GLM Observations of Bolides
LI MAG Meeting #9

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Observational Entry Data
Asteroid Threat Assessment Project

NASA Advanced Supercomputing Division
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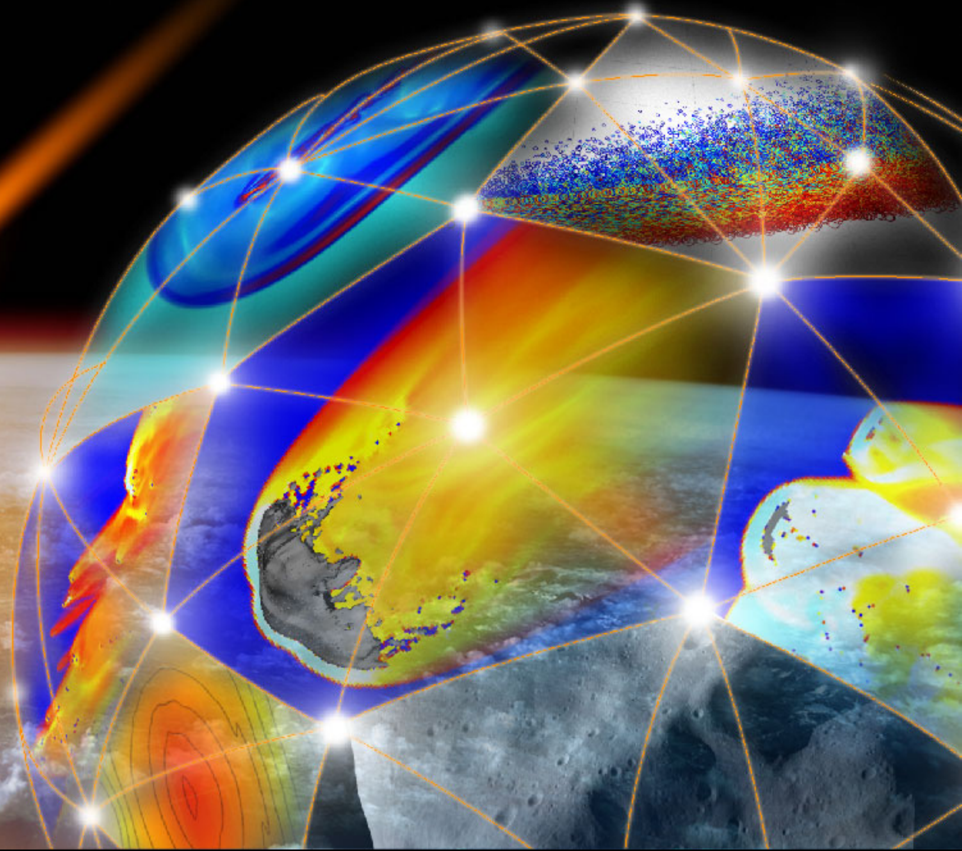
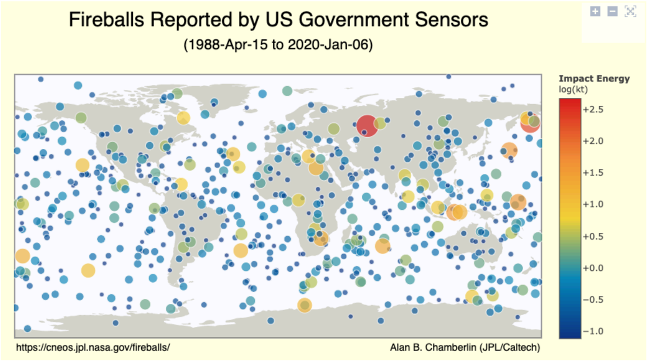
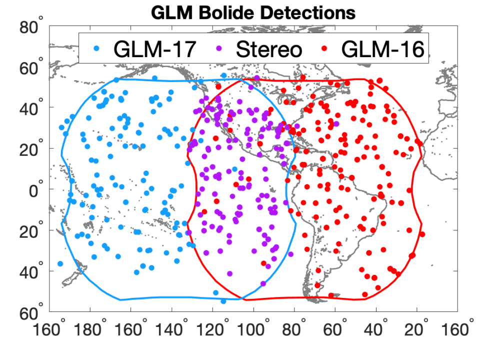
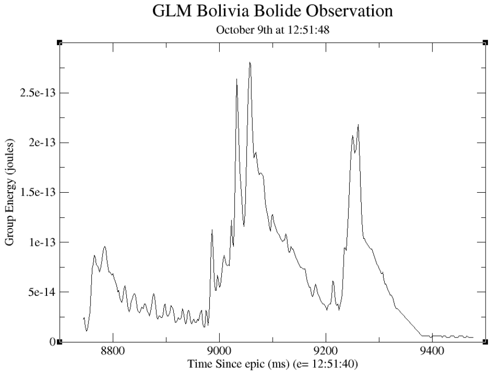


Why is Observational Data Important?

- Observational data including GLM data are needed by NASA's Planetary Defense Coordination Office to better understand the threat posed by larger asteroids hitting Earth
  - Situational awareness of what is hitting the earth
  - GLM Light Curves (LC) are measurements of narrow-band visible spectrum optical intensity as a function of time that record the disintegration of a Small Asteroid (SA) as it impacts the Earth's atmosphere
  - GLM LCs can be used to infer SA pre-entry characteristics (structure/strength, size, mass)
  - GLM LCs can inform development of physics models (fragmentation models, ablation models, and airburst models)
  - GLM LCs provide high fidelity, high cadence "snapshots" of the breakup, fragmentation and ablation of SA impactors – **no other data is as rich in informing and constraining the fragmentation processes needed to improve impact models**

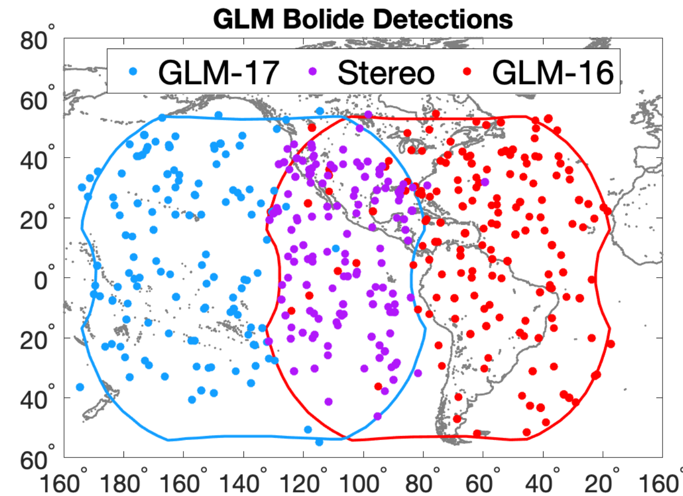






Lightning Mapper Coverage

- There are two GLMs on-orbit
  - GLM 16 on GOES east (75W)
  - GLM 17 on GOES west (137W)
- Coverage up to +/-55 deg latitude
- Europeans will fly LI sensor starting 2021
- PDCO would like to use LI data in combination with GLM
  - More stereo detections
  - More coverage
  - Higher time fidelity LCs



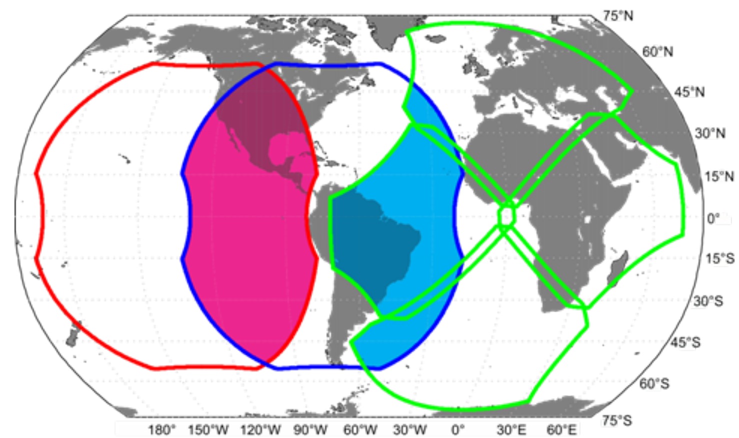


Figure 5. GLM (GOES-East and GOES-West) and LI FOV overlap. The overlap area for GLM on GOES-East and West (red and blue outlines) is the magenta filled area while the GLM on GOES-East and LI (blue and green outlines) is the cyan filled area. Note that GLM on GOES-East and GOES-West have the same footprint. The physical footprints of each LI sub-telescope are also the same. The differences seen on the map (for both LI and GLM FOVs) are from map projection distortions.

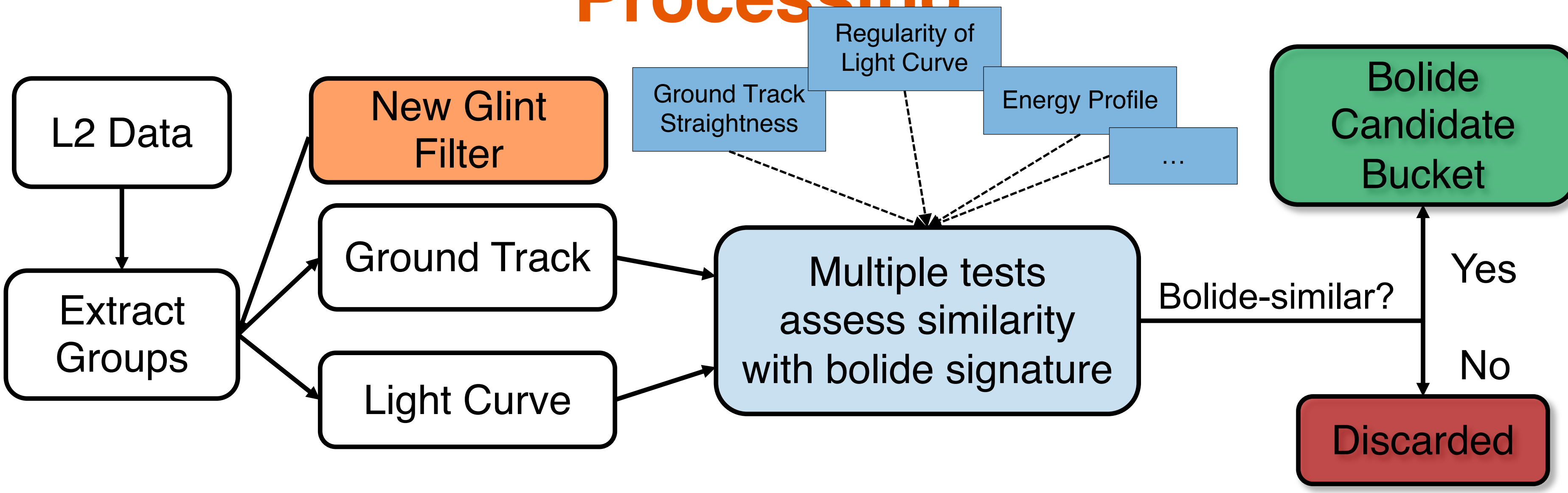
GLM work at NASA Ames

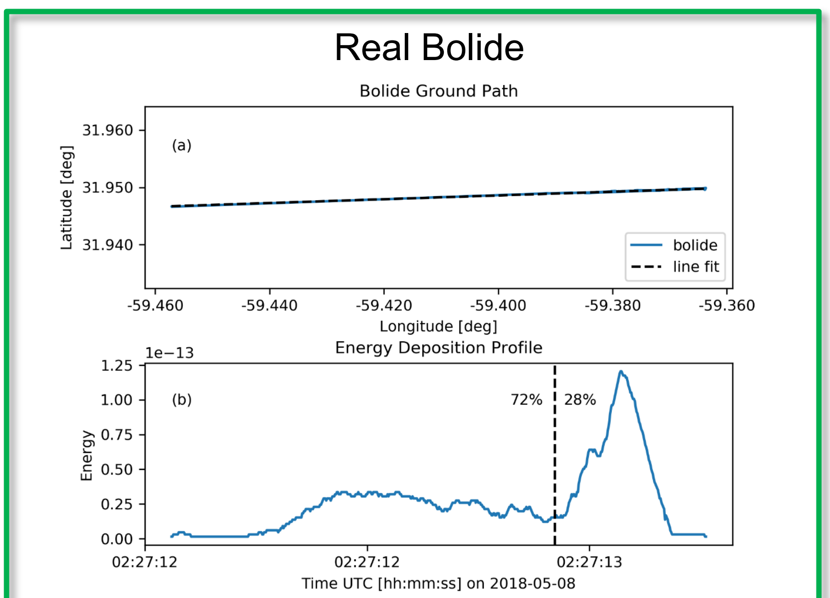
- Asteroid Threat Assessment Project (ATAP) at NASA Ames is integrating bolide detections from GLM into our observational data program. This effort includes:
  - Autonomous detection algorithm development
  - Data pipeline and processing
  - Data visualization
  - L0/L2 light curve reconstruction
  - Database and website development
    - Meta data analysis examples
  - Trajectory re-construction from GLM stereo detections
    - If successful this would allow orbit determination which is important to determine source regions (where did it come from) and aid in meteorite recovery
  - Daily analysis of GLM data
- In a separate effort in support of the NASA/Planetary Defense Coordination Office (PDCO) automated bolide reporting system
  - Investigating providing near real-time GLM ***candidate*** bolide detections
  - Although GLM is not global it provides a lower threshold than current capabilities and records the disintegration of bolides as they break-up in the atmosphere at a high cadence
  - Events published on the NASA Ames web site will require human review before release

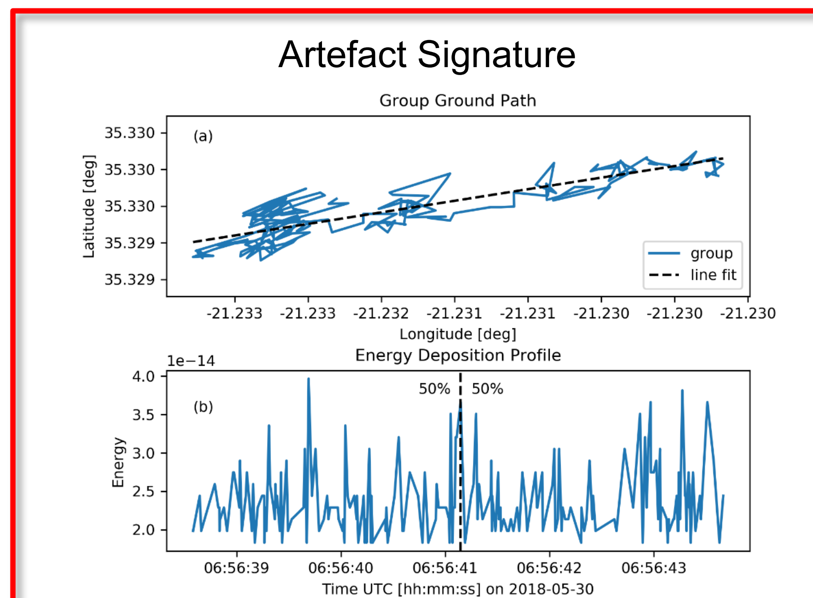
GLM Autonomous Detection Algorithm Development

- L0 vs L2 for detection
  - The L0 data offers a more robust data set for finding bright meteors or bolides
    - Having adjacent pixel information has proven very useful and simplifies bolide detection algorithms
    - L0 data is not filtered and processed which gives access to what is happening on the detector during a bolide event
    - Once we find a detection in L0 we then look for it in the calibrated L2 data
- Parallel development paths using L0 and L2 data
  - During development each data set complements the other
    - L2 grouping helps in finding bolides

Current L2 Automated Detection Processing

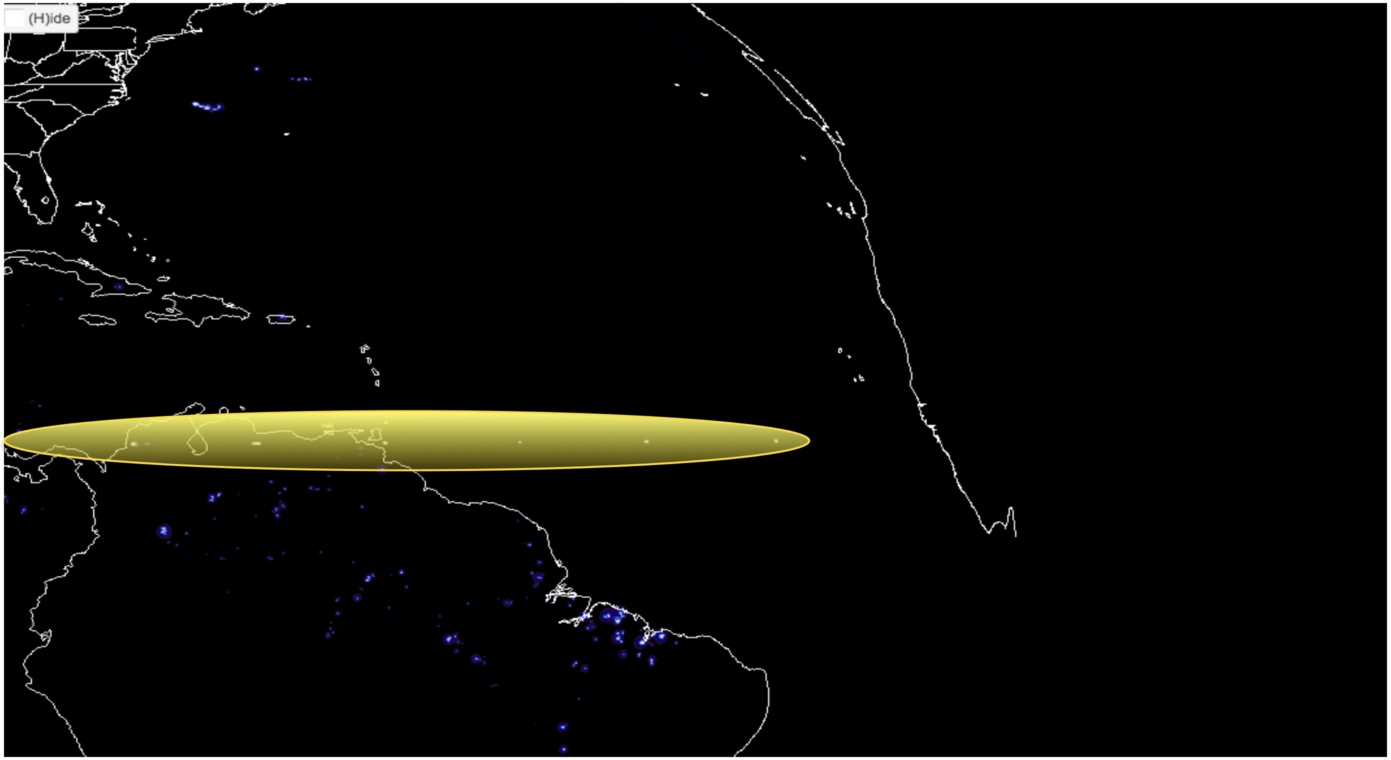




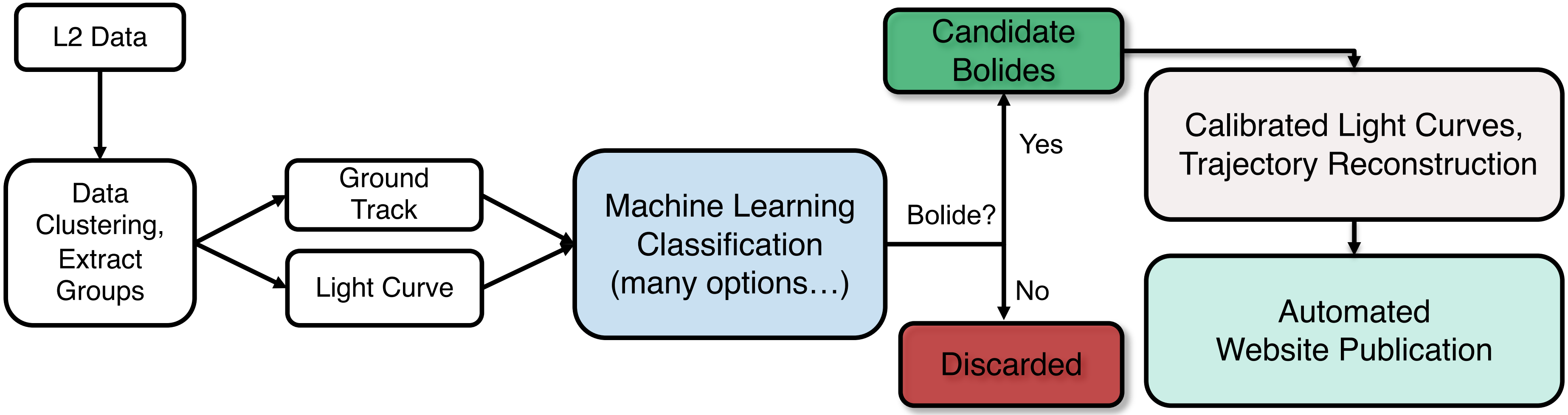


Recently Added Glint Filter

- First a glint point is calculated
- Then an ellipse is overlaid at the centroid of the glint point
  - The shape of the ellipse is determined empirically and is different on GLM-16 and GLM-17



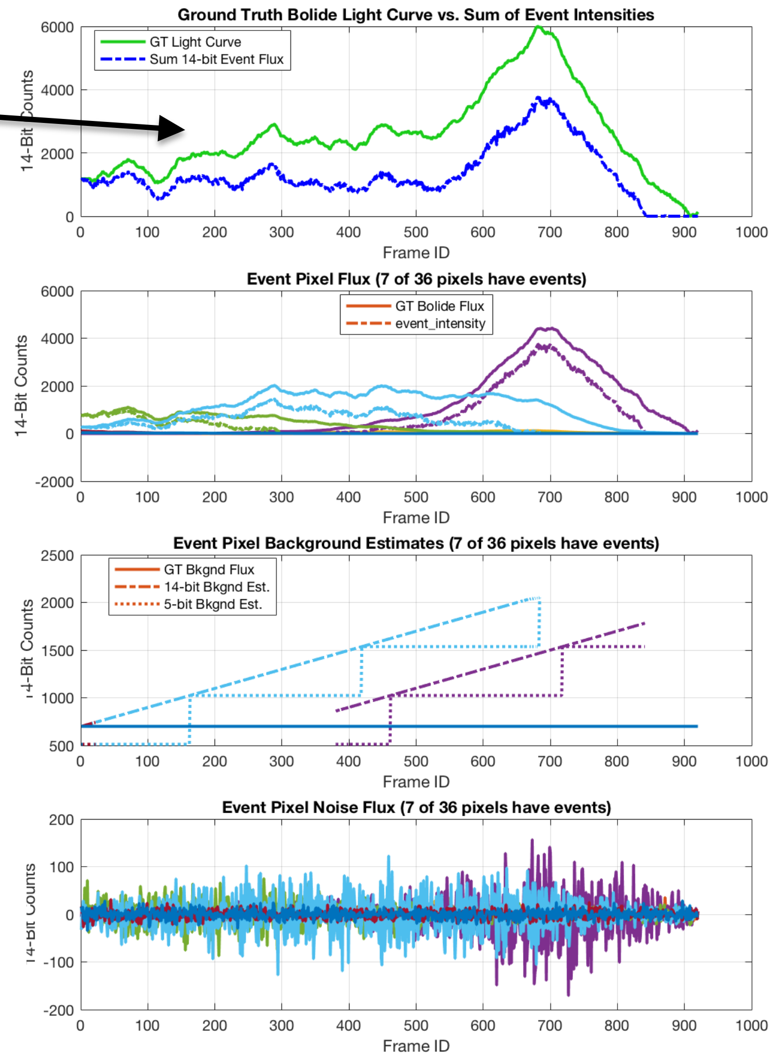
Future Improvements to GLM Bolide Detection Pipeline

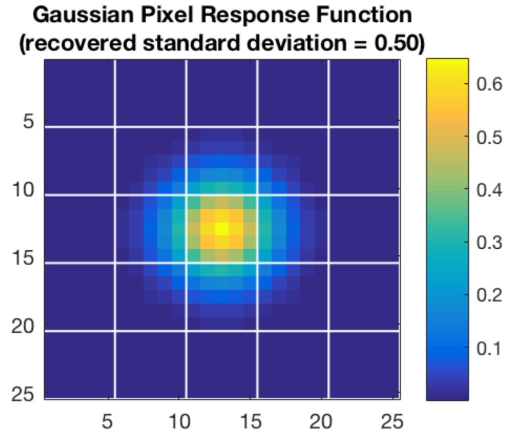


- ***Current***: running on NASA Ames Supercomputer
  - Daily processing of any new GLM L2 data
    - Based on classical sequential matched filter techniques (Rumpf et al. 2019)
    - Can process an entire day in ~15 minutes
    - Finds dozens of promising events daily
    - Requires manual vetting to obtain set for publication on website
- ***Future improvements***:
  - Apply more sophisticated Machine Learning techniques to the detection and classification of candidate GLM Bolides
  - Reduce false positives such that full processing from detection to website publication can be automated
  - Automatic calibration of light curves and trajectory reconstruction from raw L0 data on any detected bolides

Light Curve Reconstruction

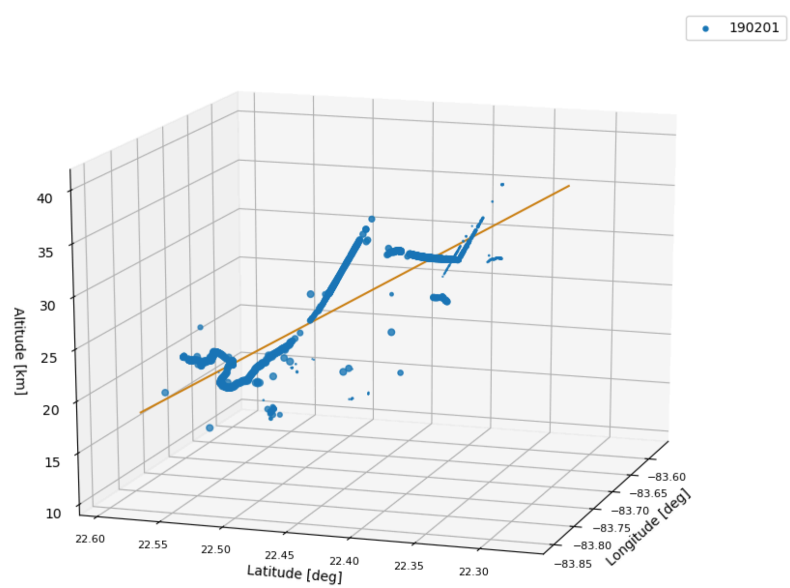
- GLM onboard processing algorithms discard significant bolide flux.
- We are investigating a method for reconstructing high-quality bolide light curves.
- **Approach**: Fit a model of GLM data generation to the available data for a known bolide. Effectively, fills in missing data.

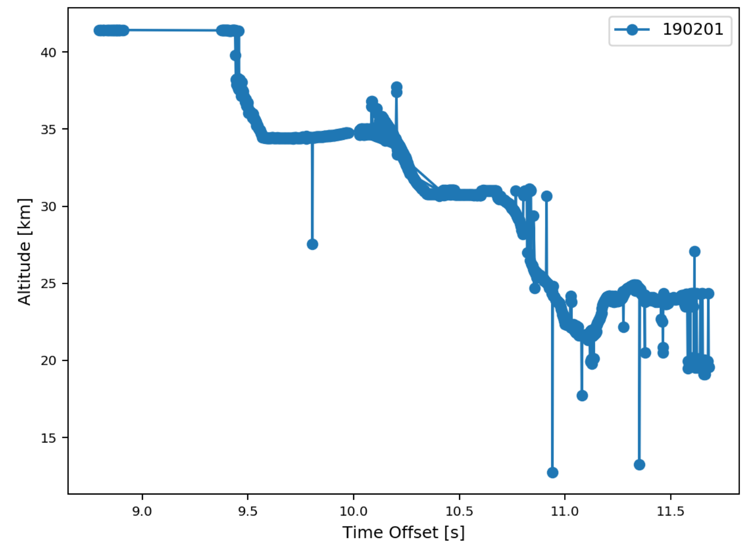




Trajectory Reconstruction

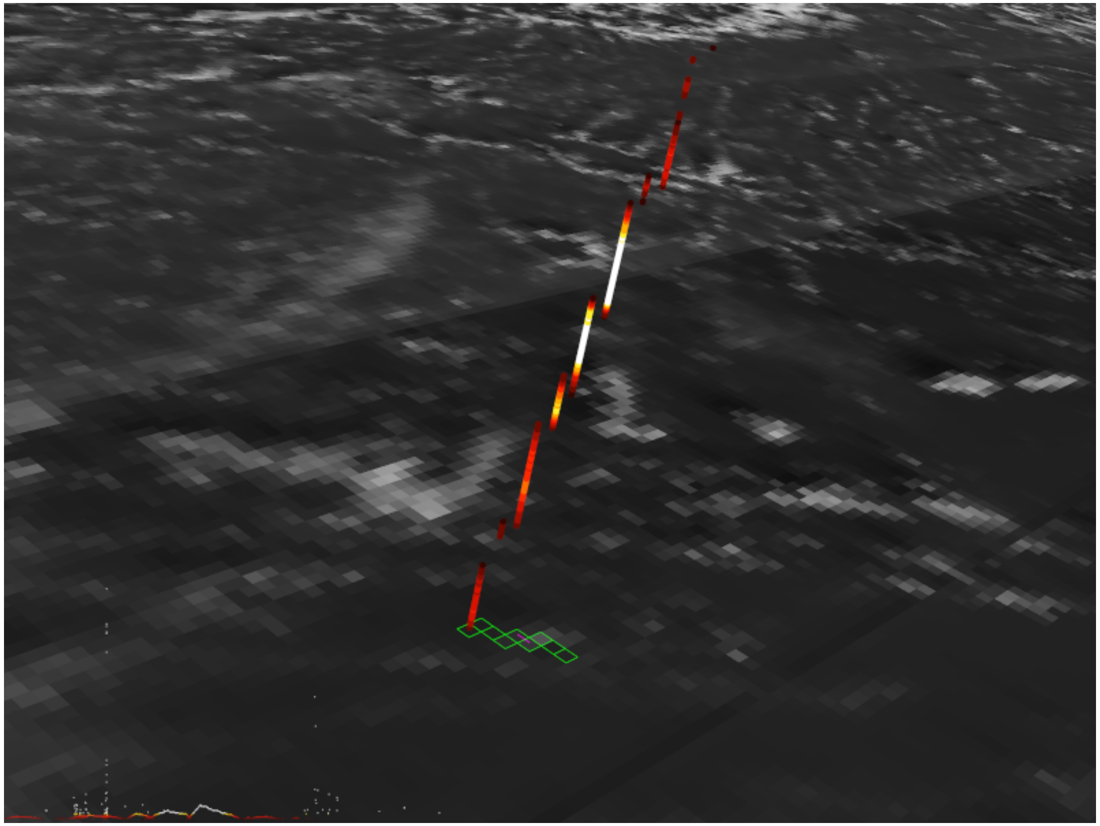
- Investigate solutions to getting the most accurate trajectories from stereo GLM Bolide detections
- Investigate improved techniques for centroiding the GLM group data to minimize stair stepping effects
- Compare trajectories from GLM with Allsky network produced trajectories
- We have multiple stereo GLM and Allsky coincident events to work with
  - will investigate less than optimum combinations to determine if contributions to an accurate trajectory and orbit determination are possible through the fusion of the two disparate (space/ground) data sources





Visualization of GLM Bolide Data

- Developing visualization tools for both L0 and L2 GLM data



In this figure time is the vertical axis. The detecting pixels are shown in green

GLM Bolide Website

- NASA Ames GLM Bolide website has been developed and we are currently populating with GLM bolide events
- Right now we show raw L2 data but have plans to increase the functionality of the website and provide calibrated light curves and reconstructed trajectories
- Currently we have over 150 GLM bolide events
  - Averaging two to three events per day
- Web address
  - https://neo-bolide-ndc.nasa.gov
- User interface includes a map showing impact location, light curve(s), and ground track(s)

GLM Bolide Website

- User can download event CSV data file
- More detailed information can be obtained by clicking “View Data” on the main web page

#Day Of Yea	147		
#Event Date:	##########		
#Original Ne	ORGLM-L2-LCFAG17s20191471605400e20191471605580c20191471606127.nc		
#Platform:	G17		
#Satellite (la	0.0 / -75.199997 / 35786.02km		
#Event Info:	stereo		
#Description	detected by: GLM-16 GLM-17 | How found: algorithm | other detecting sources: ? | co		
#Date Archiv	##########		
#URL:	https://neo-bolide-stg.ndc.nasa.gov		
time (ms)	longitude	latitude	energy (joules)
1.559E+12	-110.78268	-41.438507	3.05E-15
1.559E+12	-110.78271	-41.438469	3.05E-15
1.559E+12	-110.78275	-41.438431	3.05E-15
1.559E+12	-110.78275	-41.438427	3.05E-15
1.559E+12	-110.78276	-41.438419	3.05E-15
1.559E+12	-110.78278	-41.438416	3.05E-15
1.559E+12	-110.78278	-41.438408	3.05E-15
1.559E+12	-110.7828	-41.438404	3.05E-15
1.559E+12	-110.78282	-41.4384	3.05E-15
1.559E+12	-110.78285	-41.4384	3.05E-15
1.559E+12	-110.78288	-41.4384	3.05E-15
1.559E+12	-110.78291	-41.4384	3.05E-15
1.559E+12	-110.78293	-41.4384	3.05E-15
1.559E+12	-110.78291	-41.438419	3.05E-15
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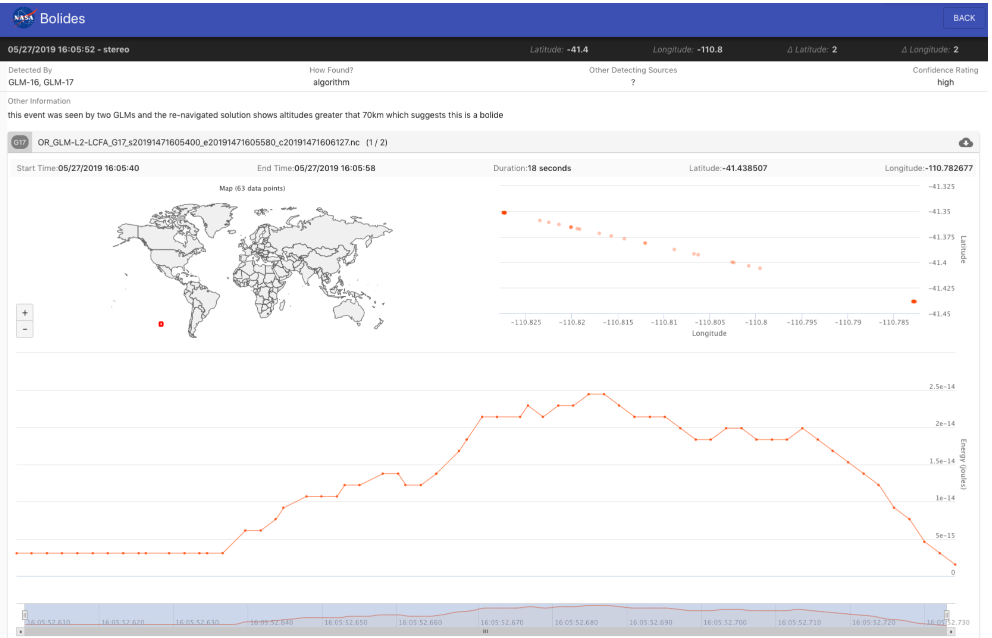
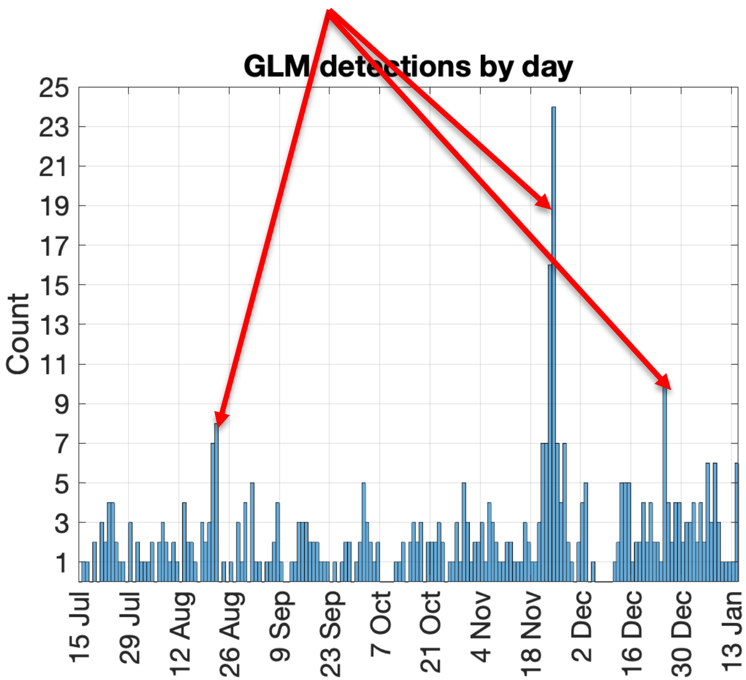
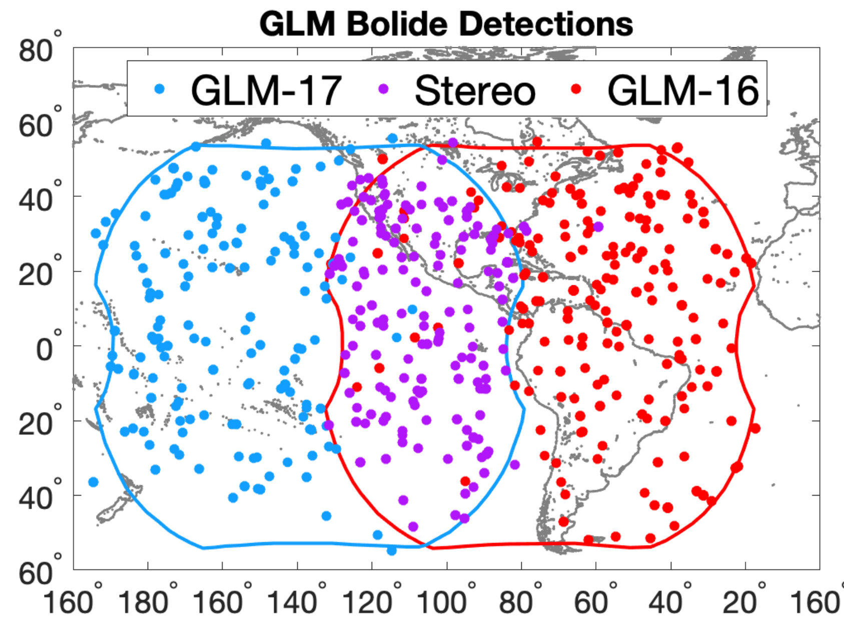
1.559E+12	-110.79954	-41.405891	6.10E-15



Geographic Distribution of GLM Bolide Detections

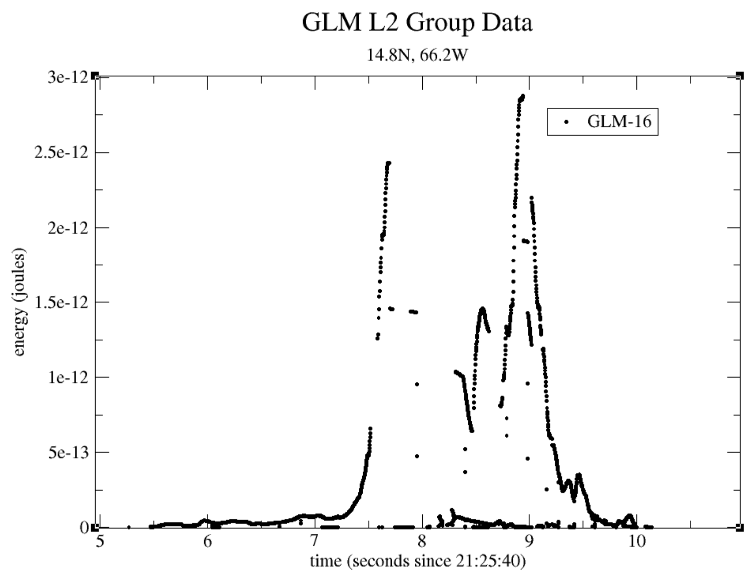
Meteor Shower?





- Detection rates are dependent on algorithms ability to find them
  - For example we know there are dimmer events not being found by the current algorithm
- As we increase our detection catalog, we will have enough events to perform statistical analysis of bolide populations

Largest GLM Detection So Far



Peak Brightness Date/Time (UT)	Latitude (deg.)	Longitude (deg.)	Altitude (km)	Velocity (km/s)	Velocity Components (km/s)			Total Radiated Energy (J)	Calculated Total Impact Energy (kt)
					vx	vy	vz		
2019-06-30 16:52:58	21.2N	129.5W	59.0	42.3	25.2	31.2	-13.3	3.2e10	0.11
2019-06-30 08:11:29	2.5S	168.7E						2.1e10	0.076
2019-06-22 21:25:48	14.9N	66.2W	25.0	14.9	-13.4	6.0	2.5	294.7e10	6

JPL Fireball Web Site:
https://cneos.jpl.nasa.gov/fireballs/

GLM Publications and Contact Information

- Jenniskens, P., Albers, J., Tillier, C. E., Edgington, S. F., Longenbaugh, R. S., Goodman, S. J., et al., 2018. Detection of meteoroid impacts by the Geostationary Lightning Mapper on the GOES-16 satellite. *Meteoritics & Planetary Science*, *53*(12), 2445–2469. http://doi.org/10.1111/maps.13137
- Rumpf, C., Longenbaugh, R., Henze, C., Chavez, J., Mathias, D., 2019. Algorithmic Approach for Detecting Bolides with the Geostationary Lightning Mapper. Sensors, Remote Sensors, Manuscript ID: sensors-429054
- Fall, 2019 AGU presentations
  - **"Extracting Bolide Light Curves from GOES GLM Data"** Abstract ID: 620917 **-** Robert Morris, Jeffrey C. Smith, Jessie Dotson, Randy Longenbaugh, Clemens Rumpf, Christopher Henze, Donovan Mathias
  - **"An Automated Bolide Detection and Lightcurve Pipeline from GOES GLM data"** Abstract ID: 567787 **-** Jeffrey C. Smith, Clemens Rumpf, Robert Morris, Randy Longenbaugh, Jessie Dotson, Christopher Henze, Donovan Mathias
- Other relevant Publications
  - AGU - "Using Deep Learning to Automate Inference of Meteoroid Pre-Entry Properties" Abstract ID: 519737, by Ana M Tarano
- POC Information
  - Randolph Longenbaugh - randolph.s.longenbaugh@nasa.gov

Backup Slides

GLM Prelim

- GLM has a meteoroid detection threshold of about an absolute (distance = 100 km) -14 visual magnitude meteor (GLM capable of detecting several dm to meter-sized asteroids impacting Earth atmosphere)
- Comparison with other light curve measurements implies that GLM samples the meteoroid disintegration light curve nearly completely unaffected by onboard processing and downlink processes tailored to lightning data
- Calculated total optical radiant energies correspond well to those reported from broad-band USG sensor data which suggests that during the meteoroid's peak brightness the GLM pass-band is dominated by continuum emission, rather than O I line emission
- Saturation limitations for large events (14 bits of dynamic range)
- Meteoroid impact assessment must account for instrument effects such as CCD blooming, event FIFO overflows, background noise influences, LSB limitations, and assumed lightning altitudes to produce best representation of the light curve recording, best geo-location, and timing