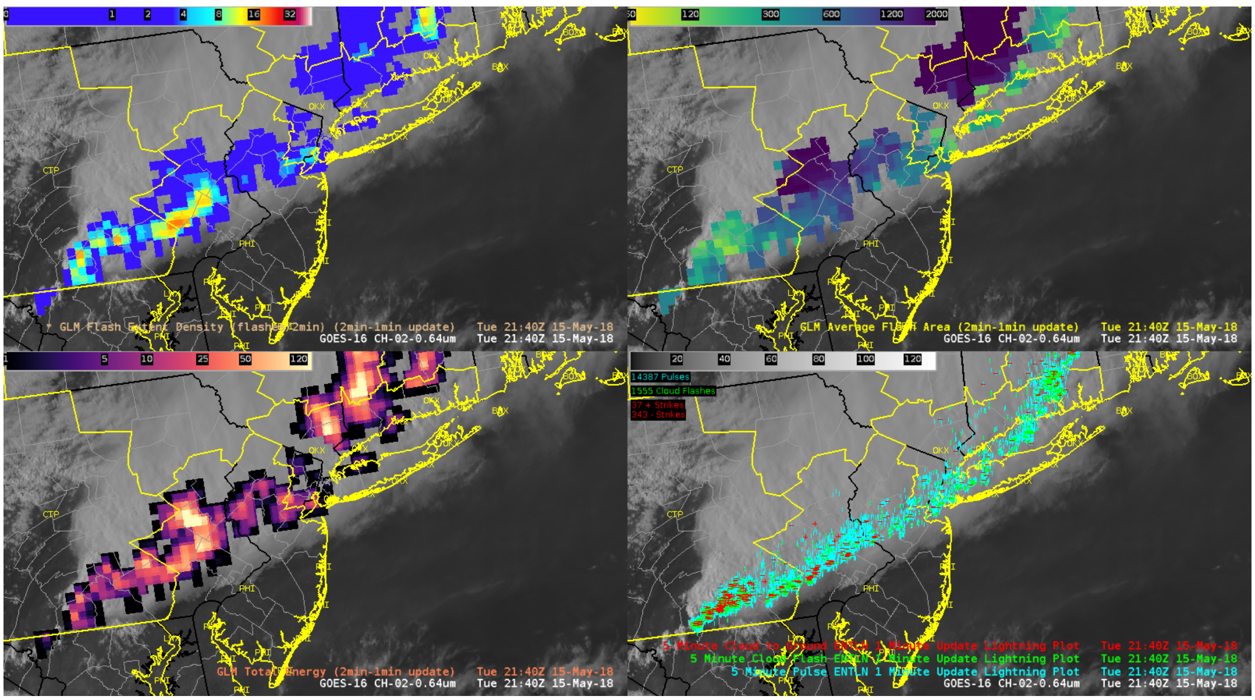
Hazardous Weather Testbed
GOES Proving Ground

Feedback and Recommendations for the Geostationary Lightning Mapper (GLM) in Severe and Hazardous Weather Forecasting and Warning Operations



Flash Event Density (top left), Flash Size (Top right) and Total Energy (lower left) from GLM and ground-based lightning detections from Earth Networks Total Lightning Network (ENTLN) at 2140 on 15 May 2018.

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Executive Summary

The Geostationary Lightning Mapper (GLM) was introduced to National Weather Service (NWS) forecasters and broadcast meteorologists as part of the 2018 Hazardous Weather Testbed (HWT) and GOES/JPSS Proving Ground Spring Experiment. Throughout the month of May, forecasters evaluated the GLM products in the context of live severe and hazardous weather issuing regional discussions, special weather statements, and warnings; forecasters provided feedback through surveys, live blogs, and lightning scientists. The 2018 GLM products were developed based upon forecaster feedback from the 2017 HWT and Operations Proving Ground evaluations and through previous research focused on visualizing the spatial and temporal applications of total lightning data.

Initial products in 2018 included (all at 1-min with 1-min updates): Flash Extent Density, Event Density, Group Extent Density, Average Flash Size, Average Group Size, Total Optical Energy, Flash Centroid Density and Group Centroid Density. Immediate feedback early in the experiment resulted in the creation of 5-min and 2-min summary products (with 1-min updates) to provide forecasters a better visualization of lightning trends over time. Forecasters highly utilized the 5-min Flash Extent Density (with one-min updates) as the primary GLM product. For deeper storm interrogation, storm-electrification understanding, and spatial coverage prediction forecasters also gravitated to the Average Flash Size and Total Optical Energy products at 5 min totals (with one minute updates). Other products such as the Flash Centroid Density were not highly utilized by forecasters in an operational environment, but will likely see use in data fusion applications that incorporate flash rates and for data assimilation efforts into convective allowing models such as the High-Resolution Rapid Refresh (HRRR).

Based on feedback and survey results from 2018, we have three recommendations regarding operational implementation of the GLM data:

(1) Flash Extent Density, Average Flash Size, and Total Optical Energy products (5 min and 1 min products both with 1 min update) are a minimal baseline for operational display of the GLM data within NWS. The products mutually reinforce one another, promoting forecaster confidence and clear thinking about storm processes.
(2) Due to the inherent use of the data within rapidly changing environments, the latency of the product needs to be consistently no more than 1-2 min maximum.
(3) Increased training opportunities need to be provided to forecasters at the time of the operational implementation beyond previous required training modules and quick guides. These training modules should be developed with a regional and applied focus, allowing forecasters to participate in *active* and practical training options in context of other data and within local, real weather events. In addition to storm-growth and severe-storm-interrogation, training should address likely GLM uses such as Decision-Support Services and lightning safety, fire weather, aviation warnings and use over radar-sparse regions.

Introduction and Background

The Geostationary Lightning Mapper (GLM) was introduced to National Weather Service (NWS) forecasters and broadcast meteorologists as part of the Hazardous Weather Testbed and GOES-JPSS Proving Ground Spring Experiment. The experiment began 30 Apr 2018 running through 25 May 2018. Each week three to five NWS forecasters and one broadcast participant evaluated the data in the context of live weather.

Forecasters worked in pairs were given different NWS office / county warning areas daily dependent upon the likelihood of severe and/or near severe weather across the United States. Initial activity focused on the timing and location of convective-storm initiation. Forecasters then switched to warning operations as storms developed over their region of interest. Forecasters were asked to issue mesoscale discussions and warnings utilizing not only the GLM products, but other GOES-16 and JPSS experimental and operational products. Forecasters were given access to the full NWS operational suite of products including radar, Multi-Radar Multi-Sensor (MRMS), ground-based lightning detection systems, and model data. Monday was utilized primarily for training, familiarization and discussion. Tuesday, Wednesday, and Thursday operated as a flexible start time with the goal of maximizing the time in severe weather operations. Friday was used for feedback, discussion and a webinar through the NWS Warning Decision Training Division.

For the experiment a variety of updated GLM products were created based on feedback from the initial review in the HWT and Operations Proving Ground in 2017. Initial products included (all at 1-min with 1-min updates): Flash Extent Density (FED), Event Density, Group Extent Density, Average Flash Size, Average Group Size, Total Optical Energy, Flash Centroid Density and Group Centroid Density. Due to the rapid development of these GLM products, forecasters were brought into the HWT without previous training or use of GLM data in these formats.

Feedback from Forecaster Blogs and Discussion

Based on topics from the blogs and discussion, use of GLM data by the forecasters during the experiment operations in the HWT is grouped into five major categories: (1) situational awareness, (2) understanding and monitoring convective evolution, (3) comparison with ground-based lightning networks comparisons, (4) lightning safety communication, and (5) training and scientific understanding.

(1) Situational Awareness

Most forecasters chose to utilize the Flash Extent Density either at 2-min or 5-min summations (updated every min) to maintain awareness of storm activity across the area of interest. Overall, forecasters found Flash Extent Density, particularly when summed across multiple minutes, could provide easily understood guidance on the strongest cells or call attention to quickly intensifying storms cells at a glance. Some forecasters also utilized the flash energy product for this purpose.

> *"The GLM provides a good situational awareness whereas the ENI data is somewhat difficult to see given the small size of the data points."*
> *14 May 2018, Blog Post "*

> *"The main reason this cell stood out was because of a significant increase in Flash Extent Density. This increase really drew my eye to that part of the line where a cell was rapidly intensifying."*
> *15 May 2018, Blog post: "New Cell and Lightning Trend"*

> *"The flash extent density and total energy products (two upper panels) both seem to do a pretty good job of highlighting the more active core."*
> *15 May 2018, Blog post: "GLM Lightning with Initiating Cores"*

If warranted by this first glance, forecasters would typically follow-up with a deeper dive into the GLM products and comparison against ground-based systems such as radar and CG lightning for storms nearing threshold of severe.

(2) Understanding and monitoring convective evolution

Forecasters used the lightning data in tandem with other routinely used convective monitoring tools such as radar, 1-min satellite data, and algorithms blending data such as ProbSevere. Used in this manner, the GLM data often provided more confidence in warning decisions:

> *"We issued four severe warnings for northern Indiana and southern Michigan. All storms displayed good dual pol signatures, but we also noticed a sharp uptick in GLM Total Energy and Event Density on the storms we issued for. This increased our overall confidence in warning issuance."*
> *9 May 2018, Blog post: "GLM Upticks before warning issuances"*

> *"Little to no increasing trend in GLM Flash Density makes me even more confident in anticipating little to no development of this convection over southern NM"*
> *21 May 2018, Blog post: "ABQ - 2300Z Update"*

> *"Storms continue to maintain (if not increase) their strength as their pivot north and northeast through the Billings CWA. Of particular interest is the rapid increase in GLM flash extent density collocated with smaller average flash area and high total energy with a quickly-developing and strengthening updraft. The increase in flash*

event density also aided in the decision to put out a warning for the storm (particularly given the environment), even as ProbSevere values were below 50% (but increasing). With just ProbSevere or just GLM, or just CTT data to look at, confidence would be lower than when taking in all of the datasets together."
23 May 2018, Blog post: "GLM Data on Rapidly Developing Storm"

Forecasters continuously stressed the importance of seeing the GLM data across multiple products (specifically Flash Extent Density, Total Energy, and Flash Area) and in context of other data for a better understanding of both the lightning data itself and using it to better estimate convective strength. Group discussions with forecasters commonly reviewed how a single product such as Flash Extent Density could provide some information about a flash and potentially about storm behavior. However, pairing Flash Extent Density with Flash Area allowed forecasters to more easily diagnose convective specifics, for example, identifying long flashes through the stratiform region. Additionally, higher flash rates associated with the smaller flash sizes helped forecasters identify new or intensifying updraft regions within a longer convective lines. This combination of new data provided forecasters additional understanding in how storms were evolving throughout a convective event.

"As expected, an extensive trailing stratiform region developed with the maturing MCS as it moved into the central part of ICT area. One long flash was captured at 2146 UTC. Of note, flash area was in excess of 3000 km2 in the stratiform region. The total energy in the stratiform region was equivalent to that in the updraft region as the large charge reservoir was extinguished. More frequent replenishment of charges in the more turbulent storm-scale updraft compensated for the individually smaller/weaker flashes there (ref McGorman, Bruning). There was a depression in flash area along the line while the group area had more continuous flash sizes along. The larger number of groups helped make this more continuous versus the lower flash count. "
-2 May 2018, Blog post: "Trailing Stratiform Region Flash"

"… the GLM Flash Density and Total Energy increased markedly as the merger took place. With all of these updrafts so close together, am also seeing a marked increase in Average Flash Area-especially over Grant/Cherry counties."
10 May 2018, Blog post: "Supercell Merger in NE using ProbTools/GLM"

"Of particular interest to me was the increase in lightning as the merging between the cells and the line took place, followed by a decrease in lightning as the mesocyclone formed… As the more robust thunderstorm activity moved southeast of the DC area, you could see how by using the NEXRAD data along with the

satellite and lightning data the tornado threat might have been on the increase toward the DC area, while a more significant wind, hail, and heavy rain threat was favoring areas to the south."
14 May 2018, Blog post: "Tornado Potential Near Washington D.C"

Similar to past reviews of total lightning data, forecasters commonly noted how "*GLM data provides a supplemental dataset for monitoring storm activity in the absence of traditional radar interrogation techniques."* Forecasters commonly commented on this during operation days across and nearing the intermountain west where radar coverage was poor or when examining oceanic areas where the aviation community is routinely required to route traffic.

One thing that GLM data is going to change for aviation forecasters at the Aviation Weather Center, CWSUs, etc. is Convective SIGMET (C-SIG) and CWA size…As GLM data becomes available to aviation forecasters, I think it is going to open some eyes as to just how much areal extent to lightning there can be in individual t-storms & t-storm clusters/lines/line segments."
23 May 2018, "Aviation t-storm forecasting/warning: GLM Avg Flash Area vs CWA and SIGMET sizes"

"Over the Atlantic Ocean, GLM data will eliminate much of the guesswork in determining what is and what is not a thunderstorm. Not only will this help the aviation community, but it will help the Navy as well as shipping, fishing, marine, recreational boating and cruise liner communities, to name a few"
24 May 2018 "using GLM data over the Atlantic Ocean"

(3) Comparison with Ground-based Networks
With access to multiple lightning networks simultaneously, forecasters frequently examined the differences between these networks throughout the lifecycle of convective storms. Comparisons in timing, location, accuracy, and detection efficiency between these networks were routinely part of discussions and blog posts. Often, forecasters noted lightning within the GLM data prior to the ground based networks, particularly when comparing to cloud-to-ground (CG) activity. Additionally, forecasters found the GLM better represented the spatial extent of the lightning than the ground-based networks.

"GLM first picked up cloud flashes around 2019Z in Hancock County while the first appreciable CG strikes occurred around 2040Z. GLM shows to be beneficial in highlighting areas of convective initiation before cloud to ground sensors."
8 May 2018, Blog post: "GLM vs Ground Network Lightning detection"

> *"… the GLM Flash Extent Density shows a much larger horizontal extent of lightning vs. the ENI pulses. The GLM average flash and group areas (two lower panels) show average flash area increasing over time as the storm grows, going from light green to medium or dark blue. "*
> *15 May 2018, Blog post: "GLM Lightning with Initiating Cores"*

> *"…a noticeable increasing lightning trend with ENTLN data wasn't really noticed until 1905-1910Z as well so GLM was able to capture the initial electrification of this storm with few minutes extra lead time. On a day like today when monitoring areas of cumulus for the first convective echoes to develop, GLM (especially GLM total energy) was especially useful."*
> *24 May 2018, Blog post: "GLM first identified developing storm in WI"*

However, forecasters often voiced confusion and concern if the flash rates and trends were different between the GLM and ground systems. As the GLM science team continues to better understand why the GLM may not perform the same for all convective environments, it is important that these caveats are communicated to the operational forecasters as well.

> *"Over the course of the week I have been concerned with comparing the consistently low FED values (single digit for most storms) with the other lightning fields including ground-based networks. Visually the low counts per pixel do not grab your attention when looking at a busy scene with storms in a variety of stages of their life cycle…"*
> *3 May 2018, Blog post: "FED vs GED"*

> *I noticed rather low values of GLM flash extent density & total energy with a severe warned storm near Wheatland in eastern WY so out of curiosity I decided to plot observed CG & cloud flashes from the ENTLN. Despite low values of Flash extent density & total energy the earth based network observed a rather active storm with numerous CG flashes & even more cloud flashes. The total energy product seemed to perform better than flash extent density in conveying the lightning activity in the storm & potential strength of the storm, but if I was only using GLM in a vacuum I likely would have greatly underestimated the potential of this storm. It is becoming more evident to me that the GLM output can differ drastically for "severe" storms depending on the environment, geographic region, & even from storm to storm during the same event.*
> *23 May 2018, Blog post: Comparison of GLM & ENTLN lightning data*

Through this comparison process, forecasters often noted the obvious displacement (parallax) of the GLM locations relative to the ground based system. This apparent shift in position away from the actual location was not unexpected as forecasters as acclimated to parallax with other satellite data. However, many forecasters suggested that training and best practices remind forecasters specifically to pair the lightning data from satellite to total lightning data from the ground based systems for storm-based warning polygon locations.

"The image [Fig. 1] compares cloud lightning flashes from Earth networks with GLM total energy. The GLM image gives a much more complete picture of the extent of lightning, however there is a noticeable north/south discrepancy between the two. The GLM max just southeast of the main line is shifted northward by about 10 miles relative to the ENI lightning cluster" 14 May 2018: "GLM Parallax" and "Notable Parallax Errors on GLM"

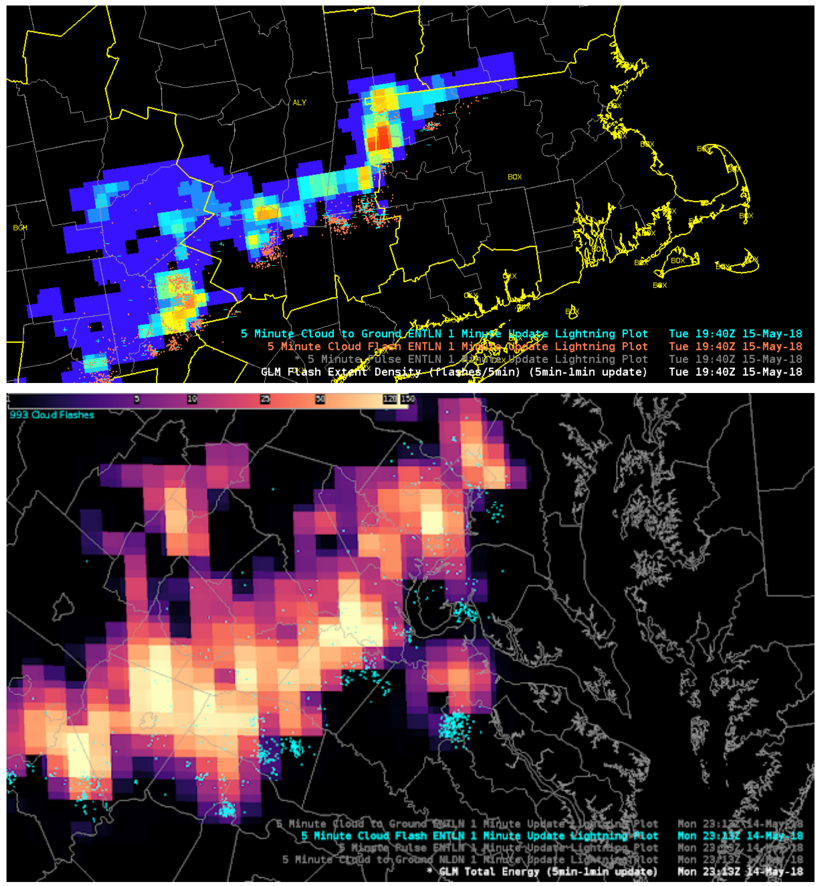

Fig. 1. Forecaster screenshots from the northeastern United States depicting the parallax errors from GLM in comparison to the Earth Networks total lightning data. Top: 5-min GLM Flash Extent Density and ENTLN CG (blue) and Cloud flashes (orange). Bottom: 5-min GLM total energy (grid) and 5-min ENTLN cloud pulses (blue).

(4) Lightning Safety and Communication

Both the broadcast meteorologists and NWS forecasters discussed how the increased spatial coverage apparent within the GLM data provided an opportunity to connect and communicate with end-users and the public regarding lightning safety. Additionally, as the NWS continues to grow decision-support services, forecasters noted the impact the GLM data could have in providing guidance for outdoor venues, fire coverage, and airport weather warnings.

"As the flash extended north into MN and another CWA, this information could be used to enhance DSS since the main convective line was still 50-60 mi away. ENI and other commercial lightning networks would not have alerted to the threat of lightning overhead at such a great distance. An event organizer or EM looking at static radar also may not be aware of the increased threat of lightning well ahead of the main storm band."
3 May 2018, Blog post: "Give me Flash Area or give me death…"

"I was able to note the 1 minute average flash area spread well out ahead of the precipitation area in front on the storm and also extend in the anvil behind the storm as well. As a broadcast meteorologist, it was a great way to explain to viewers the lightning threat away from the precipitation."
14 May 2018, Blog post: "Severe Weather Over Virginia/Maryland"

(5) Training, future development and general concerns
The HWT served as an introduction to each of the participants on using and integration of GLM data into their daily operations. This included completely new and unique visualizations of lightning data for most participants, thus discussions frequently addressed training and specifically the need for more hands-on, locally-focused training opportunities.

Forecasters routinely stressed the importance of integrating expert knowledge (such as that available throughout their own HWT experience) at their home offices. They found this greatly reduced confusion and frustration in integrating the products into their operational product suite. Additionally, forecasters desired more time and additional guidance to better understand each of the GLM products relative to the meteorology and also to other lightning observing systems (such as Earth Networks).

Forecasters suggested that the context for use (such as DSS, warning operations, fire weather, or aviation) was important and this should *"drive various need/demand for individual GLM products."* Additionally, caveats regarding viewing angle, parallax, and meteorological environments or storm types should be clearly communicated within available training. At the end of their week, most forecasters saw the utility of the data, but were still left with questions regarding the individual products or relationships to meteorological phenomena. Training and future scientific research should continue to strive to answer these questions and provide context to GLM in an operational environment.

"I noted this storm [Fig. 2] in southern Arkansas was indicating a 2 minute Flash Extent Density near 45 which is near the high end of the default color table. The

Total Energy registered 240 fJ at this time, which is double the top end of that respective color table.

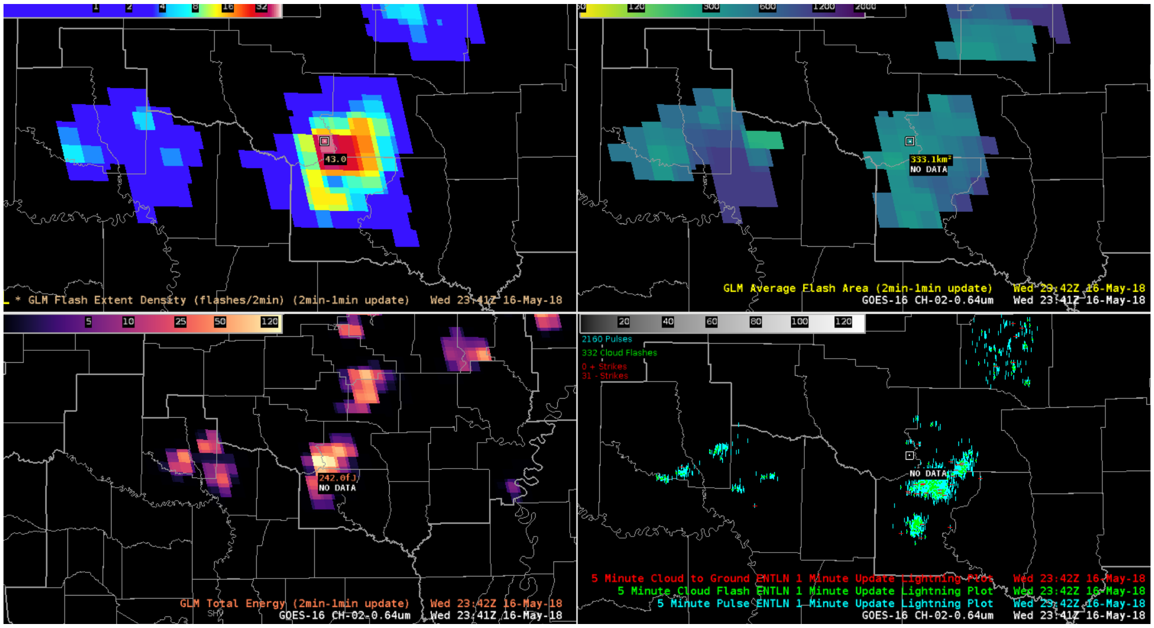

Fig. 2. Forecaster screenshot from blog post on 16 May 2018. Top left: 2-min sum of Flash Extent Density. Top right: 2-min Average flash area. Bottom left: 2-min sum of Total Energy. Bottom right: ENTLN pulses (blue), flashes (green) and CG lightning (red).

It makes me wonder what all factors contribute to high energy for a particular storm over another storm in a similar environment. What processes are at work in this instance? It's all very fascinating and could have potential benefits in the warning environment -should a correlation become evident."
16 May 2018, Blog post: "GLM Total Power"

"I would like to see more training on the average flash area in how to show how the lightning strike area coincides with the event density and Total Energy. ***Please do not just do another module, especially for something so new as GLM! It has taken me personally hours of handling the data WITH the presence of the GLM SMEs*** *[subject matter experts]* ***at the EWP to have even a modest understanding of the flash area, total energy, and flash extent.*** *Perhaps average flash area is more of a IDSS application product than use in warning operations."*
8 May 2018, Blog post: "FSD Mesoanlysis"

Results from Daily Surveys

The daily surveys characterize many of the aspects forecasters addressed throughout the blogs and captured during discussion in the HWT. For the GLM, the daily survey included five questions:

(1) Did you find any of the following specific GLM products useful today? [rank each product for today's weather from 'Not at all Useful' to 'Extremely Useful']. Why?
(2) What was your confidence (i.e., your understanding) of each of these GLM products? [rank each from 'None' to 'Very High']. What influenced this?
(3) What update frequency did you use most often or wish you had for today's weather?
(4) What changes do suggest to the visualization/color tables (if any) based on your use today?
(5) Please note any other recommendations you have for improving GLM applications.

Forecasters ranked Flash Extent Density and Flash Energy as the most useful products, but also considered the Flash Area, Event Density, and Group area products as useful overall (Fig. 3, top panel). The centroid products were found considerably less useful by forecasters, averaging as "somewhat" or "not at all useful."

Follow up comments clearly described why FED, Flash Energy and Flash Area had the highest use. Forecasters noted they *"like to see the flash extent data and avg flash area, in conjunction with the total energy. I can conceptualize how intense or widespread a storm is by using all three."* Additionally, they noted at these three products *"helped show strengthening, weakening, and maintaining intensity"* and *"seemed to correlate to what I would estimate updraft strength."* While FED was the most highly used and ranked, some forecasters preferred Flash Energy, noting: *"I did find the total energy the most useful because I can relate to total energy better than the other parameters. It's like thinking about and looking at a 100 Watt light bulb…That's easier for operational forecasters to think about."* However, some forecasters did not utilize the energy product as easily, noting that *"measuring how bright a storm is…isn't necessarily reflective of how strong a storm is."*

Though forecasters initially ranked FED and Energy higher during the the week, the usefulness of flash area generally increased as the week continued as forecasters became more familiar with the product and how to use it. For example, one forecaster noted that *"the ability to differentiate between small flashes within the core of a developing storm and broad, long flashes throughout the anvil is very nice. This can not only provide some warning decision making tools, but is also a useful product for IDSS purposes."*

As for the centroid products, forecasters believed these looked to much like the ground system detections and cluttered the screen: *"The centroid density looks so similar to CG* *strikes. I had to remind myself that's not what the product is"* Initially, some forecasters ranked all of the GLM products poorly due to lack of experience and training, noting: *"I do not have a good understanding of what the GLM products are displaying."* Rankings for all products, except the centroids, generally increased as the week continued, primarily due to increased exposure to the products.

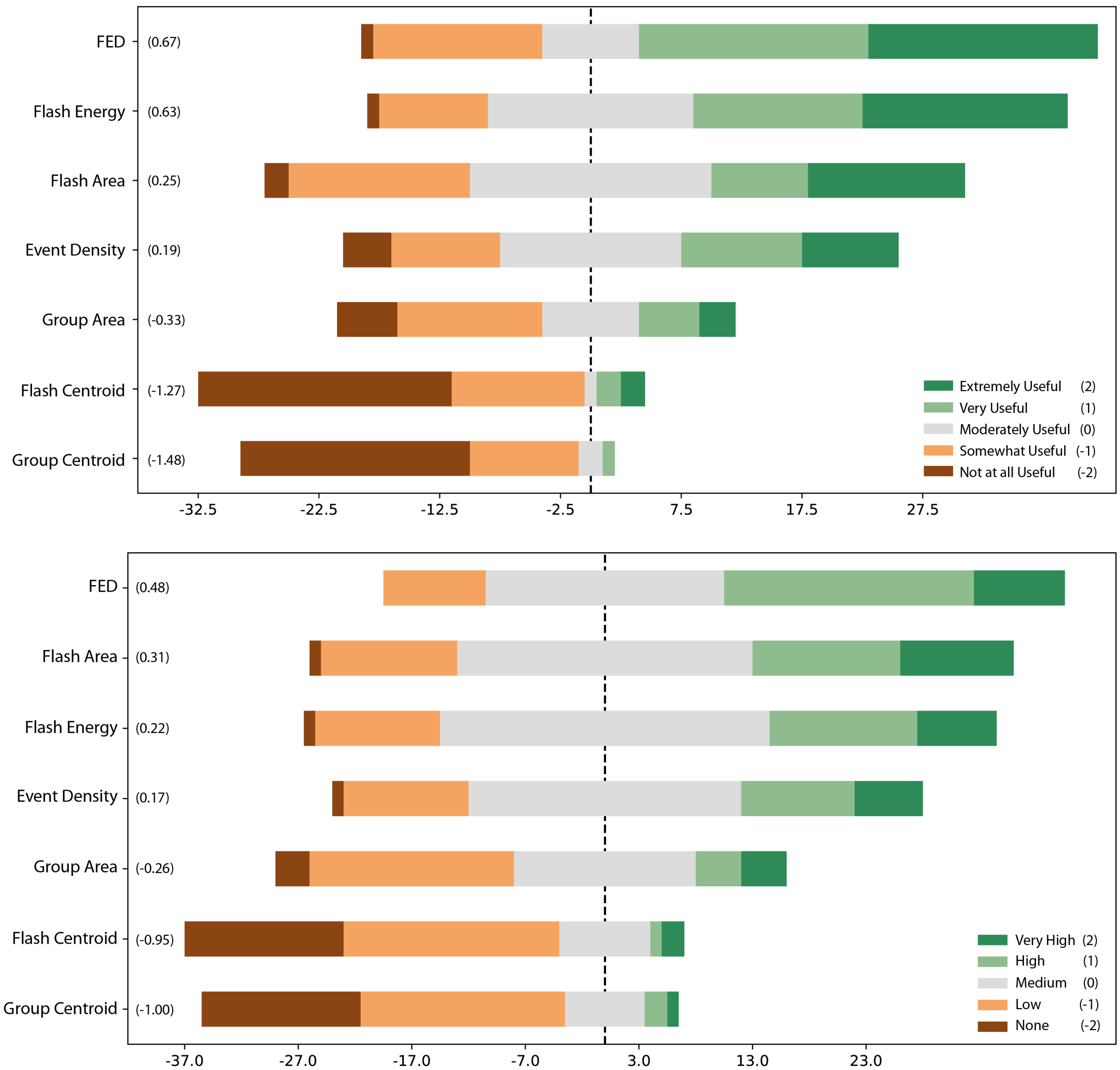

Fig. 3. Results from daily surveys. Top: Forecaster opinions of product usefulness from Extremely Useful (Dark Green) to Not at Useful (Dark Brown). Bottom: Forecaster understanding of each product from Very High (Dark Green) to None (Dark Brown). Products are sorted by decreasing average in each plot. Averages were calculated according to points shown in legend and are shown to the right of each product on the y-axis.

Forecaster confidence in or understanding of each of the GLM products similarly increased as the week continued, centroid-based products withstanding. However, very few forecasters ranked their own confidence in any of the products as "very high" even late in the week (Fig. 3, bottom panel). Averaged across the week, forecasters had a medium confidence in understanding what a majority of the GLM products were showing them. FED and Flash Area were ranked highest, followed closely by Flash Energy and Event Density. Group area and the centroid products averaged a low understanding by the forecasters.

Forecasters found the number one thing influencing their confidence in using the products was hands-on experience working with subject-matter experts. Repeatedly in the comments forecasters noted *"getting thorough explanations from the developers was a big confidence help"* and *"it will take time to get high confidence. It's still lots of information at the cutting edge of science."* Seeing the products in context of multiple events, different environments, and *"comparing it to what was happening and seeing what warnings were issued and the severe weather reports that were received"* greatly influenced the confidence in use. However, if the GLM data did not match trends in the ground-systems or other observations forecasters during an event did lose confidence in the products. For example, one forecaster commented: *"[I] Did not see much correlation between storm intensification trends & the GLM data, but I did notice some in the ENTLN data. This lowered my confidence in the GLM for this event."* This problem was compounded when working in regions of high parallax errors or in environments in the west central US (Colorado, West Texas) where charge distributions and lightning height could influence the GLM detection efficiency. Forecasters desired more specifics as to how these things influenced the GLM products, comments included: *"How parallax affects GLM data is a mystery to me. It would seem to degrade it, but by how much?"*

Finally, forecasters struggled with some of the terminology and meaning of the sub-products of GLM: events and groups. This complicated the overall understanding of the GLM relative to the meteorological phenomena and other lightning detection systems. Forecasters noted that the *"Flash products are intuitive. I easily grasp the concept of a Flash and the density and areal coverage make perfect sense. The "**arbitrariness**" of the Event/Group products makes them slightly more difficult to grasp."* Similarly, even when forecasters found that the event/group products were understood, the *"somewhat mysterious definitions of event/group reduce confidence in my ability to comprehend exactly how to use the information."*

The 5-min summation updating every minute was by far the most used product times. This timing allowed forecasters to visualize trends, but still receive a rapidly updating product. Forecasters that used the 1-min update accumulations felt the data was too chaotic to sensibly use for situational awareness or visualizing trends. Once the 2-min summation was made available many forecasters gravitated to both that as well as the 5-min product, but continued to list the 5-min as the primary product for severe weather applications. Still, some forecasters found value in the 1-min products throughout the experiment as these allowed them to see the greater detailed variation in the storm-scale cores.

As future products are being developed and changes made for the operational implementation, some forecasters also suggested that increased smoothing in the products (beyond the AWIPS 'interpolation') would be desired. Additionally, it was suggested that the GLM data is combined with ground-based systems to help with geolocation errors and detection efficiency.

Finally, forecasters commonly used the last question of the survey to address the need for increased training opportunities prior to and as the GLM data becomes part of the operational data feed. Specifically, they are looking for *"additional training on the products and their applications, points of failure, weaknesses."* This training should address "*how the fields interact with each other & what that suggests the storm is doing lightning-wise (i.e. high total energy but low flash extend density, etc.)*" and should show "*the benefits of using this data in operations and what additional information may be gleaned from it over the surface based systems.*" At least one forecaster suggested that discussion with subject-matter experts should become more broadly available to those required to train others (e.g., local office focal points and science operations officers): *"While the hands-on experience is extremely valuable, I gained just as much knowledge about the products from the discussion about what I'm looking at. The brief discussion on why short flashes develop near the core of developing updrafts and longer flashes tend to occur in the anvil areas is something that I may not have grasped learning about the products remotely. It's very important to some people to explain the output and not rely on someone to intuitively understand the theory."*

Recommendations for Operational Implementation

Forecasters utilized the 5-min Flash Extent Density (with one-min updates) as the primary GLM product. For deeper storm interrogation, storm-electrification understanding, and spatial coverage prediction forecasters also gravitated to the Average Flash Size and Total Optical Energy products at 5 min totals (with one minute updates). Forecasters found limited-to-no usefulness and understanding of the centroid and group products. Some forecasters did prefer the Event Density Product to the Flash Extent Density due to the increased values and spatial variability, but a majority of forecasters were confused at the difference and uniqueness of one product versus the other. Forecasters also quickly gravitated to the 5-min summation and averaging products to better analyze trends than the 1-min and 2-min products, but still greatly depended on the 1-min updates to these products. **It is therefore recommended that the 5-min (with one-min updates) Flash Extent Density, Average Flash Size, and Total Optical Energy products are a minimal baseline for operational display of GLM within AWIPS.**

Latency of this product greatly introduces decreased and inattentive use. Latency of only 5-min at any given time-step greatly decreases the utility of the product in rapidly changing environments. Latency beyond 10-min resulted in forecasters choosing to ignore the product completely. **It is recommended that latency of the product is consistently less than 2 min for operational use.** *(Note: The code-base for the GLM was updated prior to the final week of the experiment and appeared to adequately address this problem).*

Usefulness of the products was consistently regarded higher than general understanding of all the GLM products, including the Flash Extent Density. **It is therefore recommended that increased training opportunities are provided to forecasters at the time of the operational implementation beyond previous required training modules and quick guides.** Locally-relevant training utilizing local cases and expertise (such as from lightning and severe weather focal points) should be developed at an office or sub-regional level. Hands-on training should be given the highest priority. In addition to storm-growth and severe-storm-interrogation, training should address context-specific use such as Decision-Support Services and lightning safety, fire weather, aviation warnings and use over radar-sparse regions (where appropriate) and best practices for integrating the GLM data with other data sets.

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