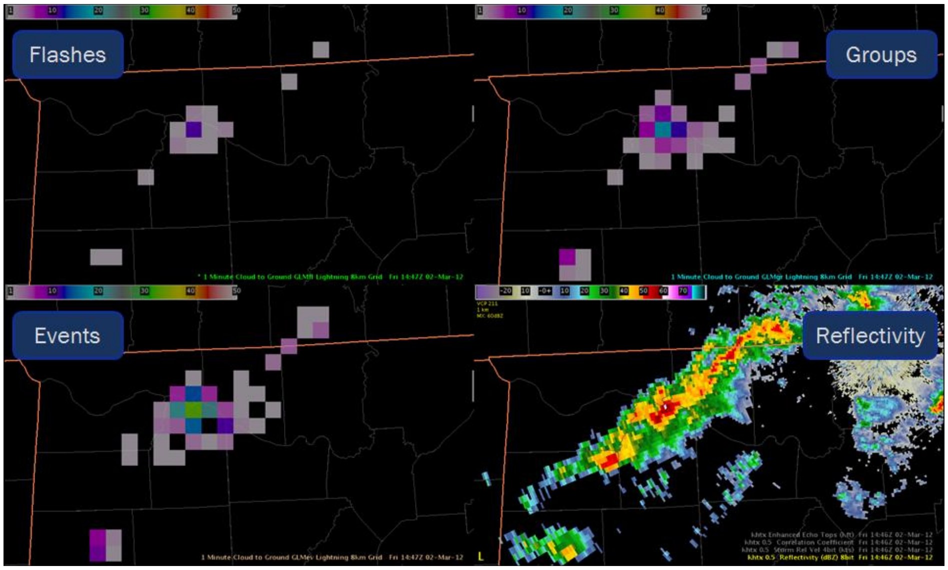

Figure 5: A visualization of the GLM proxy demonstration GLM events (lower left), groups (upper right), flashes (upper left), and the corresponding radar reflectivity.

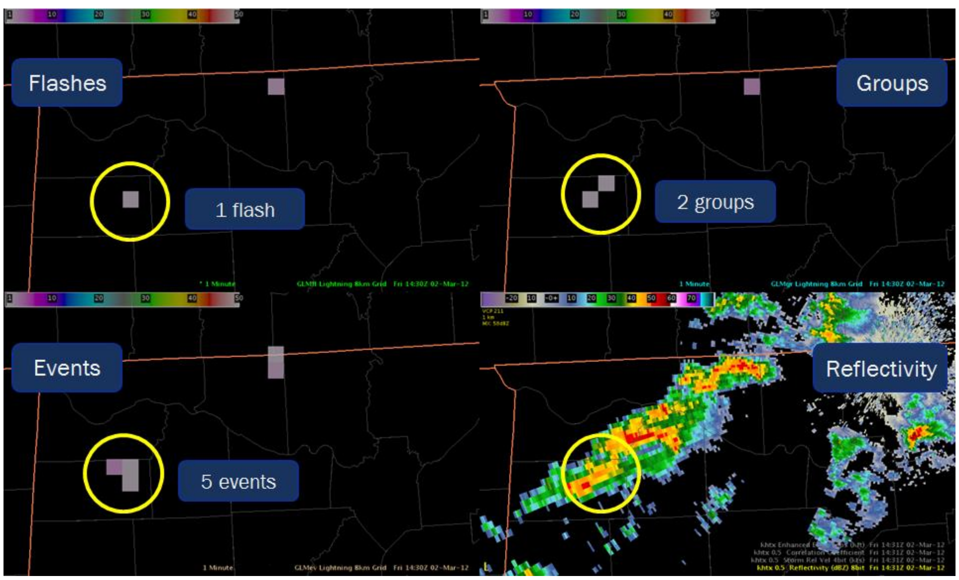

Figure 6: This is similar to Fig. 5, but shows how a single flash (circled in yellow) is broken into groups (2) and events (5) as well as the corresponding location in the radar reflectivity. Note that a flash can have various combinations of events and groups.

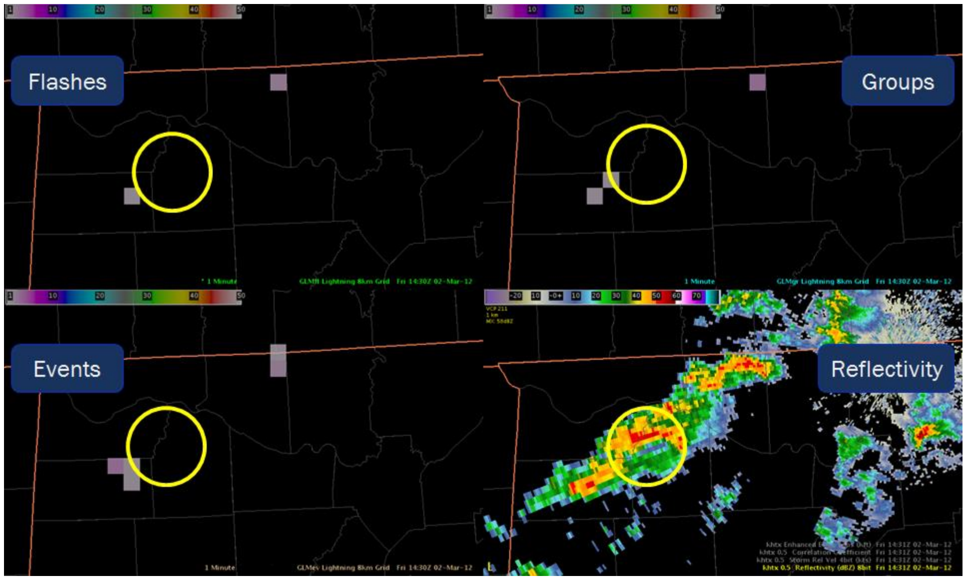

Figure 7: An example of GLM proxy events, groups, and flashes as well as the corresponding radar reflectivity in northern Alabama (United States) at 1430 UTC. The yellow circles highlight an area of interest.

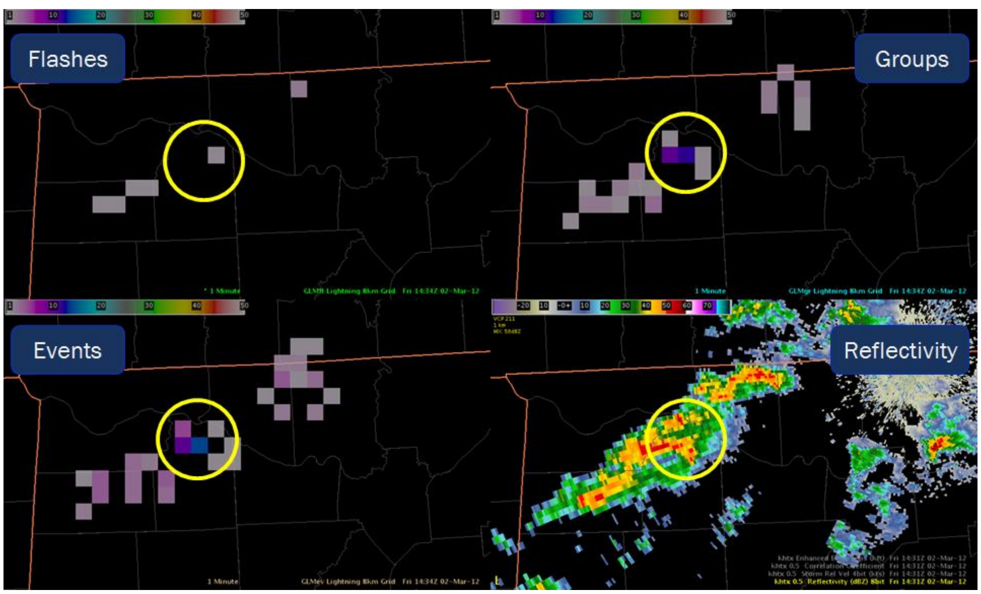

Figure 8: This is the same as Fig. 7, but four minutes later at 1434 UTC.

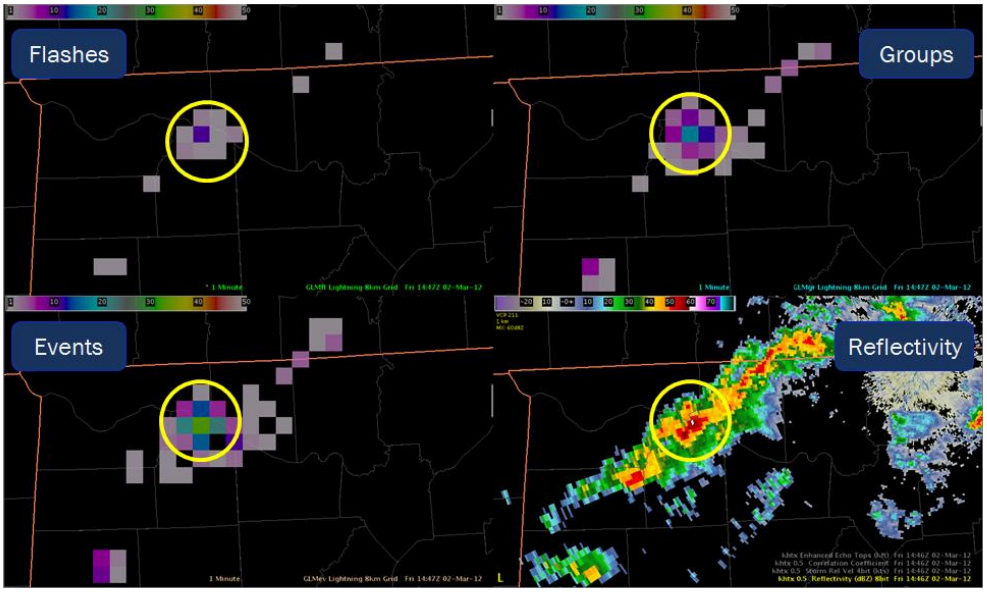

Figure 9: Same as Fig. 7, but 17 minutes later at 1447 UTC.

Figure 10: An example of the AWIPS meteogram trace tool from the United States National Weather Service's AWIPS display system. This shows a one hour time series trend of the GLM proxy observations (events – upper left, groups – middle left, and flashes – lower left) as well as the corresponding trend in radar reflectivity.