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Visualizing Geostationary Lightning Mapper Data

Scott D. Rudlosky
NOAA/NEDIS/STAR
University of Maryland
College Park, MD, USA
scott.rudlosky@noaa.gov

Michael J. Peterson
Earth System Science Interdisciplinary Center
University of Maryland
College Park, MD, USA
mpeterso@umd.edu

***Abstract* — Geostationary Lightning Mapper (GLM) observations provide great value but must be visualized to communicate this new information. The GLM launched during November 2016 aboard the first Geostationary Operational Environmental Satellite R-series (GOES-R/16). The GLM differs from the more familiar ground-based lightning detection networks, so focused efforts are required to guide the application of these new data. For many years researchers and operational users have explored lightning visualization techniques in preparation for the GLM. Real data proved necessary to push development of these visualization tools. Visualizations have been developed for public consumption and National Weather Service (NWS) forecasters. This paper provides examples of these new visualization tools and their operational applications.**

Keywords* — *lightning, satellite, GOES, GLM

I. Introduction

The Geostationary Lightning Mapper (GLM; Goodman et al. 2013) on GOES-16 is one of four instruments that will provide lightning mapping over most of the western hemisphere through 2036. The GLM first light occurred on 4 January 2017, but useable ground system data were delayed until 24 April. Since then, the GLM science team has undertaken extensive efforts to calibrate and validate these data and ensure that the best operational products are available to National Weather Service (NWS) forecasters. Outreach efforts also leverage GLM observations to help better inform the public of the lightning hazard. Social media posts, online visualization tools, and various training activities convey important information to users and clearly demonstrate the usefulness of the GLM observations. This paper aims to document the evolution of GLM visualization techniques since real observations became available.

II. Background

The GLM is the first step in the operational space-based observing constellation for continuous measurements of total lightning on a global-scale. It builds on a legacy of optical lightning observations from low earth orbit from the NASA Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM, 1997-2015) and the Optical Transient Detector (OTD) on the OrbComm-1 satellite (1995-2000). The GLM is a staring Charge-Coupled Device (CCD) imager (1372x1300 pixels) at a single band (777.4 nm) at ~500 frames per second. The GLM coverage extends to 54° N/S, with near uniform spatial resolution of ~8 km at nadir to ~14 km at the limbs. When averaged over 24 h, the GLM detects >70% of all flashes. The GLM data flow from the satellite observation to operational users in < 20 sec.

The ground processing algorithms are an extension of the algorithms developed for the earlier OTD and LIS research instruments (Mach et al. 2007). Concepts for the GLM have been explored since the early 1980s culminating with the single telescope design having high detection efficiency for total lightning with near uniform storm-scale spatial resolution owing to the variable pitch pixel detector array design (Goodman et al. 2013). The high detection efficiency is made possible by the data telemetry bandwidth of 7.7 mbps. This allows the GLM to be set at more sensitive (lower) detection thresholds allowing up to 100,000 events per second (nominally 40,000 lightning events and the remainder noise) to be transmitted to the ground where the ground processing algorithms filter out the non-lightning events.

The GLM creates background images every 2 min, then detects changes in brightness relative to the background every ~2 ms. Illuminated pixels are termed GLM events. Filters determine the likelihood that events are real lightning. The Lightning Cluster Filter Algorithm (LCFA) then combines events into groups and groups into flashes. An event is the occurrence of a single pixel exceeding the detection threshold during one ~2 ms frame. A group is one or more simultaneous events observed in adjacent (neighboring or diagonal) pixels. A flash is 1 or more sequential groups separated by less than 330 ms and 16.5 km. The GLM events, groups, and flashes are all useful for developing visualizations.

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III. GLM VISUALIZATIONS

GLM observations can be illustrated on a variety of scales and alongside many other data sources. The appropriate visualization depends on the application, with scientists often interested in the very fine temporal scale (flash level information) and weather forecasters more interested in the larger spatial scales (i.e., regional to hemispheric coverage). This section presents examples across this range of scales to illustrate the value of the GLM observations.

A. Detailed Flash-by-Flash Observations

The GLM maps the spatial extent of the cloud illuminated by individual flashes. Groups in each flash are connected to create flash skeletons. Figure 1 shows that despite scattering, the GLM flash skeleton traces a sensible path through the cloud. Peterson et al. (2017) documented the composition, morphology, and motion of extreme optical lightning flashes observed by the Lightning Imaging Sensor (LIS). They identified the most exceptional examples of flash structure, energetics, scattering, and evolution in the optical TRMM-LIS data set. LIS measurements were used to quantify the length, the areal extent, the duration, the peak radiance, the number of visible branches, the number of distinct radiant pulses, and the longest interval of nearly continuous illumination in each flash. The furthest separation of LIS events (groups) in any flash was 135 km (89 km), the flash with the largest footprint had an illuminated area of 10,604 km^2, and the most dendritic flash had 234 visible branches. The authors showed that optical lightning observations provide helpful insights into the horizontal flash structure, which can be used to make inferences regarding lightning physics and storm structure.

Fig. 1. Flash skeleton for a GLM flash observed on July 4, 2017. The main panel shows a plan view, and the panel immediately right (above) depicts the temporal evolution by latitude (longitude). The bottom illustrates group occurrence and energies as a function of time.

Observing individual flashes best illustrates that the GLM is an imager rather than a detector. Figure 2 provides another example of an individual GLM flash. The main panel in Fig. 2 shows a plan view, the panel immediately right (above) depicts the temporal evolution by latitude (longitude), and the top panel shows the group occurrence and areas as a function of time. This flash contained 98 groups, lasted 0.424 sec, and covered 3536 km^2. This example clearly illustrates an ability for the GLM to detect the spatial extent of flashes as well as their path through the cloud.

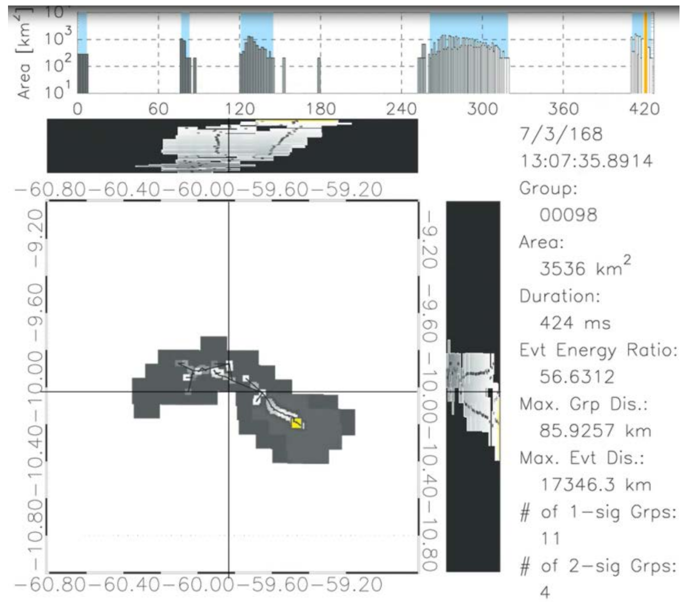

Fig. 2. Flash skeleton for a GLM flash observed on July 3, 2017. The main panel shows a plan view, the panel immediately right (above) depicts the temporal evolution by latitude (longitude), and the top panel shows the group occurrence and areas as a function of time.

Peterson et al. (2017) discussed the factors that impact these optical measures of flash morphology and evolution. While it is apparent that LIS can record the horizontal development of the lightning channel in some cases, radiative transfer within the cloud limits the flash extent and level of detail measured from orbit. Their analyses nonetheless suggest that lightning imagers such as LIS and GLM can complement ground-based lightning locating systems for studying lightning physics across large geospatial domains.

B. Composite Imagery

The GLM data have great potential for promoting lightning safety, in part because its imagery can clearly communicate the lightning threat. Imagery similar to that you would expect to observe from above can be made by combining GLM observations with the Advanced Baseline Imager (ABI). Overlaying this imagery onto maps illustrates the spatial distribution of lightning in an intuitive manner.

Figure 3 shows GLM observations overlaid on ABI clouds on September 5, 2017. This image clearly depicts both Hurricane Irma and a strong frontal system over the U.S. The GLM events are used to brighten the ABI pixels using the composite GLM-reported energy per pixel. Yellow lines connect all groups within their parent flashes. This type of imagery helps promote situational awareness by allowing forecasters to observe the earliest lightning in storms and track storm motion throughout entire lifecycles. It is useful anywhere the lightning threat needs to be communicated to the public.

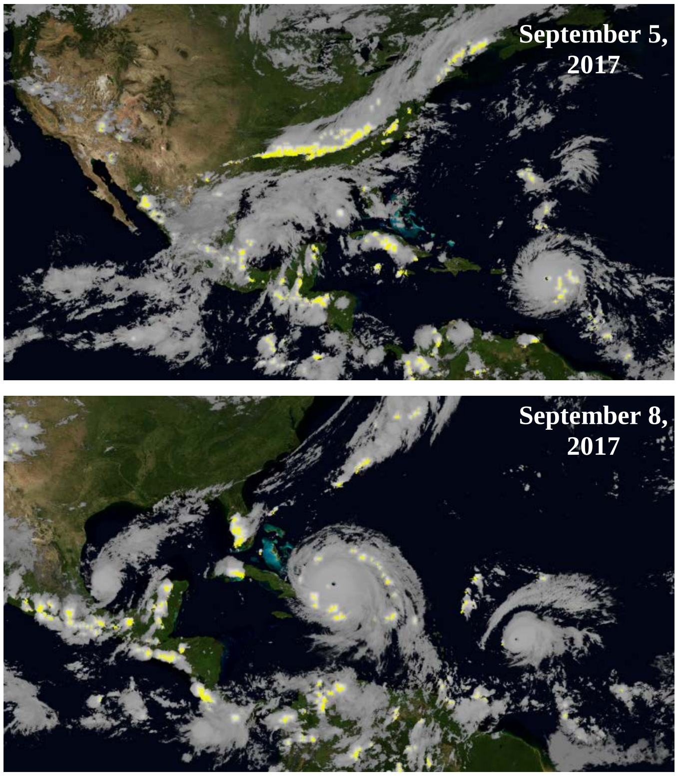

Fig. 3. GLM observations overlaid on ABI clouds. The GLM events are used to brighten the ABI pixels using the composite GLM-reported energy per pixel. Yellow lines connect all groups within their parent flashes.

This combined imagery can be projected in a number of ways. Most common are static images and animations on flat screens. However, these data are being generated and shared with the NOAA Science on a Sphere (SOS) program as well. The SOS program distributes imagery to dozens of institutions across the country, greatly increasing the visibility of these data. Avenues for public outreach are continually explored.

C. Visualization Website

A visualization website has been developed to ease access to GLM and ABI imagery (http://lightning.umd.edu; Figure 4). This site provides access to imagery from the most recent seven days, with zoom, pan, and animate functionality. The day and time are selected from a timeline at the bottom, and playback controls are available in the lower left (i.e., play, pause, speed up, slow down). These functions are readily available because of the use of the Cesium framework (https://cesium.com). Several background maps are available including the black marble or nighttime lights of the world. On mobile devices or virtual reality (VR) goggles, selecting the goggle icon in the lower right will switch the imagery into VR mode. Unlike other satellite product visualization tools, this website is tailored specifically to the GOES GLM. This allows focus on integrating new functionality rather than new products. Archive cases illustrate the lightning distribution at 15-min intervals over entire seasons within the same framework.

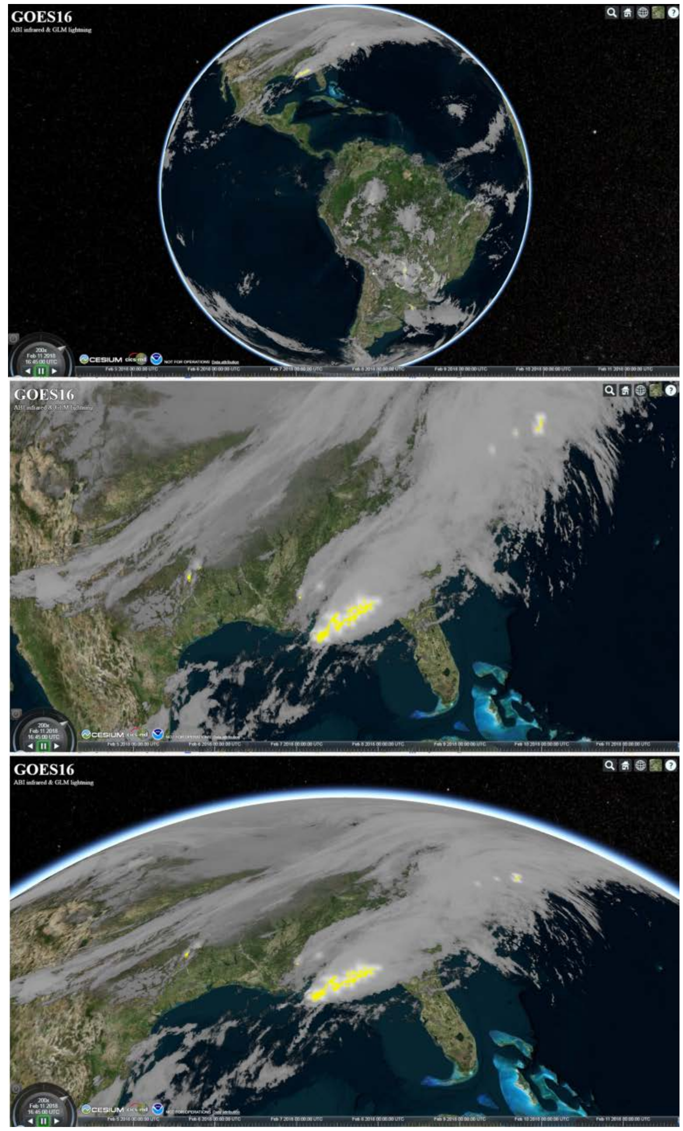

Fig. 4. Depiction of the interactive GLM website. The GLM events are used to brighten the ABI pixels using the composite GLM-reported energy per pixel. Yellow lines connect all groups within all parent flashes.

D. AWIPS Displays

The GLM differs from the ground-based lightning detection networks most familiar to National Weather Service (NWS) forecasters. The GLM has no IC/CG discernment, polarity, or peak current estimate, rather the GLM provides information on the extent, radiance, duration, and group/flash area. Similar to lightning mapping arrays (LMA), the GLM reports the full spatial (horizontal) extent of flashes. Planning is underway to optimize the fusion of the satellite and ground-based lightning observations to provide the most useful tools to forecasters.

The NWS uses the Advanced Weather Interactive Processing System (AWIPS) software to visualize weather data. The initial GLM tool in AWIPS was far too similar to the tool for ground-based networks, so much so that it was never deployed to the field. This AWIPS tool is useful for examining some basic differences between the datasets. Figure 5 shows GLM events, groups, and flashes, alongside ENTLN pulses, flashes, and strokes, NLDN cloud-to-ground flashes, and GLD360 strokes. It is important to note that no relative performance should be inferred solely from this figure (examples are but two of millions). Figure 5 shows two examples of flashes where all of the networks lined up well. The GLM events (blue squares) illustrate the increased spatial extent information provided by the GLM.

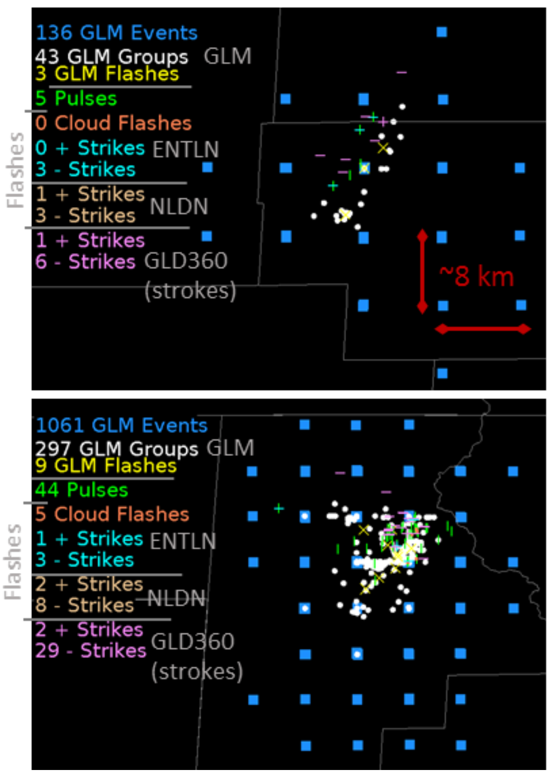

Fig. 5. Early AWIPS display of GLM events (blue squares), groups (white dots), and flashes (yellow Xs), alongside ENTLN cloud pulses (green lines), cloud flashes (orange squares), CG flashes (cyan – and +), NLDN CG flashes (brown – and +), and GLD360 strokes (purple – and +).

The initial AWIPS gridding procedures were not well suited for the GLM data. Various spatial resolutions were examined, with a 9 by 9 km grid appearing best. Figure 6 combines this gridded image with the visible imagery to reveal the evolution of a squall line over the Atlantic Ocean. An animation of this imagery (not shown) reveals the ability of GLM to resolve storm scale changes in lightning activity that may provide insights into storm evolution and intensity.

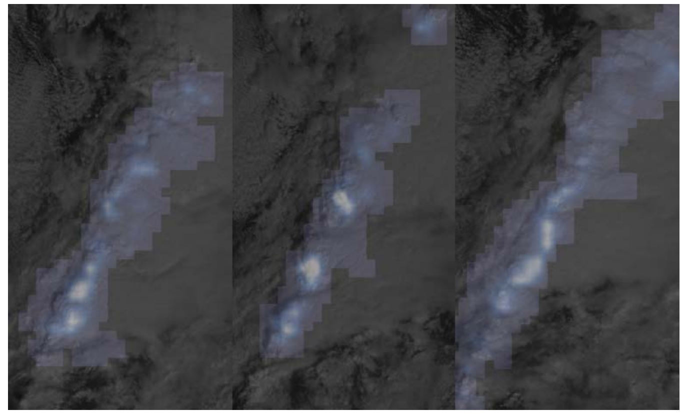

Fig. 6. Example of GLM grids (9 by 9 km) combined with the visible ABI imagery in AWIPS.

In part to mitigate AWIPS deficiencies, a new gridded GLM product is being developed upstream from NWS users. The initial set of GLM grids will be a flash extent density product that combines the spatial extent information provided by GLM events with the storm trending information provided by the GLM flashes. New gridding approaches were employed to portray the GLM information on the 2 by 2 km ABI fixed grid. Figure 7 provides an example of the resulting FED grids. Additional gridded products are under development for deployment during the second half of 2018 (e.g., flash size and energy). Forecaster feedback will help refine these grids and ensure availability of the most useful tools possible.

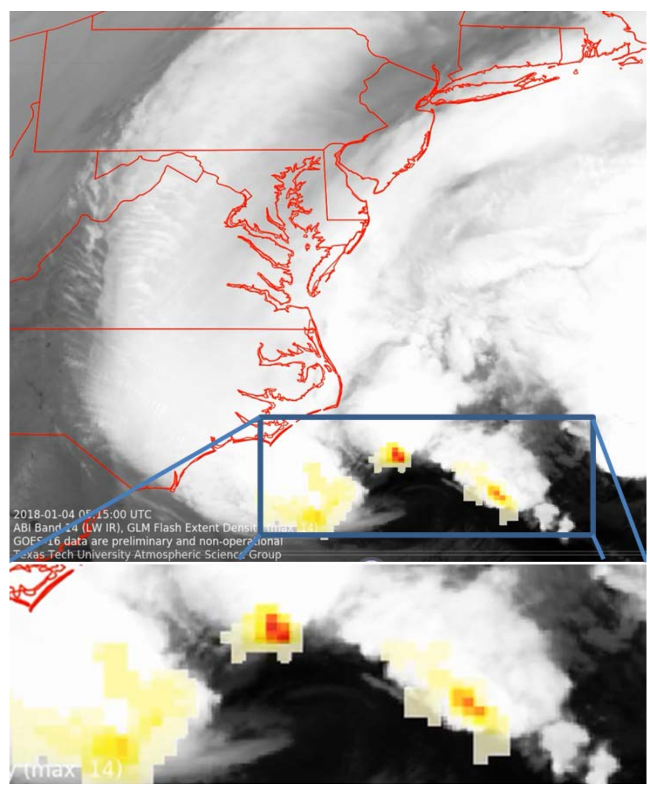

Fig. 7. Example flash extent density (FED) grids created using the new gridding approach and the 2 by 2 km ABI fixed grid.

IV. APPLICATIONS

Forecasters and scientists have documented a wide range of operational applications for lightning data. The GLM will provide forecasters with continuous, full disk total lightning measurements throughout the GOES field of view. This will allow users to detect electrically active storms, determine the areal extent of the lightning threat, track convective cells embedded in larger features, identify strengthening and weakening storms, monitor convective mode and storm evolution, supplement radar data where coverage is poor, characterize storms as they transition offshore, distinguish thunderstorms from rain-only areas, and gain insights into tropical cyclone intensity changes. GLM flash rates are most closely tied to updraft and storm evolution, event locations best depict the spatial extent, and groups are most similar to ground-based network strokes/pulses. Rapidly updating GLM data reveal convective storm development and evolution throughout the GOES-16 field of view. The most anticipated GLM application is the lightning jump: Rapid increase in total lightning that signifies an increased threat for severe weather, which supports warning decisions. The GLM community is just scratching the surface, and this new instrument will continue to provide new insights well into the future.

V. SUMMARY

This paper documents the evolution of GLM visualization techniques since real observations became available. GLM observations can be illustrated on a variety of scales and alongside many other data sources. The appropriate visualization depends on the application, with scientists often interested in the very fine temporal scale and weather forecasters more interested in the larger spatial scales.

The GLM maps the spatial extent of the cloud illuminated by individual flashes. Groups in each flash are connected to create flash skeletons that trace sensible paths through clouds. Studies have shown that optical lightning observations provide helpful insights into the horizontal flash structure, which can be used to make inferences regarding lightning physics and storm structure. Individual flash observations best illustrate that the GLM is an imager rather than a detector by clearly demonstrating the ability to detect the spatial extent of flashes as well as their path through the cloud. Lightning imagers such as the GLM can complement ground-based lightning locating systems for studying physical lightning phenomena across large geospatial domains.

The GLM data have great potential for promoting lightning safety, in part because its imagery can clearly communicate the lightning threat. Intuitive imagery similar to that you would expect to observe from above can be made by combining observations from the GLM with those from the Advanced Baseline Imager (ABI). Overlaying this imagery onto maps illustrates the spatial distribution of lightning. This type of imagery helps promote situational awareness by allowing forecasters to observe the earliest lightning in storms and track storm motion throughout entire lifecycles. It is useful anywhere the lightning threat needs to be communicated to the public.

A visualization website (http://lightning.umd.edu) has been developed to ease access to GLM and ABI imagery. This site provides access to imagery from the most recent seven days, with zoom, pan, and animate functionality. On mobile devices or virtual reality (VR) goggles, selecting the goggle icon in the lower right will switch the imagery into VR mode. Unlike other satellite product visualization tools, this website is tailored specifically to the GOES GLM. This allows focus on integrating new functionality rather than new products.

The National Weather Service (NWS) uses the AWIPS software to visualize weather data. AWIPS visualizations reveal the ability of GLM to resolve storm scale changes in lightning activity that provide insights into storm evolution and intensity. The initial set of GLM grids available to NWS forecasters will be a flash extent density product that combines the spatial extent information provided by GLM events with the storm trending information provided by the GLM flashes. Additional gridded products are under development for deployment during the second half of 2018.

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