ASSESSMENT OF THE PGLM AT THE SPRING PROGRAM AND SUMMER EXPERIMENT

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Since 2010, the de facto Geostationary Lightning Mapper (GLM) demonstration product has been the Pseudo-Geostationary Lightning Mapper (PGLM) product suite. Originally prepared for the Hazardous Weather Testbed's Spring Program (specifically the Experimental Warning Program) when only four ground-based lightning mapping arrays were available, the effort now spans collaborations with several institutions and eight collaborative networks. For 2013, NASA's Short-term Prediction Research and Transition (SPoRT) Center and NOAA's National Severe Storms Laboratory have worked to collaborate with each network to obtain data in real-time. This has gone into producing the SPoRT variant of the PGLM that was demonstrated in AWIPS II for the 2013 Spring Program. Alongside the PGLM products, the SPoRT / Meteorological Development Laboratory's total lightning tracking tool also was evaluated to assess not just another visualization of future GLM data but how to best extract more information while in the operational environment. Specifically, this tool addressed the leading request by forecasters during evaluations; provide a time series trend of total lightning in real-time. In addition to the Spring Program, SPoRT is providing the PGLM "mosaic" to the Aviation Weather Center (AWC) and Storm Prediction Center. This is the same as what is used at the Hazardous Weather Testbed, but combines all available networks into one display for use at the national centers. This year, the mosaic was evaluated during the AWC's Summer Experiment. An important distinction between this and the Spring Program is that the Summer Experiment focuses on the national center perspective and not at the local forecast office level. Specifically, the Summer Experiment focuses on aviation needs and concerns and brings together operational forecaster, developers, and FAA representatives. This presentation will focus on the evaluation of SPoRT's pseudo-GLM products in these separate test beds. The emphasis will be on how future GLM observations can support operations at both the local and national scale and how the PGLM was used in combination with other lightning data sets. Evaluations for the PGLM were quite favorable with forecasters appreciating the high temporal resolution, the ability to look for rapid increases in lightning activity ahead of severe weather, as well as situational awareness for where convection is firing and for flight routing.

1. INTRODUCTION

A major component of the GOES-R Proving Ground has been its participation with the Hazardous Weather Testbed's Spring Program. Specifically, with respect to total lightning (cloud-to-ground and intra-cloud observations), this effort has been part of the Experimental Warning Program. NASA's Short-term Prediction Research and Transition (SPoRT; Darden et al. 2002; Goodman et al., 2004) (http://weather.msfc.nasa.gov/sport/) Center has been supporting this effort specifically with the pseudo-geostationary lightning mapper product suite (PGLM; Stano et al. 2010, 2011; Stano et al. 2012). Initially conceived in 2009, SPoRT has been coordinating the collaboration of multiple ground-based lightning mapping arrays to participate in the Spring Program (Fig. 1) and producing the PGLM. SPoRT's efforts culminated with the SPoRT version of the PGLM being used at the Spring Program in 2013 utilizing the SPoRT LMA visualization plug-in for AWIPS II.

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In addition to supporting the Spring Program as part of SPoRT's GOES-R Proving Ground efforts, SPoRT has been a collaborating partner with the Aviation Weather Center's Summer Experiment since 2012 (Stano et al. 2013). Unlike the Spring Program, where the emphasis is on Weather Forecast Office (WFO) operations with the focus on a single lightning mapping array network at a time, SPoRT has developed the PGLM mosaic for use at the national centers. This product provides the PGLM observations for all collaborating lightning mapping arrays in one product that is viewable in the national center display system; N-AWIPS.

In addition to providing PGLM observations in 2013 to both the Spring and Summer experiments, SPoRT provided the Total Lightning Tracking Tool (TLTT). The TLTT is a joint project between NASA SPoRT and the Meteorological Development Laboratory (MDL). It is an outgrowth of MDL's moving meteogram tool, which is designed to produce a time series of most meteorological parameters in AWIPS II. For the 2013 evaluations, the TLTT only created a time series display of the PGLM products. As this is an AWIPS II product, it was only available for evaluation at the Spring Program in Norman, Oklahoma.

This write up will briefly review the evaluation of the PGLM products and TLTT, where appropriate. The emphasis has been on how to incorporate these demonstration and training data for the Geostationary Lightning Mapper (GLM; Christian et al. 1989, 1992, 2006; Goodman et al. 2013) into real-time operations. The Spring Program has primarily focused on severe weather applications at the WFO-scale, while the Summer Experiment emphasizes the use of total lightning at the national scale for aviation purposes.

2. EVALUATED PRODUCTS AND TOOLS

2.1 Pseudo-Geostationary Lightning Mapper

The primary product was NASA SPoRT's PGLM flash extent density product (Stano et al. 2010, 2011, 2012, 2014), which now incorporated eight collaborative lightning mapping arrays at the time. The SPoRT PGLM product was designed to be a simple demonstration and training product for forecasters to prepare for the GLM that will be aboard GOES-R (Goodman et al. 2013). It is not a true proxy for the GLM, but is an excellent tool to train forecasters about the GLM as the PGLM can be viewed with other observations in AWIPS II in a real-time setting. It provides an opportunity to discuss what total lightning is and how it can be fused in operations. The PGLM is the de facto training product for the GOES-R PG and has been used with the HWT's Spring Program since 2010 (Kingfield and Magsig 2009; Kuhlman et al. 2010; Stumpf et al. 2010). The NASA SPoRT version, including the LMA plug-in, was used in 2013.

This product took the raw very high frequency observations, or sources, from the ground-based lightning mapping arrays and recombined them via a flash creation algorithm (McCaul et al. 2005, 2009). From there, the flashes were gridded on an 8×8 km grid to mimic the basic resolution of the GLM. The final PGLM flash extent density product counts the number of flashes that enter each grid box. Each flash was counted only once for any given grid box. SPoRT generated two variant products, including a flash origin density and a maximum flash density.

The flash origin density follows the same procedure as the flash extent density during the initial production. However, instead of counting all of the grid boxes the flash extends into, the flash origin density only counts the grid boxes where the flash initiates. This provides a less cluttered image that highlights the individual storm cells.

The second variant product was the maximum flash density. Here, the standard flash extent density product is saved for the past 30 min. Instead of plotting the current 1 or 2 min flash extent density (depending on the particular lightning mapping array), the largest flash extent density for the past 30 min for each grid box is plotted. The resulting maximum flash density product provides a very simple way to plot how active the lightning activity in the storm has been. When compared to the current 1 or 2 min flash extent density, the forecaster can see if the current flash extent density is greater (smaller) than the corresponding maximum density and can infer that the storm is strengthening (weakening). An example of the standard PGLM flash extent density and maximum flash density as they are viewed in AWIPS II is shown in Fig. 2.

For the Summer Experiment, a different display of PGLM flash extent density observations was required. This requirement was due to the Aviation Weather Center using N-AWIPS as the primary display system and not AWIPS II. As an aside, this is the same system currently used by the Storm Prediction Center. Additionally, since the summer experiment was focused on Aviation Weather Center operations and not individual WFO domains, there needed to be an easy way for forecasters to observe all of the collaborating lightning mapping array PGLM observations at once.

The solution was the PGLM mosaic product (Stano et al. 2013). For the Summer Experiment, only the flash extent density was requested. Like the PGLM mosaic is the same product as that used for the Spring Program. The only difference is that the data format is changed to allow it to be viewed in N-AWIPS. Also, since the PGLM mosaic is meant to be viewed at a national scale, two supplemental pieces of information are provided. The first is a range ring. This shows the rough observational range of the best observations for each ground-based lightning mapping array. This allows forecasters to know when they are observing weather conditions not supported by the PGLM. The second addition is a network status bar that are color coded green, yellow, and red. The network status bar alerts forecasters to when the PGLM mosaic data may be deteriorating in utility, either through the lightning mapping array running at reduced efficiency or if the network is not providing any observations. This enables forecasters to determine, at a glance, whether there is truly no lightning in a particular PGLM domain or if it is due to a network outage. Figure 3 provides an example of the PGLM mosaic as used by the Summer Experiment.

2.2 The Total Lightning Tracking Tool (TLTT)

For the 2013 Spring Program, NASA SPoRT provided the total lightning tracking tool, also described in Stano et al. (2014). The TLTT was only available to the Spring Program as the tool only works with AWIPS II. This was collaboratively developed with the NOAA / National Weather Service (NWS) Meteorological Development Laboratory (MDL). The basic concept was the same as used by earlier interactive display systems, such as MDL's System for Convection Analysis and Nowcasting (SCAN; Smith et al. 1998) and the Lightning Imaging Sensor Data Application Display (LISDAD; Boldi et al. 1998; Weber et al. 1998), which relied on the NOAA / National Severe Storm Laboratory Storm Cell Identification and Tracking (SCIT; Johnson et al. 1998) algorithm.

This tracking tool was developed for total lightning data in response to NWS forecaster feedback requesting the ability to visualize the time series of total lightning observations associated with individually tracked storms in real-time. Currently, NWS forecasters must mentally assemble a time series by applying the AWIPS sampling tool to each individual storm. AWIPS

II's ability to accept custom plug-ins will enable forecasters to incorporate SPoRT's TLTT. To use this tool, a forecaster selects a storm of interest and indicates the storm's path. The tool then generates a pop-up display of the time-series.

The TLTT is a sub-piece of the larger MDL moving meteogram tool that will be baselined in AWIPS II in 2014. The full tool will be able to create time series plots of numerous meteorological variables. The current TLTT is just used for the PGLM products. The evaluation of the TLTT in 2013, which was the first evaluation, was intended to get a first look at the tool's capabilities and limitations. Figure 4 provides a sample of what the TLTT user selected track looks like in AWIPS II, along with the corresponding time series display.

3. RESULTS FROM 2013

3.1 Spring Program, Norman, Oklahoma

The 2013 Spring Program was the third year of assessment of the PGLM in an operational test setting. However, it was the first year using the SPoRT produced PGLM product that relied on SPoRT's ingest and visualization plug-in for AWIPS II.

The primary goal for the multiple observations is to reach as many operational forecasters as possible. Each week the Spring Program brings 4-5 forecasters to the Experimental Warning Program. Here, the forecasters and attending subject matter experts can discuss the uses of experimental products, like the PGLM, and evaluate how they work in an operational setting with other real-time data sets. In the case of the PGLM, it also serves as an opportunity to educate end users about the GLM and total lightning applications. While total lightning has many uses beyond severe weather, the Experimental Warning Program generally focuses on the use of lightning jumps (Schultz et al. 2009, 2011; Gatling and Goodman 2010) as a precursor to severe weather events. The added assessment for this year was to evaluate how effective the TLTT tool was in operations. Two short examples are presented here before a summary of the overall assessment of the PGLM and TLTT.

3.1.1 PGLM comparison with Maximum Estimated Size of Hail output (15 May 2013)

This particular case was of interest as it was primarily focused on investigating the trend in total lightning, through the TLTT, with respect to the trends observed the multi-radar derived Maximum Estimated Size of Hail (MESH; Cintineo et al. 2012). The forecaster at the time was using the PGLM with MESH to both determine when a severe storm warning should be issued and to determine what the characteristics were between each product's trend.

Figure 5 shows the time series trend of PGLM flash extent density observations from 1850-1950 UTC on 15 May 2013. The main feature that is recognizable is the lightning jump that can be confirmed at 1909 UTC when the PGLM observations surge to 40 flashes in a single minute for the selected storm cell. This lightning jump signifies that severe weather is extremely likely for this storm cell. Based on the local storm environment, the forecaster concluded that the threat was for severe hail and not a tornado.

Concurrently, the MESH was being observed and examples are shown for 1910 and 1912 UTC in Figs. 6 and 7, respectively. At 1910, the MESH estimate was approximately 1.60 cm (0.63 in), which is below severe criteria. The next MESH observation at 1912 UTC (Fig. 7) indicated a maximum hail size of 2.79 cm (1.1 in), which exceeded the severe hail criteria of 2.54 cm (1.0 in). Surface observations then observed severe hail of 2.54 cm (1.0 in) at 1926 UTC and confirming the threat of severe weather indicated by both PGLM and MESH.

For this case, the PGLM supported by a time series plot from the TLTT provided an additional 3 min of lead time on the potential severe weather with the lightning jump occurring at 1909 UTC versus MESH exceeding 2.54 cm estimates at 1912 UTC. This demonstrated the importance of the rapid temporal update of the PGLM and future GLM observations. Further, by using these two observations in concert, the forecaster received multiple indicators of potential severe weather from independent sources.

3.1.2 9 May 2012 linear convection

The second, short example is shown in Fig. 8. Here the PGLM flash extent density was being compared to the composite radar reflectivity and MESH observations. In this case the forecasters were observing two linear clusters of storms west of Oklahoma City, Oklahoma. As the forecasters watched these storm clusters, three items were apparent. First, both clusters had relatively similar composite reflectivity signatures. That alone would not help with warning decision support. Secondly, the MESH observations were only indicating hail in the northern cluster of cells, but the observation was below severe criteria (e.g., 2.54 cm). Using this alone the forecasters considered a severe thunderstorm warning on the northern cluster. The deciding factor came with the PGLM observations. Here the increase in PGLM activity was up to about 30 flashes in one minute for a single grid box, which subjectively would be weak for a lightning jump. However, this PGLM increase was only observed on the northern cells with only weak PGLM observations with the southern cells. Seeing this weak lightning jump in conjunction with the MESH observations and strong composite reflectivity, the forecasters issued a severe thunderstorm warning. This particular event did not verify, but the forecasters were very impressed with how the PGLM highlighted the strongest cells in both storm clusters.

3.2 Summer Experiment, Kansas City, Missouri

The Summer Experiment, hosted by the Aviation Weather Center, attempts to evaluate experimental products like Spring Program. It brings in aviation forecasters to work in an operational setting along with researchers and other individuals involved with aviation forecasting. The major difference is that the Summer Experiment's scale of operations is not limited to individual WFO county warning areas. The Summer Experiment focuses on the far larger area of operations of the Aviation Weather Center. This presented unique challenges to evaluating the PGLM as it is limited to the very small lightning mapping array domains. The PGLM was further limited by a lack of convective activity in the PGLM domains during the two week Experiment. Still, one real-time case and one archived case were notable.

3.2.1 Flight routes

This particular case occurred in the PGLM domain of the Houston Lightning Mapping Array owned by Texas A&M University on 15 August 2013. At the initial time of the event at 2002 UTC (Fig. 9 – PGLM; Fig. 10 – radar reflectivity) convection can be seen developing in the vicinity of the flight corridor between Houston and Dallas – Ft. Worth, Texas. Of particular note are the colored lines representing aircraft flight tracks in Figs. 9 and 10. These flight tracks show that the aircraft were flying quite close to the convection as it had been deemed that the aircraft would not violate the 20 nautical mile exclusion zone around active convection. At 2002 UTC, only a single flash was observed in two cells in the circled region of interest.

By 2030 UTC (Fig. 11 – PGLM; Fig. 12 – radar reflectivity), the individual cells have merged (Fig. 12) and the easternmost cell is observing approximately 28 flashes in one minute in one grid box. Correspondingly, the aircraft flight tracks can be observed to no longer cut straight through this region of convection, but are now beginning to navigate around this strong storm cell.

There are two items of note in this case. First, the actual storm severity was not a major concern. The aviation forecasters want the aircraft to avoid any active convection. The PGLM observations are another tool to confirm the existence of convection. Secondly, for this particular case, the forecasters indicated that radar reflectivity would still be the primary tool to use in this nowcasting scenario. However, the availability of the PGLM now was very important.

By having access to the PGLM in N-AWIPS the forecasters had the opportunity to see how PGLM observations compare to radar observations. In this way forecasters have the opportunity to see how total lightning and radar observations relate ahead of the launch of GOES-R and the GLM. This way, forecasters obtain familiarity with total lightning and will be comfortable with integrating GLM observations in the future. This is particularly important with data sparse regions (e.g., trans-oceanic flight corridors) where forecasters will have no radar observations and only GLM observations.

3.2.2 Trailing lightning activity (19 September 2012)

The second case from the Summer Experiment was an archived case. The SPoRT representative to the Summer Experiment had the opportunity to work with an Aviation Weather Center forecaster on this post-event analysis during a quieter afternoon. The main point of this case is demonstrated in Figs. 13 and 14.

Figures 13 and 14 show a line of convective storms observed by radar reflectivity and PGLM flash extent density, respectively on 19 September 2012 at ~2018 UTC. The forecaster was impressed by the ability of the PGLM to highlight the strongest cells in the line of storms, similar to that discussed in the linear convection example at the Spring Program. The other total lightning observation that was of interest was the spatial extent of the lightning.

Here, the forecaster noted that the majority of total lightning was concentrated in the main convective region. However, in several locations the PGLM observations noted that lightning was extended tens of km behind the main convection. This could have impact on future issuances of Aviation Weather Center Convective SIGMETS (significant meteorological information statement).

In general, convective SIGMETs are designed to alert the aviation community to active convection to avoid. These alerts are designed to maximize aircraft safety while allowing as much space as possible for air traffic. Looking at this post-event analysis demonstrated that in some cases a convective SIGMET may end too close to a storm as the lightning can extend well behind the main convection. This will remain an open area of further exploration by the Aviation Weather Center.

4. SUMMARY AND FUTURE WORK

The 2013 Spring Program and Summer Experiment were both successful in their primary goal. Each provided training and real-time demonstrations of total lightning to operational end users. More importantly, these were provided in the end users' decision support system (AWIPS II and N-AWIPS, respectively) in order that they could be integrated with other, existing operational products. Combined, these activities provided operational end users to further learn about how to integrate future Geostationary Lightning Mapper observations from GOES-R into operations.

The four examples shown, two from each activity, qualitatively demonstrated the value of total lightning observations for situational awareness, severe weather decision support, and aviation weather decision support. Even though the PGLM, and the future GLM, will have approximately an 8 km resolution, forecasters found the PGLM data useful. The primary advantages of PGLM data were its rapid temporal update of 1 to 2 min (depending on the particular lightning mapping array) and the relation of the total lightning observations to a storm's updraft. This allowed for greater insight into storm development. Furthermore, the Aviation Weather Center noted the importance of comparing PGLM data with radar data side-by-side now, so that forecasters develop familiarity with future GLM observations. This will allow the Aviation Weather Center to more readily integrate GLM observations in the future when only GLM observations are available in data sparse regions.

The end user evaluations noted several more specific recommendations and critiques in the evaluations. First, quantitatively, the PGLM observations scored a 3.95 out of 5 for all evaluations. The PGLM observations were ranked useful to very useful as well. The evaluators did not some issues with the color curve in use at both locations. The trouble was particularly acute with very low flash rate storms. The aviation evaluators have requested the data be brought to N-AWIPS in a grib2 format versus an AREA format. This will allow for an improved updates of the display as new data arrive and better overlays.

The total lightning tracking tool (TLTT), which underwent its first formal evaluation, generated a great deal of comment. The overall response was that the TLTT was conceptually very good, but had issues in actual implementation. Specifically, the TLTT was evaluated as difficult to implement and too time consuming for the operational environment. Also, the AWIPS II display would be cluttered for slow moving storms, making it difficult to modify or update the manual cell track. Another evaluation requested a fixed y-axis for the display versus the current, dynamic y-axis. This would make it easier to monitor the magnitude of lightning activity. In spite of these criticisms in the operational implementation, the TLTT still scored a 3.24 out of 5 during the assessment. Evaluator comments indicated that if the various implementation issues could be corrected, the TLTT would be a very powerful tool in operations.

Looking forward to spring 2014, SPoRT, the Spring Program, and the Summer Experiment have worked during the off season to address the feedback from 2013. For the Summer Experiment, SPoRT will modify the PGLM mosaic data format to improve its utility in the N-AWIPS display. Additionally, SPoRT will have alternate color curves available for the 2014 evaluations of the PGLM data as well as demonstrations on how to modify an existing AWIPS II color curve on the fly. SPoRT also is working with other lightning mapping array owners and hopes to bring the total number of collaborators to 10 networks prior to the 2014 evaluations. Lastly, the TLTT has seen extensive work. It will be much closer to the final Meteorological Development Laboratory moving meteogram tool. This update will allow the TLTT tool to be used on numerous meteorological parameters and gridded products in AWIPS II. It will also undergo evaluation with the Operations Proving Ground. The feedback from 2013 has been used to make changes to the implementation of the TLTT, which should improve its real-time utility.

Acknowledgements: The authors wish thank the GOES-R program for funding the various lightning mapping arrays that are used in the creation of the PGLM products. Additionally, we would like to thank the lightning mapping array collaborators as well for sharing their data for these activities.

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6. FIGURES

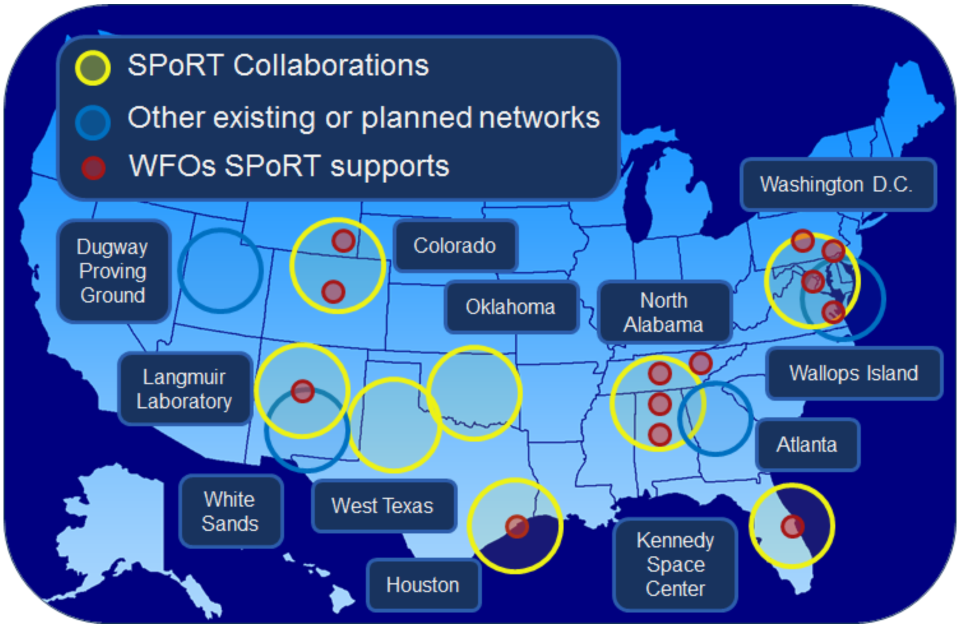

Figure 1. This map shows the locations of the various lightning mapping arrays across the United States. The rings indicate the approximate range of each lightning mapping array with yellow rings indicating networks collaborating with NASA SPoRT and blue rings indicating other networks that are net yet available for collaborations. The red circles highlight the local National Weather Service Offices that are receiving total lightning observations from SPoRT via these collaborations.

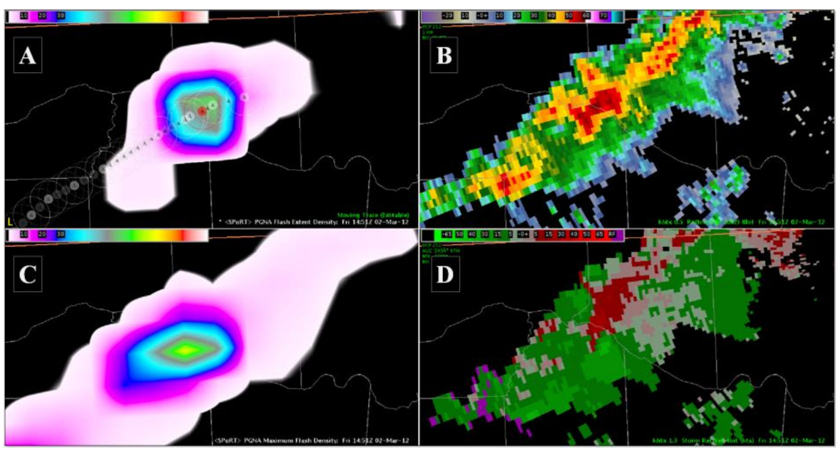

Figure 2. An AWIPS II four panel display demonstrating the pseudo-geostationary lightning mapper (PGLM) flash extent density (A), radar reflectivity (B), PGLM 30 min maximum flash density (C), and storm relative velocity (D). The dots and circles in panel A are part of the Total Lightning Tracking Tool shown in Fig. 4.

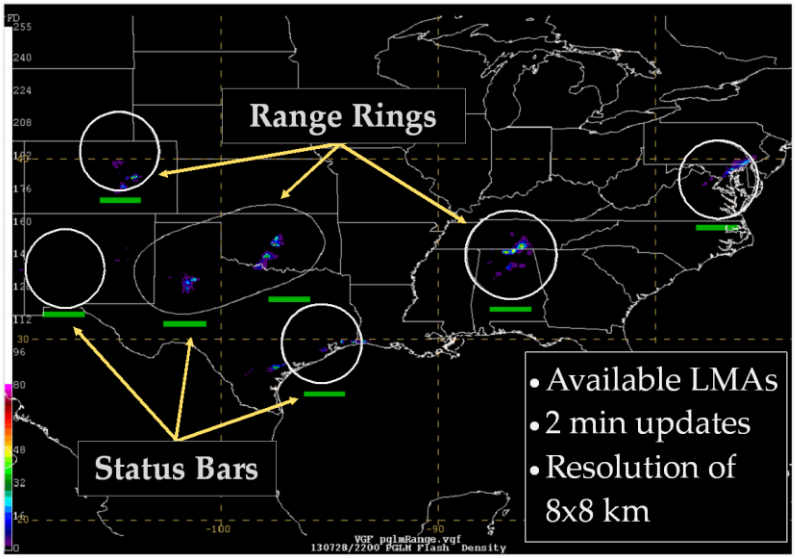

Figure 3. An example image of the pseudo-geostationary lightning mapper (PGLM) PGLM mosaic product as it would appear in N-AWIPS for NASA SPoRT's national center end users. The rings indicate the approximate range of the best observations from each ground-based lightning mapping array. The horizontal bars represent the status of each individual network. In this case, all of the bars are green indicating there are no issues with any network.

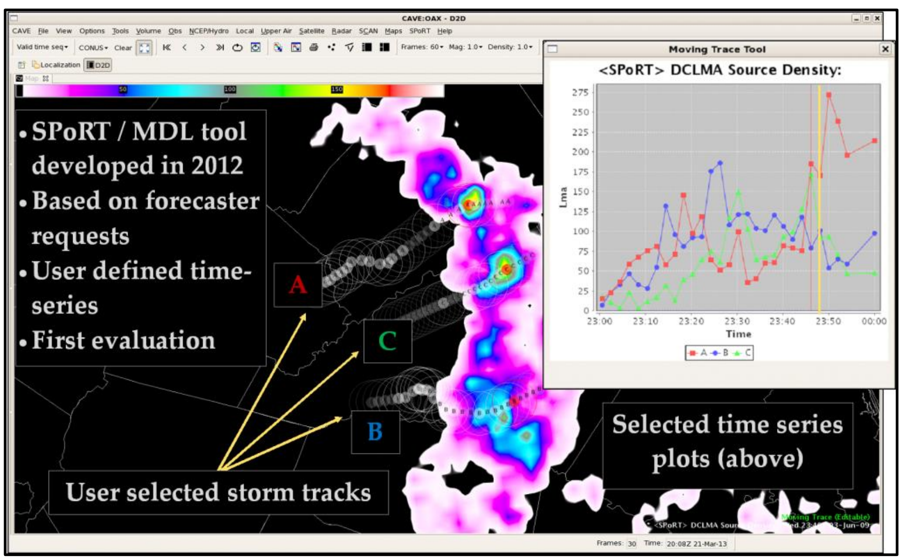

Figure 4. An example of how the total lightning data are viewed in AWIPS II (example from the Washington D.C. domain) with the cell tracks plotted for three cells in the main display. The pop-up window in the upper right shows the actual time series display for all three selected cells. The vertical yellow bar in the pop-up display corresponds to the current time in the AWIPS II display.

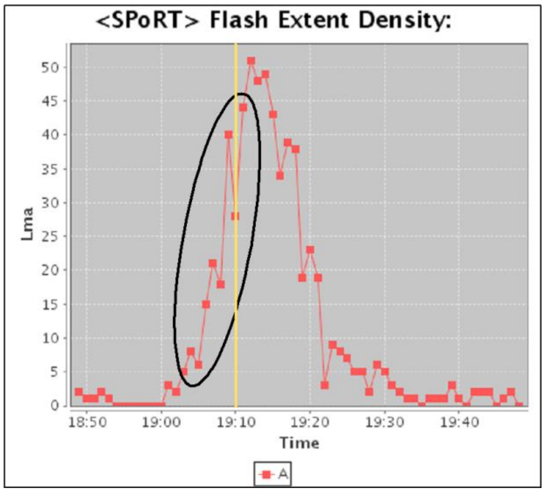

Figure 5. The Total Lightning Tracking Tool time series display for the pseudo-geostationary lightning mapper flash extent density product from 1850-1950 UTC on 15 May 2013. The circled region indicates where the lightning jump is occurring. The vertical yellow bar indicates where in time the AWIPS II display is (not shown).

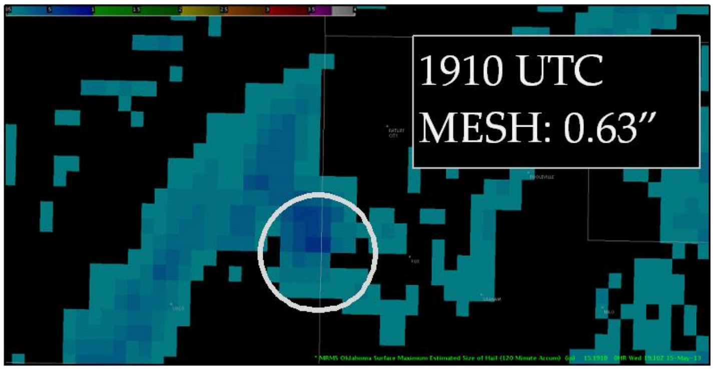

Figure 6. The corresponding radar maximum estimated size of hail (MESH) product at 1910 UTC on 15 May 2013 that corresponds to Fig. 5. The region of interest (where the PGLM track was made for Fig. 5) is circled with an estimated hail size of 1.60 cm (0.63 in).

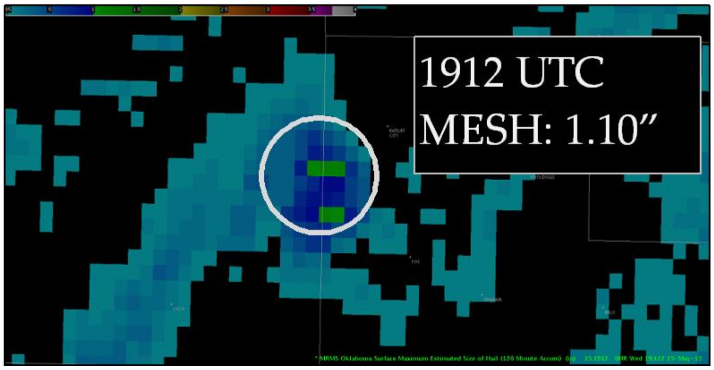

Figure 7. This is the same as Fig. 6, but for 1912 UTC on 15 May 2013. Here the maximum estimated size of hail is 2.79 cm (1.10 in).

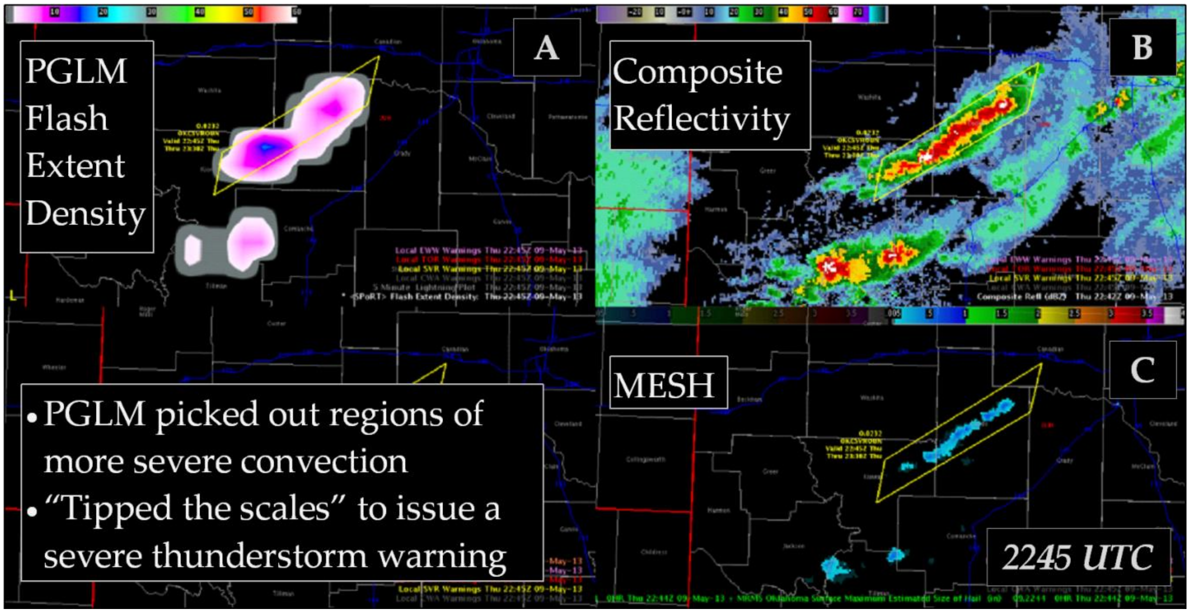

Figure 8. An AWIPS II four panel display showing the pseudo-geostationary lightning mapper flash extent density (A), composite radar reflectivity (B) and radar derived maximum estimated size of hail (C) at 2245 UTC in Central Oklahoma at 9 May 2013.

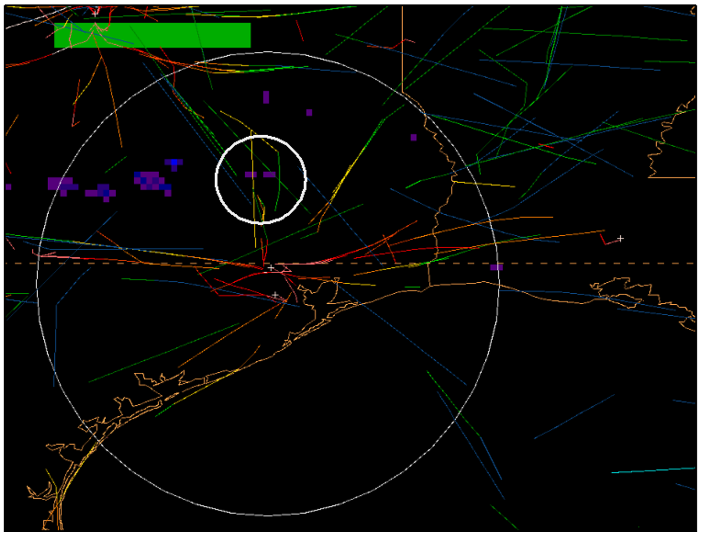

Figure 9. A pseudo-geostationary lightning mapper flash extent density mosaic display in N-AWIPS from the Houston lightning mapping array at 2002 UTC on 15 August 2013 during the Aviation Weather Center's Summer Experiment. The large circle is the rough range of the network. The small circle is the region of interest. The various colored lines are the flight tracks of aircraft.

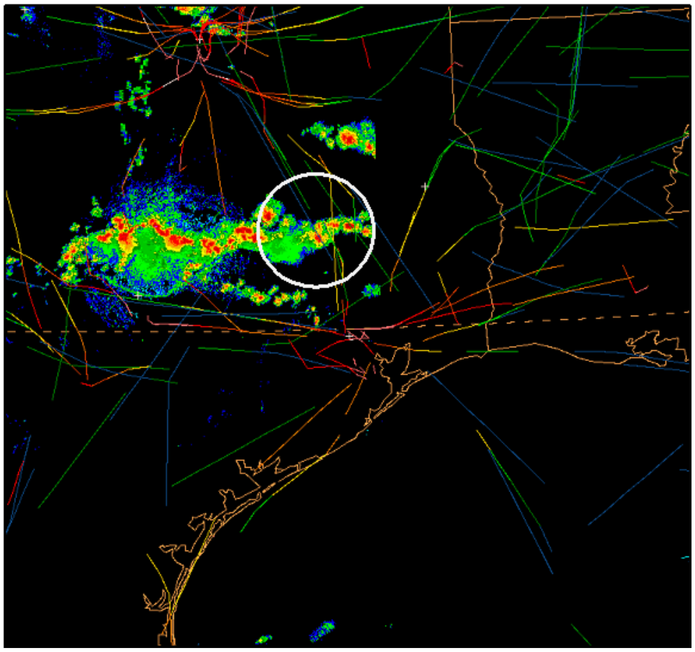

Figure 10. The radar reflectivity at 2002 UTC on 15 August 2013 and flight tracks corresponding to the PGLM mosaic image in Fig. 9 shown in N-AWIPS during the Aviation Weather Center's Summer Experiment. Not the aircraft tracks indicating aircraft skirting around the active convection in the circled region.

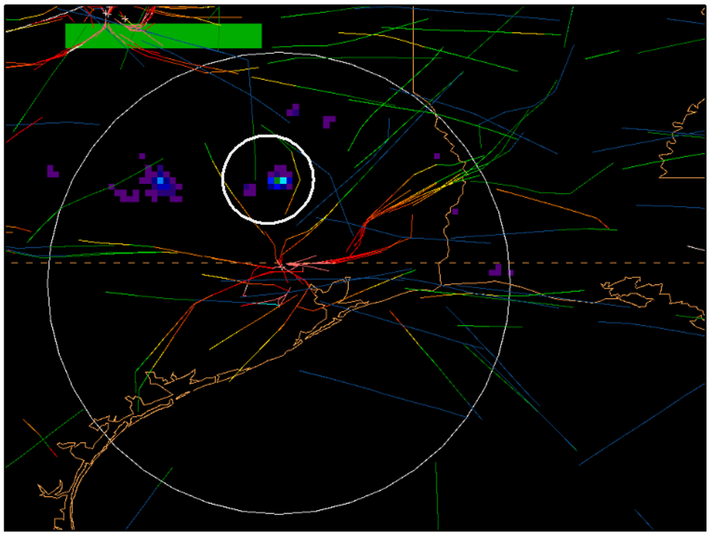

Figure 11. This is the same as Fig. 9, but now for 2030 UTC on 15 August 2013. Note the larger PGLM flash extent density values in the small, circled region indicating stronger convection.

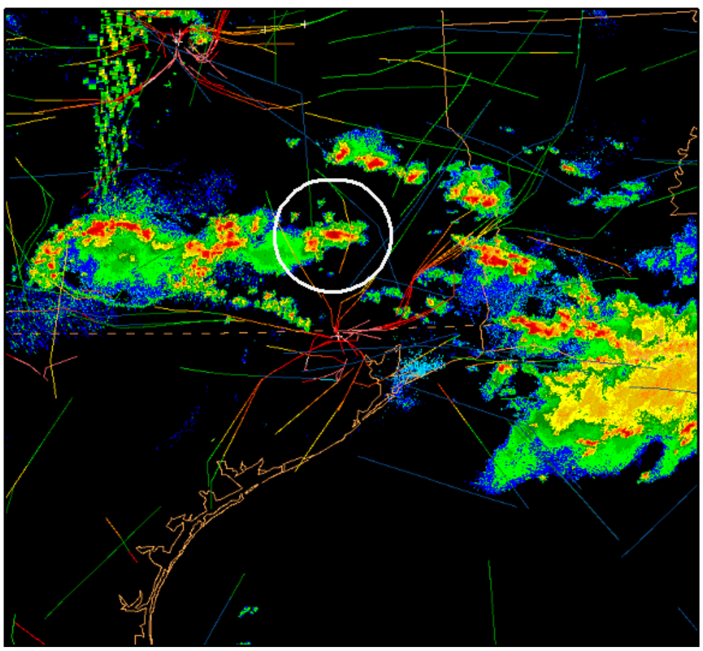

Figure 12. This is the same as Fig. 10 but for 2030 UTC on 15 August 2013. At this time the convection has increased in intensity and filled out in the circled region of interest. The flight tracks are now completely deviating around the convection as opposed to trying to fly in between individual storm cells.

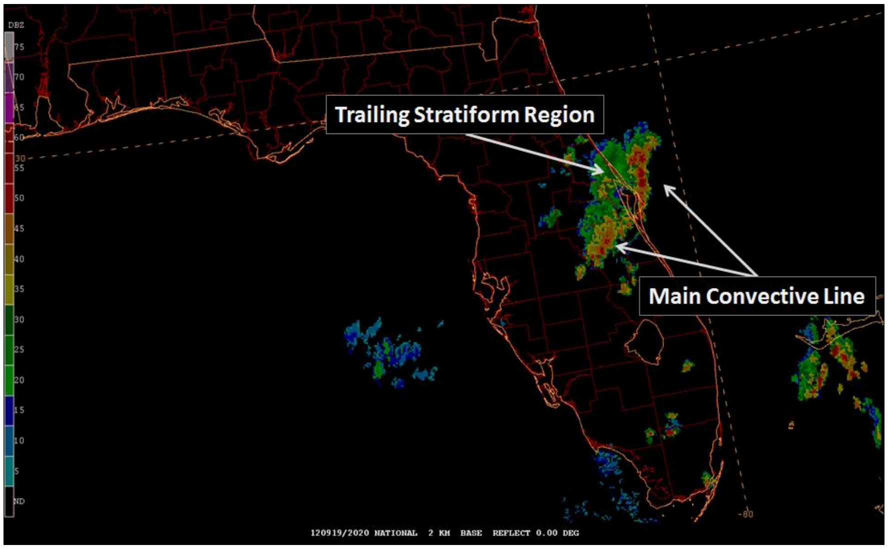

Figure 13. The composite radar reflectivity over central Florida in N-AWIPS at 2020 UTC on 19 September 2012. Note the location of the main convective line stretching from Kissimmee / St. Cloud, Florida in the south and paralleling the Space Coast just offshore to the north and east. The trailing stratiform rain is west of this line around Orlando and Daytona Beach, Florida. (Image courtesy of Ed Holicky, Aviation Weather Center.)

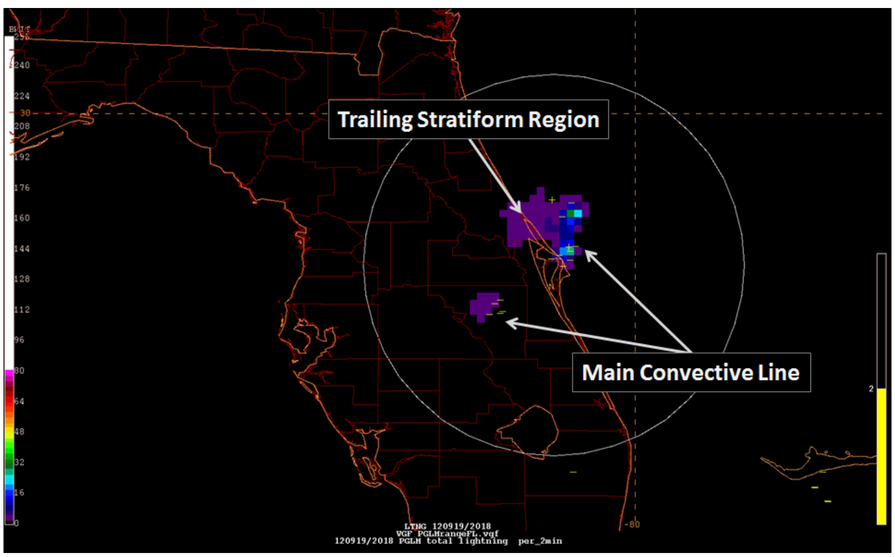

Figure 14. The corresponding 2 min PGLM flash extent density N-AWIPS in the same vicinity as Fig. 13 at 2018 UTC on 19 September 2012. The small '+' and '-' symbols correspond to cloud-to-ground strike locations observed by the National Lightning Detection Network from 2017-2018 UTC. Note how the cloud-to-ground strikes are clustered in the leading edge of the convection observed in the radar reflectivity in Fig. 13. Of particular note are the 1 or 2 flashes of intra-cloud lightning observed by the PGLM extending into the stratiform region of the line of storms just off the Space Coast towards Daytona Beach, Florida. (Image courtesy of Ed Holicky, Aviation Weather Center.)