GOES-18 Geostationary Lightning Mapper (GLM) Full Validation PS-PVR

November 08, 2023

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(with inputs from additional Cal/Val Team Members, OSPO, CVCT PRO, NASA Flight, and MOST)

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Outline

- Introduction
- Performance Summary
- PLPT Details
- Progress Since Provisional Review
- Assessment of Maturity
- Summary and Recommendations

Outline

Introduction

Performance Summary

PLPT Details

Progress Since Provisional Review

Assessment of Maturity

Summary and Recommendations

Cal/Val Team Members

NSSTC (Huntsville, AL)

GOES-R Program Subj. Matter Expert: Steve Goodman (Thunderbolt Global Analytics)

Core Team: William Koshak (MSFC), Doug Mach (USRA), Monte Bateman, Dennis Buechler & Katrina Virts (UAH); Rich Blakeslee (MSFC emeritus)
Support Team (lower left): Phillip Bitzer & Jeff Burchfield (UAH)

NOAA/NESDIS/STAR

Scott Rudlosky
(GOES-R Science; NWS Activities Specialist)

MIT-Lincoln Lab

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(Core Team Member)

Various Remote (past studies)

- Eric Bruning (TTU)
- Jacquelyn Ringhausen (CIWRO)
- Jeff Lapierre (AEM)
- Ken Cummins (UA)
- Steve Rutledge (CSU)
- Adam Clayton (formerly CSU)
- Max Marchand (CIRA)
- Bob Holzworth (Univ. WA)
- Michael McCarthy (Univ. WA)
- Ron Thomas (NMT)
- Randy Longenbaugh (SNL)
- Michael Peterson (LANL)

INR Team (OSPO, MOST)

- David Igli
- Alan Reth
- Bin Tan
- Noah Curtiss
- Alana Semple

Special Thanks to CVCT PRO

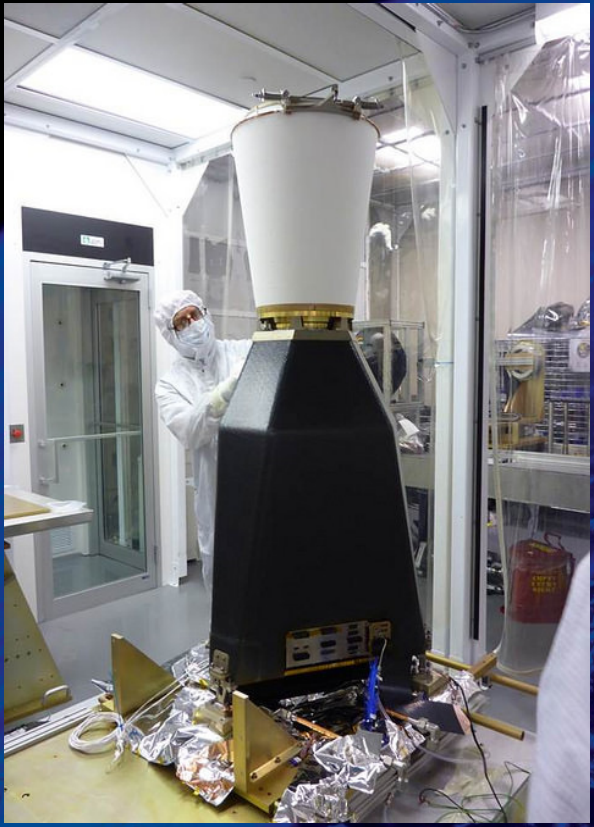
- Liz Kline
- Jon Fulbright

Photos courtesy of William Koshak & Pete Armstrong, or publicly available

GLM Overview

REQUIREMENTS:

- Provide continuous, full-disk lightning measurements for storm warning and nowcasting.
- Provide early warning of tornadic activity.
- Accumulate a long-term database to track decadal changes [of lightning].



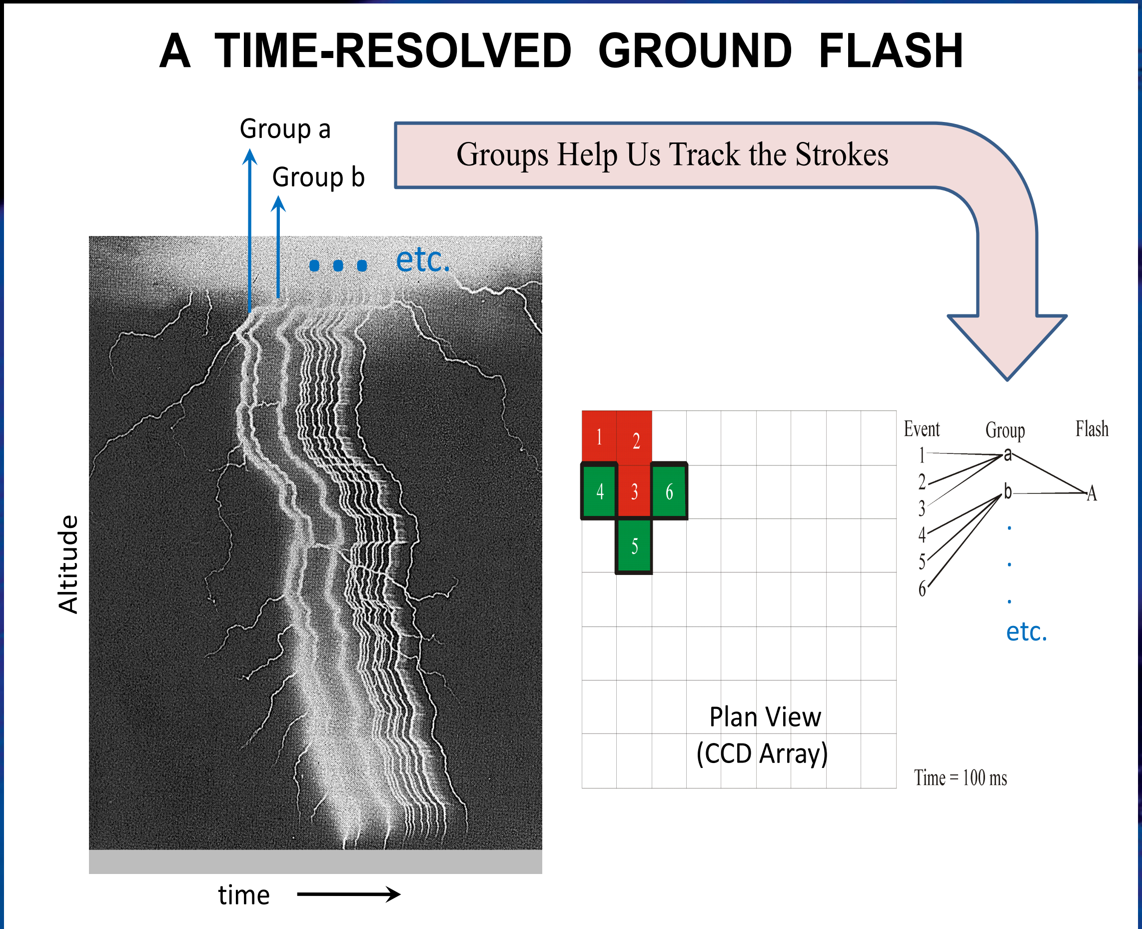
INSTRUMENT DETAILS:

- High-speed nadir-staring camera
- CCD imager (1372x1300 pixels)
- Near uniform spatial resolution
- 8 km nadir, 14 km edge of FOV
- Coverage ~ ± 54 latitude
- Single band 777.4 nm
- 2 ms frame rate
- 7.7 Mbps downlink data rate
  - TRMM/LIS only 8 kbps
- 20 sec product latency

GLM is the first lightning mapper to be flown in geostationary orbit. Heritage LEO sensors include: Optical Transient Detector (1995-2000), and TRMM/LIS (1997-2015)

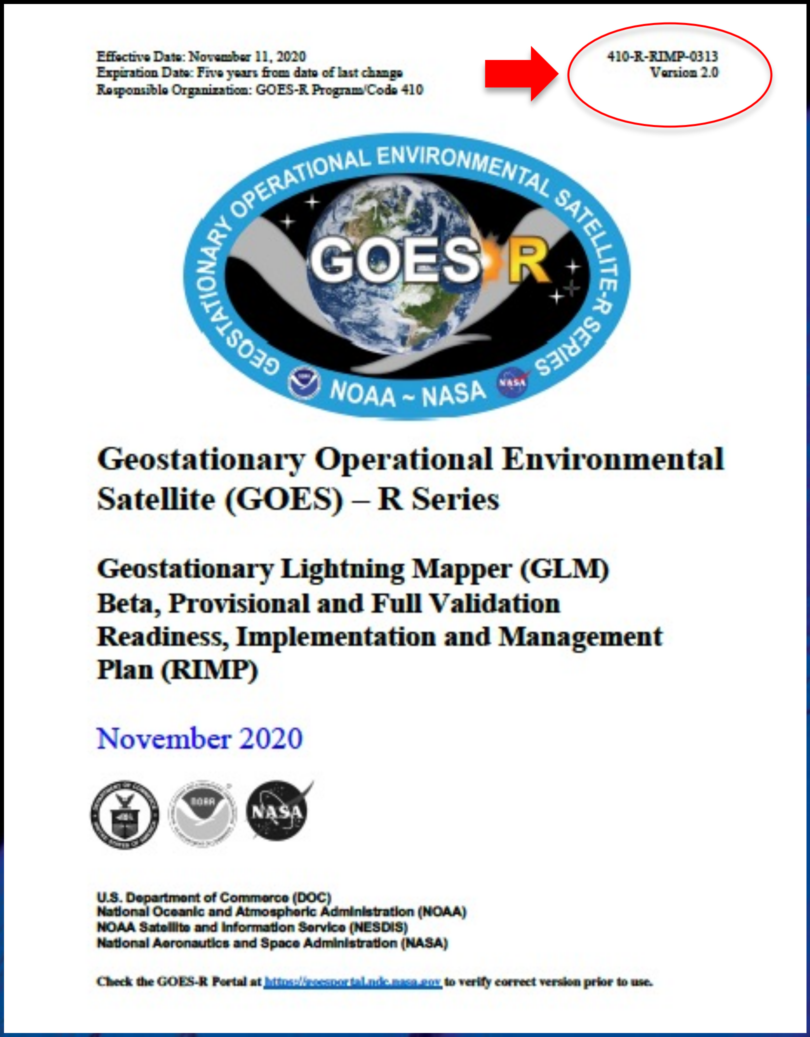
GLM Data Products Description

- Events: pixel-level optical detection in one frame.
- Groups: one or more (side/corner) adjacent pixel detections in one frame.
- Flashes: one or more groups within 330 ms (i.e. ~ interstroke duration), & within 16.5km.



Important Validation Principles

(see RIMP for more details)



Effective Date: November 11, 2020
Expiration Date: Five years from date of last change
Responsible Organization: GOES-R Program/Code 410

410-R-RIMP-0313
Version 2.0

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE-R SERIES
GOES-R
NOAA ~ NASA

Geostationary Operational Environmental Satellite (GOES) – R Series

Geostationary Lightning Mapper (GLM) Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP)

November 2020

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
NOAA Satellite and Information Service (NESDIS)
National Aeronautics and Space Administration (NASA)

Check the GOES-R Portal at https://goesportal.ndc.nasa.gov to verify correct version prior to use.

- Targets of Opportunity (TOO): VAL of a Lightning Sensor differs from VAL of typical imager; i.e. since lightning transient, VAL is restricted to TOO.
- Flash DE & FAR are Estimates: Because reference data normally doesn'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., LMAs see discharge breakdown in the VHF that might not show up in optical → apple/orange).
- Source Scattering: Optical is cloud-scattered, but cloud is transparent to radio. So often see GLM detections near cloud edges where no radio sources.
- ISS/LIS & FEGS are Critical: More of an apple/apple comparison w/GLM.

Performance Baseline Mapping

MRD	Parameter	MRD Value	Perf. Baseline (Model)	Related PLPTs
1259	Production Mapping Accuracy [INR]	**5km** (= $\|\boldsymbol{\mu}\|+3\sigma < 140$ μrad)	Nav error (7 d averaging) of 103 μrad for GOES-W	-011, (also -001, -002,-003, -004, -005, -006)
1260	Product Measurement Range	(0-41900 evts/s, 0-8170 grps/s, **0-600 flsh/s**)	Instr Vendor showed can handle peak 100Kevts/s (600flsh/s)	G16/17 Independent [see -009,-010 in G16 Full PS-PVR]
1261	Product Measurement Accuracy	**70%** total flash detection efficiency (DE)	Instr. Side: EOL* Primary: **90.3%** Redundant: 90.5%	-001, -002,-003, -004, -005, -006, -009,-010
1264	Product Measurement Precision	**5%**	Open, with Flight reporting FAR ~ 2.6%	-001, -002,-003, -004, -005, -006, -009,-010
2112	Product Time Tag	**GOES-R system shall time tag product observations**	n/a	-001, -002,-003, -004, -005, -006

*EOL = End of Life with reduction to flash DE by ~6% due to Coherency Filter removing single-group flashes

Time-Line Highlights

GOES-18
Drift: 89.5W to 136.8W
May 16 - June 6, 2022
Nudge: 136.8 to 137.0
July 5-21, 2022
… and GOES-17 137.2 to 137.3 same period.

- 01 Mar 2022 GOES-T Launch (4 yrs to the day of GOES-S Launch)
- 14 Mar 2022 Attained Geo. Orbit (now GOES-18)
- 29 Mar 2022 GLM Powered On
- 14 Apr 2022 GLM Door Opened & 1st Light
- 12-14 May 2022 Pre-Drift GLM-18 Quicklooks (Huntsville/Koshak/Virts)
- 02 Jun 2022 Public Release (video of GLM-18 lightning)
- 07-13 Jun 2022 Post-Drift GLM-18 Quicklooks (Huntsville/Virts)
- 01 Sep 2022 CDRL079 LUT Update went live @ 18:58 UT
- 05-16 Sep 2022 Beta Certification Quicklooks (Huntsville/Koshak/Virts)
- **16 Sep 2022 Beta Certification**
- **31 Oct 2022 PS-PVR PROVISIONAL Achieved**
- Progress from provisional to present discussed later

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- **Performance Summary**
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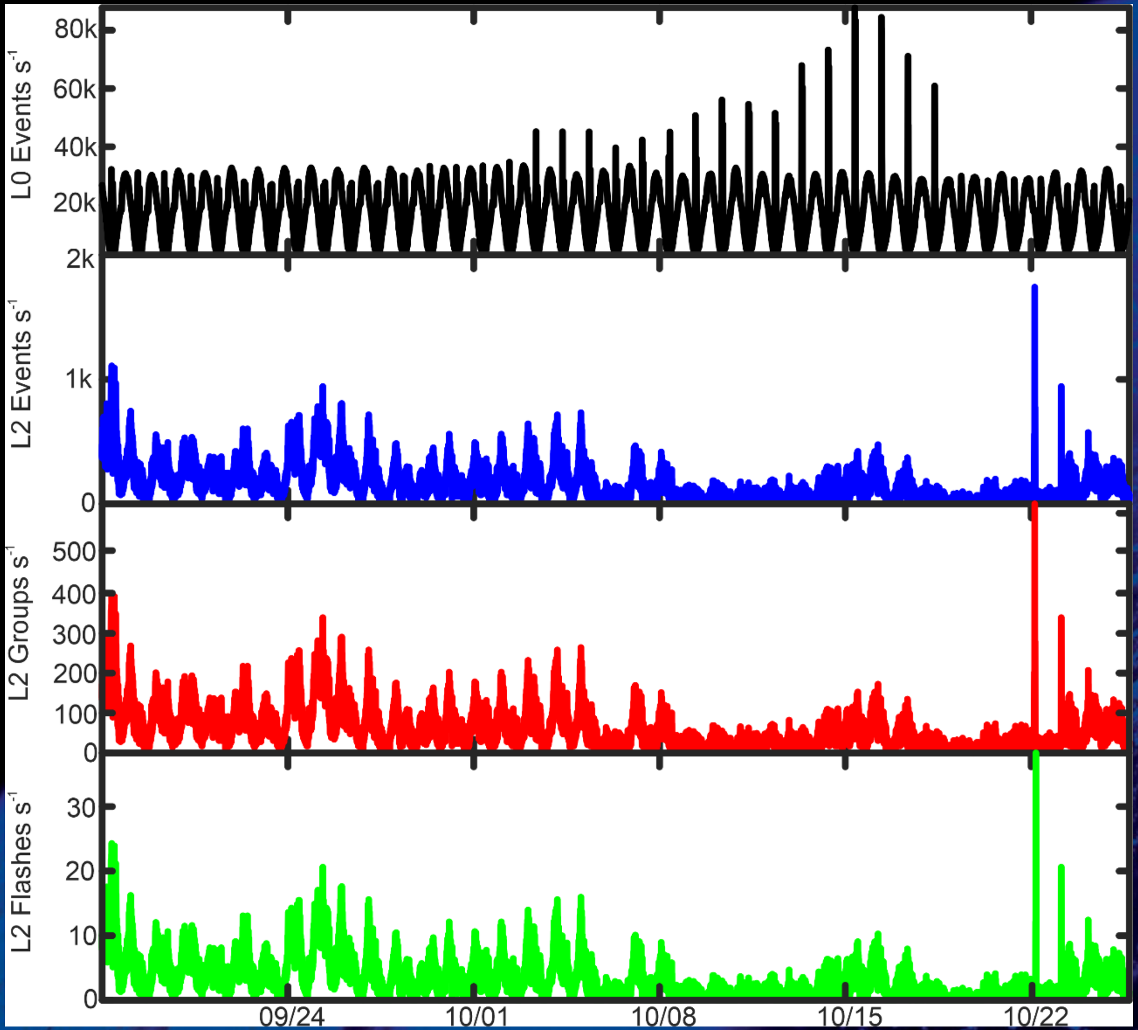
Performance Summary

MRD	Parameter	MRD Value	Performance Result			
			ValiD	LATA	INR	Mach SIT
1259	Production Mapping Accuracy	5km (= $\lvert\boldsymbol{\mu}\rvert+3\sigma < 140$ µrad)	n/a	**4.0 km**	**133 µrad**	n/a
1260	Product Measurement Range	(0-41900 evts/s, 0-8170 grps/s, 0-600 flsh/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%**	n/a	n/a	n/a
1264	Product Measurement Precision	5% (flash FAR) [also MRD 639 which states same 5% value]	**13%** (inferred to 5%)	n/a	n/a	n/a
2112	Product Time Tag	GOES-R system shall time tag product observations	n/a	**-0.8 ms**	n/a	n/a

*LCFA = Lightning Cluster Filter Algorithm.

GLM-18 LCFA Peak Rate Spec (Mach/USRA)



- **Algorithm did not crash during test period ~80k events/sec**
- **The LCFA continued to process the filtered events into groups and flashes**
- **No cases were found where the algorithm crashed in the latest GLM-18 files**

Flash DE Performance Summary

(GLM-18 vs Combined Ground Networks; ±1 sec window; VaLiD tool)

Period (2023)	Flash DE	Flash DE (day)	Flash DE (night)
Jan	0.86	0.85	0.87
Feb	0.84	0.84	0.86
Mar	0.82	0.79	0.84
Apr	0.81	0.79	0.83
May	0.79	0.76	0.83
Jun	0.78	0.72	0.81
Jul	0.76	0.71	0.80
Aug	0.76	0.70	0.80
Sep	0.76	0.72	0.80
Jan-Sep	**0.81**	**0.80**	**0.84**

Flash FAR Performance Summary

(GLM-18 vs Combined Ground Networks; ±10 min window; VaLiD tool)

Period (2023)	Flash FAR	Flash FAR (day)	Flash FAR (night)
Jan	0.09	0.05	0.08
Feb	0.08	0.05	0.05
Mar	0.08	0.05	0.02
Apr	0.08	0.05	0.05
May	0.06	0.03	0.02
Jun	0.07	0.03	0.02
Jul	0.11	0.06	0.06
Aug	0.07	0.02	0.02
Sep	0.05	0.02	0.02
Jan-Sep	**0.13**	**0.08**	**0.11**

Poor Ref Network DE over ocean unfairly amplifies GLM FAR.

Timing/Location Consistency (Virts/UAH)

GLM-18 vs. ENGLN and GLD360

Period	Peak Location Offset (km)	Peak Timing Offset (ms)
Nov 2022	3.8 km	-0.8 ms
Dec 2022	3.6 km	-0.8 ms
Jan 2023	3.3 km	-0.8 ms
Feb 2023	3.4 km	-0.8 ms
Mar 2023	3.6 km	-0.8 ms
Apr 2023	3.8 km	-0.8 ms
May 2023	3.9 km	-0.8 ms
Jun 2023	4.3 km	-0.7 ms
Jul 2023	4.0 km	-0.8 ms
Aug 2023	3.9 km	-0.8 ms
Sep 2023	3.8 km	-0.8 ms
Oct 1-21, 2023	4.0 km	-0.8 ms
Nov 2022 – Oct 21, 2023	**3.8 km**	**-0.8 ms**

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Analysis Period for Full Validation

31 Oct 2022 GLM-18 PS-PVR PROVISIONAL

08 Nov 2022 G18 GLM CDRL79 Rev F (ADR1291) via PR.09.08.38

09 Nov 2022 Acceptable start time for reasonable analyses

01 Sep 2023 START TIME FOR OPTIMAL ANALYSES

31 Oct 2023 END TIME (integration of PS-PVR slides begin)

08 Nov 2023 GLM-18 PS-PVR FULL

Post-Launch Product Tests

Test ID	Abbreviated Test Titles for GLM
PLPT-GLM-001	Validate DE/FAR using med/long-range networks (e.g., NLDN, EN, GLD360)
PLPT-GLM-002	Validate DE/FAR using short-range networks (e.g., LMAs)
PLPT-GLM-003	Validate Storm DE and Storm FAR using very long-range systems (WWLLN, NEXRAD)
PLPT-GLM-004	Validate DE/FAR using very short-range optical systems (FEGS)
PLPT-GLM-005	Validate DE/FAR using orbit-based optical systems (e.g., ISS/LIS)
PLPT-GLM-006*	Validate DE/FAR using ground-based E-field networks (e.g. HAMMA, LIP)
PLPT-GLM-009	Validate L1b-L2 Cluster/Filter by comparing w/Spec (i.e. Mach) code
PLPT-GLM-010	Validate L0-L1b Filter Algorithms by comparing w/Spec (i.e. Mach) code
PLPT-GLM-011	Validate GLM INR w/comparisons to well-located ground points
PLPT-GLM-012	Validate GLM BG DCC radiances with trending & comparisons
PLPT-GLM-013	Validate GLM Flash Energies with trending & comparisons

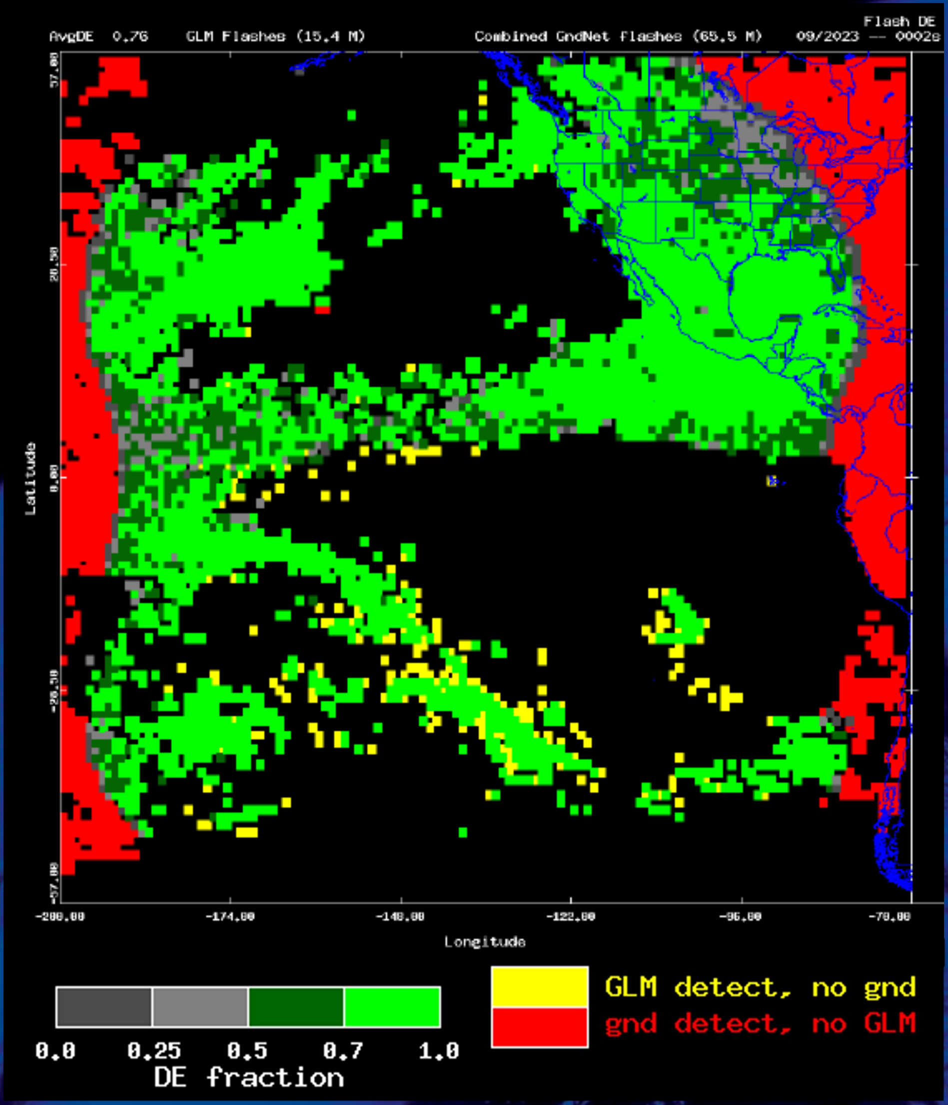
*PLPT covered by LMA analyses

Full test plans and procedures are given in the GLM Readiness, Implementation, and Management Plan (RIMP v2.0; 410-R-RIMP-0313)

Primary PLPT Tools

Item	Tool	Description	Code Language	Developer
1	VaLiD	Validate Lightning Data tool performs shallow/deep dives of GLM data using wide range of ground-based datasets discussed in RIMP.	C	Bateman/UAH
2	Cluster/Filter	In-house code for L0-L1b and L1b-L2 processing	Matlab	Mach/USRA
3	HUDAT	Huntsville Area Marx Meter Array (HAMMA) User Data Analysis Technology with emphasis on lightning energy/physics.	IDL	Bitzer/UAH
4	STROKE	STorm Retrievals frOm KSC E-Fields examines ground-based electric fields, lightning field changes, and the charges deposited by lightning in KSC, Florida.	IDL	Koshak/MSFC
5	INR/Parallax	Validates GLM INR with comparisons to well-located ground points and employs GLM background images & lightning, ABI background images, and Laser beacon data	IDL	Buechler/UAH
6	TT/DCC	Trending Tools for long-term trending of Deep Convective Clouds.	IDL	Buechler/UAH
7	TT/Lightning	Trending Tools for long-term trending of lightning counts, flash duration, and lightning energy.	IDL, WL	Buechler/UAH Koshak/MSFC
8	LMT	24/7 Lightning Monitoring Tool (aka "Product Monitor") that alerts of problematic GLM performance	TBD	Product Area Lead
9	CompareLLS	Compare Lightning Location System tool performs shallow/deep dives of GLM data using wide range of ground-based datasets discussed in RIMP.	Matlab	Cummins, UA
10	XLMA	X Lightning Mapping Array tool for making standard 4-D plots of flashes.	IDL	Krehbiel & Rison of NMT
11	lmatools	Analyzes LMA data [sort VHF source data into flashes; calculate flash areas, volumes, and channel lengths; produce gridded products; time series statistics of flash rate and size data; simulate LMA performance].	Python	Bruning/TTU
12	FEGST	Fly's Eye GLM Simulator Tool: Data acquisition, display, storage software, and s/w for analyzing FEGS data & inter-comparing it with other lightning optical datasets (e.g. GLM, ISS/LIS).	IDL	Quick/MSFC
13	ADTs	Ancillary Dataset Tools will be developed for processing datasets such as ABI, NEXRAD, SEVERI, WWLLN; some of these tools will be piggybacked to VaLiD.	Matlab & McIDas scripts	Mach/USRA Bateman/UAH
14	SITs	Specialized Impromptu Tools written “on-the-fly” to handle any analyses that are needed, but that were unexpected.	C, IDL, Matlab, WL	Cal/Val Team
15	LATA	Location And Time Accuracy (LATA) Tool: Produces a variety of plots/histograms that characterize the overall location/time accuracy of GLM flashes/groups/events.	Matlab	Virts/UAH

GLM-18 DE (Bateman/UAH)
(Sep 2023)

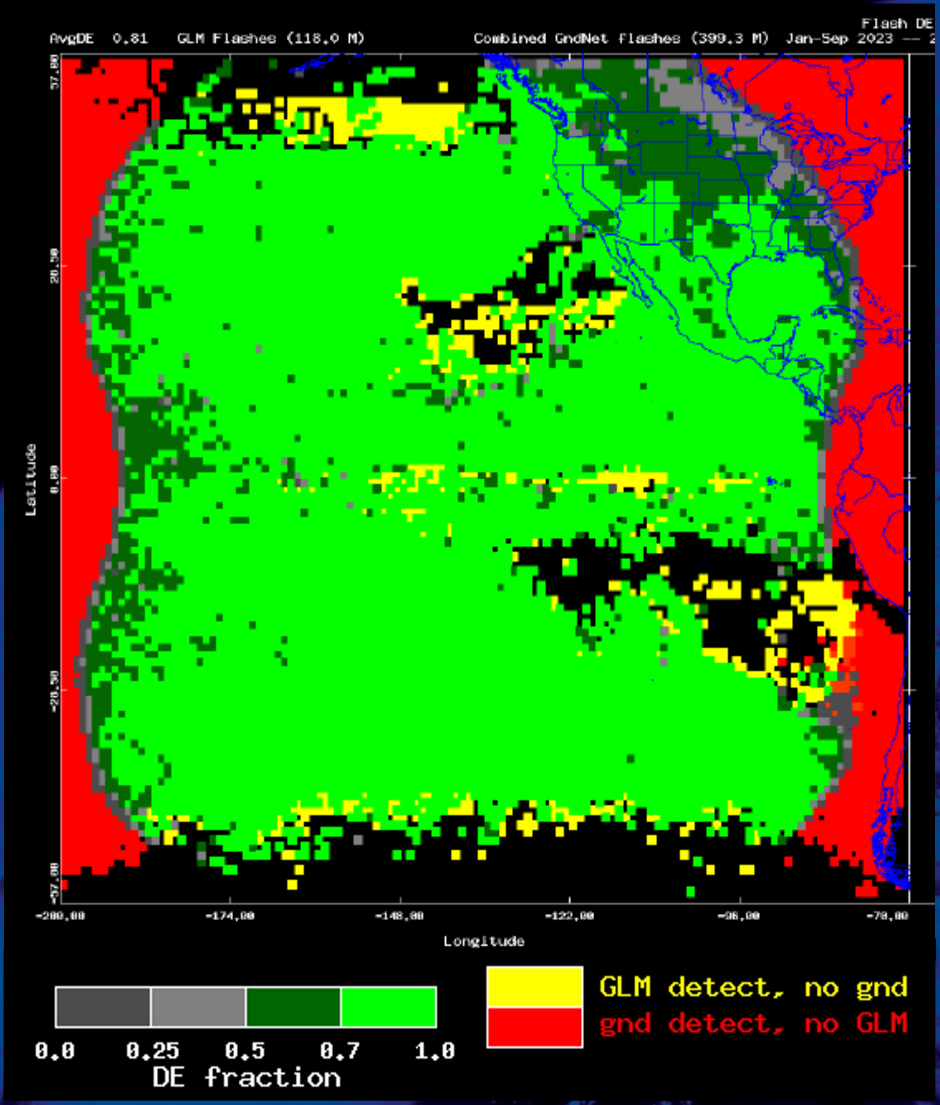


PASSED

PLPT-GLM-001/003

- GLM-18 compared to clustered ground networks
- **0.76** DE bulk value across FOV
- Optimal ±1 sec time window

GLM-18 DE (Bateman/UAH)
(Jan - Sep 2023)

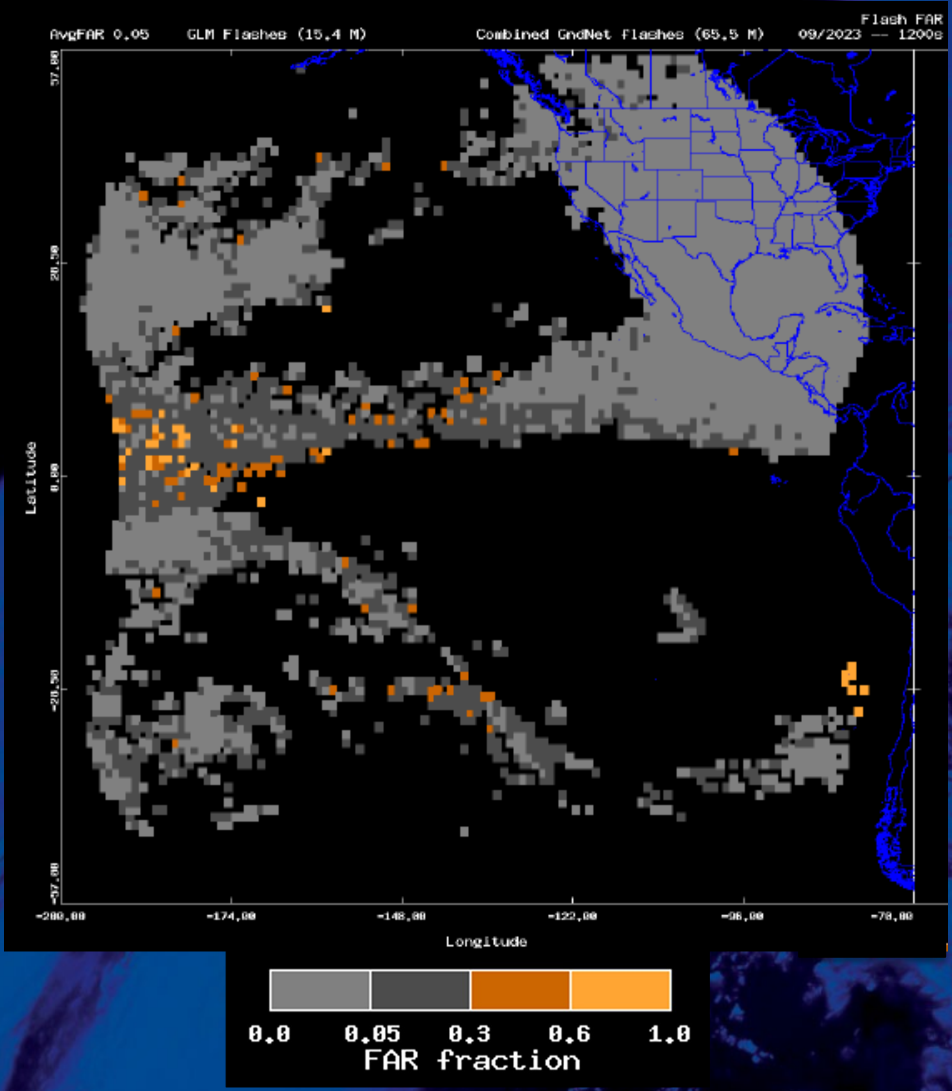


PASSED

PLPT-GLM-001/003

- GLM-18 compared to clustered ground networks
- **0.81** DE bulk value across FOV
- Optimal ±1 sec time window

GLM-18 FAR (Bateman/UAH)
(Sep 2023)



PASSED

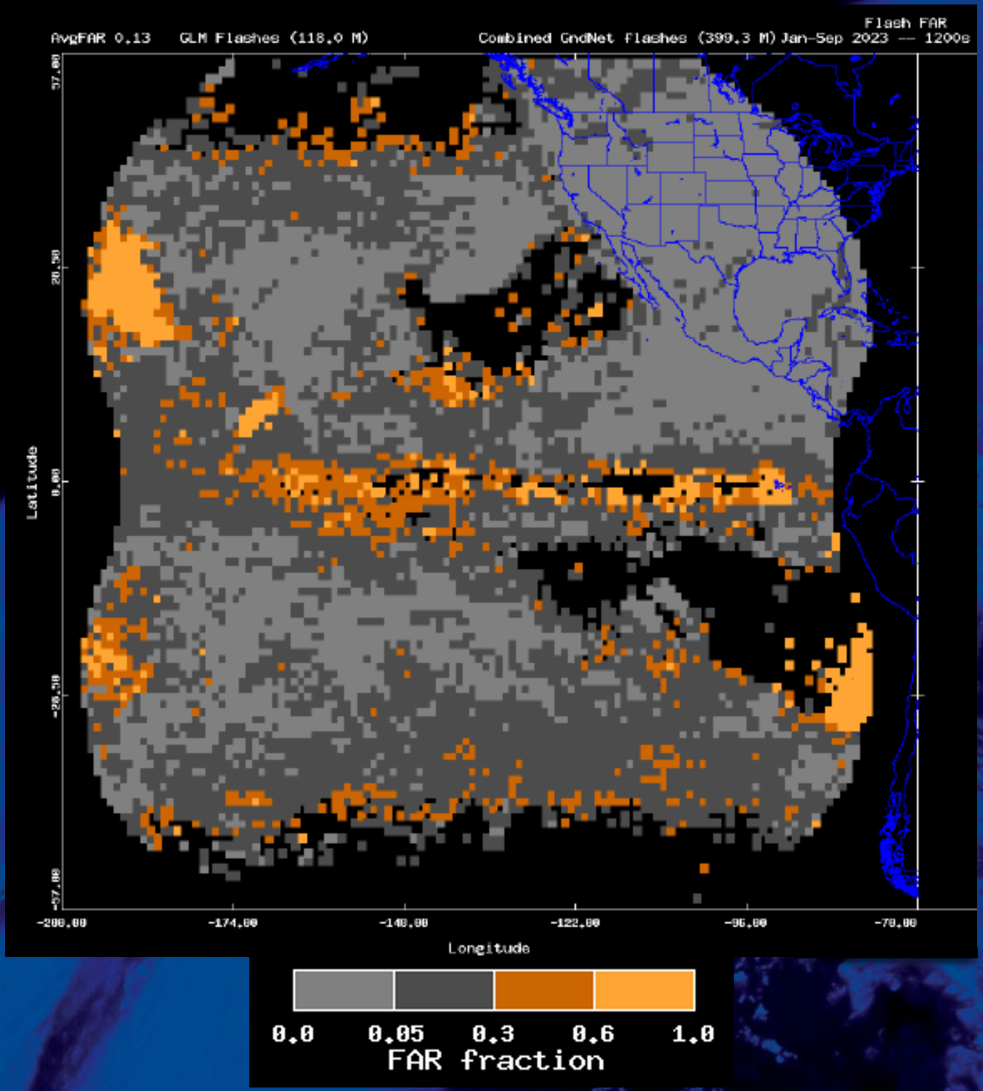
PLPT-GLM-001/003

- GLM-18 compared to clustered ground networks
- **0.05** FAR bulk value across FOV
- Optimal ±10 min time window

GLM-18 FAR (Bateman/UAH)
(Jan - Sep 2023)

PASSED

PLPT-GLM-001/003



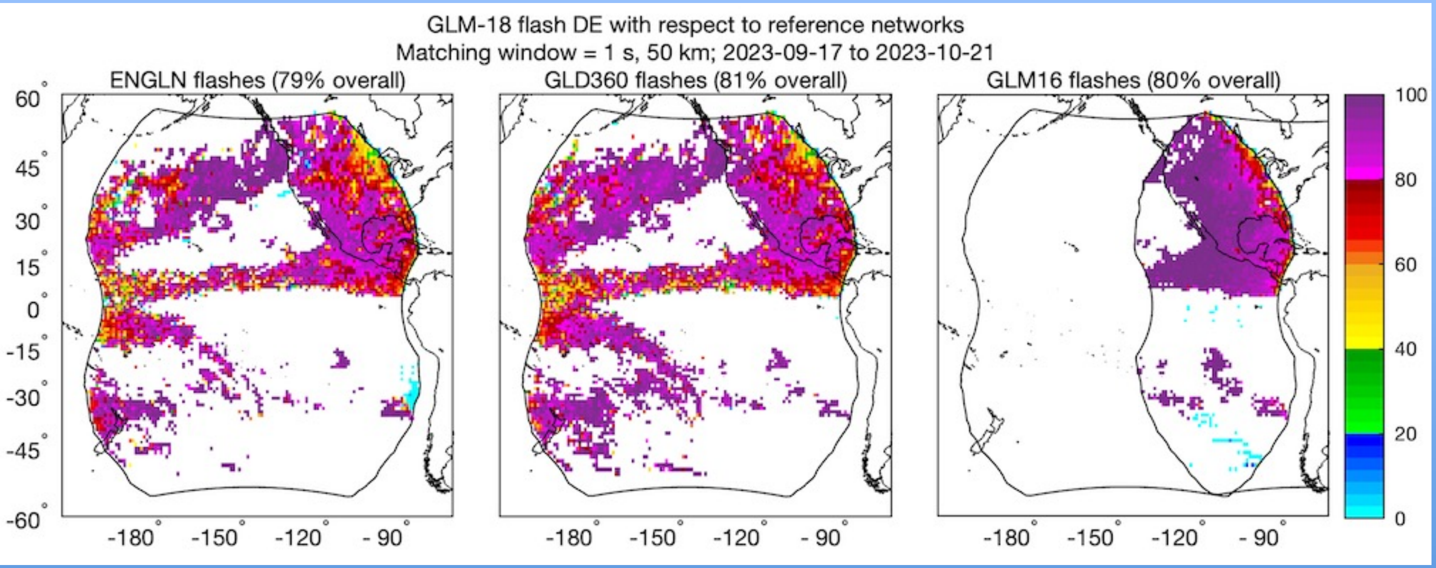
- GLM-18 compared to clustered ground networks
- **0.13** FAR bulk value across FOV
    - **Small Ref Network DE over Ocean Unfairly Inflates FAR**
- Optimal ±10 min time window

Flash Detection Efficiency (Virts/UAH)

GLM-18 vs. ENGLN, GLD360, and GLM-16

PASSED

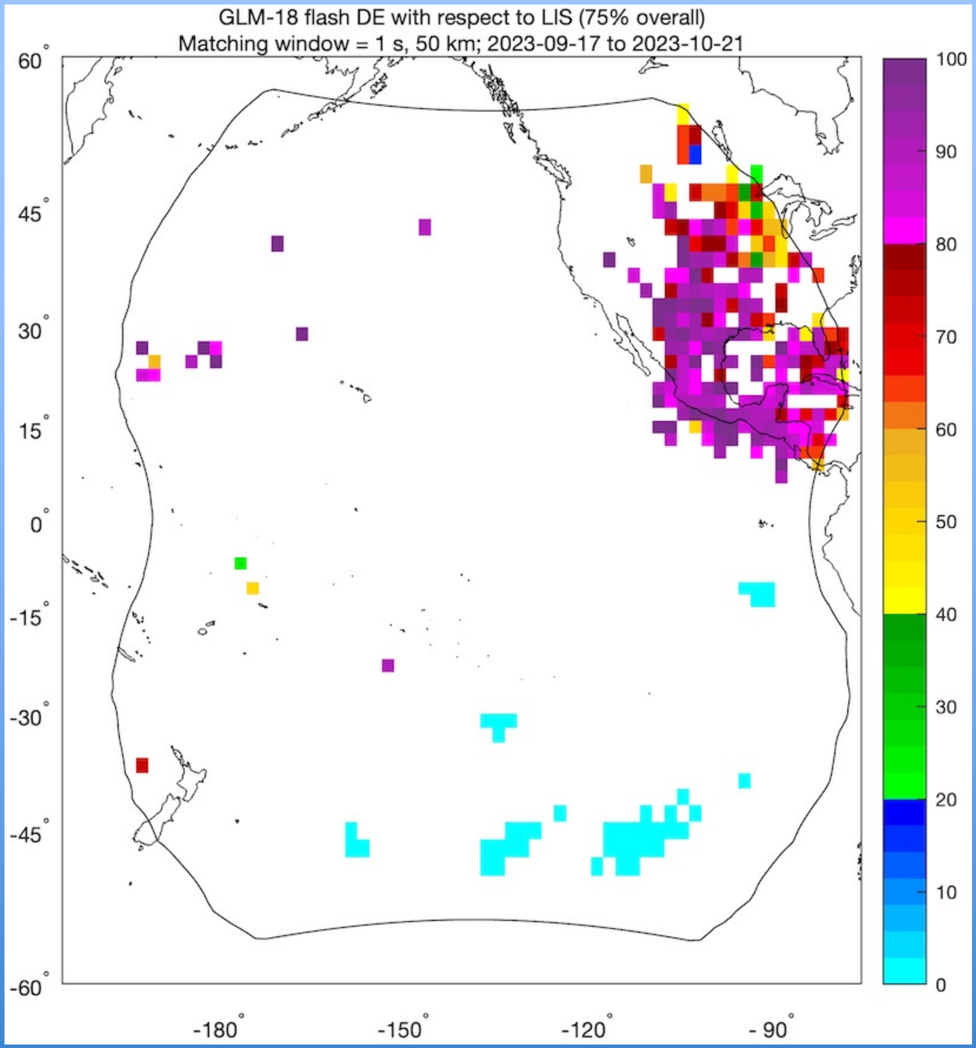
PLPT-GLM-001



- Simulations indicate temporal matching windows of ~±1 s most accurately estimate the true aggregate GLM DE
- DE vs. GLM-16 is 80% (lower near the limb)
- DE vs. ground networks is 79-81% (lower near the limb)

Flash Detection Efficiency (Virts/UAH)

GLM-18 vs. ISS LIS

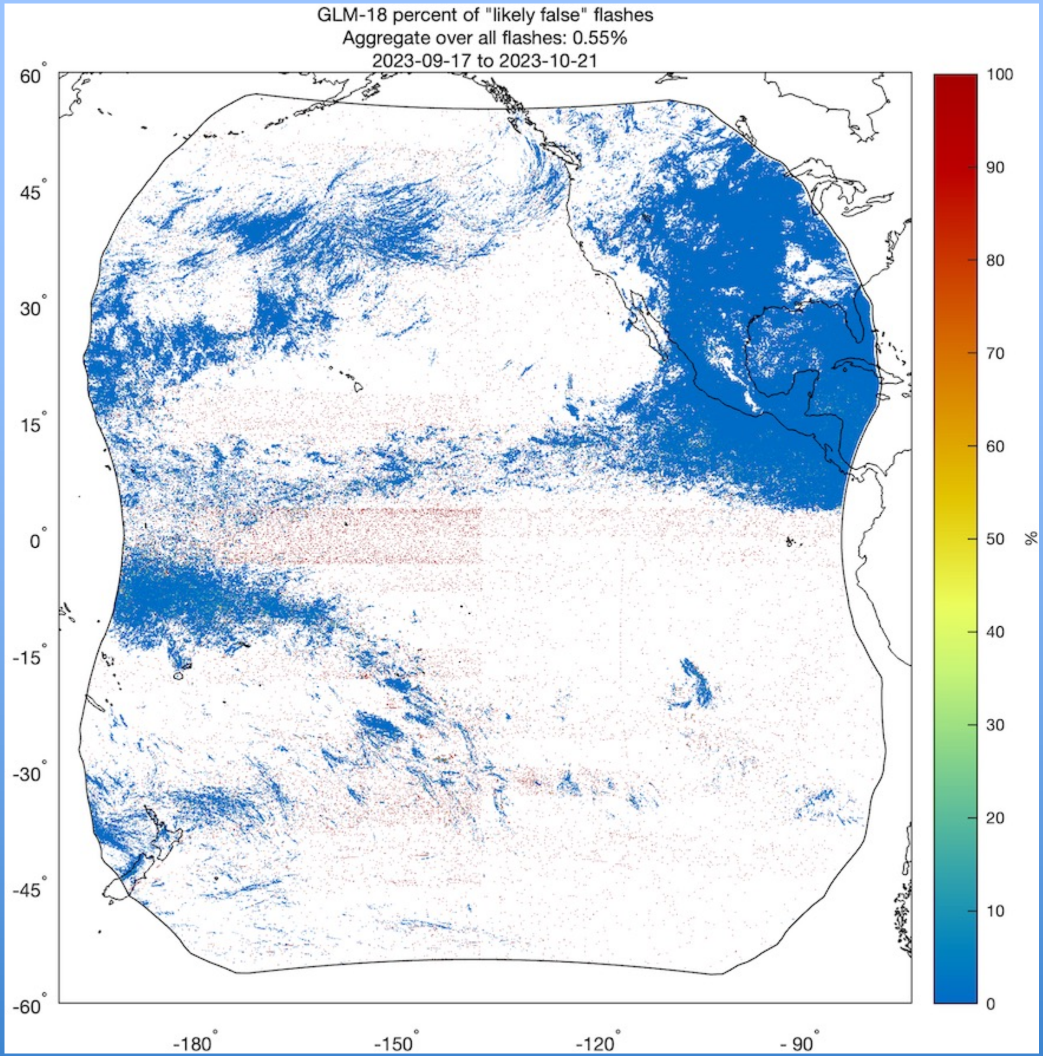


PASSED

PLPT-GLM-005

- **DE vs. ISS LIS is 75% (lower near the limb)**
- **Sample size is small (~14k) for the 5-week analysis period, but similar DE is observed for the entire provisional period**
- **DE would be higher if comparing with QC'd LIS data**

Flash False Alarm Ratio (Virts/UAH)
GLM-18 vs. ENGLN, GLD360, and GLM-16



PASSED

PLPT-GLM-001

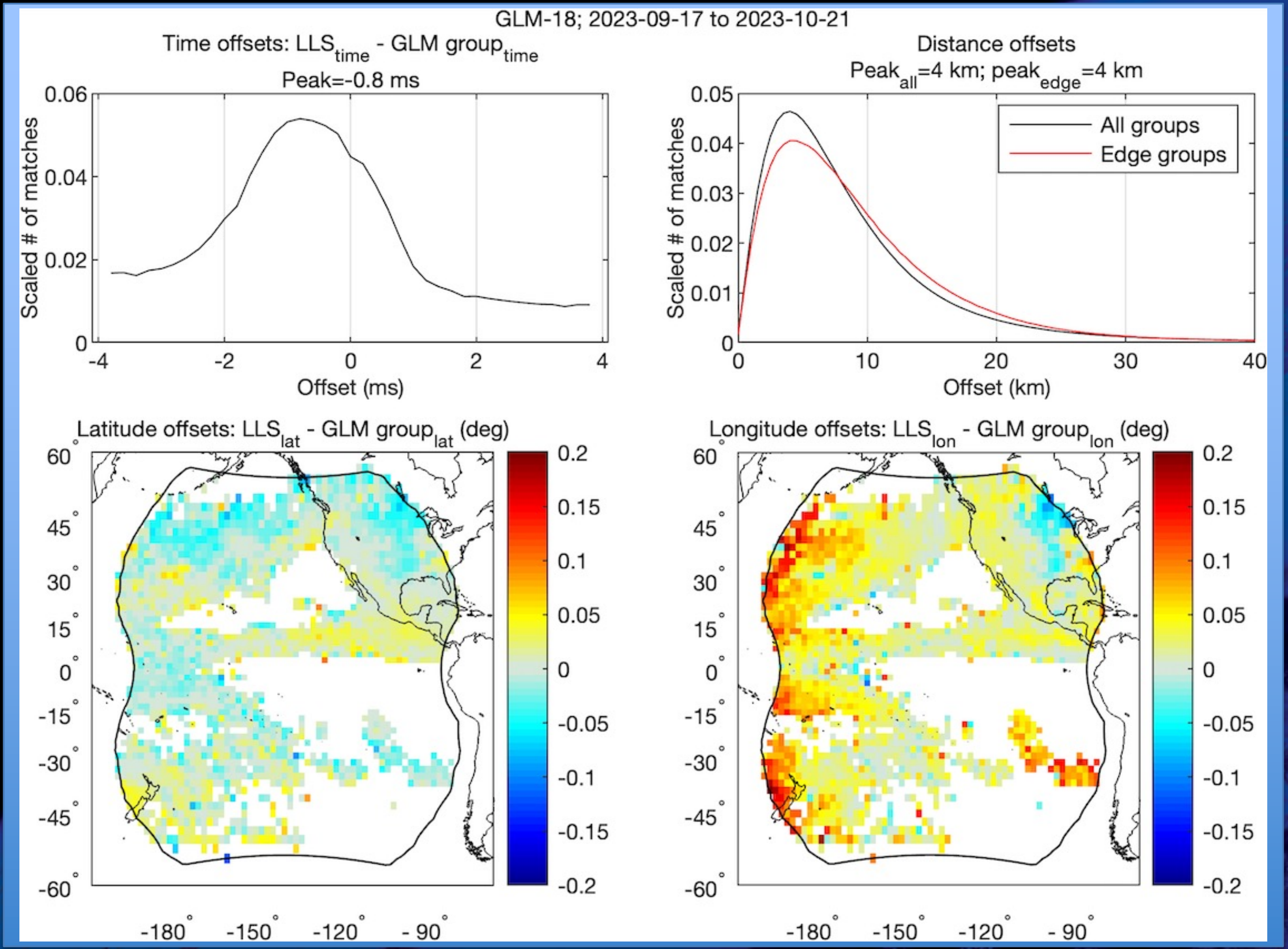
- **Simulations indicate temporal matching windows of ~minutes most accurately estimate the true aggregate GLM FAR**
- **Only 0.55% of GLM-18 flashes cannot be matched with any reference flash**
- **False alarms in grid boxes with little true lightning produce high FAR (red pixels) -> FAR is much higher when aggregating over grid boxes**

Timing/Location Accuracy (Virts/UAH)

GLM-18 vs. ENGLN and GLD360

PASSED

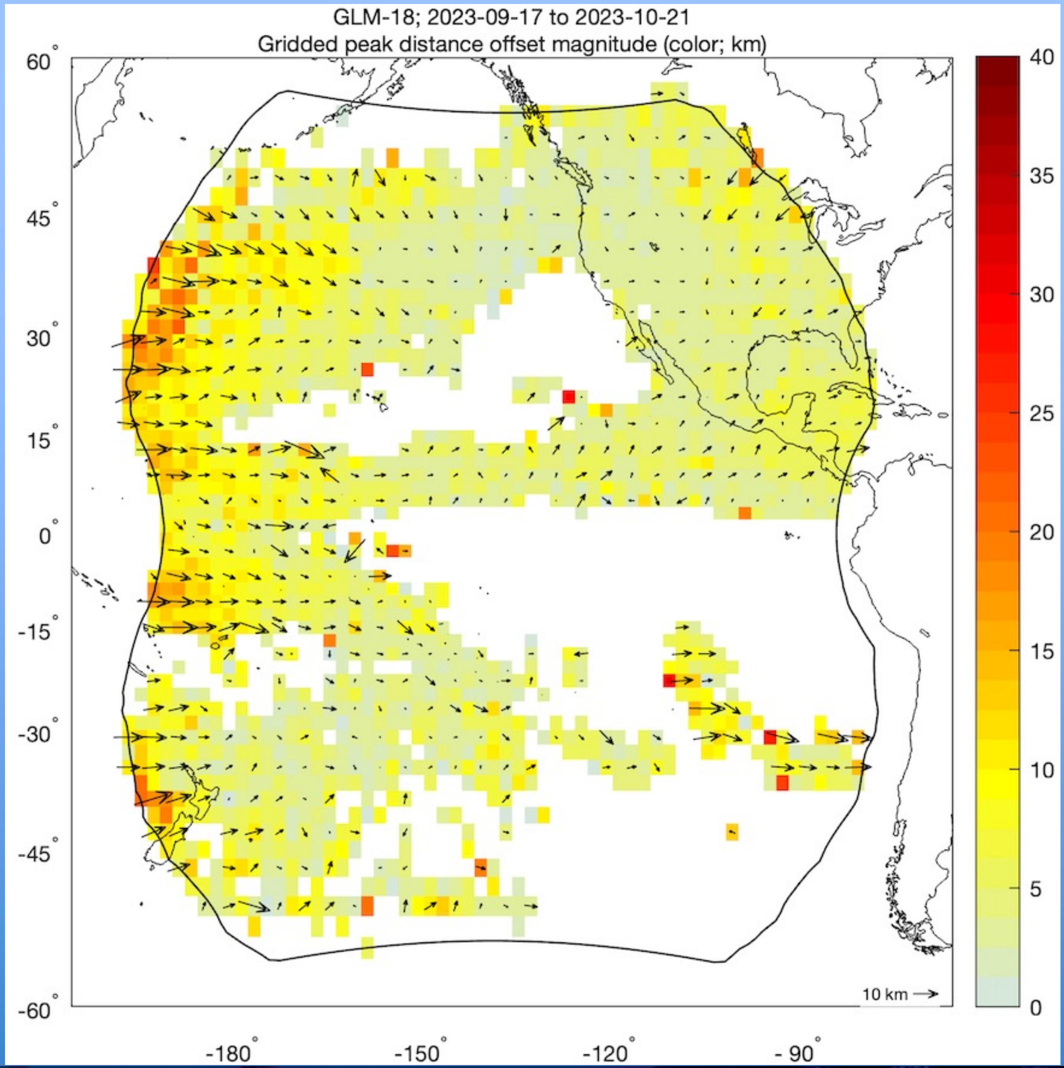
PLPT-GLM-011



- **Offsets between GLM-18 group and "best" reference match**
- **Sub-millisecond timing accuracy**
- **~Half-pixel location accuracy over most of the domain**

Location Accuracy (Virts/UAH)

GLM-18 vs. ENGLN and GLD360



PASSED

PLPT-GLM-011

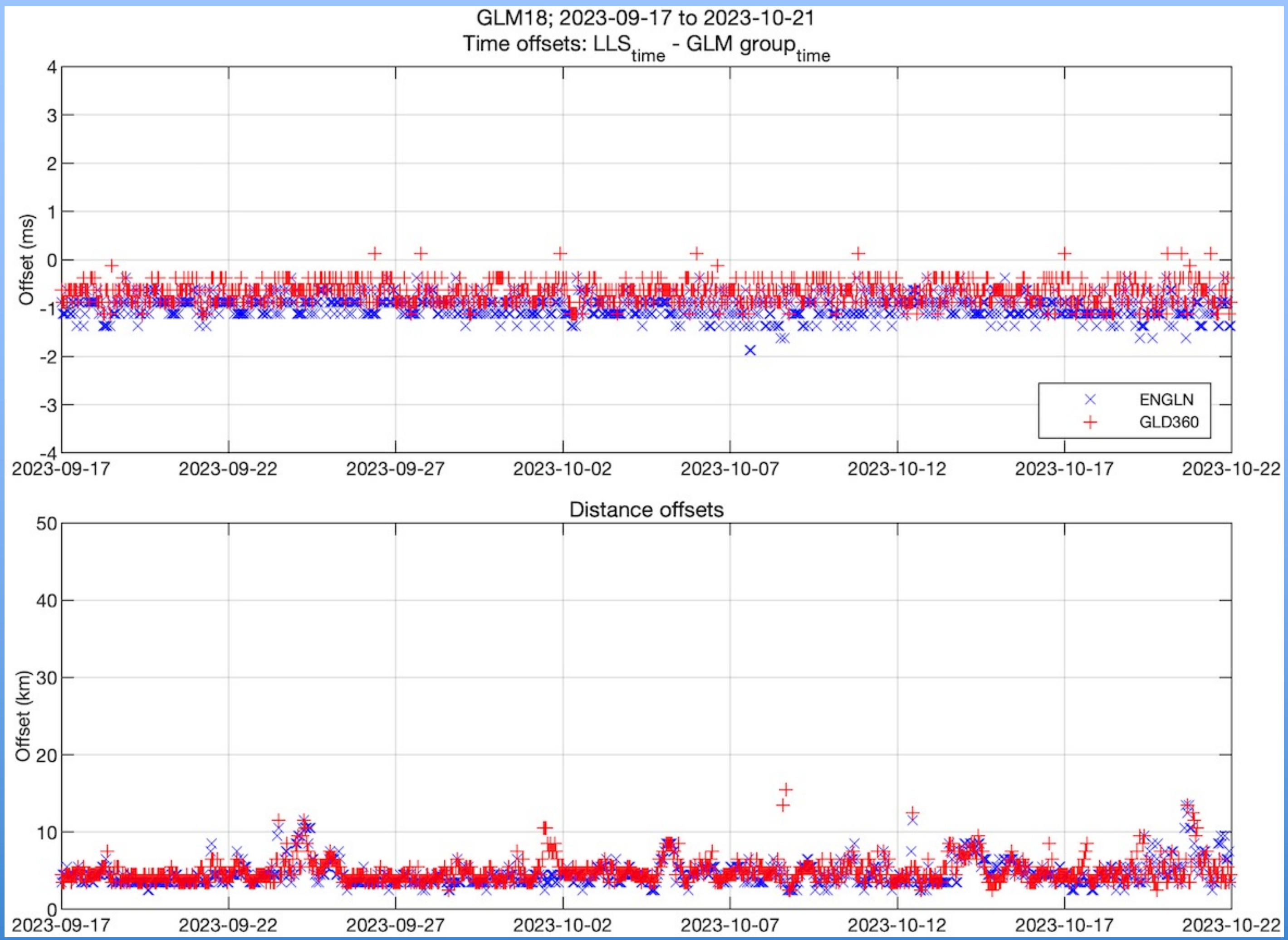
- **Vectors indicate how GLM-18 groups would need to be shifted to best match the reference networks**
- **Iterative tuning with Lockheed Martin has reduced parallax errors**
- **Largest offsets at the western limb**

Timing/Location Consistency (Virts/UAH)

GLM-18 vs. ENGLN and GLD360

PASSED

PLPT-GLM-011



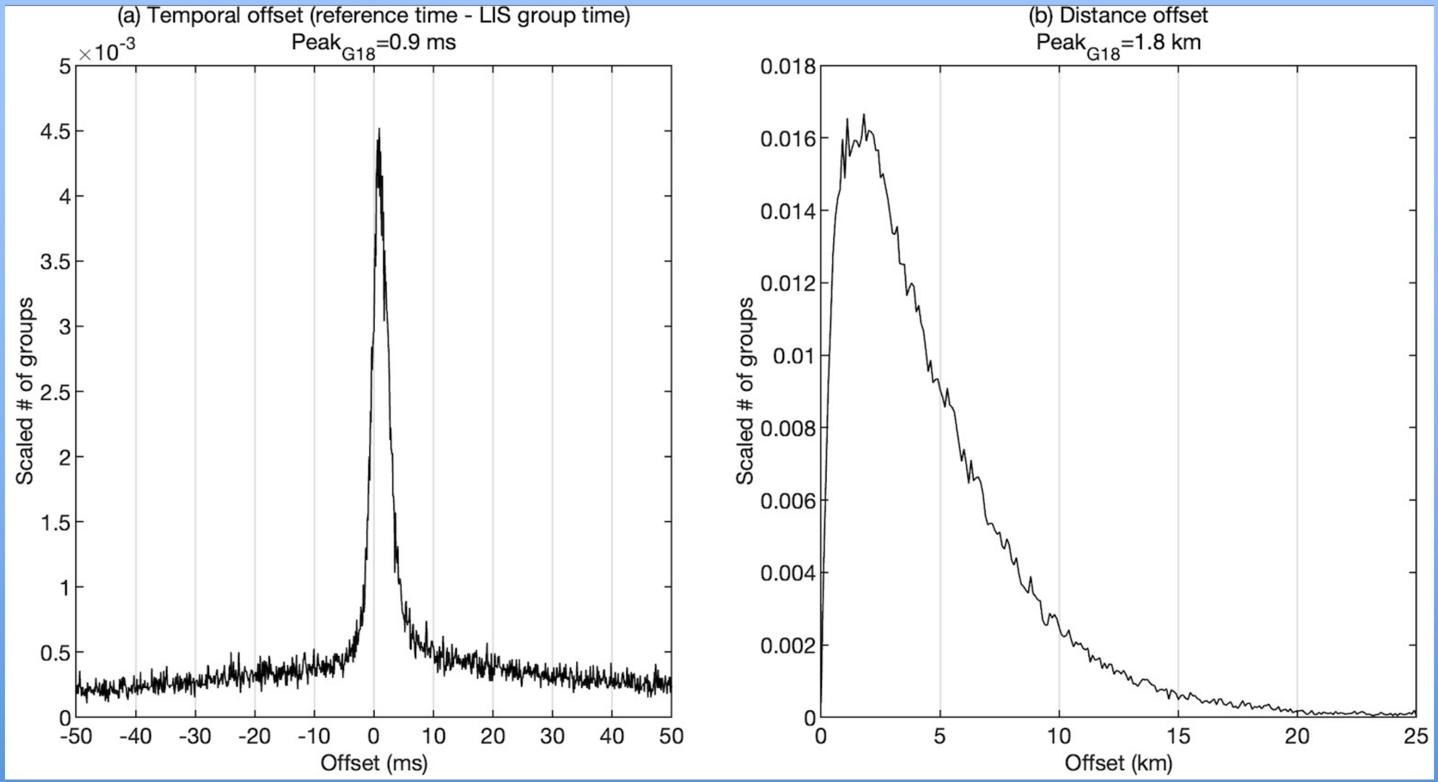
- **Hourly time series of peak time and distance offsets from the reference networks**
- **Consistent temporal and spatial accuracy over the ~1 month analysis period**
- **Standard deviation = 0.2 ms and 1.5-1.6 km**

Timing/Location Accuracy (Virts/UAH)

GLM-18 vs. ISS LIS

PASSED

PLPT-GLM-005



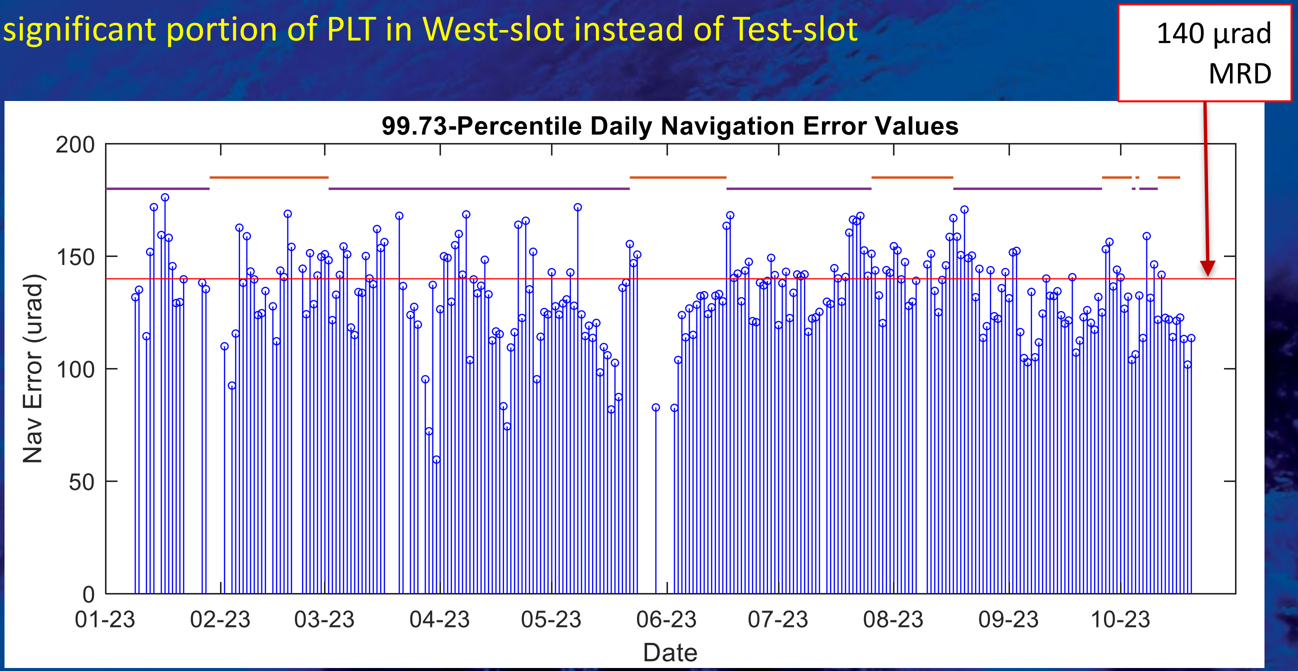
- **Sub-millisecond timing accuracy**
- **~Quarter-GLM pixel location accuracy**

INR Analyses

(OSPO and MOST INR Teams; Armstrong/MIT LL)

- IPATS total INR error (μ + 3σ values) plotted for 2023 comparing GLM background images relative to ABI Band 3 (NVIR)
- Mean navigation error (mean(daily(μ + 3σ) values) during period was 133 μrad
  - Consistent with lightning navigation
  - 37% daily navigation errors exceeded MRD product mapping accuracy requirement (140 μrad)
- IPATS indicates G18 GLM does not navigate as well as G17 GLM
  - G18 conducted significant portion of PLT in West-slot instead of Test-slot

- Primary data operations site indicated by purple (WCDAS) and orange (CBU) horizontal lines
- Exceedances independent of primary data site

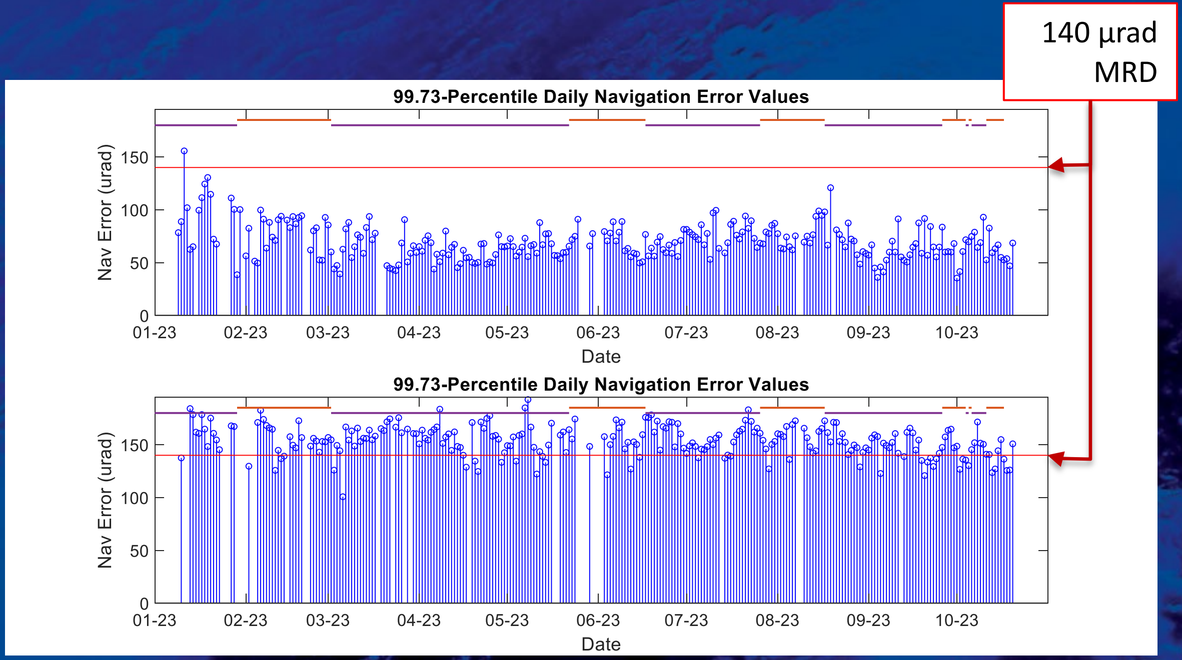


INR Analyses

(OSPO and MOST INR Teams; Armstrong/MIT LL)

- Plotted eastern (top) and western (bottom) portions of field-of-view (FOV) separately
- Eastern FOV dominated by North America
  - Region had mean navigation error of 70 µrad and one (1) MRD exceedance
  - One outlier occurred while GS processing was at risk due to on-site testing
- Western FOV dominated by small islands
  - Region had mean navigation error of 154 µrad, where 210 out of 251 daily errors violated MRD requirement

- IPATS indicates G18 GLM has very good navigate accuracy for eastern FOV, including western US
- G18 GLM navigation performance west of satellite location misses GLM data product mapping accuracy requirement



GOES-18 GLM DE (Bitzer/UAH)

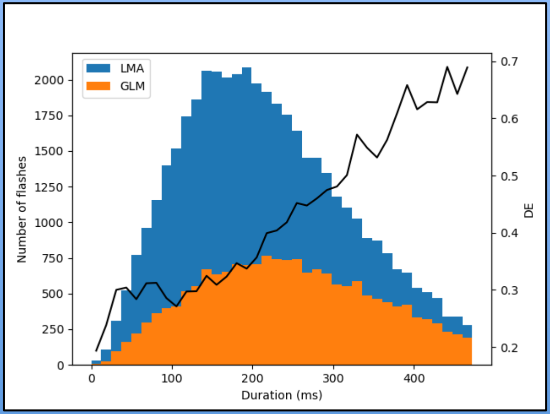
Detection Efficiency Relative to Lightning Mapping Array

PASSED

PLPT-GLM-002

- As a reference lightning data set, use the North Alabama Lightning Mapping Array (NALMA).
- Sort NALMA VHF sources into flashes, and find GLM-18 data that occurs during a flash and within the spatial footprint.
- Analysis is from selected storms in Sept-Oct 2023.

Area (km2)	Num Flashes	DE GOES-18
All	46156	0.421
> 8	31149	0.526
> 16	21436	0.595
> 32	12089	0.675
> 64	5476	0.773
> 100	2700	0.830



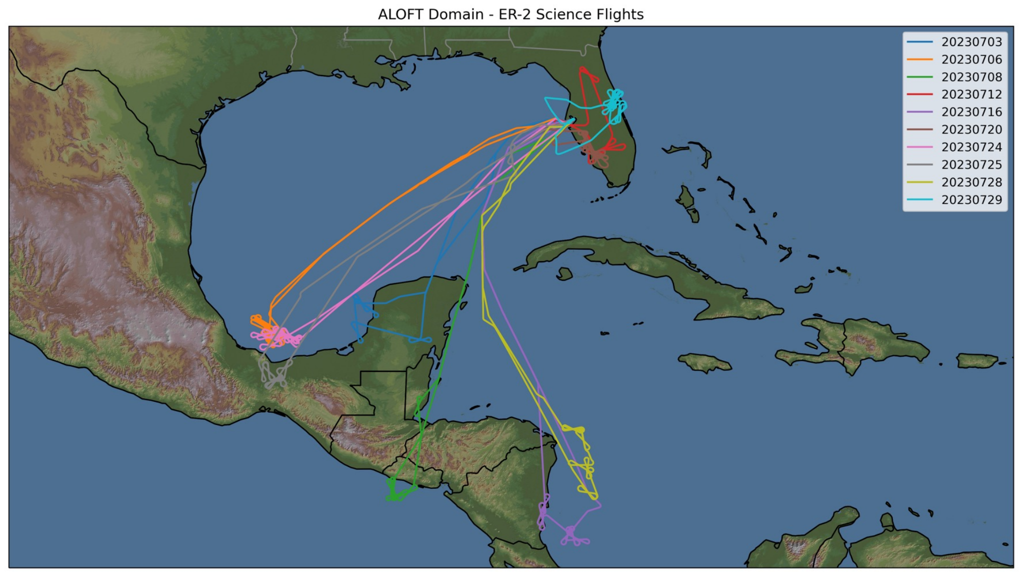
- **For flashes with an area of a pixel or larger, the GLM DE is >70%.**
- **The study area is at a large off-nadir angle.**
- **The longer in time a flash, the more likely to be detected.**

ALOFT (Lang/NASA MSFC)

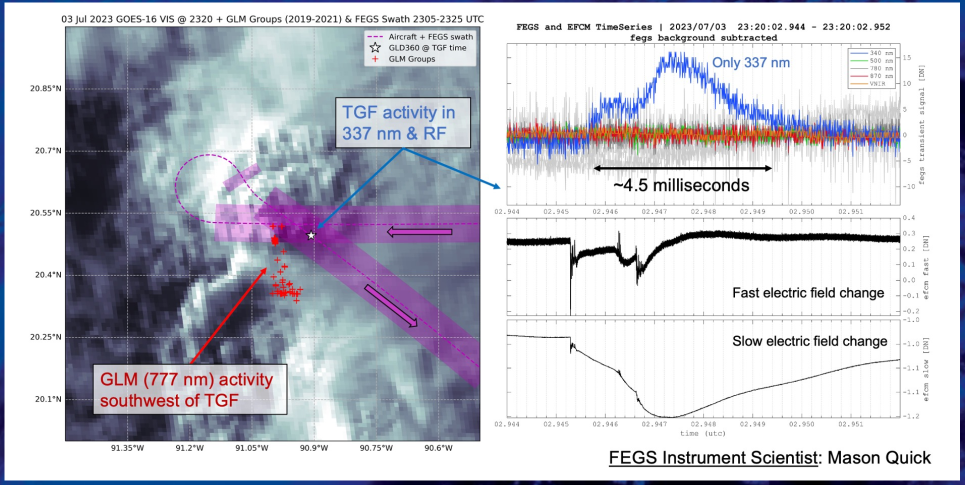
Airborne Lightning Observatory for FEGS and TGFs

PASSED

PLPT-GLM-004



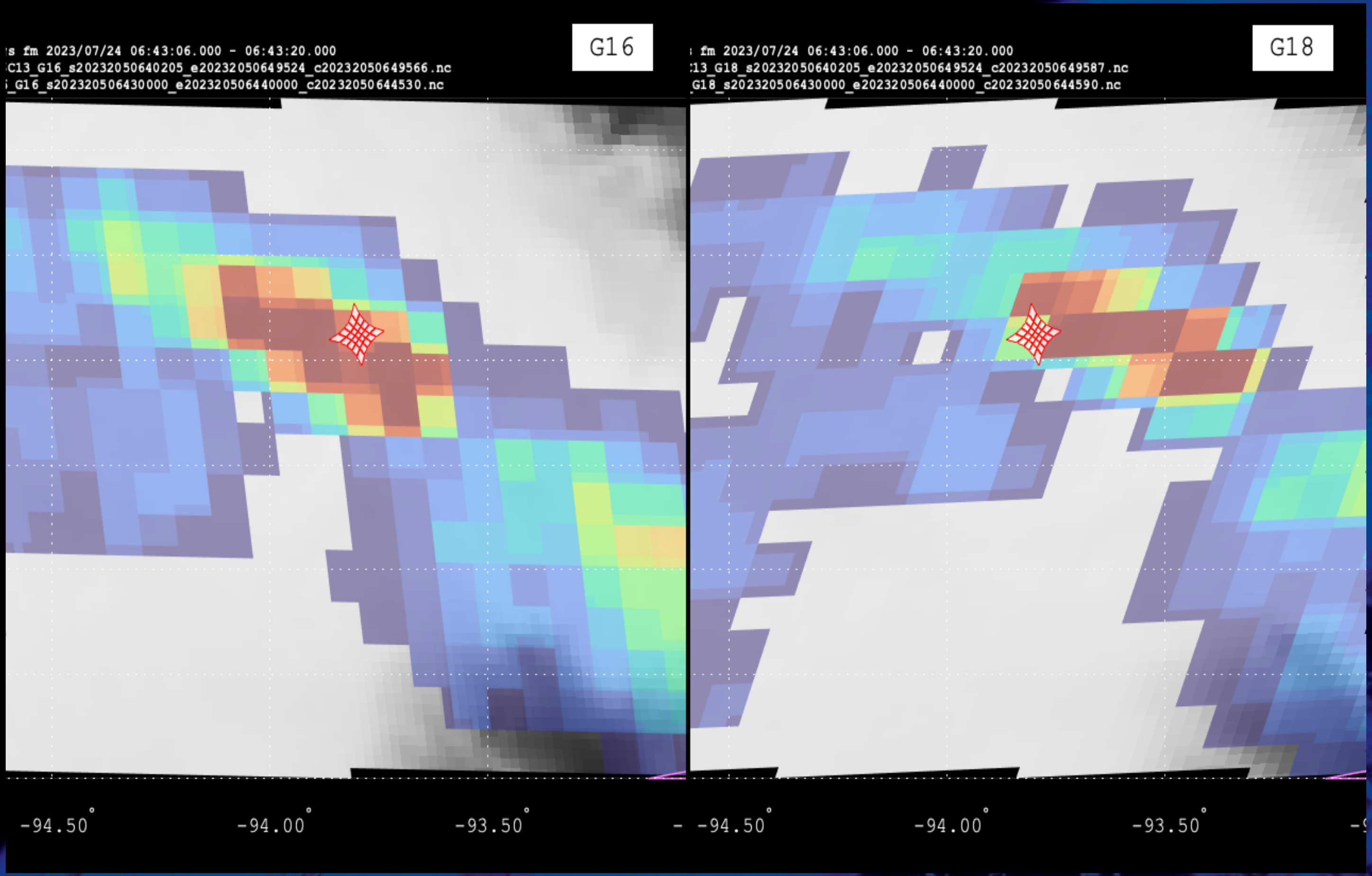
- **60+ flight hours July 2023**
- **Included FEGS, EFCM, and LIP instruments**
- **FEGS upgraded with 337- and 868-nm channels in addition to 777-nm array**



- **Repeated bowties on storms**
- **All 10 flights within stereo GLM-16/18**

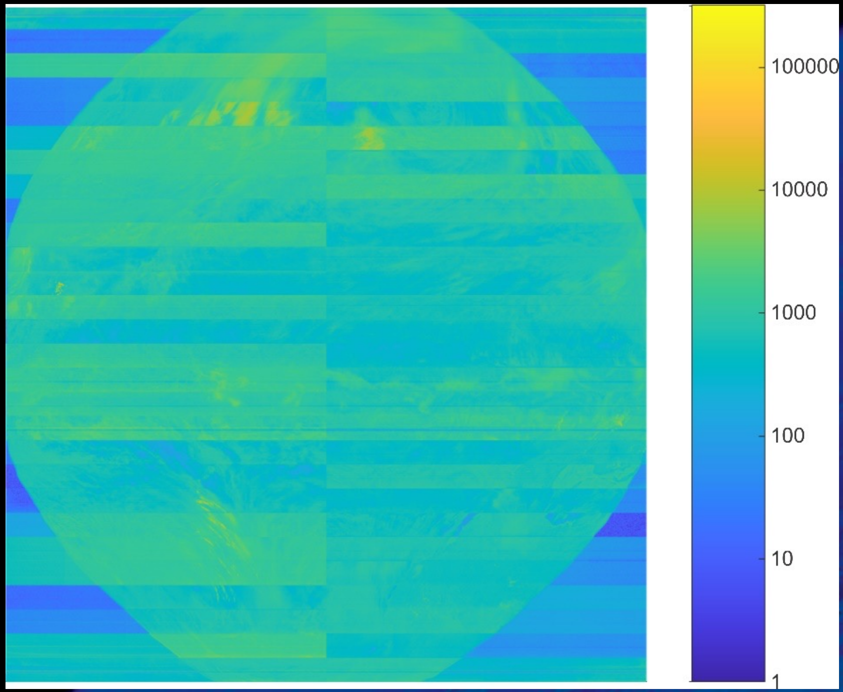
ALOFT (Quick/NASA MSFC)

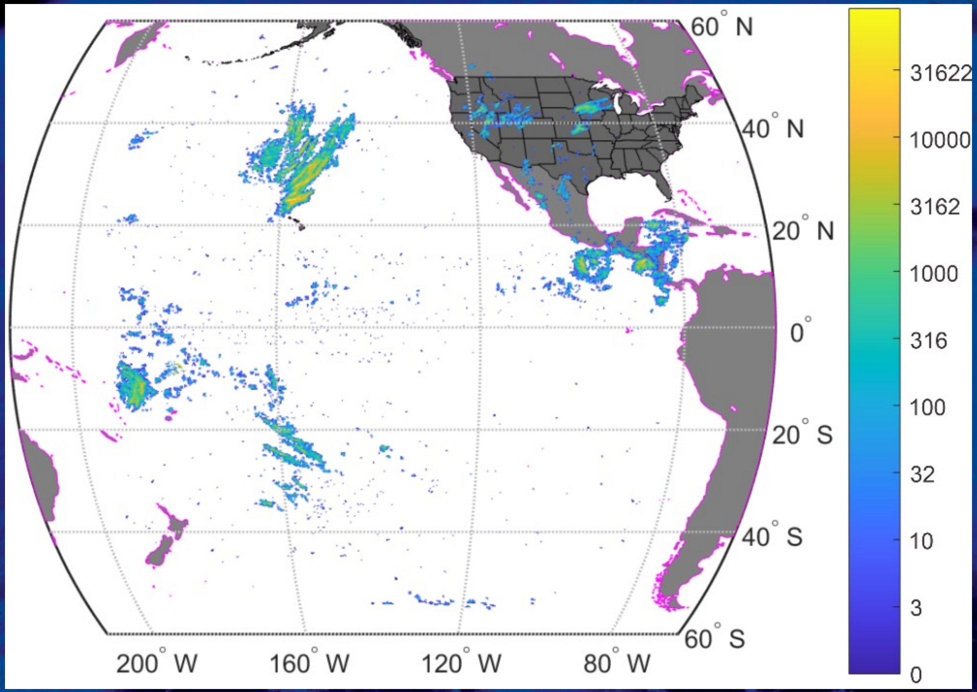
Airborne Lightning Observatory for FEGS and TGFs



- **Sample FEGS - GLM-16/18 comparison 24 July 2023**
- **GLM-16 matches-up better due to less parallax, as expected**

GLM-18 Raw (L0, Left) and Filtered (L2, Right) Events (Mach/USRA)



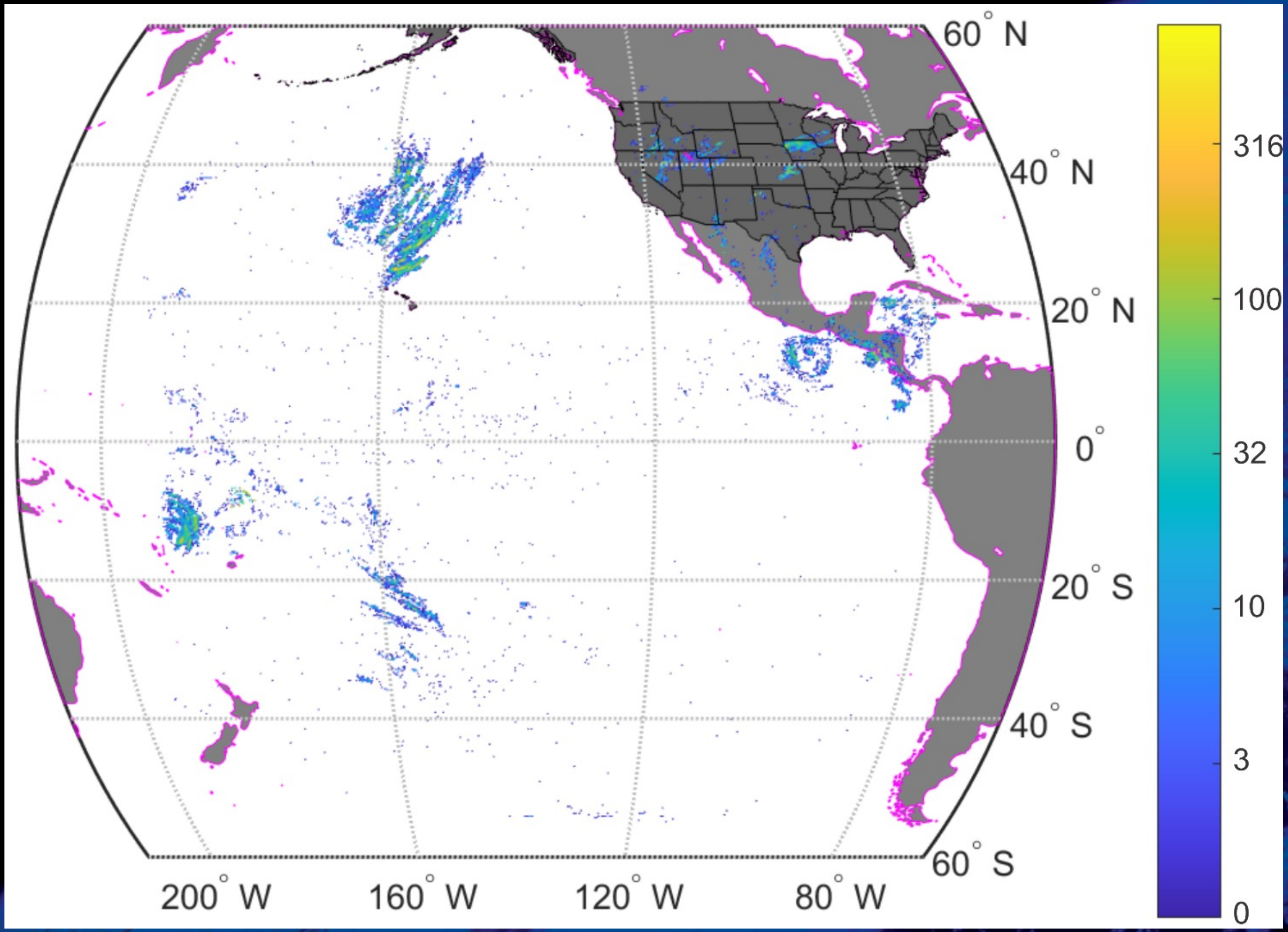


- **24 hour L0 Events 23-Oct-2023**
- **GLM-18 24 Hour L0 Event Count: 1510066479**
- **GLM-18 24 Hour L2 Event Count: 9403807**

L1b-L2 LCFA Code (Mach/USRA)

PASSED

PLPT-GLM-009

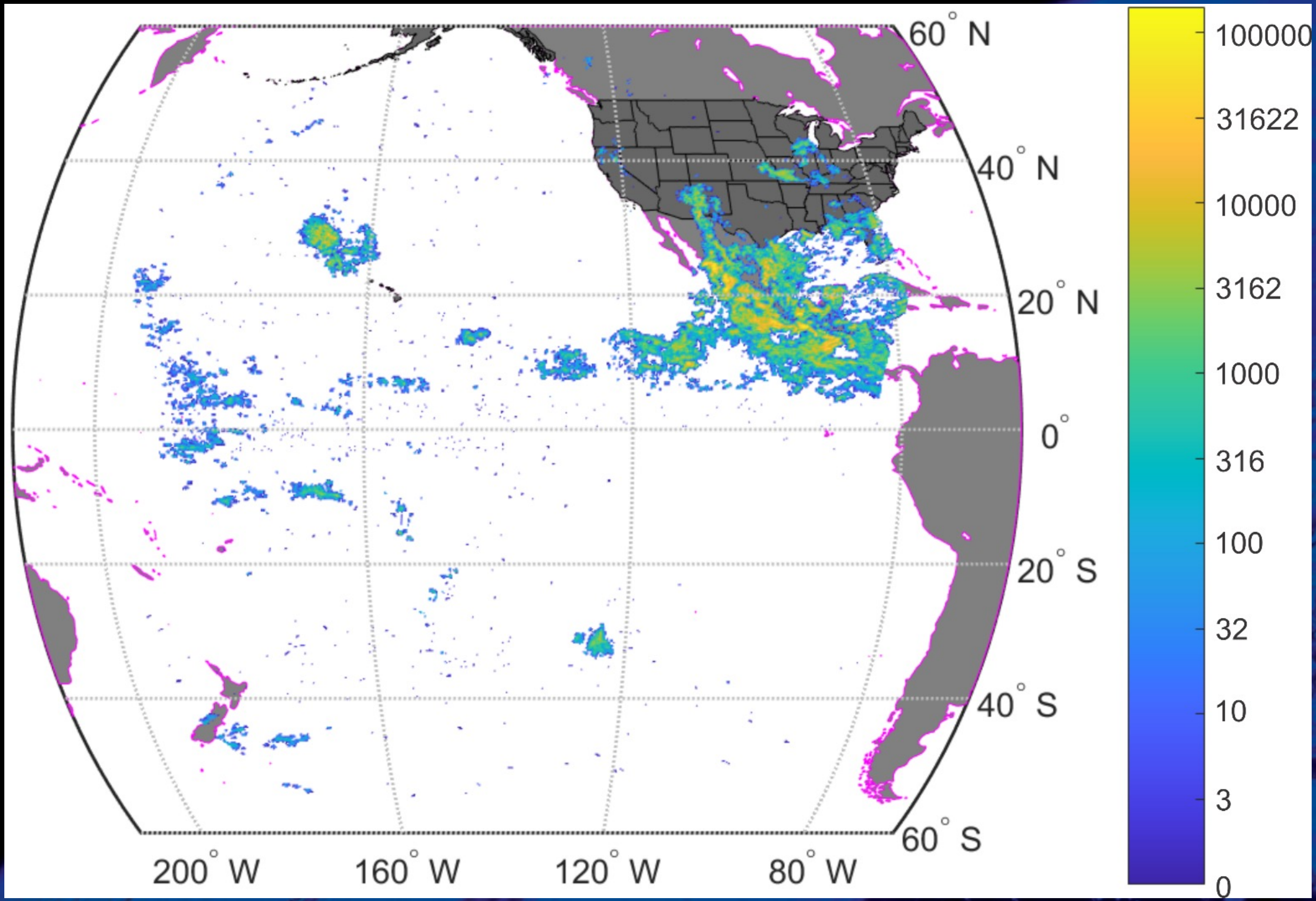


- **Example LCFA Flashes for 23-Oct-2023**
- **Clustering working well (other than artificial limits)**
- **Filtering can be improved**
- **Hurricane Otis**

L0-L1b Code (Mach/USRA)

PASSED

PLPT-GLM-010

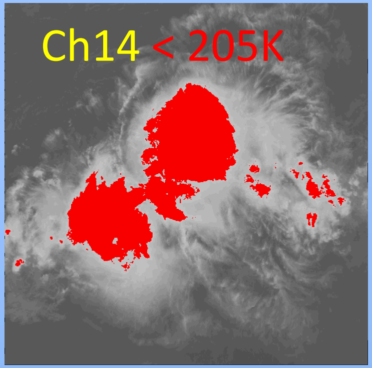


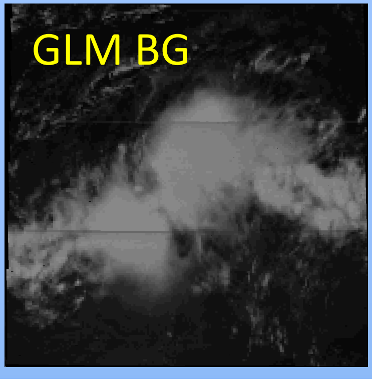
- **Example Filtered Events for 23-Oct-2023**
- **Nearly all glint/blooming artifacts removed**
- **Improvements to noise removal continue**

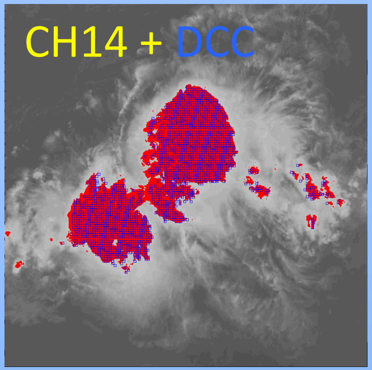
GLM-18 Deep Convective Cloud (DCC) Analysis (Buechler/UAH)

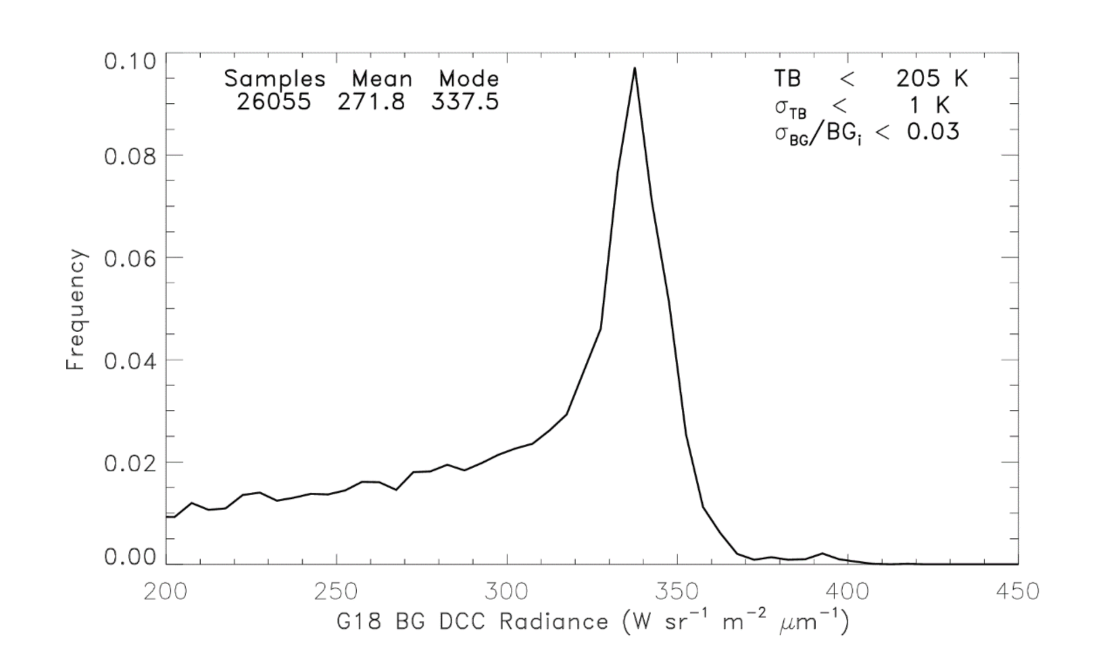
PASSED

PLPT-GLM-012





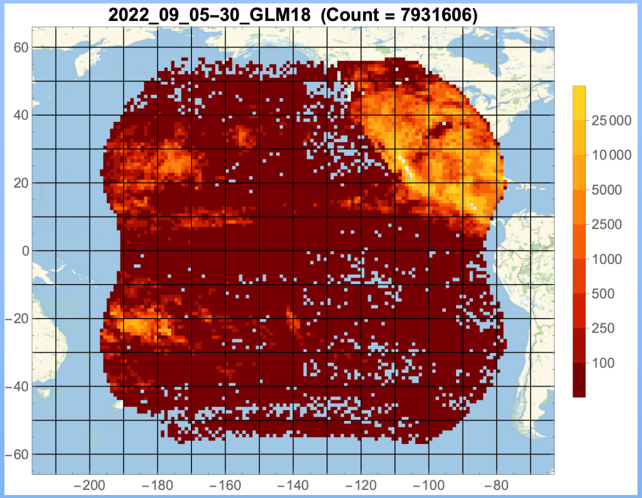


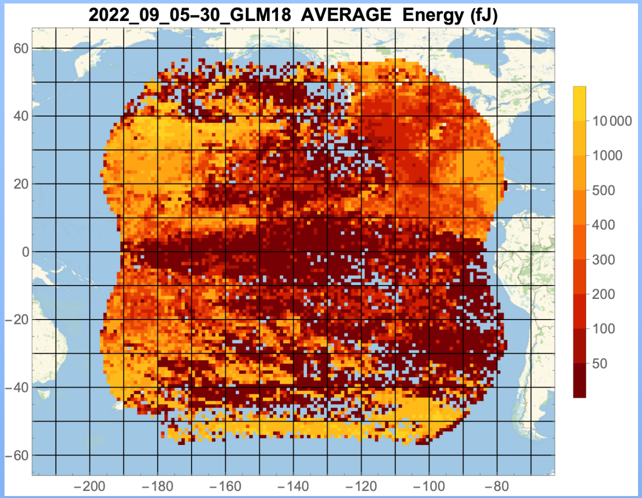


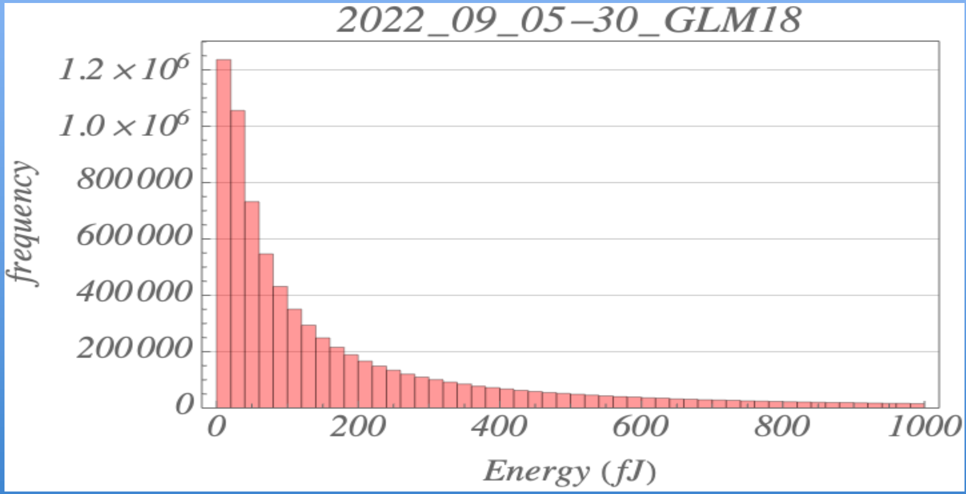
- **GLM background pixels co-located with ABI CH14 TB < 205 K**
- **Solar & Sensor Zenith Angles are < 40°**
- **Mode of distribution is 337.5 W sr^{-1} m^{-2} μm^{-1}**
- **Results consistent with theoretical expected values**
- **Values consistent with LIS**

Optical Energy (Koshak/MSFC)

Bench-marking for long-term degradation checks







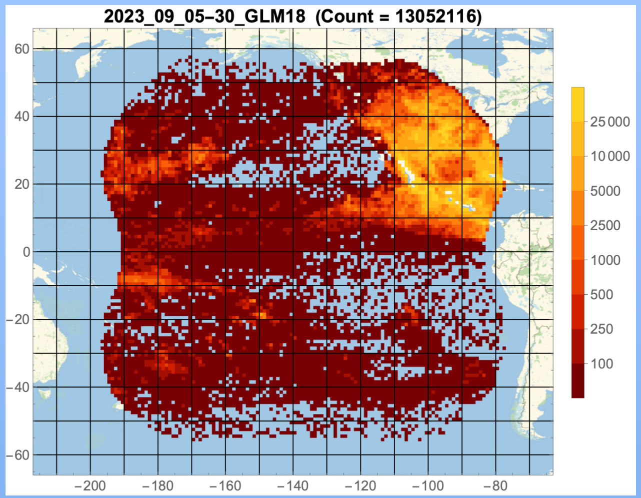
PASSED

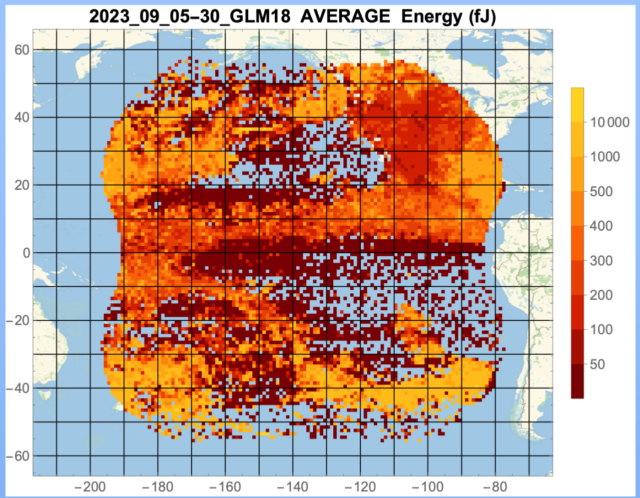
PLPT-GLM-RAD-013

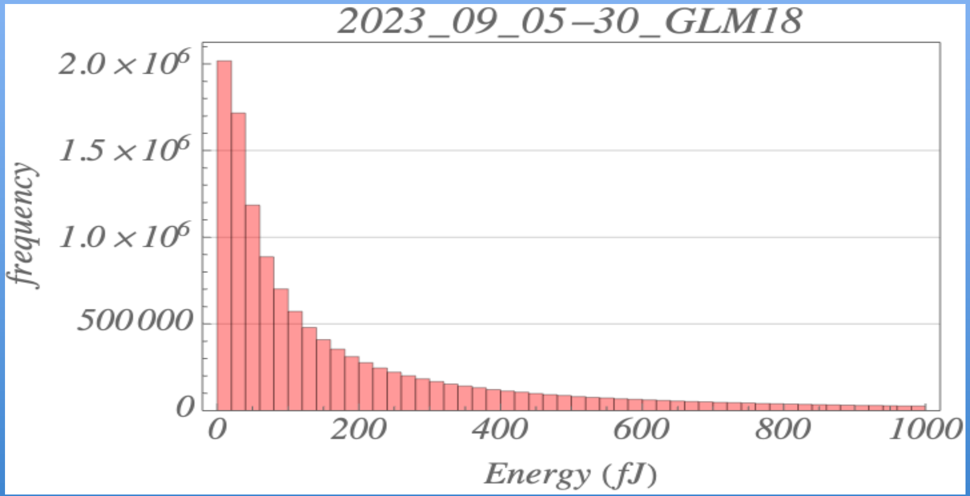
- **GLM-18**
- **Sep 5-30, 2022**
- **7.9 M flashes**
- **314.6 fJ ave**

Optical Energy (Koshak/MSFC)

Bench-marking for long-term degradation checks







PASSED

PLPT-GLM-RAD-013

- **GLM-18**
- **Sep 5-30, 2023**
- **13.1 M flashes**
- **309.0 fJ ave**

Outline

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Some History Prior to Provisional

WR	ADR	Title	PR or DO	Date in OE	Impact to this VAL
	1211	G18 GLM LUTs for Test Slot (CDRL79 Rev C)	PR.09.08.19	4/1/22	high
	1196	Inability to read/edit GLM Semi-static parameters	CLOSED	N/A (5/11/22)	Documentation obtained
9167		G18 GLM Background Images missed processing or in wrong order	CLOSED	5/13/22	low
	1241	G18 GLM LUTs for West Slot (CDRL79 Rev C)	PR.09.08.27	6/1/22	high
9653		GOES-R GLM Geolocation Errors	CLOSED	7/13/22	high
	1264	G18 GLM CDRL79 Rev D	PR.09.08.32	7/29/22	high
	1268	G18 GLM CDRL79 Rev E	PR.09.08.34	9/1/22	high
6412	549	Eliminate GLM L1b dependency on APIDs 384 and 385 - ADR 549	DO.11.00.00	10/1/22	medium
7178	906	GLM CDRL79-to-GS LUT translation tool - ADR 906	DO.11.00.00	10/1/22	medium
8478		Add GLM Flash Extent Density product	DO.11.00.00	10/1/22	medium
	1278	GLM RTEP errors and warnings	CANCELLED	10/3/22	medium

Status at Provisional Maturity

	Past Status	Current Status	Future Outlook

DE	• NO BETA VALIDATION DONE, ONLY QUICKLOOKS (Sep 5-16, 2022) FOR BETA CERTIFICATION:
	  • 75% (wrt ENGLN)
	  • 79% (wrt GLD360)
		• More validation data accumulated with some regional gap filling.
		• +/- 1 sec time window used is optimal based on detailed simulations
		• Low DE values near limb (large water/ice absorption on long slant path)
		• **Bulk (full FOV) spatially averaged performance value meeting 70% spec.**
			• Add Put Back Algorithm to further improve DE.
			• Keep 1st event in flashes not retained by the Coherency Algorithm in DO.08 (not only increases DE but increases detected details of a flash)
			• Modify Single Group Flash (SGF) filter to save those SGFs that are likely due to lightning (i.e., employ Innocence by Association Filter).

FAR	• NO BETA VALIDATION DONE, AND NO SPECIFIC COMPUTATION OF FAR PERFORMED AS PART OF QUICKLOOKS: • But quicklooks showed that GLM-18 had substantial improvement in flash count over CONUS after 9/1/2022 LUT update installed.	• More validation data accumulated with some regional gap filling. • +/- 10 min time window used is optimal based on detailed simulations • **Bulk (full FOV) spatially averaged performance value of 12% still above 5% spec, but in-family with GLM-17.**	• Tuning of Blooming Filter in LUT update on 11/1/2022 (est.) expected to further reduce FAR. • FAR could be reduced by raising thresholds and/or tuning filters. HSV group prefers the latter (but is not our decision).

INR/time	• NO BETA VALIDATION DONE, ONLY QUICKLOOKS (Sep 5-16, 2022) FOR BETA CERTIFICATION; mode of the error distributions were:
	  • 3.5 km location error
	  • 0.8 ms timing error
		• Mode of the error distributions are:
		  • 3.5 km location error
		  • 0.8 ms timing error
		• **So mode of location/timing error distributions meet spec**
		• **INR NS/EW angles occasionally violate spec.**
			• Monthly 3^{o} grid cloud-top height maps preferred to reduce parallax, but hard sell to Program given spec already met
			• Maintain 7-day ave RPY values across processing string discontinuities. [If GS processing strings don't have these values, then GS shall use the initial angles provided in the most current version of CDRL079 Cal Data Books for that flight unit.]

Progress Since Provisional

Miscellaneous:

WR	ADR	Title	PR or DO	Date in OE	Impact to this VAL
	1288	Scripts to push GLM Navigated Backgrounds to eGRES	PR.09.09.00	12/6/22	low
9341		G17 GLM Navigation outliers reported at RBU	MM.11.01.00	12/9/22	none

LUTs and Related:

WR	ADR	Title	PR or DO	Date in OE	Impact to this VAL
	1291	G18 GLM CDRL79 Rev F	PR.09.08.38	11/8/22	high
9164	1234	GLM GPA LUTs for Storage slot (105W) - ADR 1234	CLOSED	4/2/23	none
9469		Unable to import openpyxl [used in GLM LUT conversion tool]	MM.12.01.00	5/4/23	low

DO Build Content:

WR	ADR	Title	PR or DO	Date in OE	Impact to this VAL
7449		GLM Geographic Coverage Extents are incorrect	DO.12.01.02	5/23/23	low
9062	906	GLM Background Gain Cal-INR generation method - ADR 906	DO.12.00.00	5/23/23	medium
9315		GLM Nav out of spec for 48hrs	DO.12.01.00	6/16/23	low

Progress Since Provisional
(cont.)

GLM FED/Gridded Products:

WR	ADR	Title	PR or DO	Date in OE	Impact to this VAL
8964		Store GLM Flash Extent Density product to LZSS	DO.11.02.00	12/1/22	low
9168		GLM Flash Extent Density tile file naming - PRO Type 2	DO.11.02.00	12/1/22	low
9646		GLM FED Outages	Closed	6/29/23	low
8479		Add 5-minute accumulation to GLM Flash Extent Density	Closed	9/22/23	low

Status at Full Maturity

	Past Status	Current Status	Future Outlook
DE	• More validation data accumulated with some regional gap filling. • +/- 1 sec time window used is optimal based on detailed simulations • Low DE values near limb (large water/ice absorption on long slant path) • **Bulk (full FOV) spatially averaged performance value meeting 70% spec.**	• Performance has been good and stable without critical issues & meets spec • DE has now also been independently assessed using Bayesian analyses, which gave results very similar to the results obtained with the standard VaLiD tool.	• Add Put Back Algorithm to further improve DE; includes keeping 1st event and/or 1st group in flash. • Modify Single Group Flash (SGF) filter to save those SGFs that are likely due to lightning (i.e., employ Innocence by Association Filter).
FAR	• More validation data accumulated with some regional gap filling. • +/- 10 min time window used is optimal based on detailed simulations • **Bulk (full FOV) spatially averaged performance value of 12% still above 5% spec, but in-family with GLM-17.**	• Reference networks determined to be inadequate outside of CONUS to give true GLM FAR (as verified by simulations) • Increasing time window in VaLiD & Simulations both indicate GLM is homogeneous (so inferred to meet spec over its full FOV just as over CONUS)	• Blooming Filter tuning (ADR1345) expected to further reduce FAR.

INR/time	• Mode of the error distributions are:
	    • 3.5 km location error
	    • 0.8 ms timing error
	• **So mode of location/timing error distributions meet spec**
	• **INR NS/EW angles occasionally violate spec.**
		• Analysis of location/time errors using ground-truth indicates performance has been good and stable without critical issues & meets spec.	• Monthly 3^{o} grid cloud-top height maps preferred to reduce parallax, but hard sell to Program given spec already met
			• Maintain 7-day ave RPY values across processing string discontinuities. [If GS processing strings don't have these values, then GS shall use the initial angles provided in the most current version of CDRL079 Cal Data Books for that flight unit.]

Future (Fixes, Updates or Holds)

WR	ADR	Title	PR or DO	Date in OE	Impact
7538	1060	Interim Solution to Facilitate GLM Gridded Product	HOLD	TBD	low
9187		Unable to Load GLM Events in PADIV	HOLD	HOLD	none
9667		G16/G18 GLM L2 Product Outage to GeoCloud Endpoint	TBD		none
9700		COOP FINDING: G16/G18 GLM L2/INST-CAL Archive Impacts to MLS/LZSSc	TBD		none
9720	1345	GLM Blooming Filter tuning - ADR 1345	Flight	LUTs to be delivered	high
9724		CBU GLM Landmarking Very Delayed	TBD		low
	1348	GLM Coastline intermittent Read and Write errors	HOLD	HOLD	low
9641	1350	G19 GLMFED is not produced in the TEST SLOT and STORAGE Slot - ADR 1350	DO.13.00.00	11/22/23	low
9735		Remove GLM FED reliance on TBSM	DO.13.00.00	11/22/23	low
9517		GLMFED Failed to Rename Errors to AWIPS TNCF in ITE	TBD		low
9736		Update GLM FED to handle NFS slowness	TBD		low
9808		GGSS Ops: SOZ OE GLM FED OUTAGE J275	TBD		low

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Product Maturity Assessment

Preparation Activities	Assessment
Validation, QA, and anomaly resolution activities are ongoing	PLPTs have been completed. Validation in the form of near real time monitoring and periodic summary will continue. Anomaly resolution is ongoing.
Incremental product improvements may still be occurring	ADRs and WRs continue to be generated and resolved, as expected in normal operation.
Users are engaged and user feedback is assessed	Yes [ongoing]. GLM Value Assessment report completed.

Product Maturity Assessment (cont.)

End State	Assessment
Product performance for all products is defined and documented over a wide range of representative conditions via ongoing ground-truth and validation efforts	All aspects of performance for all GLM-18 L2 products have been defined in MRD and prelaunch baseline, evaluated with a series of PLPTs at Provisional and recently (for Full) over a wide range of representative conditions via ongoing validation efforts.
Products are operationally optimized, as necessary, considering mission parameters of cost, schedule, and technical competence as compared to user expectations	GLM-18 L2 products have been produced operational by the GS according to spec. [Val Ref data inadequate to fully evaluate FAR, but adjusts to VaLiD time window, and Simulations both point to GLM-18 meeting FAR spec, like it does over CONUS]
All known product anomalies are documented and shared with the user community	ReadMe and the PS-PVR presentation are documented and shared with user community.
Product is operational	GLM-18 L2 products have been operational since 31 Oct 2022 (PROV PS-PVR).

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- **Summary and Recommendations**

Summary

(all specs met: see slide 11 for summary of numerical details)

- **Flash DE meeting spec:**
  - Substantiated in detail by VaLiD tool using combined ground reference network data
  - Substantiated by Virts application of Bayesian analysis using ref network data, and also LIS comparisons
- **Flash FAR inferred to meet spec:**
  - Ref networks have low DE over the vast oceans, so are inadequate in assessing GLM FAR there.
  - Low DE Ref networks miss flashes → makes GLM look like it is false alarming when in fact it is not.
  - Increasing VaLiD time-window, and simulations, both show GLM-18 FAR is actually better than low DE ref network analyses suggests.
  - Moreover, GLM-18 is a homogeneous detector, so we believe best estimate of GLM-18 FAR are the (spec-meeting) values over CONUS.
- **Location and associated INR meeting spec:**
  - Parallax mitigated since lightning ellipsoid parameters have been improved quite awhile ago
  - Technically, further improvements could be obtained if Monthly Topography Model is implemented
- **Timing accuracy meeting spec:**
  - Side note: low-priority time-order issue (ADR 375 and its follow-on ADR 1140) were both CLOSED.
- **Max Data Rates meeting spec:**
  - Can handle max Event, Group, and Flash data rates
- **Future improvements:**
  - Replace Single Group Filter (SGF) with a More Sophisticated SGF (ie, Innocence by Association Filter)
  - Implement a "put back filter"; includes keeping first event and/or group in flash
  - Gridded Product Updates (Data Quality ADR 461, Background Imagery) need implementation plans.

Recommendation for Full Maturity

- Introduced CWG principles & approaches to GLM Val pursuant to the RIMP.
- Provided Performance Baselines to be validated, and summarized overall compliance with requirements.
- Summarized results from pertinent PLPTs that further detail compliance (including associated recent ongoing analyses).
- Reviewed progress since PROV (including any fixes of issues identified at PROV PS-PVR), and assessed current status (including open ADRs/WRs).
- Made Assessment of the Full Validation Maturity per GOES-R program.

Recommendation

CWG believes that the GOES-18 GLM L2 product (events, groups, flashes) has reached Full Maturity as defined by the GOES-R Program, and therefore recommends that this product be transitioned to Full Validation Maturity status at this time.

Appendix

Discussion & Analysis of FAR

William Koshak, NASA/MSFC

General Situation & Nuances

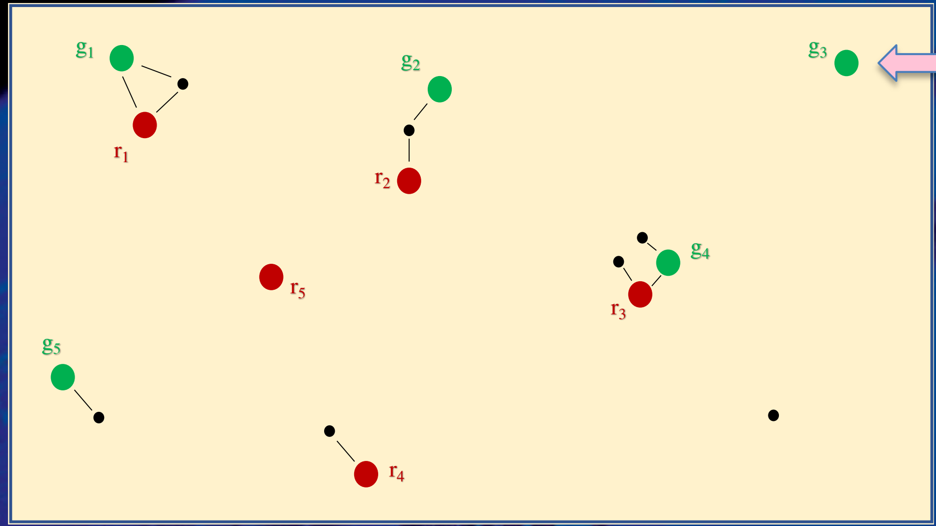
For example, suppose: (m = 5, n = 5):

For a given region and period GLM claims m flashes:

$$G = \{g_1, g_2, \ldots, g_m\}.$$

Whereas the Ref Network claims n flashes:

$$R = \{r_1, r_2, \ldots, r_n\}$$



- (g_1, r_1): This represents the straight-forward case of a legitimate flash (black dot) being detected by both G (i.e., GLM) and R (i.e., reference network).
- (g_2, r_2): This is a case where both G and R detect the flash, but g_2 is too distant in spacetime to be matched with spacetime point r_2, therefore no black line is drawn between point g_2 and point r_2.
- g_3: This is a false alarm by G.
- (g_4, r_3): This is a case where G and R technically detect distinct flashes, but are matched together (as if there was only one flash).
- Lower right black dot: This is a real flash not detected by G and R.
- r_4: R detected the real flash, but G did not.
- g_5: G detected the real flash, but R did not.
- r_5: This is a false alarm by R.

Flash False Alarm Rate (FAR)

The **true** flash FAR is given by:

$$F = p/m$$

p = # GLM flashes having no corresponding actual flash

m = # GLM flashes

The **estimated** flash FAR is given by:

$$f = q/m$$

q = # GLM flashes having no corresponding Ref Network flash

Effect of Ref Network DE

To isolate the effect, assume Ref Network FAR is low* (a pretty good assumption anyways). Then note how Detection Efficiency (DE) of the Ref Network influences the GLM FAR estimate:

- Ref Network DE good, like over the CONUS, then

$$q \approx p \quad \Rightarrow \quad f \approx F$$

- Ref Network DE poor, like over the ocean,

$$q > p \quad \Rightarrow \quad f > F$$

  – A poor Ref Network DE means it misses flashes and thus makes it look like GLM false alarmed (i.e., incorrectly increases q).

- *If the Ref Network had a ridiculously high FAR, then some GLM flashes could possibly be matched to some of the random Ref Network false alarms, which incorrectly decreases the value of q.*

Comparing Instruments

Comparison of GLM-16/17/18 DE and FAR values from the official FULL validation PS-PVRs is given. Whereas the DE values can be trusted, the FAR (Bateman) values are over-estimates (given low Ref Network DE over certain regions, and spatial averaging done to obtain the bulk FAR value). Results are in-family when same computational approach is used. In addition, DE improved from GLM-17 to GLM-18.

Instrument	**DE**	**FAR** (Bateman)	**FAR** (Virts)
GLM-16	78%	22% (±1 sec window; so larger because pre-dates use of ±10 min window)	Pre-dates start of this computation
GLM-17	73%	10% (±10 min window)	Pre-dates start of this computation
GLM-18	81%	13% (±10 min window)	2% (±10 min window)

Overall, the evidence (see "Summary of Key Points" to follow) suggests that all three GLM instruments are in fact meeting the 5% FAR spec.

Comparing FAR Calculations

Period	Flash FAR (Bateman)	Flash FAR (Virts)
Nov 2022	-	8.5%
Dec 2022	-	7.3%
Jan 2023	9.0%	7.9%
Feb 2023	8.0%	4.2%
Mar 2023	8.0%	2.4%
Apr 2023	6.0%	1.2%
May 2023	6.0%	1.8%
Jun 2023	7.0%	2.0%
Jul 2023	11.0%	1.1%
Aug 2023	7.0%	0.6%
Sep 2023	5.0%	0.4%
Oct 1-21 2023	-	1.2%
Jan-Sep	**13.0%**	-
Nov 2022 –Oct 21 2023	**-**	**2.0%**

Comparing GLM-18 FAR Computational Approaches:

- **Both use +/- 10 min matching window. This helps reduce over-estimation of FAR due to low Ref Net DE over ocean.**
- **Bateman approach is from a map perspective wherein FAR is computed for each grid-cell, and then equal-weight averaging done over all those cells to obtain a bulk FAR value. This leads to over-estimation in bulk FAR (and the over-estimation typically increases the longer the analysis period).**
- **Virts approach is from a flash count perspective wherein bulk FAR is computed based always on flash count.**
- **Bateman uses 5 Ref Networks, whereas Virts uses 2.**
- **FAR decreased in early 2023 primarily due to a reduction in blooming artifacts.**

Comparing FAR Calculations (cont.)

Bateman FAR calculation (with M grid cells):

$$B = \frac{\sum_{i=1}^{M} F_i}{M} \qquad i = 1, \ldots, M$$

Virts FAR calculation (with N_{ave} the average # GLM flashes in a grid cell):

$$V = \frac{\sum_{i=1}^{M} N_i F_i}{N} = \frac{\sum_{i=1}^{M} \frac{N_i}{N_{\mathrm{ave}}} F_i}{M} = \frac{\sum_{i=1}^{M} c_i F_i}{M}$$

These expressions allow one to compare the relative magnitudes of B and V. As one can see, the expressions are of the same form except that V weights the FAR in a cell by the ratio N_i / N_{ave}.

Comparing FAR Calculations (cont.)

Consider a simple example of just 2 grid cells, to see what could happen:

$N_1 = 5$ **FAR: $F_1 = 4/5 = 0.8$**	**$N_2 = 45$** **FAR: $F_2 = 1/45 = 0.0222$**

$$B = \frac{1}{2}\left(0.8 + \frac{1}{45}\right) = 0.4111$$

$$V = \frac{1}{50}\left(5(0.8) + 45(\frac{1}{45})\right) = 0.1$$

$$\frac{V}{B} = 0.2432$$

… so, in this case, the simple spatial averaging by Bateman inflates the FAR value relative to the Virts approach.

Comparing FAR Calculations (cont.)

Example of the ratio V/B for large range in factors (alpha, beta) for the simple case of M = 2 grid cells. Sometimes V>B, sometimes V=B, and sometimes V<B, depending on specifics.

$$\alpha = \frac{N_2}{N_1} \quad , \qquad \beta = \frac{F_2}{F_1} \quad , \qquad \frac{V}{B} = \frac{2(\alpha\beta + 1)}{(\alpha + 1)(\beta + 1)}$$

(values of V/B given in table below)

α \ β	0	1	2	3	4	5	6	7	8	9	10
10	0.18	1.00	1.27	1.41	1.49	1.55	1.58	1.61	1.64	1.65	1.67
9	0.20	1.00	1.27	1.40	1.48	1.53	1.57	1.60	1.62	1.64	1.65
8	0.22	1.00	1.26	1.39	1.47	1.52	1.56	1.58	1.60	1.62	1.64
7	0.25	1.00	1.25	1.38	1.45	1.50	1.54	1.56	1.58	1.60	1.61
6	0.29	1.00	1.24	1.36	1.43	1.48	1.51	1.54	1.56	1.57	1.58
5	0.33	1.00	1.22	1.33	1.40	1.44	1.48	1.50	1.52	1.53	1.55
4	0.40	1.00	1.20	1.30	1.36	1.40	1.43	1.45	1.47	1.48	1.49
3	0.50	1.00	1.17	1.25	1.30	1.33	1.36	1.38	1.39	1.40	1.41
2	0.67	1.00	1.11	1.17	1.20	1.22	1.24	1.25	1.26	1.27	1.27
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	2.00	1.00	0.67	0.50	0.40	0.33	0.29	0.25	0.22	0.20	0.18

Summary of Key Points

- A low Ref Network DE inflates the FAR value. This effect can be mitigated to a certain extent by opening the matching time window from ±1 sec to ±10 min.
- Specific error in the retrieval of FAR depends on the specific computational approach (i.e., Bateman's or Virt's) used, the specific analysis period/region analyzed, and the specific Ref Network(s) data used.
- Low DE of the oceanic Ref Network, makes it FUNDAMENTALLY difficult to determine (from the oceanic data alone) just exactly how much estimation error in FAR is involved.
- However, we have done many *independent checks* to assess GLM FAR:
    1. **CONUS:** Simply look at CONUS results where Ref Network DE is good … the GLM FAR meets spec there! Since natural & instrumental variations in glint/blooming across the GLM FOV are reasonably uniform, we do not expect any enormous increases in FAR moving from CONUS to ocean. So CONUS FAR is an important "sanity check".
    2. **INSTRUMENT VENDOR MODELING:** predicted FAR of 2.6% which meets spec, and is in-family with our CONUS FAR result obtained by Virts.
    3. **SIMULATIONS:** Published Virts & Koshak Simulation paper indicated that a spec-meeting GLM (i.e. DE = 70%, FAR = 5%) that observes over an oceanic Ref Network DE = 68% gives a retrieved GLM-FAR of 38% (i.e., simulation confirms a HUGE overestimate of the true/known 5% FAR value given in the simulation!).
    4. **OPENING MATCHING WINDOW:** The Simulation paper also confirms that increasing the matching time window (to +/- 10 min) does reduce (but does not eliminate) the over-estimation error … and this is exactly what we find with our FAR analyses. This demonstrates that our overall understanding is consistent/correct.
    5. **SPATIAL AVERAGING:** Bateman's bulk FAR value is a spatial average of his map perspective. But spatial averaging can inflate FAR under the right conditions (e.g., when large FAR occurs in grid cells having few flashes).
    6. **VIRTS LATEST FAR COMPUTATION:** Again, Virts most recently obtained an FAR = 2% for GLM-18.
- Therefore, considering all available evidence, GLM meets the FAR spec.