Hazardous Weather Testbed — GOES Proving Ground
2019 Experimental Warning Program

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

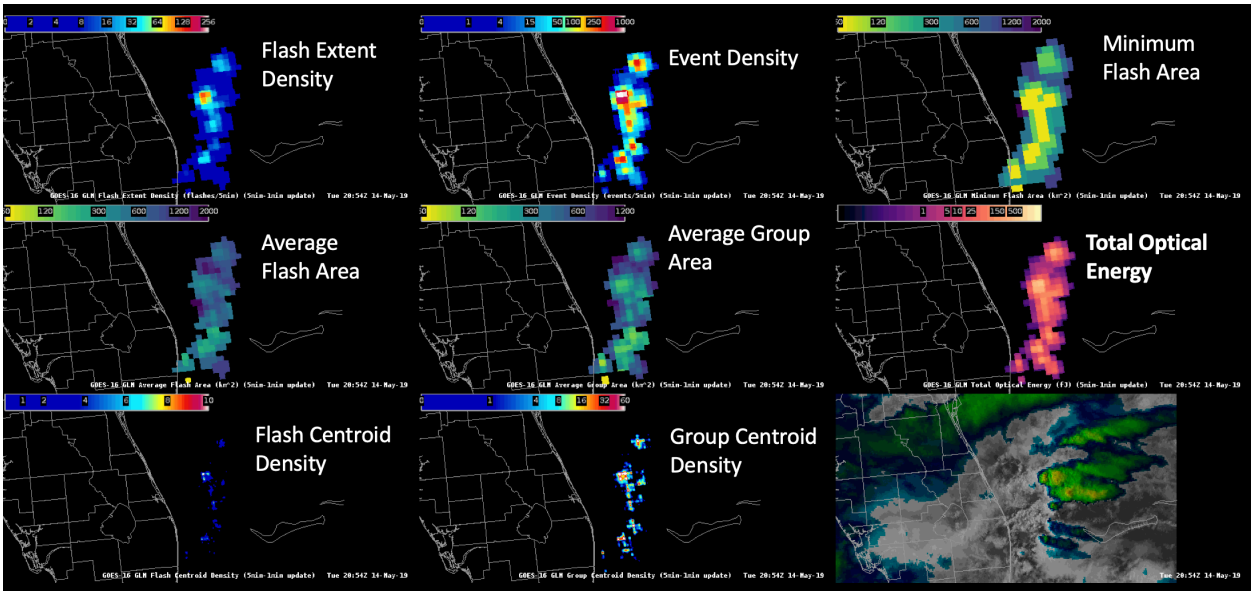

Fig. 1. The GOES-16 GLM gridded products included in the 2019 HWT Proving Ground Demonstration/Spring Experiment. Image is screenshot from a forecaster AWIPS display of storms off the coast of Florida on 14 May 2019 at 2054 UTC.
Visit https://blog.nssl.noaa.gov/ewp/2019/05/14/glm-florida-coast/ to view the animated loop.

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31 July 2019

Executive Summary

Over a period of six weeks (29 Apr - 7 June 2019) in the Hazardous Weather Testbed (HWT), National Weather Service (NWS) forecasters were asked to review and provide feedback on multiple Geostationary Lightning Mapper (GLM) gridded products from both GOES-16 and GOES-17 for use in operations during severe and hazardous weather. The products included: Flash Extent Density, Flash Energy, Minimum Flash Size, Average Flash Size, Average Group Area, Event Density, Flash/Group Centroid Density, GLM-IR RGB.

Overall, forecasters had a better understanding of the products in 2019 than in 2018. Average confidence in the products was much higher than in 2018 with most forecasters ranking most products high or very high in terms of understanding. This was likely due to a longer period of exposure and increased time with subject matter experts. The top two products in terms of usefulness during severe weather operations were the Flash Extent Density (FED) and Minimum Flash Area products. Event Density and Flash Energy were also considered useful by the forecasters.

A GLM-IR RGB product was created in collaboration with Drs. Christopher Schultz (NASA) and Eric Bruning (TTU) to help integrate the IR imagery with the GLM products due to 2018 HWT comments regarding the lack of screen space for integrating the GLM products. The goal of this product is to highlight the areas with the coldest cloud tops, highest FED, and smallest flashes. While this was the initial product development, forecasters showed interest and further development will continue.

Based on feedback from the 2019 HWT, we recommend the gridded product rollout of GLM continue and should become integrated into the base products from GLM. In particular, FED, min flash size, event density, and flash energy should be made available. We also recommend the GOES-17 GLM CONUS projection move or expand to cover areas across the north central plains and central United States where it appears that GOES17 have the same or better detection efficiency as GOES-16. Additionally, we suggest the NWS take multiple steps to continue training efforts with local offices. Again in 2019, forecasters reported having a subject matter expert available to answer questions made the greatest impact on product understanding and use throughout the week. We would like to stress forecasters use the GLM products in conjunction with the ground-based lightning products including Earth Networks Total Lightning Network, Vaisala's National Lightning Detection Network, and/or GLD360, as appropriate. It should also be stressed in training that GLM may have a highest degree of impact in Decision Support Services as the network is the only one available to NWS forecasters that depicts the entire extent of lightning activity in a storm or region.

Introduction and Background

Gridded products from the Geostationary Lightning Mapper (GLM) on both GOES-16 and GOES-17 were included Hazardous Weather Testbed GOES-JPSS Proving Ground Spring Experiment. 30 forecasters from National Weather Service (NWS), 2 Air Force Meteorologists, and 3 Broadcast Meteorologists, examined the products in the context of issuing warnings and advisories during live weather activity across six different weeks, beginning 29 April and ending 7 June 2019.

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. Following storm initiation, forecasters switched to warning operations as storms developed over their region of interest. The 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 numerical 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 2018. Initial products included (all at 1-min or 5-min with 1-min updates): Flash Extent Density (FED), Event Density, Average Flash Area (AFA), Minimum Flash Area (MFA), Average Group Size, Total Optical Energy (TOE), Flash Centroid Density and Group Centroid Density. Prior to arrival at the HWT, some forecasters had access to the GLM Flash Extent Density, a small number of other forecasters had access to the Average Flash Area and Flash Energy gridded products as well; however, most did not have access to them routinely in operations. All forecasters had previously taken the required GOES GLM training, though some noted it was more than a year prior.

Results from Daily and Weekly Surveys

Surveys were taken following the conclusion of operations each day in the HWT, with forecasters answering the questions relative to the activities and weather of the day. Weekly surveys were used primarily to understand the impact of using the data across the week and to help guide future training and research needs. The GLM questions were a subset of a larger survey of GOES / JPSS and Radar Operations Center products. The survey asked all forecasters to provide details on the location or local forecast offices used and the forcing mechanisms and primary convective mode of the day for context relative to the other questions. If forecasters did not use the GLM data, they could skip the GLM-related questions. Over the six weeks the daily survey was taken 138 times; of the 138 surveys, the GLM questions were skipped 7 times.

For consistency and comparison with the 2018 evaluation, the 2019 survey used similar GLM questions to the 2018 evaluation. The questions on the 2019 daily survey included:

(1) Briefly describe the specific role lightning data played (or did not play) for this event. What were the strengths and weaknesses of lightning data within this event? What products did you use in conjunction with the GLM data?
(2) 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?**
(3) What was your confidence (i.e., your understanding) of each of these GLM products? [rank each from 'None' to 'Very High']. **What influenced this?**
(4) What update frequency did you use most often or wish you had for today's weather?
(5) Did the color tables make sense to you fore each of the products? What changes do suggest to the visualization/color tables (if any) based on your use today?
(6) Please note any other recommendations you have for improving GLM applications.

A wide variety of cases were examined by forecasters across the six weeks. Both discrete and linear systems were seen throughout the experiment. A majority of days had an evolution of storm clusters and modes, generally beginning with isolated and supercell storms growing upscale to a linear system. Classified by the primary storm mode of the day, forecasters examined the GLM data in context of: (1) weak and/or marginally severe convection [6 events], (2) mixed-mode, single-cell, multi-cell severe convection [5 events], (3) linear and quasi-linear convective systems with strong straight line winds and embedded rotation [8 events], and (4) discrete supercell storms [7 events].

GLM use evolved across the week, with forecasters commonly noting less confidence in the products early in the week and gaining trust and greater understanding across the four days of operations. During events, GLM data was most often used "to monitor and identify new updrafts and storm glaciation", "identify convective trends", and for situational awareness to "focus attention onto storms that needed to be closely watched." Forecasters initially noted using only the FED product early in the week, but later integrated both the MFA and TOE to in conjunction with FED to "observe behavior" and help "diagnose trends of the storms."

Across all weeks, FED was the primary product for GLM storm interrogation. In the surveys, forecasters commented they used FED "to pick out trends", "watch for lightning jumps", and "compare to the ground-based networks". A common theme was to use the MFA to "identify whether a storm [updraft] was re-generating or not" as forecasters found the flash area useful "for determining weakening phases of storms when the amount of smaller stroke lightning decreased and longer flash events increased." Additionally in the daily surveys, forecasters noted they "love the minimum flash lightning data. I can see it being heavily utilized at my WFO. Was able to get lead team on convective development" and the "Minimum Flash Area continues to be a favorite during convective initiation and growth, watching how storm strength is doing."

Many forecasters commonly noted also using TOE during storm initiation and growth as well as to highlight lightning channels in the stratiform region of developing MCSs. However, forecasters commented they would like more training on TOE and how it relates to storm strength. The primary weaknesses noted in the GLM data were the inherent lower resolution (compared to other satellite and radar products), the parallax offset from the ground-based lightning detections, and lower detection efficiency on some storm types and locations.

Similar to 2018 survey responses, FED had the highest use of all the products (Fig. 1, top panel). However, the new MFA product (developed based on forecaster feedback from 2018) was the next highest used GLM product. Event density (a similar product to FED and used in much the same manner) and Total Optical Energy were the next most commonly used products. Also similar to the 2018 responses, flash centroids and group products had much less use during the experiment as these products did not provide details on the full spatial extent of the lightning.

Forecaster responses clarified that the FED and MFA products "capture my attention and increase my probability of issuing warnings sooner", were "especially helpful in detecting new updrafts", "highlight the strongest storms", and "picked up on areas that may have gone undetected with other lightning data" as reasons for the higher ranking of that data. Forecasters also commonly agreed that these two products were the "go-to as the best indicator of developing updrafts". However, a few forecasters preferred the greater range in values depicted by the event density product and opted to use this instead of FED. The forecasters that highly ranked the event density product provided the lowest rankings for FED, slightly decreasing that average overall. Both FED and event density show roughly the same behavior and current research does not favor one product over the other. The spread in rankings for TOE can be explained in part that many forecasters found TOE to be "fairly intuitive", but others also commented it was "best suited for initial development" only and that the "application to the warning process is unknown" at this time.

Overall confidence or understanding of the GLM products and how to integrate them into forecaster workflow increased greatly over the 2018 survey, FED in particular (Fig. 1, lower panel). There were two major influences on this, both due to experience with the data: 1) multiple forecasters from the 2018 HWT evaluation returned in 2019 and 2) a large percentage of forecasters had access to FED product at their home forecast office through via local data delivery hosted by the Operations Proving Ground. In the surveys, multiple forecasters noted they had access to FED coming into the HWT experiment, but that product training on day 1, conversations with subject matter experts, and additional experience and exposure across the week for a variety of storm types in an operational setting were the primary drivers of their own understanding. Universally, rankings of confidence increased as forecasters had more experience with the data for almost all GLM products.

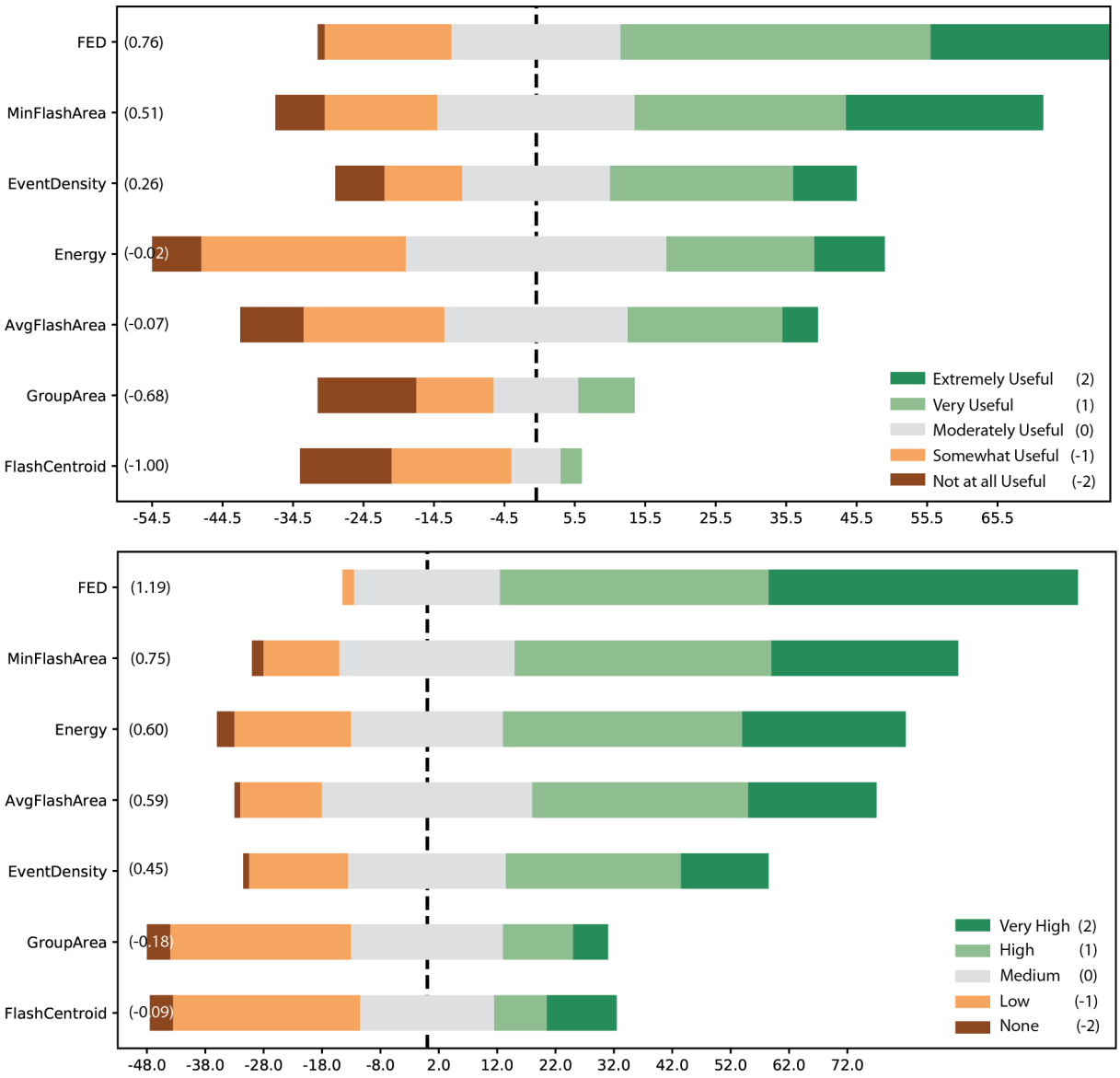

Fig. 2. Results from daily surveys. Top: Forecaster opinions of product usefulness from Extremely Useful (Dark Green) to Not at Useful (Dark Brown). Bottom: Forecaster understanding of each product from Very High (Dark Green) to None (Dark Brown). Products are sorted by decreasing average in each plot. Averages were calculated according to points shown in legend and are shown to the right of each product on the y-axis.

In terms of product timing, all forecasters used the 1-min updates from the GLM, choosing to view most products as a 5-min summation that updated every minute. They found the 5-min summation provided a clearer visualization of the data as the 1 min sum often was "too jumpy" from one time-step to the next. The 1-min update of this 5-min summation still allowed forecasters to take advantage of the instrument frequency and was able to capture rapid changes in intensity and new lightning activity for fast hazard identification. The only exception

to this was the MFA, which forecasters found viewed best as a 1 min product, updated every min.

Feedback from Forecaster Blogs and Discussion

As noted previously from the surveys, forecasters showed more confidence in the products this year, particularly from those who have previously seen the data at their local offices. Many forecasters also commented that having a subject matter expert available to answer questions made an impact on usefulness of the data. However, product and lightning training was a consistent topic of weekly discussion with multiple suggestions for implementation discussed. First, forecasters believed strongly that locally-relevant training with use cases for IDSS, airport weather warnings, and local hazard identification be provided. Specifically, forecasters asked training include more than a single "one-size-fits-all" example of a supercell storm in the plains for all offices. In addition to the details covered in the surveys, the following themes were consistently brought up during live events on the blogs and during discussions with subject-matter experts. These themes should also be considered when developing future applied research, products and algorithms, and training.

1) Differences between satellite with the ground-based lightning detection systems.

As part of best practices for display of the GLM data, subject-matter experts encouraged the forecasters to overlay the ground-based systems (including both IC lightning from ENTLN and CG data from NLDN) over the GLM data. This was suggested to provide a holistic view of lightning activity - the spatial extent from GLM and IC / CG ratio and locations from the ground-based networks. However, this suggestion often led to discussion on why the products often showed different values and trends.

> "The output from the GLM flash extent density product appears underdone when compared to data from ENTLN, which has numerous areas of clustering in the vicinity of stronger thunderstorm updrafts. Meanwhile, the GLM flash extent density data shows low values and not much variance within the same general vicinity ... It is difficult to pinpoint what might be causing this issue just by looking at the data alone."
> 20 May 2019, Blog Post: *Poor correlation GLM vs ground-based lightning networks*
> https://blog.nssl.noaa.gov/ewp/2019/05/20/poor-correlation-glm-vs-ground-based-lightning-networks/

2) Why viewing angle and / storm strength may provide different results (e.g., one storm higher flash rate or dampened energy product).

Explanations on why the GLM and ground-based systems had differences often led to further discussion and forecasters finding evidence to support or provide caveats for the previously stated reasons. Throughout the experiment subject-matter experts provided context from

ongoing research to better understand why detection efficiency of the GLM appeared lower in some storms than others. This included a discussion of optical depth (i.e., stronger storms with more and/or larger ice hydrometeors may make it difficult for the optical emission from many lightning flashes to reach cloud top optically). Additionally, flash size and rate were discussed as possible limitations on the GLM data, as GLM will not likely detect as many of the small flashes in and around the updraft since they could be grouped together due to the larger spatial resolution of GLM and may not emit much light. Since the GLM is new instrument, ongoing research will likely impact operational use of the products. ***We strongly suggest that training efforts actively involve subject matter experts for integration of the latest research results.***

> "Comparing GLM flash extent density and GLM event density to ground based ENTLN data along the Kansas/Missouri border region, there is a notable minimum in GLM data with a couple of the large clusters of ground based lightning clusters, while the other ground based lightning clusters seem to correlate relatively well with GLM data. Very strange indeed"
> 22 May 2019, Blog Post: *GLM ENTLN Comparison*
> https://blog.nssl.noaa.gov/ewp/2019/05/22/17650/

> "Earlier discussions with lightning detection experts suggested the low GLM FED count may be due to the location of lightning within the storm updraft region, which could impact how well GLM can sense it. That is difficult for the typical operational meteorologist to consider in real-time since it goes well beyond current training, and leads to decreased forecast confidence in the lightning data."
> 23 May 2019, Blog Post: *Lightning Jump in GLM FED but not Earth Networks*
> https://blog.nssl.noaa.gov/ewp/2019/05/22/lightning-jump-in-glm-fed-but-not-earth-networks-data/

3) The utility of GLM products in pulse convective environments, anticipating storm growth or dissipation, and IDSS applications.

Due to some of the inherent caveats with the GLM lightning data, forecasters found it the most useful in situations where issues of optical depth and light blockage within the intense thunderstorms were not a problem. In particular, forecasters found the data useful in monitoring trends for marginally severe storms for signs of intensification or dissipation. Additionally, due to the unique gridding of the full spatial extent of lightning (Fig. 2), forecasters also commonly highlighted the potential use for decision-support services.

> "The large FED and MFA bullseye imply the updraft is intensifying on this storm. This proved to be a useful proxy … This suite of products has a lot of utility for pulse severe events and DSS on-site weather events. "
> 21 May 2019, Blog post: *GLM Storm Intensification*
> https://blog.nssl.noaa.gov/ewp/2019/05/21/glm-storm-intensification/

"IDSS standpoint, the Minimum Flash Area and FED proved that it's necessary to look at both GLM products and ground based lightning products to see the "total" picture. The GLM products captured a larger flash that extended out into the stratiform area behind the main line that is not seen in the ENTLN and NLDN products (Fig. 2). This information can be especially important for Airport Weather Warnings and/or outdoor venues."

16 May 2019, Blog Post: 'IDSS usage from GLM minimum flash area
https://blog.nssl.noaa.gov/ewp/2019/05/16/idss-usage-from-glm-minimum-flash-area/

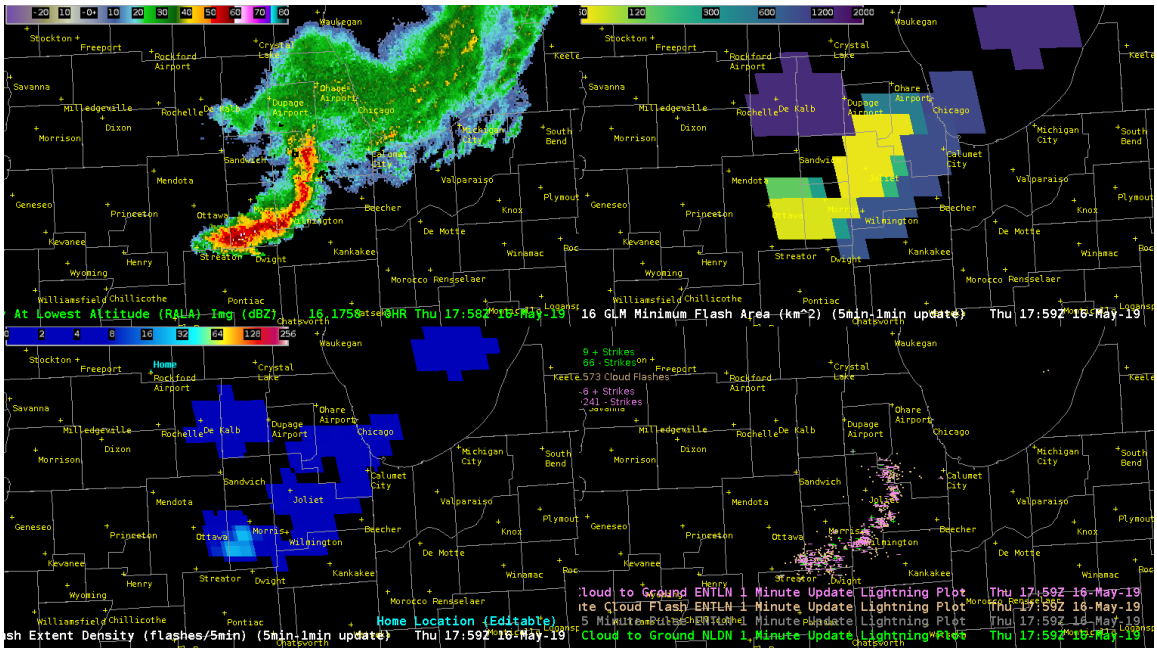

Fig. 2. MRMS Reflectivity at lowest altitude (top left), GLM Minimum Flash Area (top right), GLM FED (bottom left) and ENTLN cloud and CG flashes (points, bottom right) at 1759 UTC on 16 May 2019.

4) Increased confidence in warning decisions when GLM products matched trends from other observational platforms.

When multiple observation platforms trend in the same manner, forecasters noted enhanced confidence in warning decisions. The gridded GLM products allowed forecasters to efficiently match the GLM data with satellite, lightning and radar trends. In cases where the total flash rate trends, as noted from FED, matched trends from either base radar or ProbSevere, forecasters commonly noted increased confidence and easier warning decisions.

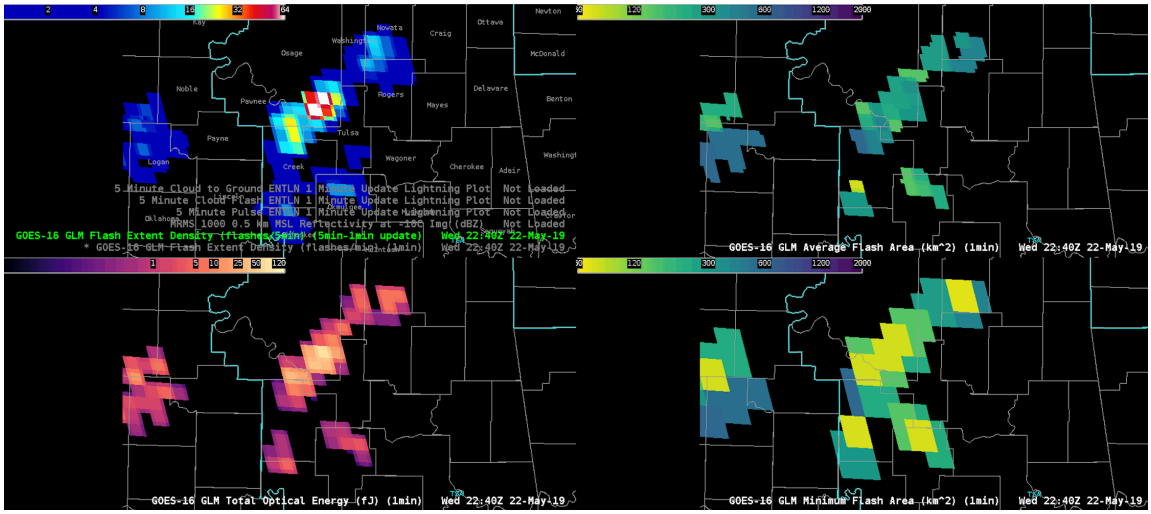

Fig. 3. Forecaster screenshot of GLM FED (top left), GLM Average Flash Area (top right), GLM Total Optical Energy (bottom left), and GLM minimum flash area (bottom right) at 2240 UTC on 22 May 2019. See associated blog post for animated loop.

"The Flash Extent Density and the Minimum Flash (top left and bottom right, respectively [see Fig. 3]), appear to have depicted strengthening updrafts in the Tulsa area… The increases in FED coincided with low areas of Minimum Flash Area. The MRMS -20C Reflectivity product shows the strengthening updrafts over the same time frame. **The GLM products increased confidence in a decision to issue two SVRs.**"
22 May 2019, Blog Post: *"GLM predicting strengthening updrafts"*
https://blog.nssl.noaa.gov/ewp/2019/05/22/glm-predicting-strengthening-updrafts/

"… seeing the FED and ground based lightning double, likely in response to the intense OT, may push a forecaster to upgrade the severity of the warning (larger hail, higher winds etc.)"
22 May 2019, Blog Post: 'Overshooting Top Precedes FED Lightning Jump"
https://blog.nssl.noaa.gov/ewp/2019/05/22/82-c-overshooting-top-precedes-fed-lightning-jump/

"While deciding whether or not to issue a warning I also looked at AFA GLM data to see if there were new flashes developing which can be indicative of growing convection. That flashes aligned with radar and increased my confidence that storms would intensify. That lead to me issuing a severe thunderstorm warning. The prob severe data also ramped up. So I felt confident about my warning."
4 June 2019, Blog Post: "Springfield Storms"
https://blog.nssl.noaa.gov/ewp/2019/06/04/springfield-storms/

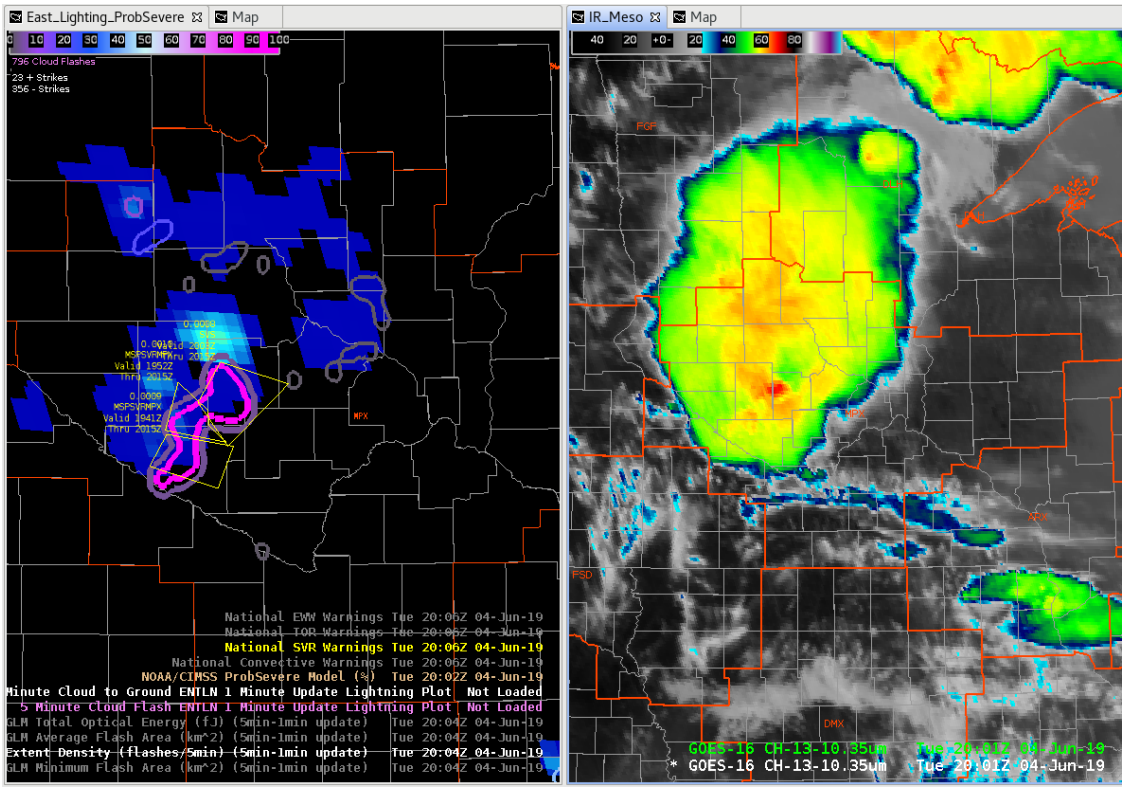

Fig. 4. Forecaster screenshot at 2004 UTC on 4 June 2019. Left panel: GLM FED (gridded product), ProbSevere (pink contour), and active warnings (yellow outlines). Right panel: GOES-16 VIS/IR 'sandwich' product.

"As you're debating issuing a tornado or severe warning, it is good to see the lightning changes over time as well as cloud tops. Both are trending more severe in [Fig. 4]."
4 June 2019, Blog Post: "Good for a quick glance"
https://blog.nssl.noaa.gov/ewp/2019/06/04/good-for-a-quick-glance/

5.) GLM minimum flash is much better than GLM average flash size for convective-scale applications.

During the 2018 experiment, forecasters consistently commented they liked the idea behind the flash area product, but the average aspect seemed to dampen the values. Since trends in the smallest flashes are most directly related to intense updrafts, active charging of hydrometeors, and regions of high turbulence, it was suggested to examine a minimum flash area product instead of average. Throughout the 2019 experiment, forecasters consistently used the minimum flash area product while the average flash area product was rarely used after the first day. The minimum flash area product was rated as the second-most useful product of the entire GLM product suite, behind only FED. For this reason, ***we suggest the Minimum Flash Area product be considered as one of the primary (or base) GLM gridded products for operations***.

"Storms are trending sub-severe across most of our CWA at this hour, but 1 cell behind the initial line started getting its act together. Here [are the products, Fig. 5] before the cell started intensifying :

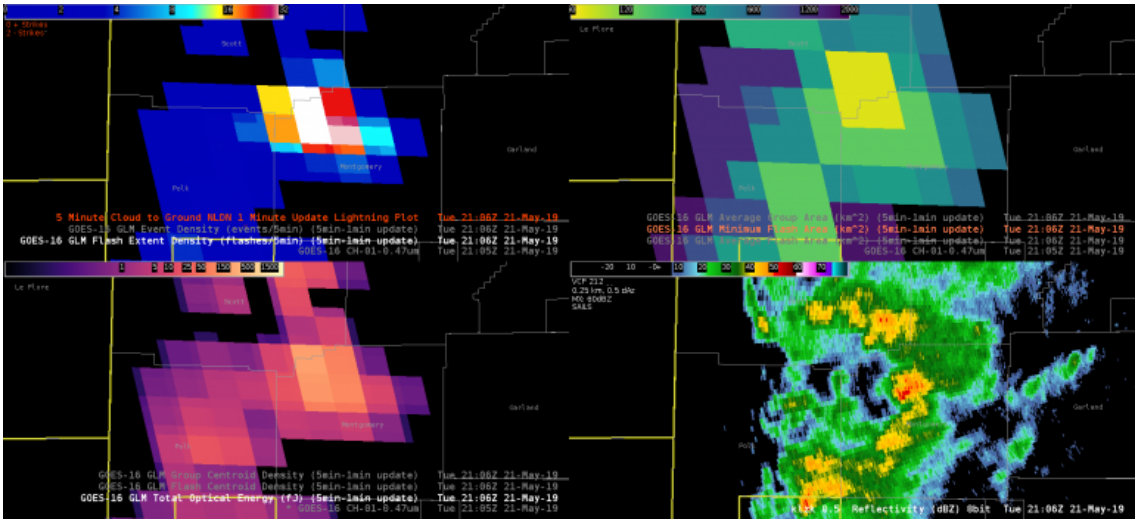

Fig. 5: GLM Flash Extent Density (top left), GLM Minimum Flash Area (top right), GLM Total Optical Energy (bottom left), and KLZK base reflectivity (bottom right) at 2206 on 21 May 2019.

The large FED and MFA bullseye imply the updraft is intensifying on this storm. ... This suite of products has a lot of utility for pulse severe events and DSS on-site weather events."
21 May 2019, Blog Post: *"GLM Storm Intensification"*
https://blog.nssl.noaa.gov/ewp/2019/05/21/glm-storm-intensification/

"Had unique opportunity to watch a line of strong to eventually severe storms ignite and strengthen rapidly along an old outflow boundary this afternoon using GLM data. It was interesting using the above 4 panel display (Fig. 6) to not only witness the ignition, but also the strengthening of each sequential cell along the line. By utilizing the GLM Minimum Flash Area (Bottom left) 1 minute imagery in a loop, we were able to sample the early-onset updraft core strengthening of each sequential cell along said line, and watch the event density jump up in accordance."
5 June 2019, Blog Post: *"ILX Case"*
https://blog.nssl.noaa.gov/ewp/2019/06/05/ilx-glm-case/

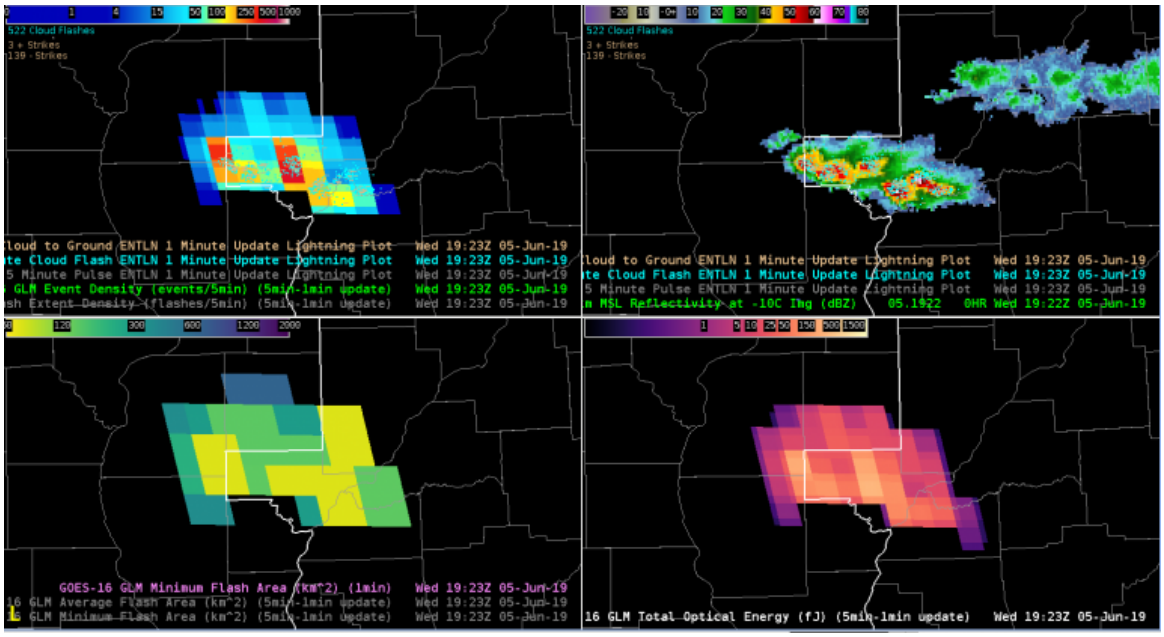

Fig. 6: GOES-16 GLM event density (top left), MRMS at -10 deg C (top right), both top panels overlaid with 1 min ground-based lightning detections from Earth Networks Total Lightning Network (ENTLN), minimum flash size (bottom left) and total optical energy (bottom right) at 1923 UTC on 5 June 2019.

6) Introduction of RGB product to handle limited screen space and help with situational awareness.

A GLM-IR RGB product was created in collaboration with Drs. Christopher Schultz (NASA) and Eric Bruning (TTU) to help integrate the IR imagery with the GLM products due to 2018 HWT comments regarding the lack of screen space for integrating the GLM products (Figs. 7 and 8). The goal of this product is to highlight the areas with the coldest cloud tops (higher blue colors using the IR temperatures from the 10.3 um band), highest FED (increased red values), and smallest flashes (increased green values from smaller MFA). While this was the initial product development, forecasters showed interest and further development will continue. Within this RGB, the strongest, mature updrafts will trend towards white. Newer convection, within warmer cloud tops, will trend towards red or yellow. Anvil flashes, with low flash rates and large size, but still within cold cloud tops will trend towards purple. The RGB product shown to forecasters in the 2019 experiment was an initial rapid prototyping of the idea during HWT activities. However, the initial feedback on the RGB was encouraging and development will continue at NASA-SPORT for the 2020 evaluation.

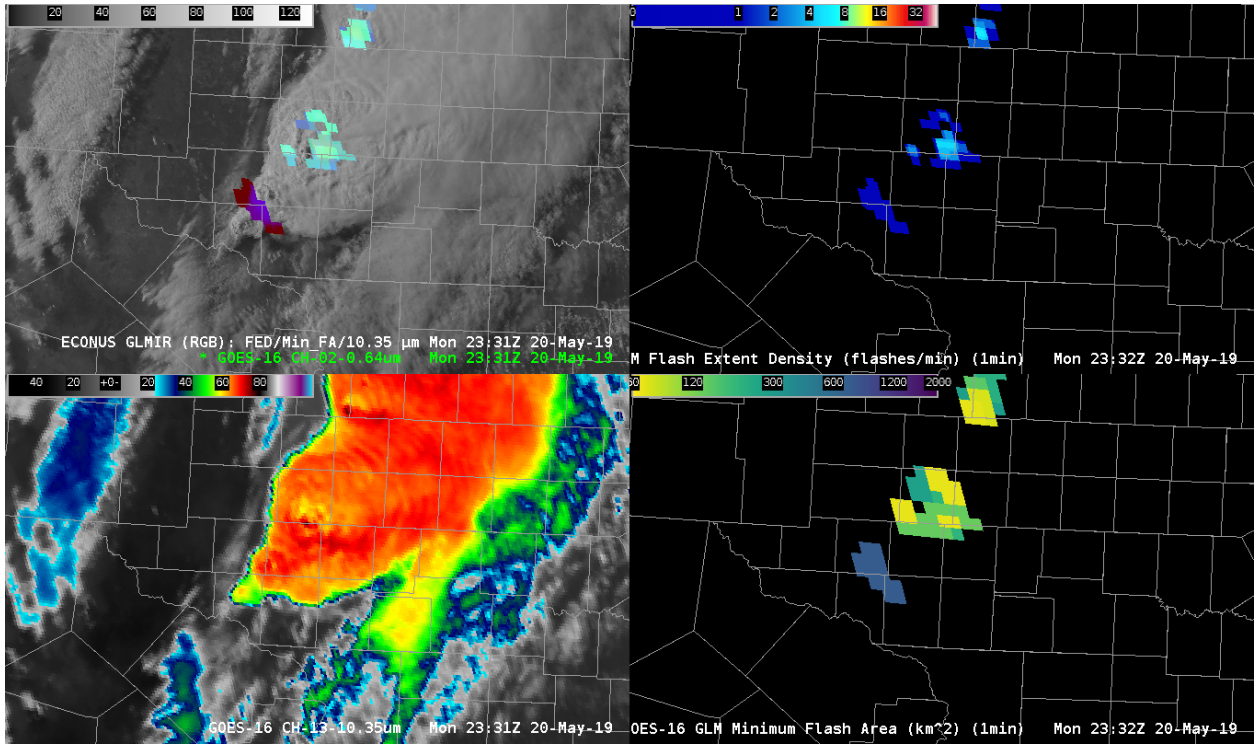

Fig. 7: GLMIR RGB and Visible Satellite Imagery (Top Left); FED (Top Right); IR satellite (Bottom Left); GLM Minimum Flash Area (Bottom Right) at 2332 UTC on 20 May 2019. See Blog Post: https://blog.nssl.noaa.gov/ewp/2019/05/20/glm-rgb-first-view/

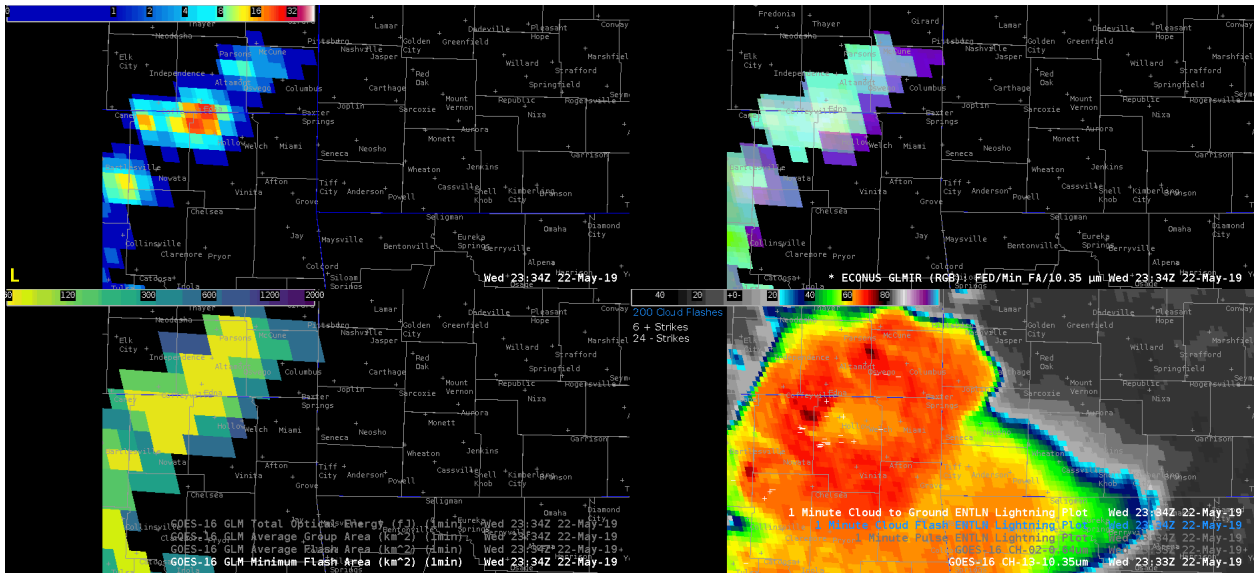

Fig. 8: GOES-16 Flash Event Density (top left), GLM- IR RGB test product (top right), GLM minimum flash size (lower right) and ABI 10.2 um IR Channel with 1 min ground-based lightning detections from Earth Networks Total Lightning Network (ENTLN) (lower left) at 2334 UTC on 22 May 2019. See Blog Post: https://blog.nssl.noaa.gov/ewp/2019/05/22/82-c-overshooting-top-precedes-fed-lightning-jump/ for animation.

Recommendations for Operational Implementation

Again in 2019, forecasters used the 5-min FED product with 1-min updates as the primary GLM product. Secondarily, forecasters found the new MFA grid useful in identifying if storm updrafts were increasing in strength, maintaining strength, or decaying. The MFA signal often came prior to other radar and satellite observations and, when tied to an increasing FED, provided forecasters additional time on possible hazard identification. A common procedure for GLM product/storm interrogation was to create a four panel of FED, MFA, TOE and a corresponding satellite or radar product for comparison using the 1-min update cycle of the GLM. Together, forecasters found these combinations helped "maintain situational awareness on individual storm intensity trends" and allowed them to "quickly decipher which storms pose the greatest risk for severe weather." Due to the consistent use of these products in tandem in the HWT, ***we recommend that FED and MFA are sent to all WFO offices, with options for additional products such TOE or Event Density available for ingest as deemed necessary by the local offices.***

A consistent message from forecasters was the integration of the GLM data with other products and data. A comparison with the ground-based lightning networks provides a holistic view of the total the lightning activity. The GLM products highlight the areal extent information and often give additional lead time on the lightning activity, both of which impact IDSS and airport weather operations. However, the ground-based total lightning networks provide enhanced detail on total flash count of small flashes often responsible for lightning jumps as well as context for the parallax in the space-borne GLM instrument. For these reasons, ***we recommend training and best practices include the use of GLM data together with information from the ground-based lightning networks.***

The 2019 evaluation was the first to view the GLM-17 CONUS products. In regions of overlap forecasters often found slightly different detection efficiency, not always related to the which was the closet instrument. At forecaster request, we increased the CONUS area from the default-ABI CONUS display to cover regions further east including the northern and central plains of the United States. Examples from the HWT showed better detection efficiency of lightning in North and South Dakota for some supercell storms. Since multiple forecasters found enhanced use of the the GLM-West coverage, ***we recommend the operational implementation of the GLM-West CONUS product move or expand to cover areas across the north central plains and central United States.***

Since GLM is our first opportunity to view lightning activity from geostationary orbit, research is still ongoing on the meteorological relationships on lightning flash rates and energy as measured from space. Through our activities in the HWT and at local offices, we know GLM offers the capability enhanced hazard identification and assessing storm trends in an operational environment. Additionally, GLM has the unique ability to do this consistently at 1-min updates and over oceanic and mountainous regions. As the research continues, forecasters in the HWT have noted the importance of integrating new research results into

training as "GLM data will be increasingly useful with better understanding of what the different data sets mean in relation to convective development or decay." ***We recommend not only continuing to integrate subject-matter experts with NWS training development both nationally and at local offices, but also using NWS forecaster feedback and comments to help guide future research and instrument design requirements.***

Acknowledgements

Multiple NWS, US Air Force, and broadcast meteorologists participated in this experiment and provided detailed feedback that has gone into the recommendations in this report, it would not be possible to complete research-to-operations without their willingness to openly test, examine, and provide feedback on experimental data. Tiffany Meyer installed and modified AWIPS2 to handle the experimental data and many changes and modifications to the products prior to and throughout the experiment. Eric Bruning was the primary developer on the code base that created the products viewed in the HWT. In addition to Eric Bruning and Tiffany Meyer, Adrian Campbell also made local changes to the code to allow for immediate test of the 2 and 5-min products that were requested. The GLM-RGB products are created based on the collaboration with NASA and GOES Risk Reduction led Christopher Schultz.

Eric Bruning (Texas Tech University), Chris Schultz (NASA-Marshall Space Flight Center), and Jonathan Smith (University of Maryland) also participated as GLM focal points and subject-matter experts and provided context in various weeks of the experiment. Additional training-focused discussions were led by Katy Christian (NWS Warning Decision Training Devision), Andrea Schumacher (CIRA), and Jonathan Smith.