EVALUATION OF NASA SPORT'S PSEUDO-GEOSTATIONARY LIGHTNING MAPPER PRODUCTS IN THE 2011 SPRING PROGRAM

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1. NASA SPORT AND THE GOES-R PROVING GROUND

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. The program is executed in concert with other government, university, and private sector partners. The primary focus is on the regional and local scale, emphasizing forecast improvements on the 0-24 hour time scale. 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. 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 transition of ground-based total lightning data into real-time operations. This originally involved the North Alabama Lightning Mapping Array (Goodman et al. 2005 – NALMA), but has since expanded to include networks at Kennedy Space Center and Washington D.C. Since the NALMA was first transitioned in 2003, SPoRT has worked with our partners to develop assessments, training, and improved visualizations of these data (Goodman et al. 2005; Nadler et al. 2009; Darden et al. 2010; Demetriades et al. 2008; Stano et al. 2011a). The goal is to provide capabilities that enhance a forecaster's situational awareness that lead to improved severe weather warnings and lightning safety. SPoRT's efforts have led to a greater utilization of total lightning data operationally and assessments have observed improved warning lead times and situational awareness (Bridenstine et al. 2005; Goodman et al. 2005; Nadler et al. 2009). While total lightning has many uses, forecasters primarily rely on a lightning jump signature for their warning decision operations (Schultz et al. 2009; Gatlin and Goodman 2010).

SPoRT's paradigm of matching data to specific forecast problems, integrating products into the end user's decision support system, and product training with user feedback has created a strong working relationship with our partners. This successful paradigm has led to SPoRT's involvement with the GOES-R Proving Ground (PG). SPoRT's expertise of using total lightning data in real-time operations and training modules has led to SPoRT's active role in preparing forecasters for the Geostationary Lightning Mapper (GLM – Christian et al. 1992; 2006).

As part of its Proving Ground activities, SPoRT has actively participated with the Hazardous Weather Testbed's Spring Program in Norman, Oklahoma (Kain et al. 2003) since 2009 (Stano et al. 2010; Stano et al. 2011b). As described in the two Stano articles, SPoRT has leveraged its internal expertise with total lightning to develop tools and training to help prepare forecasters for the GLM and to better understand how best to display these data in an operational setting. This paper will differ from the previous Stano articles and focus primarily on the evaluation of the PG lightning products that SPoRT has provided to the Spring Program.

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2. PROVING GROUND LIGHTNING ACTIVITIES

SPoRT's activities with the Proving Ground are specifically with the Experimental Warning Program (Stumpf et al. 2010) and can be classified into three categories; logistics, product development, and training. These activities are discussed in greater detail in Stano et al (2011b), but are summarized here for completeness.

Logistically, SPoRT provided raw total lightning data to the Hazardous Weather Testbed from 2009-2011 for the Spring Program. SPoRT, in collaboration with NASA's lightning group at Marshall Space Flight Center, provided data from three ground-based total lightning networks, NALMA, Washington D.C., and Kennedy Space Center. These were used along with the Oklahoma lightning mapping array (MacGorman et al. 2008). These data were used to produce the real-time pseudo-geostationary lightning mapper products (Stano et al. 2011b – PGLM) described below.

In addition to providing the raw data, SPoRT developed the PGLM product suite after the 2009 Spring Program. In 2009, it was determined that the total lightning product in use was not adequate for PG demonstrations. SPoRT developed the PGLM by creating a flash-based total lightning product from the ground-based total lightning networks and placed on a GLM-resolution grid (8 km). Through 2011, SPoRT provided the raw data to the Hazardous Weather Testbed where it was then processed locally into the SPoRT-derived PGLM.

It is important to note what the PGLM is and is not. The PGLM is not the official Algorithm Working Group (AWG) GLM proxy product. Unlike the official proxy, the PGLM does not attempt to create a GLM-style product that incorporates knowledge from the optical Lightning Imaging Sensor (Christian et al. 1999; Mach et al. 2007) aboard the Tropical Rainfall Measuring Mission (Kummerow et al. 2000) satellite. The PGLM exists as the official GLM proxy is not available in real-time and has only been produced for the NALMA network. The PGLM has the advantage of being produced in real-time and for any available ground-based total lightning network. While the PGLM is not the true GLM-proxy, it is still an extremely valuable tool. The PGLM serves as a demonstration product to train forecasters on the capabilities of total lightning and the GLM instrument itself. The PGLM also facilitates the two way discussion of how best to integrate GLM-style products into the real-time operational environment and how to integrate those products into the NWS' next generation decision support tool, AWIPS II (Tuell et al. 2009).

Since the PGLM was initially developed in 2009, it has been used at the Spring Program in 2010 and 2011 and will serve as the GLM demonstration product again for 2012. The PGLM converts the raw, ground-based sources into flashes and then plots these flashes onto a GLM-resolution grid of 8 km (Figure 1). The PGLM is available every one to two minutes, depending on the network it is derived from. It is considered the "base product" for use with the Spring Program as the PGLM directly draws on the operational utility of total lightning described in numerous other activities (Bridenstine et al. 2005; Goodman et al. 2005; Nadler et al. 2009; Schultz et al. 2009; Darden et al. 2010; Gatlin and Goodman 2010; Stano et al. 2011a)

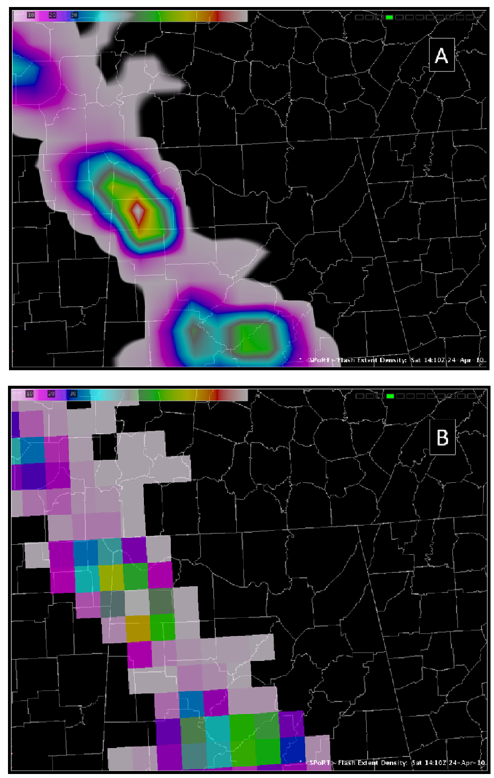

Figure 1: An example of the SPoRT developed pseudo geostationary lightning mapper flash extent density product in AWIPS II. Image A shows the interpolated display while B presents the non-interpolated display showing the individual grid boxes.

In 2011 the PGLM received two additional variant products, as described in Stano et al (2011b). These include the flash initiation density

(FID) and maximum flash density (MFD). The FID takes the standard one- or two-minute PGLM product and only plots the origin points of each flash on the GLM-resolution grid. Unlike the PGLM, the FID does not provide a map of the spatial extent of lightning. Instead, the FID more clearly shows the locations of storm updrafts and whether or not flashes are initiating in the trailing stratiform region. The FID is being evaluated to determine if it provides a clearer picture of whether or not a storm is intensifying.

The MFD is more novel than the FID and had no real-time analog product available with the ground-based networks. It has been developed specifically for the proving ground, but the concept is being transitioned by SPoRT to the current real-time data provided to our total lightning partner WFOs. The Proving Ground MFD, like the PGLM, is updated every one to two minutes, depending on the network it is derived from. Unlike the PGLM, which shows the flash extent density at every one or two minute interval, the MFD plots the maximum value of the PGLM in each grid box for a 30 minute period (Figure 2). This time period can easily be altered, as was done at the 2011 Spring Program where 60 and 120 minutes also were used. This results in a display that shows the course of individual cells in time, leading to the alternate name for this product known as the lightning track product. The purpose of this product is twofold. First, it can be directly used for lightning safety, as it displays where all lightning has occurred for the past 30 minutes (or any other chosen time frame). Secondly, it serves as a "poor man's" trending tool. The instantaneous PGLM product can be compared with the current MFD product to determine whether the cell in question in increasing or decreasing in intensity with time.

Finally, in addition to the logistics and products provided, SPoRT contributes several training tools to the GOES-R Proving Ground. One of these is the pseudo-geostationary lightning mapper training module, first developed ahead of the 2010 Spring Program. This module details the specifics of total lightning, the GLM instrument, and the PGLM product that will be used. The module is intended to be taken before forecasters arrive at the Spring Program. To facilitate the forecasters' ability to take the training, the module is available in the NWS' own learning management system. A copy also is available on SPoRT's on web page (http://weather.msfc.nasa.gov/sport/training/).

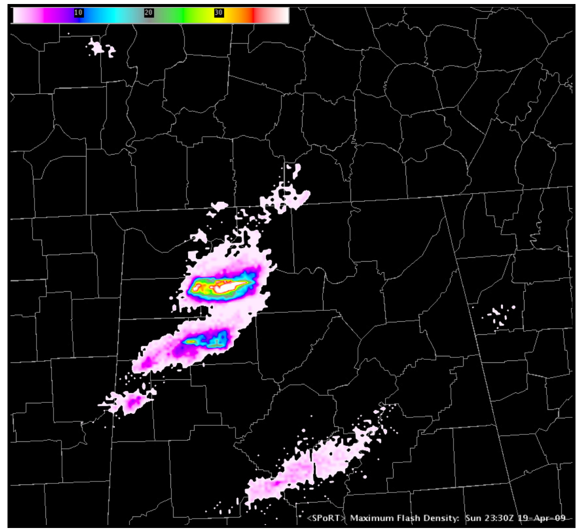

Figure 2: A maximum flash density display in AWIPS II covering a 30 minute time period.

In addition to the training module, SPoRT provides on-site training and expertise. Since 2009, a SPoRT total lightning expert has attended the Spring Program. Here, the individual provides training to the participating forecasters at the start of the week. Furthermore, throughout the week, the SPoRT personnel provide guidance on the use of the PGLM products and answer any questions that arise during the week's intensive operation periods where the PGLM products are used.

3. EVALUATION OF SPORT'S PGLM PRODUCTS

The 2011 Spring Program was the second year that the PGLM was used for evaluations and the first year for the FID and MFD. Every week for five weeks, a group of forecasters from around the country would come to participate. During the course of the week, the forecasters would receive training on several experimental products, including the PGLM for the PG activities. Additionally, the intensive operation periods attempted to focus on the regions where total lightning data were available. After each event an assessment questionnaire was filled by each forecaster. This included a section for the PGLM products, where applicable. This paper will focus on two specific events where the PGLM products were used and summarize the findings from the assessments.

3.1 Severe Weather Warning Example

During the first week of the Spring Program, the threat of severe weather existed across central Oklahoma, covered by the Oklahoma lightning mapping array. This would be the first opportunity of the 2011 Spring Program to evaluate the PGLM products. The intensive observation period did not start until the early afternoon of 12 May 2011, when storms were already occurring across the region. Figure 3 shows the existing situation at 2211 UTC with the PGLM flash extent density product (a) and the corresponding radar reflectivity (b). As can be seen on radar, there were already several well developed cells and the participating forecasters immediately issued severe thunderstorm warnings prior to 2211 UTC based on the initial radar observations.

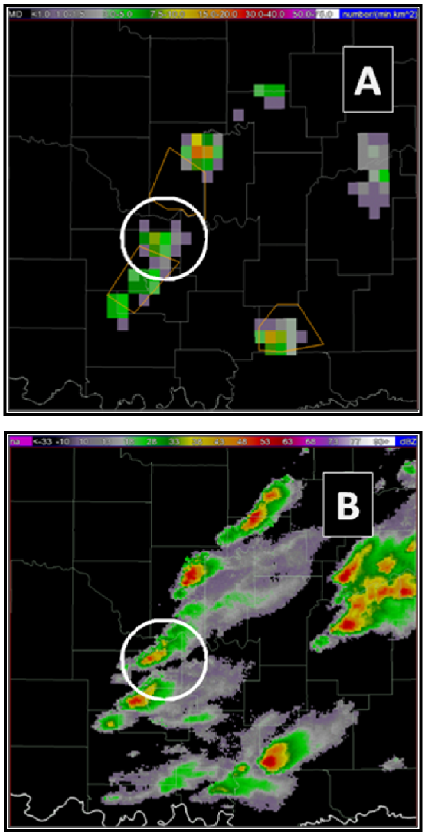

Figure 3: An example from the 2011 Spring Program showing the PGLM (A) at 2211 UTC on 12 May 2011 and the closest radar reflectivity (B) at 2209 UTC. The storm of interest is in the white circle and existing severe thunderstorm warnings are displayed.

However, the circled region in Figure 3 shows there is another cell that had been developing since 2200 UTC. Based on the radar reflectivity, the forecasters did not feel it was necessary to issue any warning for the moment. The corresponding PGLM observation showed that only 9 flashes had occurred within the past minute. From a lightning safety standpoint, this indicates that the storm is already electrically active and that a cloud-to-ground strike could occur at any moment. Based on the trend of the other cells and that lightning was already occurring, the forecasters chose to monitor this storm for further intensification.

By 2212 UTC (Figure 4), the radar signature is relatively unchanged (4b) but the PGLM flash density (4a) has increased to 16 flashes. At this time, the cell is beginning to intensify, but the forecaster believes that a warning is not yet warrented. The lightning increase is minor, but indicates that the cell in question continues to require monitoring.

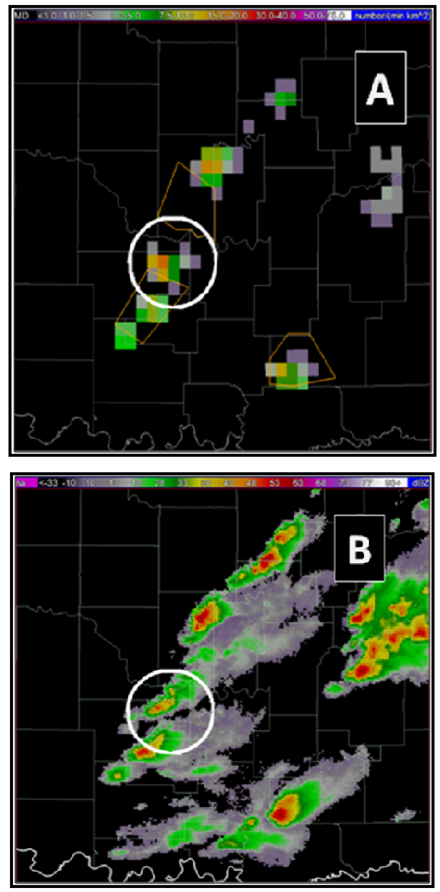

Figure 4: Same as Figure 3, but with the PGLM at 2212 UTC (A) and radar reflectivity at 2212 UTC (B).

At 2220 UTC (Figure 5) a major change in the circled cell has occurred. The PGLM flash extend density (5a) has undergone a major lightning jump. The total lightning signature has surged from 16 flashes at 2212 UTC to 76 flashes as of 2220 UTC. Given the time interval of one minute between PGLM updates, this jump is even more impressive as this shows that 76 flashes have occurred within the past minute. At this point, the total lightning expert pointed out that this was a clear lightning jump and that it was very likely this storm would become severe. The radar reflectivity (5b) was beginning to show signs of intensification as well. After further discussion, the forecaster decided to hold off on a warning, noted the lightning jump, and waited to see when or if the radar signature would support the issuance of a warning that the PGLM already supported. This provided an excellent opportunity to compare traditional radar-based warning decisions with those supported by the PGLM data.

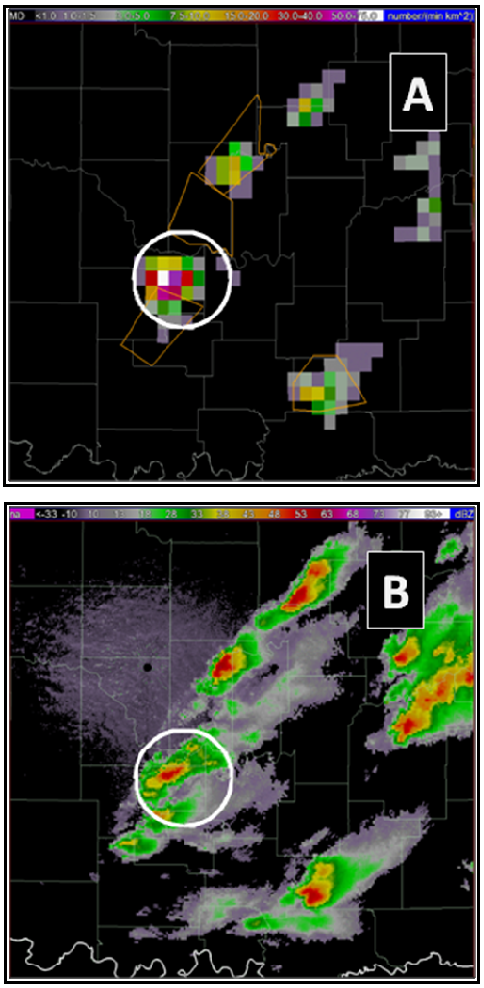

Figure 5: Same as Figure 3, but with the PGLM at 2220 UTC (A) and radar reflectivity at 2219 UTC (B).

Five minutes later at 2225 (Figure 6), the PGLM values had slightly decreased (6a), which is typical after a lightning jump. However, according to the forecaster the radar reflectivity (6b) and other observations (not shown) definitively supported the issuance of a severe thunderstorm warning at 2226 UTC.

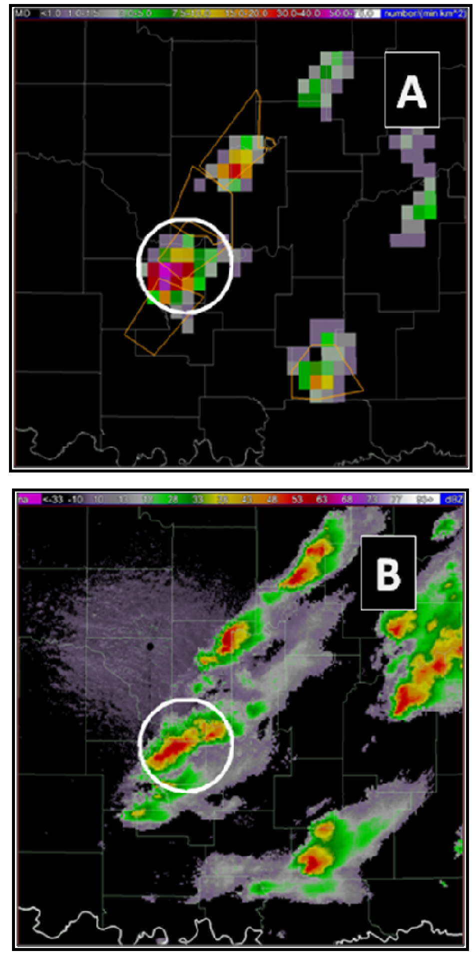

Figure 6: Same as Figure 3, but with the PGLM at 2226 UTC (A) and radar reflectivity at 2225 UTC (B).

This warning was ultimately verified at 2238 UTC when severe hail was reported in central Oklahoma. Feedback from the forecaster indicated that, in this particular case, they were impressed by the PGLM jump signature, which provided an 18 minute lead time on the onset of severe weather, compared to 12 minutes using the radar alone. The forecaster commented that the availability of additional training would certainly interest forecasters on the future capabilities of the GLM instrument, particularly since the PGLM demonstrated the ability to provide additional data, particularly in between radar volume scans, to improve the decision support process. Although just one event, the forecaster indicated they would be very interested in seeing GLM data in the future.

3.2 Lightning Safety Example

The second example from the 2011 Spring Program focused on another aspect of total lightning that the PGLM and eventually GLM will provide; enhancing lightning safety. Although the National Weather Service does not specifically forecast lightning activity, there are times where there is a need to know when cloud-to-ground lightning is imminent. These include terminal aerodrome forecasts (TAFs), airport weather warnings, and incident support forecasts.

Traditionally, this has used radar data in conjunction with the National Lightning Detection Network (Cummins et al. 1998; 1999 – NLDN). The drawback to this approach is that the NLDN only observes cloud-to-ground strikes, missing the intra-cloud component observed by total lightning. In the case of an active storm approaching a point of interest, this may not be an issue as the NLDN is likely already observing cloud-to-ground strikes. However, in a newly forming storm, there may be no active lightning detected by NLDN. This makes updating TAFs or incident support far more difficult as the forecaster must decide what storm cells may produce a cloud-to-ground strike.

Total lightning, as will be available from the GLM, can help. Studies have shown that the majority of lightning in a storm is intra-cloud. Furthermore, these studies have shown that the majority of storms initiate lightning activity with an intra-cloud flash, which can precede the first cloud-to-ground strike by 5-10 minutes (Williams et al. 1989; MacGorman and Rust 1998; Stano et al. 2010; MacGorman et al. 2011).

The example from 11 May 2011 illustrates this capability. Figure 7 is at 2055 UTC and shows observations from radar reflectivity, the PGLM, the MFD, and the NLDN near Lawton, Oklahoma. At this time, the radar reflectivity shows a broad region of stratiform precipitation on the eastern side of the domain after a line of storms moved through earlier. Additionally, the radar reflectivity shows a new, isolated cell forming (as highlighted by the circle). The MFD, set for 60 minutes, highlights how active lightning had been when the line of storms was moving through. What is interested here is that the NLDN shows no cloud-to-ground strikes in the cell of interest but the PGLM observes several flashes. This shows that the cell is already electrically active, which would not have been detected by NLDN.

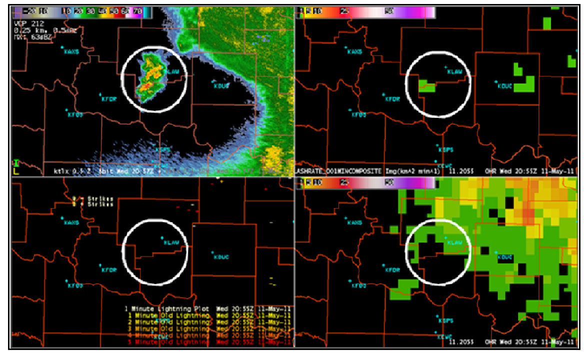

Figure 7: An AWIPS four panel display from the 2011 Spring Program on 11 May at 2055 UTC showing radar reflectivity (upper left), the PGLM (upper right), max flash density (lower right), and NLDN strikes (lower left). The area of interest is circled where there are PGLM flashes but no NLDN cloud-to-ground strikes.

Figure 8 now shows the same cell of interest at 2100 UTC. The radar recflectivity has increased slightly and the PGLM observes two additional flashes. The NLDN continues to observe no cloud-to-ground strikes.

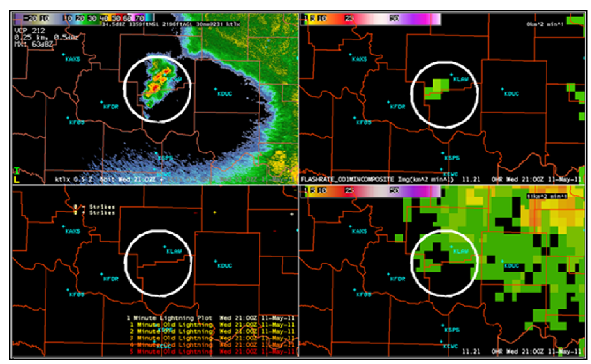

Figure 8: Same as Figure 7, but at 2100 UTC.

Finally, at 2124 UTC (Figure 9), the NLDN observes its first cloud-to-ground strike. The radar reflectivity remains strong but no significant changes have occurred since 2100. Furthermore, the PGLM shows that nearly a donzen flashes have been observed at this time. What is significant about this event is that the PGLM first observed lightning 29 minutes before the first cloud-to-ground strike observed by the NLDN. This is certainly an outlier case as most often this lead time is 5-10 minutes, but clearly illustrates the lightning safety component of total lightning observations. The PGLM provides observations that show that lightning is active in a cell, even when reflectivity may be marginal and when the NLDN may observe no flashes.

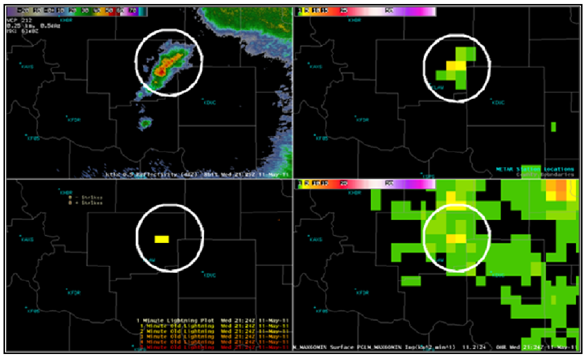

Figure 9: Same as Figure 7, but at 2124 UTC. Note the first observed cloud-to-ground strike by the NLDN came 29 minutes after the first PGLM observation.

3.3 Additional Feedback

As mentioned in the introduction, the Spring Program conducted a post-event survey with each forecaster when the PGLM was being evaluated. Thirty-five evaluations were conducted over the course of the 2011 Spring Program. The following is a summary of the evaluations conducted, as provided by the co-authors of this paper.

The evaluation included three ranking questions, where forecasters were asked to give a value from one to ten on these questions. There were six additional open-ended questions. These questions were designed to allow the forecasters to provide more insight and feedback on their thoughts and critiques on the PGLM products.

The first ranking question asked, *"How difficult were the PGLM products to interpret?"* For this question, the PGLM products fared well with almost 70% of the surveys indicating that the interpretation was easy or relatively easy. Still, one respondent indicated that the PGLM products were "extremely difficult" to interpret and the remaining 30% of the respondents covered the entire remaining spectrum of responses. This indicates that the initial training has been effective, but there is certainly room for improvement. The open-ended questions also provided insight (discussed below) as to how to improve interpretations.

The second ranked question asked, *"How often would you use a similar product during forecast and warning operations?"* Again, the responses were positive, with 19 of the 35 respondents (54%) rating this 8 or better, with 10 being "all the time." No one responded with "never", but 7 of 35 respondents (20%) rated the PGLM products a 5 or less. This can be attributed to a range of issues from the need for improved training to having poor real-time cases to demonstrate the products. The results are consistent with SPoRT's experience in transitioning total lightning data to operation WFOs where it required training and good examples to allow forecasters to feel confident in using these data.

The final ranked question asked, *"Rate the importance of incorporating total lightning data into your forecast office."* Here the results were positive with 33 of 35 respondents (94%) indicating that incorporating total lightning into operations was somewhat to extremely important (6-10). Within that grouping, 22 of 35 (63%) rated the inclusion of total lightning 8 or better.

Beyond the three ranked questions, the forecasters were given six open-ended questions. These covered several topics to gauge the forecasters' perception of the PGLM products themselves and how they may best be used operationally. The questions ranged from what were the strengths and weaknesses, what should be changed, how do you envision using these data in the future, and what are your overall impressions?

The responses can overall be classified as positive. Where the forecasters had negative critiques, the feedback was detailed and provided clear suggestions for improvements, which is greatly appreciated by the authors. One issue that forecasters raised was that some of the real-time events did not lend themselves well to learning about the PGLM products and their uses. There were some concerns about the color curves being used and that the detection efficiency appeared to vary, which is an artifact of the short-ranged nature of the ground-based lightning mapping arrays that the PGLM is derived. Forecasters appeared to prefer the original PGLM flash extent density product over the FID and MFD products.

The forecasters also provided a number of suggestions for improvement. Overwhelmingly, the suggestion was for the ability to provide a time series or rate of change plot for the lightning data. This would greatly enhance the ability to maintain awareness on how the lightning signature is evolving with time. Furthermore, there were numerous requests to view the intra-cloud versus cloud-to-ground lightning ratio with each cell.

Even with the recommended improvements, the responses gave positive feedback in the open-ended questions. There were a few major themes that can summarize the responses. Forecasters appreciated the ability to monitor convection, give a heads-up for increases in storm severity, and provide situational awareness as to which storms require additional attention. Forecasters were further impressed with the ability to gain some insight as to when the first cloud-to-ground strike may occur. Additionally, the forecasters indicated that they certainly saw a future with this product, particularly with additional training and examples to better relate what the total lightning products observe in relation to other observational data sets.

4. SUMMARY AND PREPARING FOR 2012

The 2011 Spring Program provided an excellent venue with which SPoRT and the GOES-R partner collaborators could evaluate the pseudo geostationary lightning mapper products in a real-time setting. During the course of the program, 35 evaluations were submitted by forecasters who used the PGLM products. This evaluation was facilitated to a collaborative effort between SPoRT, the GOES-R Proving Ground, and the Hazardous Weather Testbed using data, PGLM methodology, and training provided by the SPoRT program, along with data from the Oklahoma lightning mapping array and data processing.

The evaluations show that the PGLM continues to be a successful tool in demonstrating and educating forecasters about total lightning and the upcoming Geostationary Lightning Mapper. The feedback has been positive, but indicates that there are several avenues for improvement, which in turn can be provided to the GOES-R program to help develop the real-time GLM products, once the instrument is launched. Forecasters have indicated that additional training and examples would be useful as well as improved color curves for the data. The forecasters overwhelmingly indicated that a time series plot of lightning data would be immediately beneficial as well as wanting to see an intra-cloud flash to cloud-to-ground strike ratio.

The SPoRT program, as the developer of the PGLM products, has taken this feedback seriously and is preparing several actions for the upcoming 2012 Spring Program. First, the existing training module that is available on the National Weather Service's learning management system is undergoing an update. This update will incorporate suggestions and feedback from the 2010 and 2011 Spring Programs. This will include additional examples, improved graphics, and a more in-depth discussion of the available PGLM products. Additionally, this module will incorporate all of the new AWIPS II abilities SPoRT has developed with its WFO partners.

The implementation of AWIPS II by the Spring Program in 2012 will facilitate several responses to forecasters' feedback. SPoRT, along with our WFO partners, has been working to lead the way in developing plug-ins to visualize total lightning data within the AWIPS II environment. This will streamline the data flow to the Spring Program, making it easier to switch between areas of interest. Also, this will allow the inclusion of several total lightning color curves developed by WFO Huntsville, Alabama, who have used total lightning since 2003. Furthermore, a new tracking tool has been developed. This tool will allow forecasters to select a cell to follow and plot, within AWIPS II, a time series trend of the lightning activity in that cell. This will answer the number one request by forecasters in how to improve the utility of total lightning data. In addition to the time series display of total lightning, the plug-in can likely be extended to pull in National Lightning Detection Network (Cummins – NLDN) data in order to provide a real-time intra-cloud versus cloud-to-ground strike ratio.

By focusing on the feedback from the forecasters and merging that with SPoRT's subject matter experts and AWIPS II abilities, the 2012 Spring Program will be able to further build on the success of the PGLM evaluations from the past two years.

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5. REFERENCES

Bridenstine, P. V., C. B. Darden, J. Burks, and S. J. Goodman, 2005: The application of total lightning in the warning decision making process. 1st *Conf. on Meteorological Applications of Lightning Data*, Amer. Meteor. Soc., San Diego, CA, P1.2.

Christian, H. J., R. J. Blakeslee, and S. J. Goodman, 1992: Lightning Imaging Sensor for the Earth Observing System. *Tech. Rep. NASA TM-4350*, NASA, Washington, D.C.

___, and Coauthors, 1999: The Lightning Imaging Sensor. *Proc. 11th Int. Conf. on Atmospheric Electricity*, Guntersville, AL, NASA, 746-749.

___, 2006: Geostationary Lightning Mapper (GLM). *12th Conf. on Aviation Range and Aerospace Meteorology / 2nd Conf. on Meteorological Applications of Lightning Data*, Amer. Meteor. Soc., Atlanta, GA, J2.3.

Cummins, K. L., R. B. Pyle, and G. Fournier, 1999: An integrated American lightning detection network, *11th International Conference on Atmospheric Electricity*, 7-11 Jun 99, 218-221.

___, M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, 1998: A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Nework, *J. Geophys. Res.*, **103**, 9035-9044.

Darden, C., B. Carroll, S. Goodman, G. Jedlovec, B. Lapenta, 2002: *Bridging the gap between research and operations in the National Weather Service: Collaborative activities among the Huntsville meteorological community*. NOAA Technical Memorandum, PB2003-100700, NWS Southern Region, Fort Worth, TX.

___, D. J. Nadler, B. C. Carcione, G. T. Stano, and D. E. Buechler, 2010: Utilizing total lightning information to diagnose convective trends. *BAMS,* DOI: 10.1175/2009BAMS2808.1

Demetriades, N. W. S., D. E. Buechler, C. B. Darden, G. R. Patrick, and A. Makela, 2008: VHF total lightning mapping data use for thunderstorm nowcasting at weather forecast offices. *3rd Conf. Meteorological Applications of Lightning Data*, Amer. Meteor. Soc., New Orleans, LA, 20-24 Jan 08, 6 pp.

Gatlin, P. N. and S. J. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Oceanic Tech.*, **27**, 3-22.

Goodman, S. J., W. M. Lapenta, G. J. Jedlovec, J. C. Dodge, and J. T. Bradshaw, 2004: The NASA Short-term Prediction Research and Transition (SPoRT) Center: A collaborative model for accelerating research into operations. *20th Conf. on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Seattle, WA, P1.34.

Goodman, S. J., R. Blakeslee, H. Christian, W. Koshak, J. Bailey, J. Hall, E. McCaul, D. Buechler, C. Darden, J. Burks, T. Bradshaw, P. Gatlin, 2005: The North Alabama Lightning Mapping Array: Recent severe storm observations and future prospects. *Atmos. Res.*, **76**, 423-437.

Kummerow, C., and Coauthors, 2000: The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. *J. Appl. Meteor.*, **39**, 1965-1982.

MacGorman, D. R., and W. D. Rust, 1998: *The Electrical Nature of Storms*. Oxford University Press, 422 pp.

MacGorman, D. R., W. D. Rust, T. J. Schuur, M. I. Biggerstaff, J. M. Straka, C. L. Ziegler, E. R. Mansell, E. C. Bruning, K. M. Kuhlman, N. R. Lund, N. S. Biermann, C. Payne, L. D. Carey, P. R. Krehbiel, W. Rison, K. B. Each, and W. H. Beasley, 2008: TELEX The thunderstorm electrification and lightning experiment. *Bull. Amer. Meteor. Soc.*, **89**, 997-1013.

___, I. R. Apostolakopoulos, N. R. Lund, N. W. S. Demetriades, M. J. Murphy, and P. R. Krehbiel, 2011: The time of cloud-to-ground lightning relative to total lightning activity. *Mon. Wea. Rev.*, **139**, 3871-3886.

Mach, D. M., H. J. Christian, R. J. Blakeslee, D. J. Boccippio, S. J. Goodman, and W. L. Boeck, 2007: Performance assessment of the Optical Transient Detector and Lightning Imaging Sensor. *J. Geophys. Res.*, **112**, doi:10.1029/2006JD007787.

Nadler, D. J., C. B. Darden, G. T. Stano, and D. E. Buechler, 2009: An operational perspective of total lightning information. *4th Conf. on the Meteorological Applications of Lightning Data*, Amer. Meteor. Soc., Phoenix, AZ, P1.11.

Nelson, L. A., 2002: Synthesis of 3-dimensional lightning data and radar to determine the distance that naturally occurring lightning travels from thunderstorms. *M.S. Thesis*, Air Force Institute of Technology, 85 pp.

Schultz, C. J., W. A. Petersen, and L. D. Carey, 2009: Preliminary development and evaluation of lightning jump algorithms for the real-time detection of severe weather. *J. Appl. Meteor. Clim.*, **48**, 2543-2563.

Stano, G. T., H. E. Fuelberg, W. P. Roeder, 2010: Developing empirical lightning cessation forecast guidance for the Cape Canaveral Air Force Station and Kennedy Space Center. *J. Geophys. Res.*, **115**, 18 pp. DOI: 10.1029/2009JD013034.

___, K. K. Fuell, and G. J. Jedlovec, 2010: NASA SPoRT GOES-R Proving Ground activities. *6th Annual Symposium on Future National Operational Environmental Satellite Systems – NPOESS and GOES-R*. Amer. Meteor. Soc., Atlanta, GA, 17-21 Jan. 10, 8 pp.

___, ___, and ___, 2011a: Improved real-time lightning trend products. *5th Conf. on Meteorological Applications of Lightning Data*, Amer. Meteor. Soc., Seattle, WA, 23-27 Jan 11, 8.1, 8pp.

___, ___, and ___, 2011b: NASA SPoRT Prepares for the Geostationary Lightning Mapper. *7th Annual Symposium on Future National Operational Environmental Satellite Systems*. Amer. Meteor. Soc., Seattle, WA, 5.4, 24-27 Jan. 11, 8pp.

Stumpf, G. J., B. C. Baranowski, D. M. Kingfield, K. M. Kuhlman, K. L. Manross, C. W. Siewert, T. M. Smith, and S. Stough, 2010: Real-time severe convective weather warning exercises at the 2010 Experimental Warning Program (EWP2010). *25th Severe Local Storms Conf.*, AMS, 11-14 Oct 10, Denver, CO, 10 pp.

Tuell, J. P., S. S. Schotz, R. K. Henry, and D. Plummer, 2009: AWIPS II technology infusion – status update. *25th Conf. on International Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Phoenix, AZ, 8A.1.

Williams, E. R., M. E. Weber, and R. E. Orville, 1989: The relationship between lightning type and convective state of thunderclouds. *J. Geophys. Res.*, **94**, 13213-13220.