GOES-17 GLM Level 2 Data
Full Validation Product Quality
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Product Performance Guide For Data Users

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1. INTRODUCTION

The Geostationary Lightning Mapper (GLM, see Figure 1) on the Geostationary Operational Environmental Satellite Series-R (GOES-R) is the first operational lightning detection system at geostationary orbit. The overarching objectives of GLM are to: (1) provide continuous, near full-disk lightning measurements for storm warning and nowcasting, (2) provide early warning of tornadic activity, and (3) accumulate a long-term database to track decadal changes of lightning.

GLM is a high-speed nadir-staring optical (near-IR, 777.4 nm) camera Charge Coupled Device (CCD) imager (1372 x 1300 pixels) with near uniform spatial resolution (8 km at nadir, 14 km at the edge of its field-of-view, FOV). Its coverage is approximately ± 54 degrees in latitude, and it monitors lightning activity 24/7 with a 2 ms frame time across the Americas and adjacent oceanic regions. Total GLM downlink data rate is 7.7 Mbps, with a product latency requirement of under 20 s.

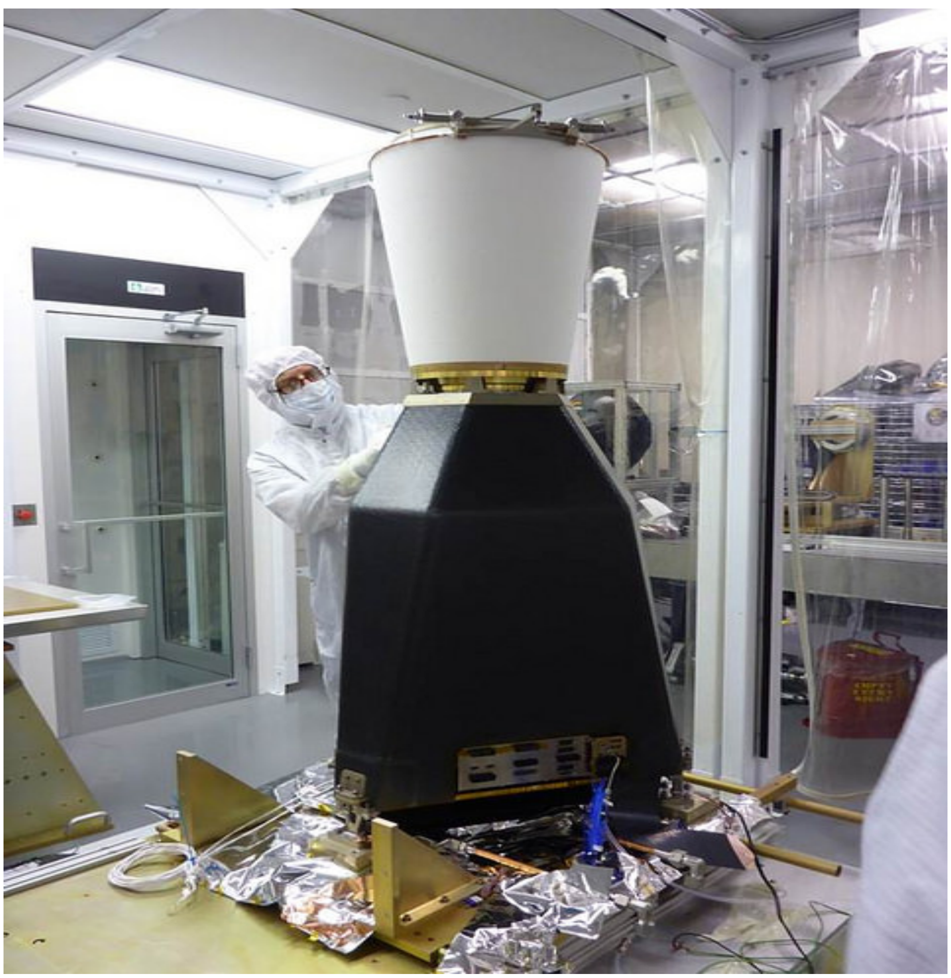


Figure 1. The Geostationary Lightning Mapper (GLM) in a clean-room laboratory setting.

For the benefit of the user community, this document summarizes the key performance and existing issues of the GOES-17 GLM Level 2 (L2) data product that were found at the time of the

Full Validation Peer Stakeholder - Product Validation Review (PS-PVR) on 24 February 2021. Additional information relevant to understanding the GLM L2 product, the performance requirements, and the methodologies for validating requirements are provided in the Product User's Guide (PUG) [1], the Mission Requirements Document (MRD) [2], and the Readiness, Implementation and Management Plan (RIMP) [3]. In order to obtain the most favorable results from the L2 lightning product, users are expected to use the data quality flags described in the PUG (e.g., flash_quality_flag values, and others), and to be aware of existing anomalies and planned improvements identified in this document. Users are also encouraged to contact the GLM calibration/validation scientists (William Koshak, william.koshak@nasa.gov; Doug Mach, dmach@nasa.gov) to report anomalies or suggest improvements.

The remainder of this section introduces some of the key characteristics of the GLM L2 product and a timeline of the GLM product validation process. Section 2 compares the measured on-orbit GLM L2 product performance to mission requirements and the predicted Performance Baseline. Section 3 describes remaining issues within the GLM L2 product, and the process toward mitigating them. Section 4 provides a brief summary, and section 5 contains references.

1.1 GLM Product Description

The GLM L2 product consists of three components:

- *Event:* pixel-level optical detection in one frame.
- *Group:* one or more (side/corner) adjacent pixel detections in one frame.
- *Flash:* one or more groups within 330 ms (i.e., interstroke duration) and within 16.5km.

For each event, group, or flash, the GLM L2 product file includes a location (energy-weighted location for groups and flashes), coverage area (for groups and flashes), time information, and amount of radiant energy. The L2 data files are broadcast every 20 seconds to meet the latency requirement. More information on the data files can be found in the Product User's Guide [1].

1.2 GOES-17 GLM Production Validation Timeline

On 1 March 2018, the second of the GOES-R Series satellites (i.e. GOES-S) was launched, and after successful orbit insertion it formally became GOES-17. The GOES-17 GLM (i.e., GLM-17) instrument was turned on 27 March 2018, and a series of Post-Launch Tests (PLTs) were then conducted to verify that the instrument was functioning properly and that products were being created as expected. Before the end of the PLT activity, Post-Launch Product Tests (PLPTs) were then conducted to perform "deep-dive" evaluations of the GLM L2 product performance using a broad collection of independent reference lightning datasets. Following the PLTs/PLPTs, a PS-PVR for Beta Maturity was conducted on 2 October 2018. The review chair declared that the GOES-17 GLM L2 products reached the Beta Maturity, which means that:

- Product is made available to users to gain familiarity with data formats and parameters (via GOES Rebroadcast, GRB)
- Product has been minimally validated and may still contain significant errors
- Product is not optimized for operational use.

Three analysis periods were chosen for the Provisional Maturity validation, as follows:

- **Period 1** (15 – 24 Oct 2018),
- … followed by a drift of the GOES-17 satellite to final park at 137.2W and several days of Image Navigation and Registration (INR) averaging,
- **Period 2** (20 – 29 Nov 2018),
- … followed by important Ground Segment software updates involving look-up table updates, Real-Time Event Processor settings, 2nd Level threshold adjustments for hot pixels, and parallax mitigation,
- **Period 3** (4 – 16 Dec 2018).

This led to the successful achievement of Provisional Maturity on 20 December 2018, which means that:

- Product performance has been demonstrated through analysis of a small number of independent measurements obtained from select locations, periods, and associated ground truth or field campaign efforts.
- Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).
- Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.
- Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.

On 24 February 2021, the final GOES-17 GLM L2 PS-PVR was held. The review concluded that the GLM L2 product has reached the Full Validation Maturity per GOES-R Program, which means that:

- Product performance for all products is defined and documented over a wide range of representative conditions via ongoing ground-truth and validation efforts.
- Products are operationally optimized, as necessary, considering mission parameters of cost, schedule, and technical competence as compared to user expectations.
- All known product anomalies are documented and shared with the user community.
- Product is operational.

2. KEY PERFORMANCE

This section provides a comparison between the measured on-orbit GLM L2 product performance with MRD requirements and the Performance Baseline predictions. The

Performance Baseline is a prediction of the on-orbit product performance compiled by a team at MIT Lincoln Lab based on vendor reports and pre-launch test data. Before this comparison is provided however, it is important to note the following over-arching validation principles since GLM is a new instrument (transient detector) unlike typical imaging instruments. The principles can be summarized as follows:

- **Targets of Opportunity (TOO):** Validation of a lightning sensor differs from that of a typical imager; i.e. since lightning is transient, validation is restricted to TOO.
- **Flash DE is an Estimate:** Determination of flash detection efficiency (DE) is only an estimate because reference data normally don't detect all lightning.
- **Source Physics:** GLM detects in the optical (near-IR) and many of the reference datasets are in the RF [e.g., Lightning Mapping Arrays (LMAs) see discharge breakdown in the VHF that might not show up in optical, which implies an "apple/orange" comparison].
- **Source Scattering:** Optical is cloud-scattered, but cloud is transparent to radio. So often there are GLM lightning detections near cloud edges where there are no associated radio sources.
- **ISS-LIS is Critical:** Since many independent lightning reference networks operate in the radio, it is critical to obtain optical (i.e., "apple/apple") comparison with GLM. The optical measurements provided by the International Space Station Lightning Imaging Sensor (ISS-LIS) make this possible.

2.1 Performance Baseline Mapping

Table 1 summarizes the Mission Requirements that were directly validated by the Post Launch Product Tests (PLPTs) (see [3] for a detailed discussion of each PLPT).

<table>
<tr><th>MRD</th><th>Parameter</th><th>MRD Value</th><th colspan="2">Perf. Baseline (Model)</th><th>Related PLPTs</th></tr>
<tr><td>1259</td><td>Production Mapping Accuracy [INR]</td><td>5km (= $|\mu|+3\sigma < 140$ μrad)</td><td colspan="2">Nav error (7 d averaging) of 108 μrad for GOES-W</td><td>-011, (also -001, -002,-003, -004, -005, -006)</td></tr>
<tr><td>1260</td><td>Product Measurement Range</td><td>(0-41900 events/s, 0-8170 groups/s, 0-600 flashes/s)</td><td colspan="2">Instr Vendor showed can handle peak 100 Kevents/s (600 flashes/s)</td><td>G16/17 Independent [see -009,-010 in G16 Full PS-PVR]</td></tr>
<tr><td rowspan="3">1261</td><td rowspan="3">Product Measurement Accuracy</td><td rowspan="3">70% total flash detection efficiency (DE)</td><td>Instr. Side</td><td>EOL</td><td rowspan="3">-001, -002,-003, -004, -005, -006, -009,-010</td></tr>
<tr><td>Primary</td><td>81%</td></tr>
<tr><td>Redundant</td><td>83%</td></tr>
<tr><td>1264</td><td>Product Measurement Precision</td><td>5%</td><td colspan="2">Open, with Flight reporting FAR ~ 1.1%, but open WRs on GS implementation loss</td><td>-001, -002,-003, -004, -005, -006, -009,-010</td></tr>
<tr><td>2112</td><td>Product Time Tag</td><td>GOES-R system shall time tag product observations</td><td colspan="2">n/a</td><td>-001, -002,-003, -004, -005, -006</td></tr>
</table>

Table 1. The association of Mission Requirements Document (MRD) values & Performance Baseline values. [Note: INR = Image Navigation and Registration; EOL = End of Life (with reduction to flash DE by ~6% due to Coherency Filter removing single group flashes); GS = Ground Segment; WRs = Work Requests.]

2.2 Performance Summary

Table 2 summarizes the performance of the GOES-17 GLM L2 relative to the mission requirements and predicted performance baseline.

MRD	Parameter	MRD Value	Performance Baseline (Model)	Performance Result			
				ValiD	LATA	INR	Mach SIT
1259	Production Mapping Accuracy	5km (= |μ|+3σ < 140 μrad)	108 μrad	n/a	**3.5 km**	**90 μrad**	n/a
1260	Product Measurement Range	(0-41900 events/s, 0-8170 groups/s, 0-600 flashes/s)	100 Kevts/s (600 flashes/s)	n/a	n/a	n/a	**no cases where LCFA unable to handle raw or filtered data rates**
1261	Product Measurement Accuracy	70% total flash detection efficiency (DE)	81%	**73%**	n/a	n/a	n/a
1264	Product Measurement Precision	5% (flash FAR) [also MRD 639 which states same 5% value]	Flight reporting FAR ~ 1.1%,	38% (2s) 10% (1200 s) **5%** (inferred from CONUS obs & simulations)	n/a	n/a	n/a
2112	Product Time Tag	GOES-R system shall time tag product observations	n/a	n/a	**-0.8 ms**	n/a	n/a

Table 2. A summary of the GOES-17 GLM L2 performance results relative to MRD requirements and the Performance Baseline. LCFA = Lightning Cluster Filter Algorithm. The instrument meets the requirements.

Note that both the flash detection efficiency (DE) and flash False Alarm Rate (FAR) vary spatially, diurnally, and seasonally. The DE and FAR values in Table 2 represent a (spatial, diurnal, and seasonal) average across the GLM FOV.

A more detailed perspective of DE performance is provided in Table 3 that shows monthly variability over the year 2020. Whereas the 2nd column of Table 3 provides the 24 hr DE estimates, the 3rd column (day) and 4th column (night) represent 6 hr periods of purely day and night periods, respectively, not contaminated by day-to-night transition periods. Figure 2 shows the spatial variability of GLM-17 flash DE for the year 2020.

The annual performance values (73% for 24 hr period, 70% for 6 hr period in the day, and 75% for 6hr period in the night) have been independently verified by a method described in [4] by Kenneth Cummins of the University of Arizona. His methodology employed International Space Station Lightning Imaging Sensor (ISS-LIS) optical data, resampled at the GLM-17 footprint, and then compared to GLM-17 instrument threshold settings [which vary by location (i.e., pixel), and background brightness] to estimate GLM-17 flash DE. The model accuracy was quite impressive, as verified by comparisons to Kennedy Space Center (KSC), FL Lightning Mapping Array (LMA) data. Moreover, the overall results compared amazingly well to the ground refence data inferred values; i.e., the same values (73%, 70% day, 75% night) were obtained when rounded to the nearest 1%. See [4] and the online PS-PVR slide package for additional details.

Period (2020)	Flash DE	Flash DE (day)	Flash DE (night)
Jan	0.76	0.75	0.76
Feb	0.74	0.75	0.78
Mar	0.74	0.72	0.76
Apr	0.73	0.71	0.77
May	0.73	0.68	0.76
Jun	0.64	0.57	0.69
Jul	0.67	0.61	0.72
Aug	0.66	0.60	0.69
Sep	0.66	0.60	0.68
Oct	0.70	0.66	0.74
Nov	0.74	0.69	0.75
Dec	0.79	0.78	0.80
YEAR	**0.73**	**0.70**	**0.75**

Table 3. A detailed look at GLM-17 flash DE performance for the year 2020. The 2nd column is based on a 24 hr period, whereas the 3rd and 4th columns are based on a 6 hr period during daytime & nighttime, respectively.

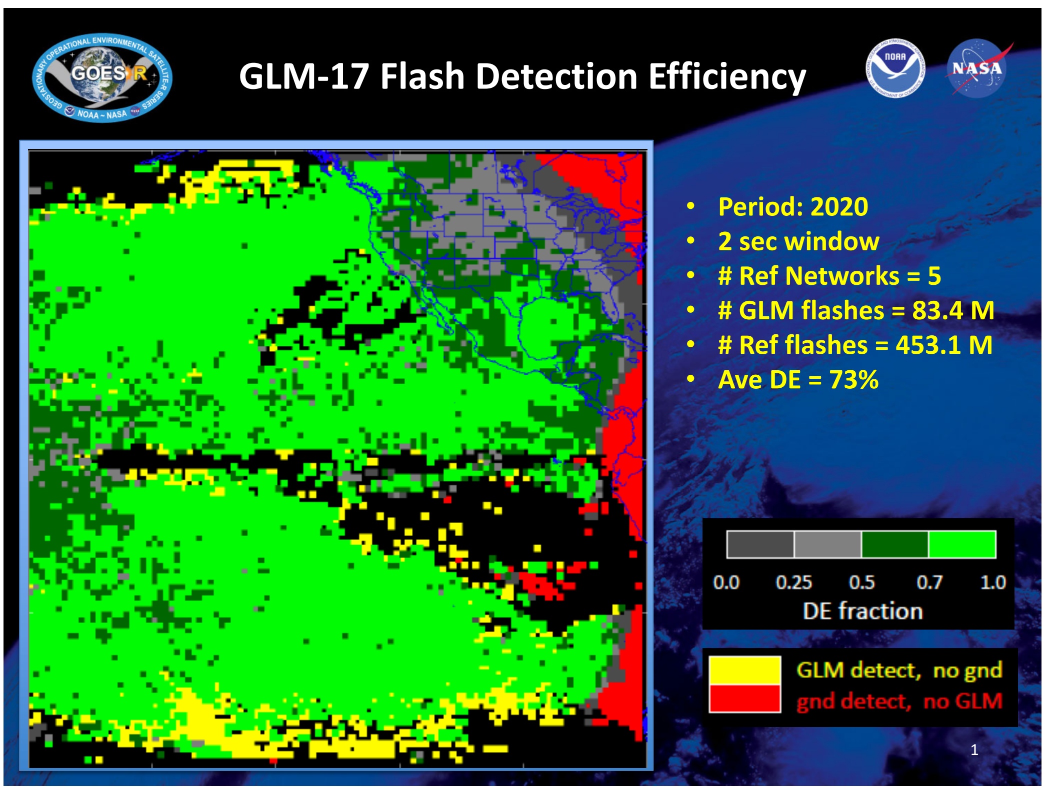


Figure 2. The GLM-17 flash DE for the year 2020. Note that the number of reference network flashes indicated (453.1 M) includes flashes outside the GLM-17 FOV. Detection falls off over CONUS since the instrument minimum detectable energy increases with boresight angle, coupled with the fact that land lightning is less energetic than oceanic lightning. [Note: gnd = ground, so yellow indicates no detection by ground network].

As described in [5] and references therein, the GLM-17 DE and FAR values were computed using a "virtual network" composed of five networks:

- Earth Network's Global Lightning Network (ENGLN) which combines the Earth Network's Total Lightning Network (**ENTLN**) with the World Wide Lightning Location Network (**WWLLN**). ENTLN provides high DE stroke data that covers the CONUS as well as northern and eastern South America. The WWLLN provides global coverage, but at a significantly lower DE (10%–20%).
- Vaisala's Global Lightning Dataset (**GLD360**) provides near global coverage, high DE lightning stroke data. Data use was limited by contract to between −30 and −150 longitude, and these limits are evident in the DE/FAR results shown here.
- Vaisala's National Lightning Detection Network (**NLDN**) stroke and flash data provide high DE lightning data over CONUS, and extend to about 100 km beyond the shores of CONUS.
- The Canadian Lightning Detection Network (**CLDN**) fills in the northern regions of the GLM FOV in North America. It provides lightning flash data with sensors similar to the NLDN.

Detailed FAR tables similar to Table 3 were also produced, but for both the standard 2 sec matching window (i.e., between ground reference flashes and GLM-17 flashes) and a larger 1200 sec window to demonstrate how the FAR reduces down. For brevity, the tables are not reproduced here; see the online PS-PVR slide package for the details.

The study in [5] discusses the decrease in inferred FAR with increasing matching window. Figure 3 summarizes the effect and shows the spatial variability of the inferred FAR across the GLM-17 FOV. As described in [5], if one system has a relatively low DE and detects different components of the lightning flash compared to another system, it is quite possible that the two systems will not see the same flashes; i.e. both systems will likely see other flashes in the same storm. Expanding the time window used to compare the two datasets helps counter this issue (resulting in the detection of some flashes from the storm by both systems). In the validation of GLM-17 the time-comparison window was extended to ±10 min (on either side of the flash duration; i.e. a 1200 sec window as mentioned above). The distance criterion was kept fixed at 50 km so as to keep the cross-storm detection chances to a minimum. The time window was not extended beyond ±10 min, since that would increase the chances of the coincident storms moving out of the grid boxes. Extending the time window to this size allows one to use the virtual network as a "storm detector," rather than an individual lightning flash detector when comparing to the GLM-17 data.

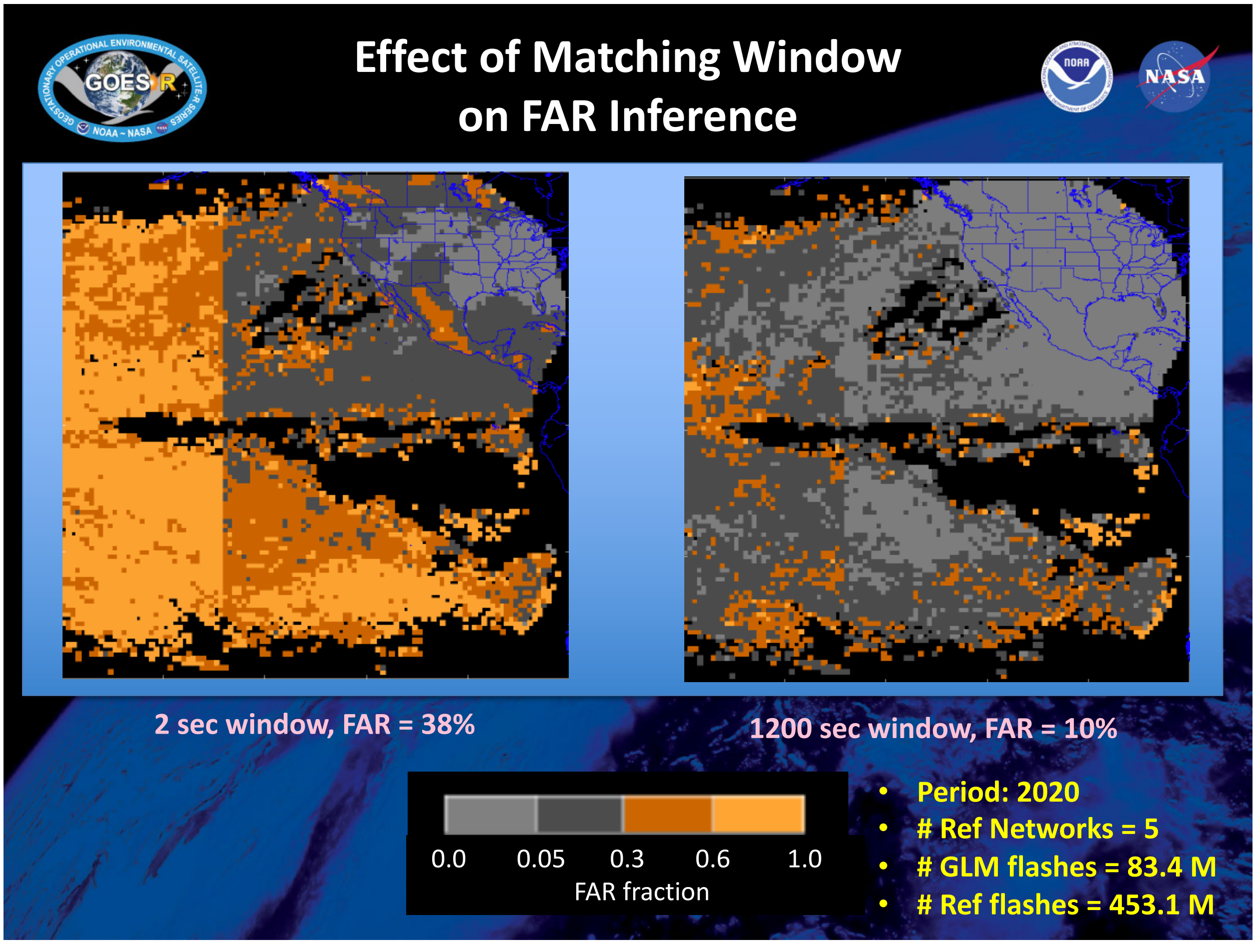


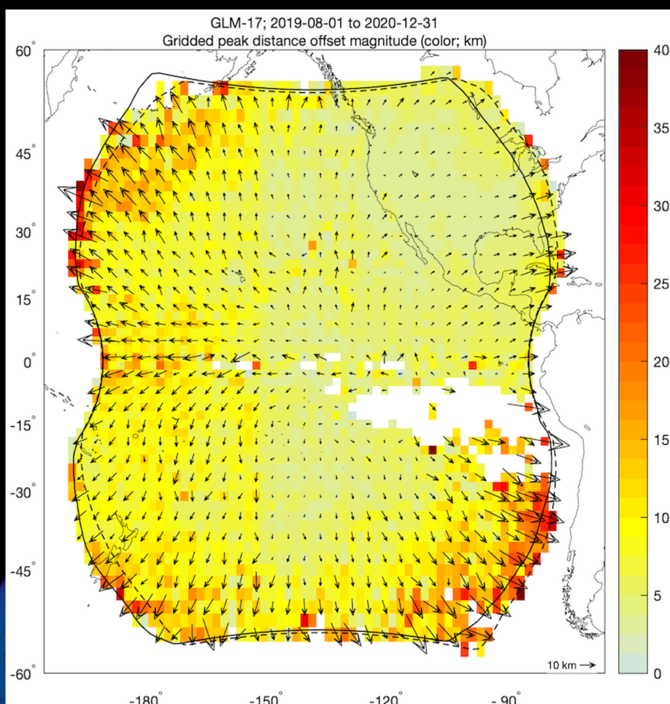
Figure 3. The (inflated) GLM-17 flash FAR values inferred for the year 2020. Increasing the matching time window from 2 sec to 1200 sec decreases the FAR, and illustrates the effect of a low reference network DE over the ocean.

Overall, the following important points regarding GLM-17 FAR should be noted:

1. The **best estimate of GLM-17 flash FAR that we have available is 5%** because that is its value over much of CONUS where the ground reference network DE is optimal within the GLM-17 FOV. The only assumption made is that the GLM-17 instrument is homogeneous across its FOV, which is a reasonable assumption given laboratory tests of the instrument.
2. The reference network flash DE over the Pacific Ocean is too low to adequately assess GLM-17 FAR.
3. A low reference network flash DE implies that a legitimate flash can be missed by the reference network while GLM-17 detects it. This leads to our validation tools incorrectly registering a GLM-17 false alarm, when in fact GLM-17 is correctly detecting the flash.
4. Therefore, the low reference network DE leads to inflated (i.e. overestimated) values of GLM-17 FAR, like the values of 38% and 10% shown in Figure 3.
5. Simulations performed in [6], and also provided in the online PS-PVR slides, demonstrate that a hypothetical spec-meeting GLM (with DE = 70%, FAR = 5%) would incorrectly appear to have an inflated FAR of 38% when the reference network has a low DE of 68%.

Finally, Figure 4 summarizes additional details on the variability of location and timing errors. The vector plot in Figure 4 indicates that the GLM-17 optical groups near the limb must be shifted outward to match the reference network data.

GLM-17 Location/Timing Accuracy



Period	Peak Location Accuracy (km)	Peak Timing Accuracy (ms)
Feb 2020	4 km	-1 ms
Mar 2020	3.5 km	-1 ms
Apr 2020	4 km	-0.8 ms
May 2020	3.5 km	-0.8 ms
Jun 2020	3.5 km	-0.8 ms
Jul 2020	3.5 km	-0.8 ms
Aug 2020	3.5 km	-0.8 ms
Sep 2020	4 km	-0.8 ms
Oct 2020	4.5 km	-0.8 ms
Nov 2020	4.5 km	-1 ms
Dec 2020	4.5 km	-1 ms
Jan 2021	4 km	-1 ms
Feb 2020-Jan 2021	**3.5 km**	**-0.8 ms**

Figure 4. The GLM-17 vector location errors (left), and peak location/timing error results (right). The model for cloud-top height (i.e., the “lightning ellipsoid”) was adjusted to mitigate parallax error near the edge of the FOV, but not all of the parallax error was removed. Overall, the instrument does meet the location and timing accuracy requirements.

3. EXISTING ISSUES & FIXES FOR USER AWARENESS

The subsections below summarize existing issues, and some noteworthy fixes. Algorithm Discrepancy Report (ADR) reference numbers associated with completed or planned software fixes are provided when applicable. A log of fixes is maintained & provided in the Appendix.

3.1 Flash Detection Depletion over CONUS

GOES-17 (and GOES-16) GLM L2 products show a notable depression in flash detection efficiency (DE) extending over fairly large regions of CONUS (specifically, see Figure 2 for the case of GLM-

17). The GLM-17 instrument filter throughput decreases (as does pixel size) with increasing boresight angle, and this effect is particularly evident moving from nadir toward CONUS. In addition, it is known from independent studies that oceanic lightning is more energetic (so more easily detectable) than lightning over land; hence, CONUS is marked by both large boresight angle and land. By contrast, the far NW, SW, and SE edges of the GLM-17 FOV are over ocean. Efforts are being made at NASA MSFC as part of ongoing National Climate Assessment (NCA) activities to optimally splice GLM-16 and GLM-17 data together to obtain a more spatially homogeneous/improved DE across CONUS.

3.2 Flash DE Depletion in Certain Storm Types

From a local perspective, there is evidence that the flash DE is substantially smaller in anomalous (i.e., inverted polarity) storms, and in severe (e.g., hail-producing) storms, or storms with deep liquid water path. In general, because the flash DE associated with reference data is itself variable and typically below 100%, it is not always possible to exactly/unambiguously determine the GLM flash DE in all cases.

3.3 False Events

In this section we briefly summarize several sources of false events.

3.3.1 Solar Glint and Solar Intrusion (ADR 374, ADR 638):

Solar glint occurs from specular reflection off of lakes, rivers, oceans, and solar farms. Sunrise and sunset leads to solar glint off the Atlantic and Pacific oceans, respectively, resulting in routine sunrise and sunset false events over predictable oceanic regions. Solar intrusion, which involves solar rays intruding directly into the GLM lens system (i.e., for relatively short periods during the eclipse season) is also a source of false events. These various noise sources lead to “blooming” which occurs when the photo-electric charge in a pixel exceeds the saturation level and spills over to adjacent pixels. To combat these noise sources, a new blooming filter algorithm was developed and tested by the Instrument Vendor and then delivered to the Ground Segment; it was implemented into the Operational Environment (OE) on 25 July 2019. The blooming filter has been shown to be effective in removing a substantial fraction of blooming events, but not every last one. Figure 5 shows the effects of the glint/blooming filter. Note that the vast majority of the high data rate raw events (likely due to glint/blooming) are removed, however there are hints in the filtered data (most easily seen in the group data) that indicate that not all glint/blooming artifacts have been removed. [Note: regarding solar glint, an improvement to the solar glint box via ADR 638 was implemented in early December of 2018. ADR 638 is a correction to the processing parameters used by the Ground Segment. The Instrument Vendor has a multiplier for the size of the glint box used in the glint filter. The correct value for this multiplier is 5, but it was previously incorrectly set to 2, so this was a relatively simple fix. However, note that the Instrument Vendor turned-off the glint filter when the blooming filter went online. The blooming filter provides better overall performance than the glint filter, and the glint filter does not provide additional filtering capability beyond the blooming filter.]

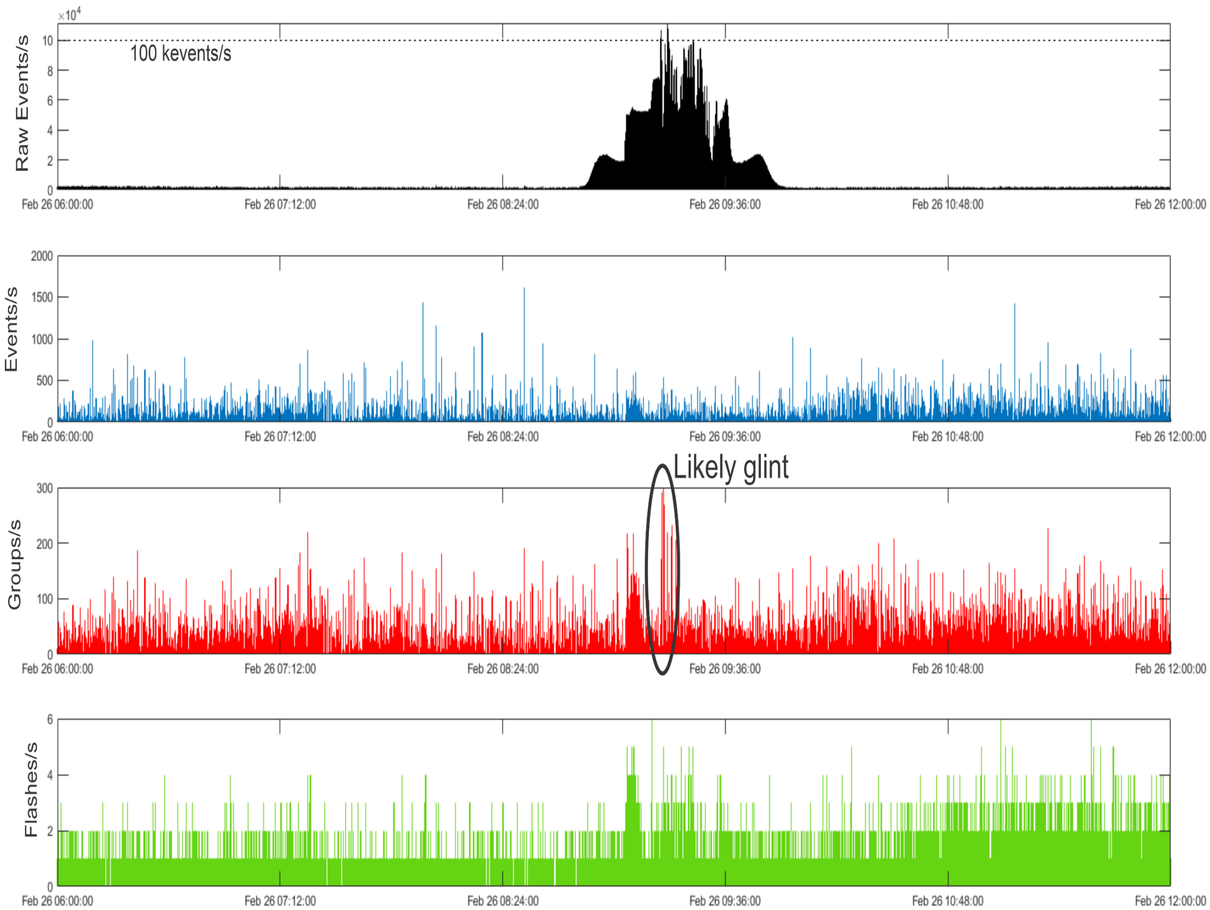


Figure 5. Example of the effects of the glint/blooming filter; it removed the vast majority of the glint/blooming events [i.e., compare event rates between the top plot (black) of raw events and the second (blue) plot of filtered events]. After clustering of the events into groups, note the somewhat anomalous group peak (red plot, black circle) that indicates there are some glint/blooming data remaining in the filtered data.

3.3.2 False Event "Bars" at RTEP Boundaries (ADR 647)

Horizontal streaks or "bars" of false events at the boundary between certain GLM Real Time Event Processors (RTEPs) occur; the first was noticed in the Bahamas and coined the "Bahama Bar". These bar artifacts have been mitigated (but not completely removed) from second-level threshold filtering as part of ADR 647 which was implemented into the OE on 27 February 2019.

3.3.3 Residual Radiation "Dots" (ADR 519)

False events due to high energy radiation particles, aka "radiation dots" have been largely removed by the implementation of a Single Group Flash (SGF) filter [also referred to as a Single Group Filter, for brevity]. This improvement was implemented on 27 October 2020. This filter is not perfect; i.e., in order to mitigate unintentional removal of legitimate flashes by the SGF, testing continues to determine if a Single Event Flash (SEF) filter should be used to replace the SGF. The SEF is an attractive alternative since it is believed that most high energy radiation noise is thought to usually only trigger one pixel.

3.3.4 Bursts Associated with Data Formatter (ADR 649)

When the GLM-17 Sensor Unit and Electronics Unit lose synchronicity, the RTEPs in the data formatter end up comparing the video signal to the wrong background pixel which results in a burst of events (although this was not a significant issue compared to GLM-16). This has been largely mitigated via the Data Formatter Burst Filter in ADR 649 that was implemented into the OE on 27 February 2019. The original filter design looked for burst characteristics in four RTEPs, but this ADR provides the ability to look at three instead of four RTEPs for the burst signature.

3.4 Additional Notes

3.4.1 Position Errors (ADR 855, ADR 645, ADR 650, ADR 879)

As part of ADR 855, a "Parallax Lite" software improvement was implemented into the OE on 3 December 2018. This helped reduce GLM-17 flash location errors by adjusting the parameters of the so-called "lightning ellipsoid" model that describes cloud-top height across the GLM FOV. Figure 4 summarizes the location errors. Note that although GLM-17 meets instrument requirements for location accuracy, the vector plot in Figure 4 shows that location errors increase near the edge of the FOV due to parallax. A more robust 3 degree gridded cloud-top model that takes into account monthly variability and that is described in [6], is desired (ADR 645) to further mitigate location errors. Mitigation of INR inaccuracies due to diurnal variations (ADR 650) has been dropped. Finally, note that the Ground Segment software could not correctly handle event longitudes West of 180W, but this issue has been fixed via ADR 879 which was implemented into the OE on 27 October 2020 (see Figure 6 as an example of the fix).

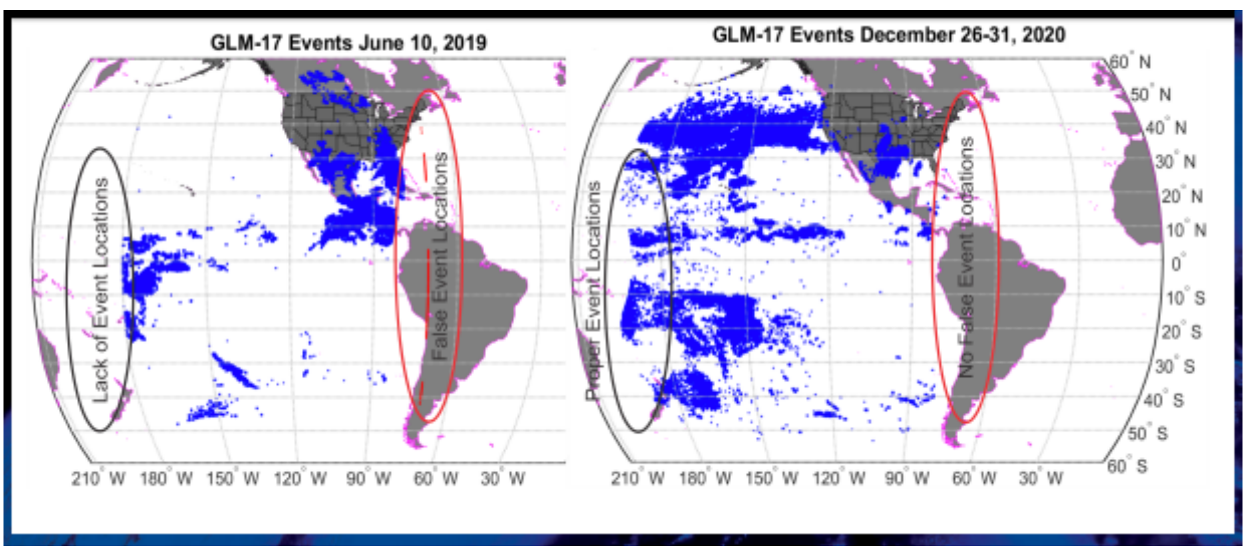


Figure 6. Example of before the event longitude fix (left) and after the fix (right). This results in the proper reporting of events west of 180W longitude, and the removal of false event artifacts near the eastern edge of the FOV.

3.4.2 Timestamp (ADR 338, ADR 375/1140)

The timestamp on events, groups, and flashes has now been fixed as part of ADR 338 that was implemented into the OE on 15 October 2018). This fix properly accounts for the Time-Of-Flight (TOF) of the photons from cloud-top to sensor. Therefore, users no longer need to perform their own TOF correction to the data following this implementation date. There are still time-order issues with L2 data event times (as well as group time, flash start time, and flash end time), but these issues normally do not pose any major problems for most analyses; a fix via ADR 375/1140 is presently on hold.

3.4.3 Unsigned Integer Read (ADR 844)

In order to save storage space, some floating-point variables (such as times, latitude, and longitude) are stored in the GLM NetCDF file as a lower resolution internal format with a "scale_factor" and "add_offset" attribute. Some of the GLM data is stored in a non-standard format (as unsigned integers). This is an issue that affects multiple instruments on GOES-16/17, and a pilot fix was worked via ADR 844 with implementation into the OE on 5 November 2018. For additional details on this subject, see the GOES-16 GLM Level 2 Data Full Validation Data Quality Product Performance Guide For Data Users.

3.4.4 Gridded Data and Data Quality Products (ADR 461, ADR 646)

These products are not yet available but are being developed, with plans for eventual submission to the Ground Segment along with fully tested meta-code.

3.4.5 Granularity, Max Energy and Dark Flashes (ADR 738, ADR 739)

The event, group, and flash energy scale_factor and add_offset parameters were adjusted to avoid poor granularity issues at the low-end (i.e., "stair-step" pattern in energy plots due to poor resolution), while at the same time being able to handle the expected maximum energy values within the allotted digital count range. This was achieved via ADR 738, which also helps rectify the dark flash energy issue (ADR 739). These ADR fixes were implemented into the OE on 2 October 2019.

3.4.6 Duplicate Groups & Events, and Zero Energy Items (ADR 740)

There were duplicative events and duplicative groups along with zero energy events and groups. On a daily basis, the number of duplicative groups ranged from about 100 to as much as 2000, and the number of duplicative events ranged from 6000 to 70,000. The number of zero energy groups ranged (on a daily basis) from about 300 to 30,000. The number of zero energy events ranged from 2000 to 200,000. The fractions are around 0.1% of the groups and events. So, it was not a huge fraction, but over the span of 6 months, the numbers were as large as 10,144,987 events with zero energy. The frequency of these errors did not show any significant patterns, either in absolute numbers or in fractions of total. To our knowledge, these artifacts were fixed with the implementation of ADR 740 into the OE on 15 October 2018.

3.4.7 Area Values and Units (ADR 382, ADR 179)

Improvements to group and flash area values (ADR 382) were implemented into the OE on 15 October 2018. In addition, group and flash area units were changed from km^2 to m^2 (ADR 179); this fix was implemented into the OE on 28 January 2019.

4. SUMMARY

Overall, GLM on GOES-17 meets mission requirements. Currently, the flash detection efficiency (DE) meets specifications against the ground truth systems. We believe the GLM-17 flash false alarm rate (FAR) is meeting specifications based on its performance over CONUS where ground reference network DE is good, and because we believe that the GLM-17 instrument is a fairly homogenous detector. Over the ocean where ground reference DE is poor, legitimate GLM-17 flash detections are unfairly tallied as false alarms. GLM-17 location and timing accuracy meet specifications; note that a software fix was implemented to properly handle event longitudes West of 180W (see section 3.4.1). In addition, maximum data processing rate requirements have been met. Fixes continue on lower priority items, and it is the user's responsibility to understand which issues have been and have not been fixed in the data being used.

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5. REFERENCES

[1] GOES-R Series Product Definition and User's Guide (PUG), Volume 5: Level 2+ Products, 416-R-PUG-L2 Plus-0349 Vol 5, Revision 2.2, December 2019.

[2] GOES-R Series Mission Requirements Document (MRD), 410-R-MRD-0070, Version: 3.31, January 2021.

[3] Geostationary Lightning Mapper (GLM) Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP), 410-R-RIMP-0313, Version 2.0, November 2020.

[4] Cummins, K. L., On the spatial and temporal variation of GLM flash detection and how to manage it, extended abstract for the American Meteorological Society (AMS) Virtual Meeting, January 2021.

[5] Bateman, M., Mach, D., & Stock, M. (2021). Further investigation into detection efficiency and false alarm rate for the geostationary lightning mappers aboard GOES-16 and GOES-17. Earth and Space Science, 8, 2020EA001237. https://doi.org/10.1029/2020EA001237.

[6] Virts, K. and W. J. Koshak, 2020: Mitigation of Geostationary Lightning Mapper geolocation errors, J. Atmos. Oceanic Technol., 37, 1725 - 1736, https://doi.org/10.1175/JTECH-D-19-0100.1.

APPENDIX

GLM GROUND SEGMENT SOFTWARE STATUS LOG

GLM Ground System Software Status **10 March 2021**

This document lists all known GLM-related changes to the Ground System (GS) software since initial deployment. The GS makes fixes through series of ADRs and WRs. Some fixes are minor while others take longer to diagnose and remedy. The WRs are implemented in new versions of the GS software that are first deployed in the Development Environment (DE) then the Operational Environment (OE). New versions are indicated by three sets of integers (e.g., DO 04.04.02). The first is the GS software version, the second indicates software patches, and the third signifies emergency patches. The Product Readiness and Operations (PRO) team developed a system to integrate less complicated fixes into the GS outside of the more rigorous GS process. The PRO team makes changes to the GS software and releases (PR) patches that follow the same numbering system. Most updates to the lookup tables (e.g., Rev G LUTs) follow the PR path. The following list is complete as of the date referenced above, and this document will be updated periodically.

GOES-R GLM Data Validation-Level Dates

GOES-R Satellite	Validation-Level	Date
GOES-16	Beta	07/05/17
GOES-16	Provisional	01/19/18
GOES-17	Beta	10/02/18
GOES-16	Full	11/01/18
GOES-17	Provisional	12/20/18
GOES-17	Full	02/24/21

Ground Segment Update Schedule:

Software Build	Date	Time (UTC) (16/17)
DO.04.02.00	01/13/17	15:00
DO.04.03.00	02/17/17	21:53
DO.04.04.00/.01	04/24/17	19:52
PR.04.04.07	06/28/17	20:00
DO.05.00.00	07/24/17	17:00
PR.05.00.01	09/07/17	18:41
DO.06.00.00	10/31/17	17:22
PR.06.01.00	11/30/17	18:41
DO.06.02.00	11/28/17	16:46
PR.06.02.03	12/14/17	15:10

PR.06.02.05	01/10/18	21:46
PR.06.07.00	02/21/18	
DO.06.03.00	06/19/18	15:27
DO.07.00.00	10/15/18	
PR.07.01.00	10/29/18	
PR.07.02.00	11/05/18	19:25
PR.07.03.00	11/15/18	18:48
PR.07.03.04	11/15/18	
PR.07.06.00	01/28/19	
PR.07.08.00	02/27/19	19:46
PR.07.10.05	04/30/19	15:19
DO.08.00.00	07/25/19	15:11 / 17:21
DO.09.02.00	10/27/20	17:26/ 18:33
Outstanding	TBD	

Table 1: ADR/WRs Resolved in DO.04.02 (01/13/17)

WR	Description
1948	GLM Group Energy Values are all set to the minimum value
1948 1950 2284	GLM energy discrepancies
2267	Improve GLM LCFA algorithm error-handling
2284	Different units between GLM L1b and GLM L2
1935	GLM Eastern RTEP mapping appears incorrect
1937	GLM L2+ product metadata errors
3556	Update GLM Navigation Parameters
3557	Update GLM RTEP Map

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Table 2: ADR/WRs Resolved in DO.04.03 (02/17/17)

WR	Description
3315	Zero Pixels at RTEP corners in GLM Background Image
3702	GLM not producing background images

(Back to Ground Segment Update Schedule)

Table 3: **ADR/WRs Resolved in DO.04.04.00/.01 (04/24/17)**

WR	Description
1949	GLM appears to have Timing Artifacts
2061	GLM OP - Change Event Filter Order to match GLM CDRL-80 Rev F
2063	GLM OP - Implement Overshoot Filter
2064	GLM OP - Implement Solar Glint Filter
2065	GLM OP - Implement Crosstalk Filter
2066	GLM OP - Update event energy computation
2067	GLM OP - Update Block-Level Metadata
2068	GLM OP - Update INR Implementation to GLM CDRL-46 Rev H
2234	Event and group count variables differ from the events, group data arrays
3033	GLM L2+ start/end times incorrect, ETE4b using MVTDS-Synthetic data
4255	GLM LCFA file names have invalid start/end date times and don't meet latency requirements

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Table 4: **ADR/WRs Resolved in PR.04.04.07 (06/28/17)**

WR	Description
	Implement GOES-16 GLM FM1 CDRL079 Rev G Rev G Change Table: Submitted HDF5 files for all 3 positions, and both sides of the instrument with the final PLT determined INR parameters for FM1. Interim updates for event filter parameters and corrections to the radiometric calibration are also included. The changes to the HDF5 file are as follows: 1. Added latest thresholds 2. Set all A/B optical distortion coefficients to 0 3. Updated PIT to remove ambiguous coasts (padded with the final value to be the same variable size as previous release) 4. Updated coastline ID observation start and stop times 5. Updated max solar angle 6. Updated all coherency filter parameters 7. Updated glint update period 8. Updated mask slightly (3 pixels changed) 9. Corrected errors in calibration table – no more negative calibration coefficients 10. Updated coastline ID parameters: water threshold, midnight offset, initial alignment values, bipod coefficients, earth rotation rate (more significant figures), and earth rotation angle offset (more significant figures), water min, min coastline pixels

	11. Updated the second level thresholds to correct an indexing error In addition to the updates to the HDF5 file, included with this CDRL submission is an update to the primary side calibration table to be used for GLM backgrounds described in section 5.2 and originally submitted under rev C. The calibration table included in the HDF5 file is for events only.

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Table 5: **ADR/WRs Resolved in DO.05.00 (07/24/17)**

WR	Description
1935	GLM Eastern RTEP mapping appears incorrect
1937	GLM L2+ product metadata errors
3556	Update GLM Navigation Parameters
3557	Update GLM RTEP Map

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Table 6: **ADR/WRs Resolved in PR.05.00.01 (09/07/17)**

WR	Description
	Implement GOES-16 GLM FM1 CDRL079 Rev H Rev H Change Table: Updated parameters for most of the event filtering parameters per GLM-004 test report (GLM06593), and added data quality algorithm parameters based on the preliminary data quality product described in GLM06090 under CDRL038 rev B. Detailed list of changes: 1. Updated second level thresholds to reapply the minimum on board threshold for that channel 2. Updated overshoot filter LUT based on on-orbit data 3. Updated contrast leakage parameters to essentially turn off the filter 4. Updated glint filter parameters 5. Updated coherency filter parameters Probability table based on on-orbit thresholds and higher amplitudes remaining after the second level threshold removes low amplitude events 6. Updated CCD frame transfer filter parameters to essentially turn off the filter 7. Added data quality parameters 8. Incorporated scaling changes into temperature conversion coefficients to mitigate focal length calculation errors that were causing nav issues (significant change)

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Table 7: **ADR/WRs Resolved in DO.06.00 (10/31/17)**

WR	Description
5140	Banded Structure in Group Geolocation GLM L2 – Fixed "Charlie Brown" stripes in L2 groups – also should greatly reduce the splitting of individual GLM flashes
2062	GLM OP - Implement data formatter burst filter
4017	GLM INR update to CDRL 46 Rev K
2691	Abnormally large group areas in the L2+ products
4589	Time offset of events, groups and flashes, GLM L2+ (only corrected in L1b)
4709	Baseline: GLM CALINR update to CDRL 79 Rev H

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Table 8: **ADR/WRs Resolved in PR.06.01.00 (11/30/17)**

WR	Description
4948	GLM L2 event time now has changed scale_factor = 1 millisecond

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*Table 9: **ADR/WRs Resolved in DO.06.02 (11/28/17)***

WR	Description
4762	Radiation 'dots', removing single-group flashes
4780	Duplicate events - Duplication dots are no longer present
5162	GLM E-W Event Navigation Error
5284	Interim solution - GLM Event Geolocation Does Not Match Vendor Results

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Table 10: **ADR/WRs Resolved in PR.06.02.03 (12/14/17 or PR.06.03.00 12/15/17)**

WR	Description
5545	GLM LUT update for East. Update to glint filter spot amplification and contrast leakage GS parameters ***Included fix to GLM Data Burst Filter – fixed issue of crash induced empty files***

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Table 11: **ADR/WRs Resolved in PR.06.05.00 (01/10/18)**

WR	Description

5426	Improves the GLM L1b algorithm by fixing the second level threshold filter and the overshoot filter. A new rpm is installed to fix these issues.

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Table 12: **ADR/WRs Resolved in PR.06.07.00 (01/29/18) or PR.06.08.01 (02/21/18)**

WR	Description
5301	GLM LUT pre-launch update for GOES-S

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Table 13: **ADR/WR Resolved in DO.06.03 (06/19/18)**

WR	Description
4762	Radiation 'dots', removing single-group flashes
4948	Lightning L2 event time scale_factor is incorrect – PRO Type 1
5399	The GLM L1 EFRC service periodically crashes when processing live data

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Table 14: **ADR/WRs Resolved in DO.07.00 (10/15/18)**

WR	Description
3561	Update GLM EFRC Algorithm to use updated CALINR format provided by GLM Flight
4477	GLM L2 LCFA product has 'n/a' for production_data_source
4507	Use adjusted event times in Lightning L2+ product (TOF & associated)
4696	Group and flash areas GLM L2 (Discrepancy 20% between GS & LM) areas
5545	GLM L1b LUT update for East- PRO Release Type 1
5525 4695	Orphan and childless events and groups in GLM L2 & Family Links

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Table 15: **ADR/WRs Resolved in PR.07.01.00 (10/29/18)**

WR	Description
6217	Update GOES-16 GLM LUT to CDRL 79 Rev J Updated lightning ellipsoid values (solves ADR637 (Parallax Lite)) New 2nd-level threshold filter w/32 levels/pixel to mitigate Bahama Bar

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Table 16: **ADR/WRs Resolved in PR.07.02.00 (11/05/18)**

WR	Description
5930	An overflow valve for when 'burst event' will cause an abnormal amount of false events to be registered in the L1b file. This surge of events causes L2 processing to bog down due to the large number events to process. The result is empty L2 files for a large period of time (multiple hours) while the algorithm either catches up or is restarted.

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Table 17: **ADR/WRs Resolved in PR.07.03.00 (11/15/18)**

WR	Description
6749	GLM L2 lightning data products needs _unsigned attribute on time offsets

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Table 18: **ADR/WRs Resolved in PR.07.03.04 (11/15/18)**

WR	Description
6681	Update GOES-17 GLM LUT to CDRL079 Rev C (GLM FM2) Updated the flat 2nd level threshold to mute the hot pixels

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Table 19: **ADR/WRs Resolved in PR.07.06.00 (01/28/19)**

WR	Description
6558	Change GLM L2 Group and Flash Area units from km^2 to m^2

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Table 20: **ADR/WRs Resolved in PR.07.08.00 (02/27/19)**

WR	Description
6097	Implement GLM 2^{nd}-level threshold filter code change (for optimal threshold adjustment)
6098	Implement GLM Data Burst filter code change (allows variable number of RTEPs within a Data Formatter to observe a data burst instead of the fixed value of four (4)

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Table 21: **ADR/WRs Resolved in PR.07.10.05 (04/30/19)**

WR	Description
7095	GOES-16 GLM FM1 CDRL 79 Rev K LUT

	• Updated the coherency probability LUT to bias it 3 DN above the average RTEP threshold. False alarms from subarrays with higher noise (subarray 35 in particular) were causing problems for forecasters, so the probability table needs to be closer to the higher noise subarrays rather than a true average. • Turned the contrast leakage filter back on. The jitter test is now run, and the leakage fraction is set to 1.0. • Updated the second level threshold to better handle the "Bahama Bar" phenomena in subarrays 7, 19, 20, 26, 35, 47, 48 and 54.
7095	GOES-17 GLM FM2 CDRL 79 Rev D LUT • Enabled contrast leakage filter with leakage fraction = 2.0 • Updated second level thresholds to balance threshold-to-noise ratio, to better suppress hot pixel false events, and to suppress "Bahama Bar" false lightning artifacts • Updated radiometric calibration to remove NaN values • Updated ZRDQ parameters for the data quality product based on PLT-006 test

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Table 22: **ADR/WRs Resolved in DO.08.00.00 (07/25/19)**

WR	Description
4758	GLM L1b INR – GLM Event Geolocation Does Not Match Vendor Results – Minor corrections to the GLM event navigation implementation.
4697	GLM L1b – GLM Blooming Filter – This adds the Blooming Filter to the suite of false event filters used in the GLM L1b ground processing algorithm to remove false lightning event detections. The blooming filter removes false events which can occur during solar glint and solar intrusion.
6096	GLM L1b – LUT Filenames not Traceable to Metadata - ABI GLM – ABI and GLM metadata will now include the names of the LUTs used in production.
6116	GLM L2 – GLM L2+ LCFA Product's Yaw Flip Flag is fill – The GLM L2 product will now output the correct yaw flip state. It was previously fill.

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Table 23: **ADR/WRs Resolved in PR.08.03.04 (10/02/19)**

WR	Description
7369	GLM Optical Energy Distortions in PDA Stream – GLM L2 Event Energy Resolution Coarser than Vendor Values – Analyzed instrument calibration data and on-orbit observations to determine optimal scale_factor and add_offset semi-static parameters for storing lightning event, group and flash data in GLM L2 data product files.

7369	GLM Zero Energy Events and Groups – Deficiency associated with the coarse energy resolution due to the semi-static parameters. Algorithm deficiency corrected using solution to ADR738.

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Table 24: **ADR/WRs Resolved in DO.09.02.00 (10/27/20)**

WR	Description
5480	GLM Lightning LCFA L2 Radiation Filter Threshold – Radiation filter threshold, with a threshold value of two (pass single-group-flashes (SGFs) containing two or more events).
6809	GOES-17 GLM Event Longitude Values – Correct event geolocation for events west of 180°.
6865	GLM Geolocate Does Not Handle Empty EFRC Output Correctly
7129	Time Error in GLM Metadata – The metadata of GLM-16 and GLM-17 data product files sometimes includes incorrect time information.

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Table 25: **Active-Outstanding ADR/WRs**

ADR/WR	Status	Description
549/6412	Analysis_Complete	Eliminate GLM L1b dependency on APIDs 384 and 385
906/7178	In_Analysis	GLM L1b – Ingest Directly Instrument Vendor CDRL079 Calibration Data Books
1060/7538	In_Analysis	Interim Solution to Facilitate GLM Gridded Data
1109/7990	In_Work	GLM Flash Area equals Fill Value for Large Flashes
1140/xxxx	On_Hold	GLM Time Order Rule Change (Update to ADR375)
xxxx/6690	In_Work	GLM L1b intermediate metadata inconsistent with product data

Dormant-Outstanding ADR/WRs

ADR461: GLM L2 Data Quality Product
ADR646: GLM Gridded Product

Glossary

ADR	Algorithm Deficiency Report
Cal/Val	Calibration and Validation Efforts and/or Team
DE	Development Environment
DO	Data Operations
EFRC	Event Filter and Radiometric Calibration – a component of the GS implementation of GLM GPA

GLM	Geostationary Lightning Mapper
GLM OP	GLM Operational Prototype
GPA	Ground Processing Algorithm
GS	Ground Segment
LUT	Look-Up Table
OE	Operational Environment
PRO	Product Readiness and Operations Team
PR	PRO Release
WR	Work Request

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