A Statistical Analysis of Bolides Detected by GOES GLM

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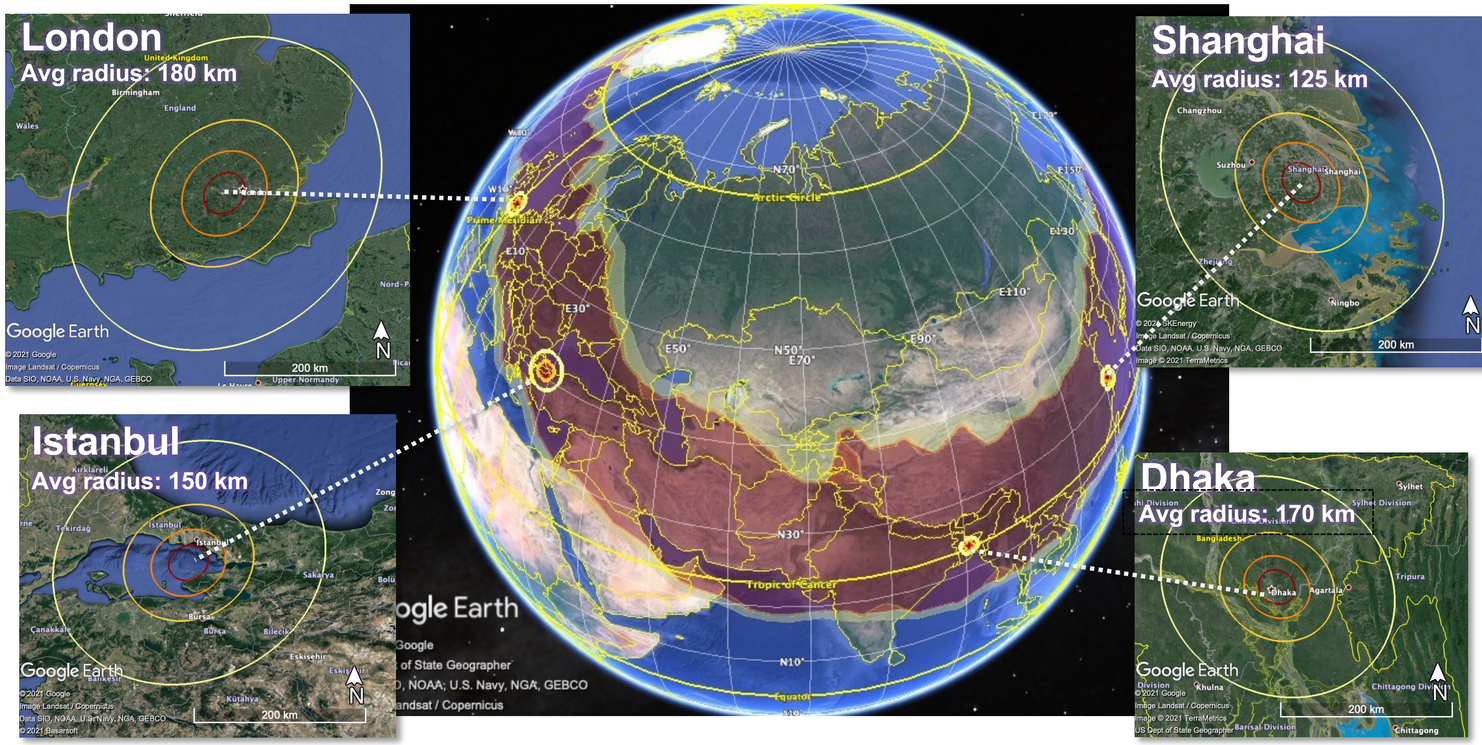
Why GOES Lightning Mapper Data to Detect Bolides?

- Ground-based meteor detectors have limited sight.
  - Fine for small meteors; there are plenty to find!
  - Fireballs and bolides are too rare, only a ~handful hit the Earth per day.
  - Want hemispherical coverage
    - Geostationary orbit ideal
- Funded by NASA's Asteroid Assessment Project (ATAP) to assess the risk of large asteroids hitting the Earth
  - Need large catalogue of calibrated bolide light curves to tune entry models to study ablations and breakup rate in atmosphere.
  - Can also be used to study meteoroid/asteroid populations studies for both solar system evolution and impact risk on Earth

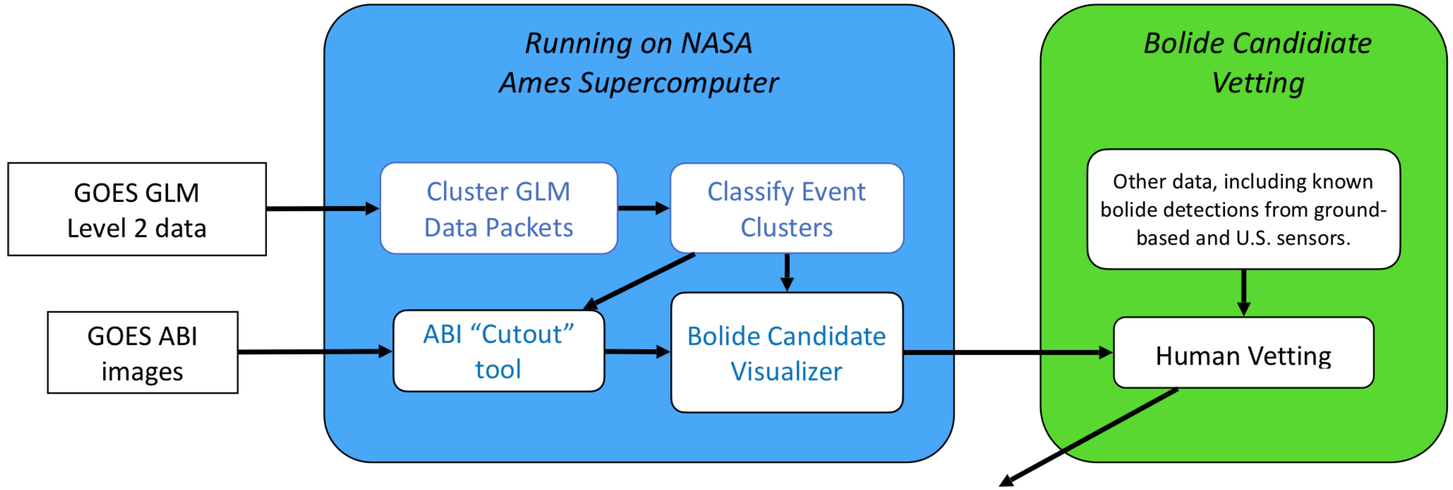


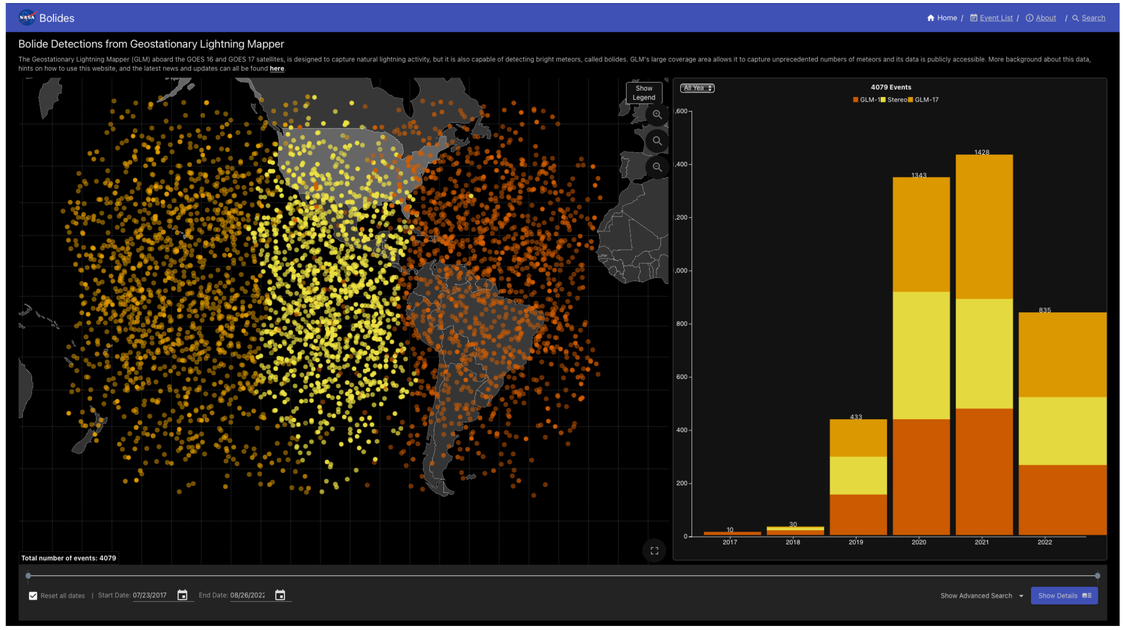
Damage swath: Full range of regions potentially at risk to local ground damage, from all modeled cases (including unlikely worst-case objects and all sampled impact locations).
Sample average damage areas: Average blast damage areas from several worst-case high-population locations across the swath.

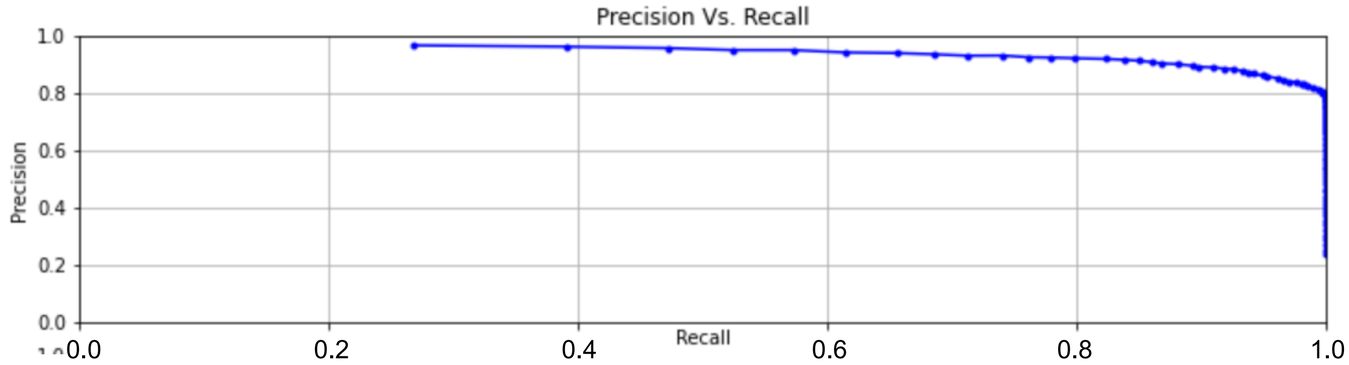
How We Detect Bolides

- Uses GLM Level 2 data products for detection
- Does not use GLM flashes. We cluster our own bolides using the group data.
- Uses supervised learning to train Random Forest classifier to detect.
  - Iterative improvements over time as we grow our training data set
- Human manual vetting before publishing at https://neo-bolide.ndc.nasa.gov

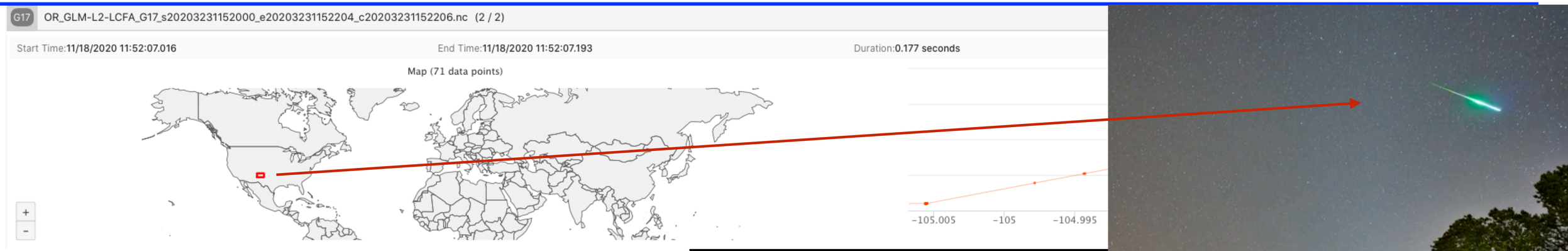
Current GOES GLM Bolide Detection Pipeline



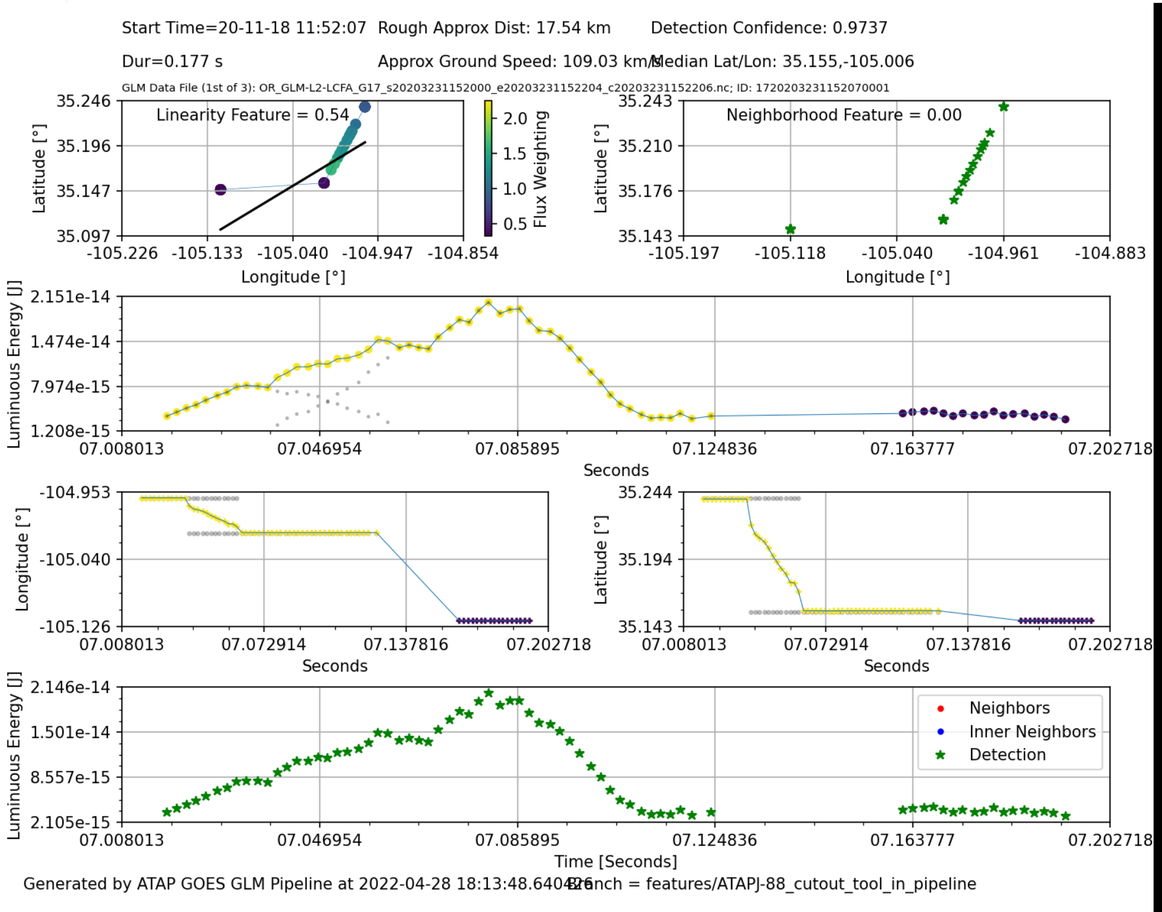


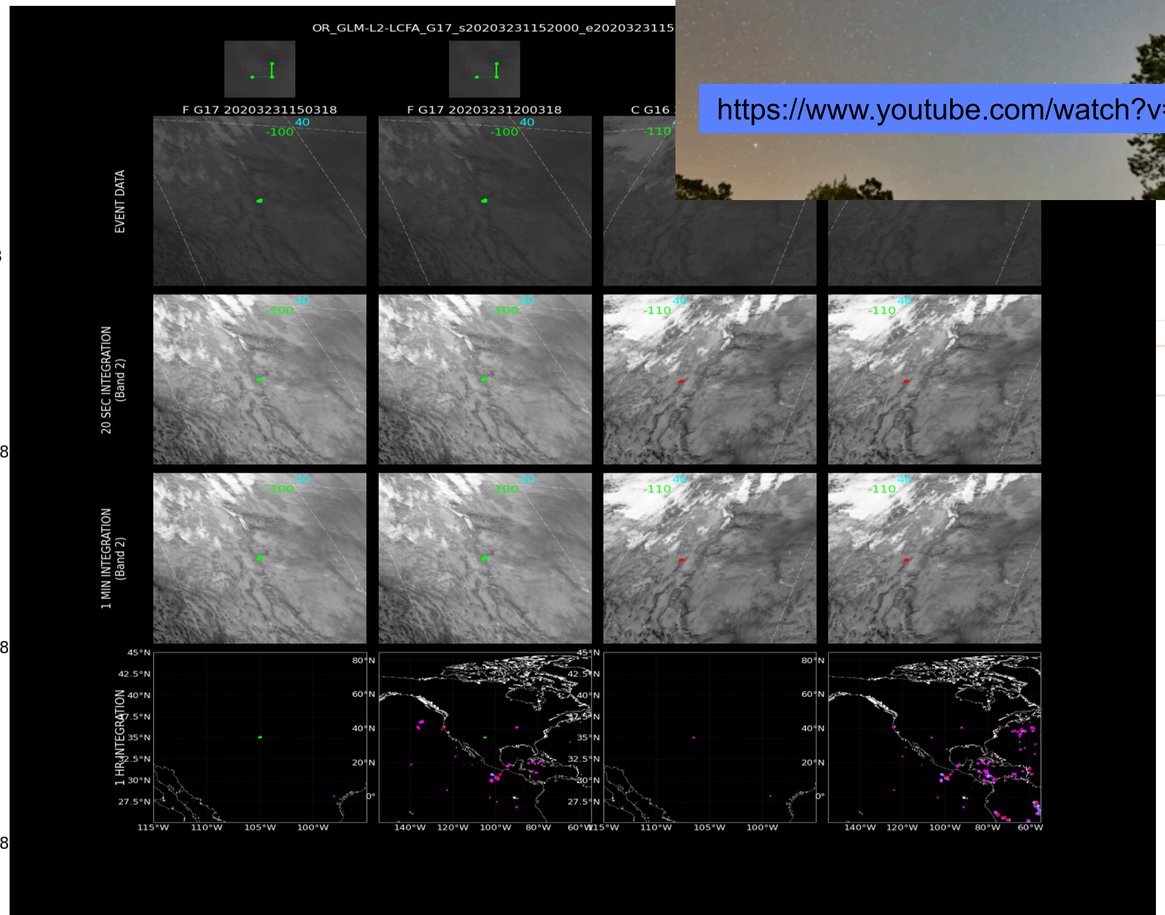


A Bolide!



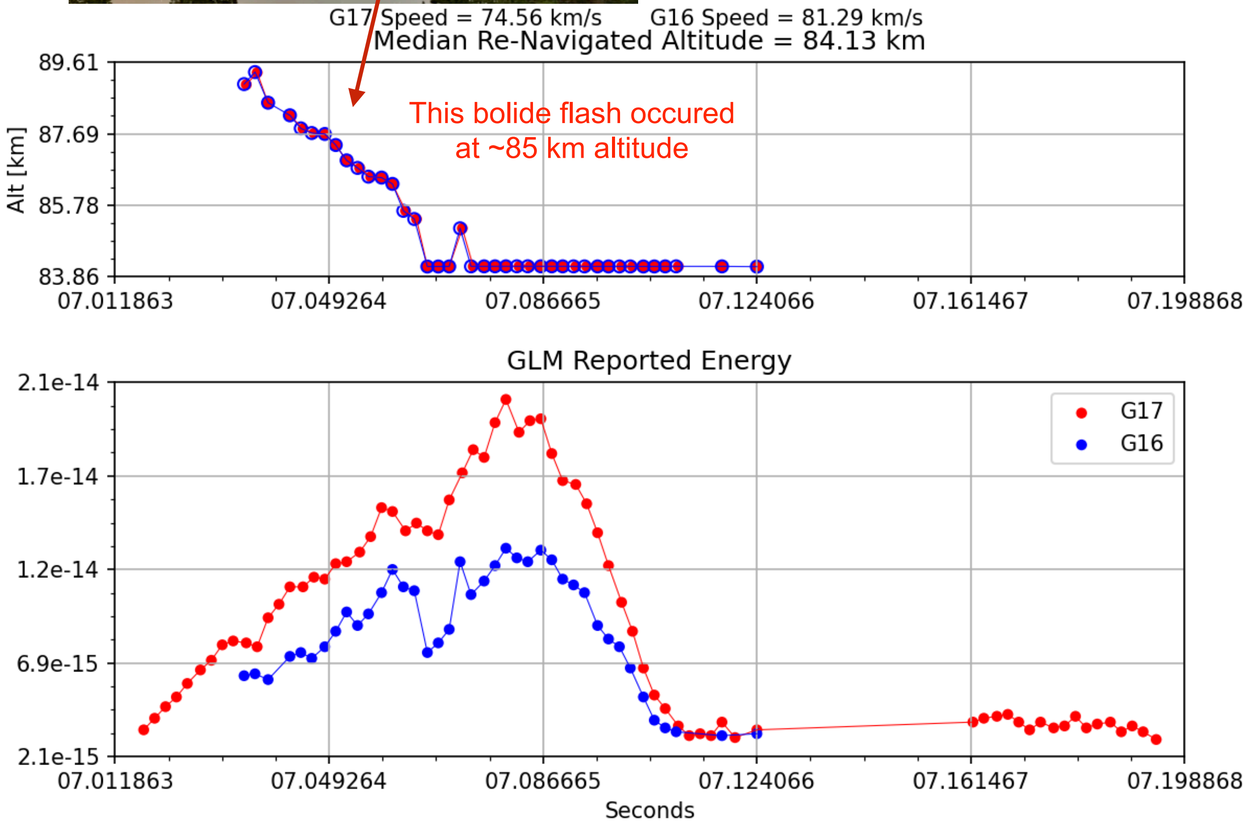
https://www.youtube.com/watch?v=eFmFQ7d-Me4

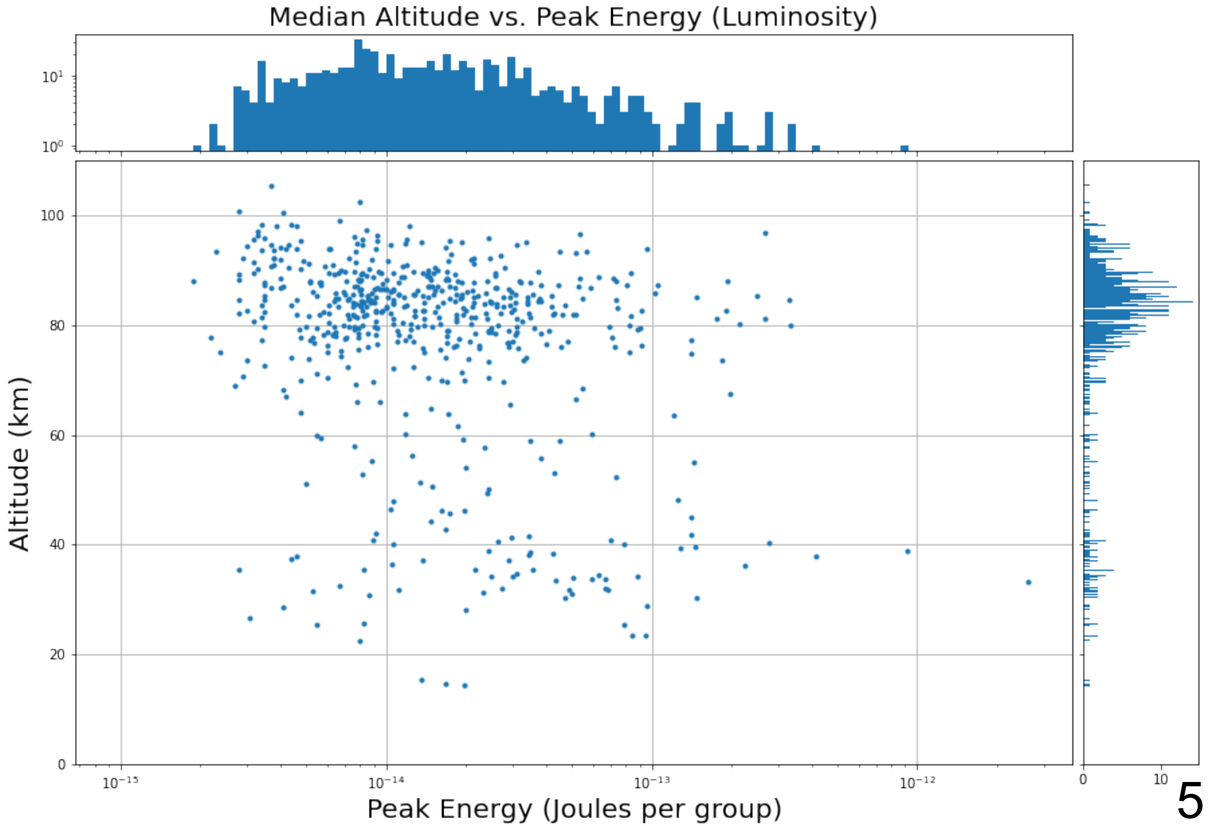




Stereo Detection Is Important

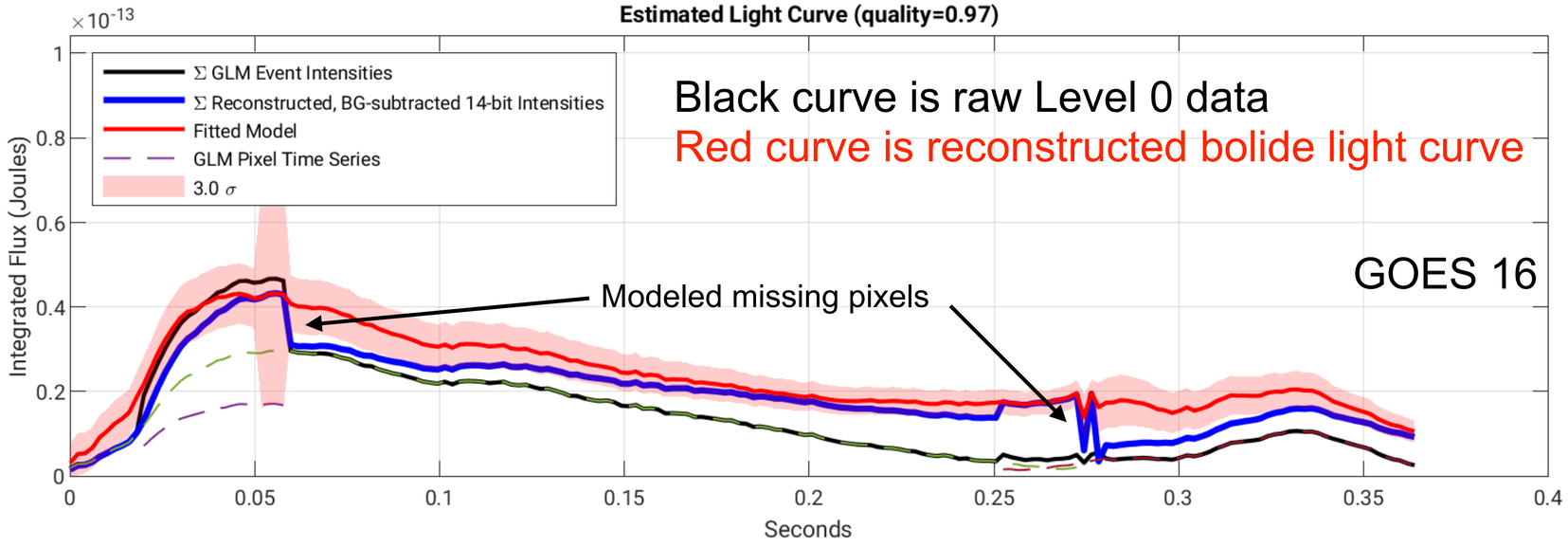
- Collecting data from multiple remote sensors is critical to inferring the energy deposition and pre-entry characteristics of asteroids/meteoroids.
- Allows for velocity reconstruction
  - Where in atmosphere is energy deposited?
  - Trajectory reconstruction and solar system origins of meteoroid

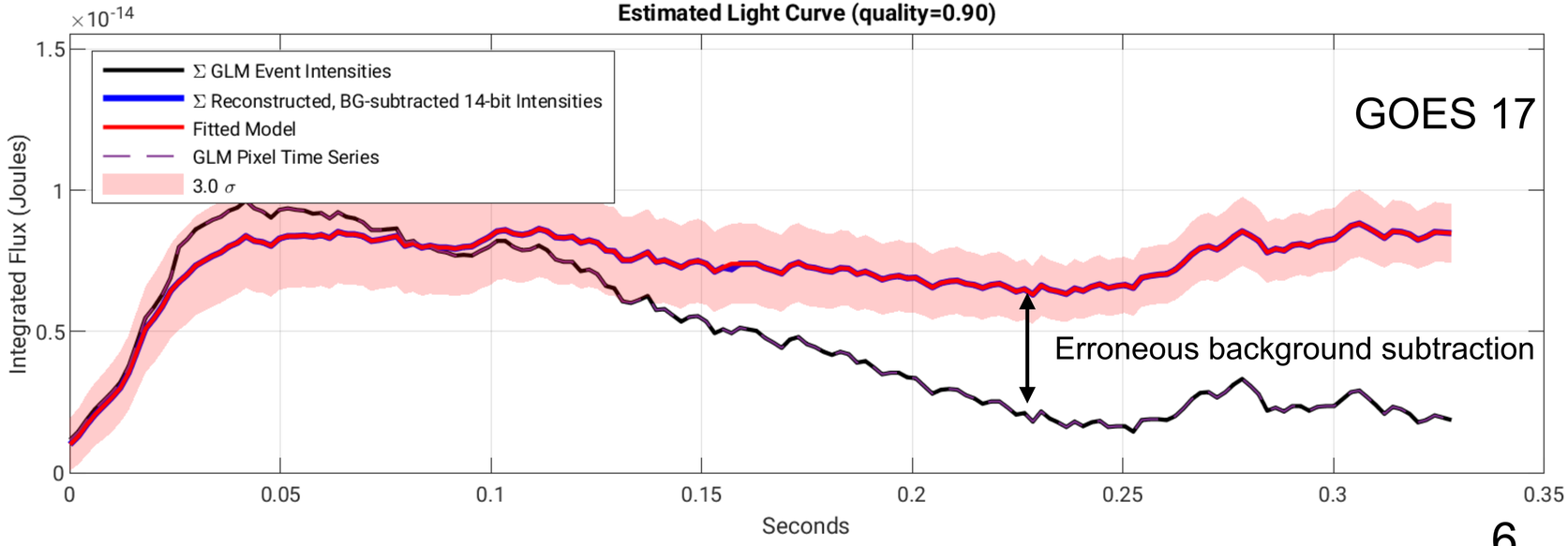




Generating Bolide Light Curves From Lightning Data Sets

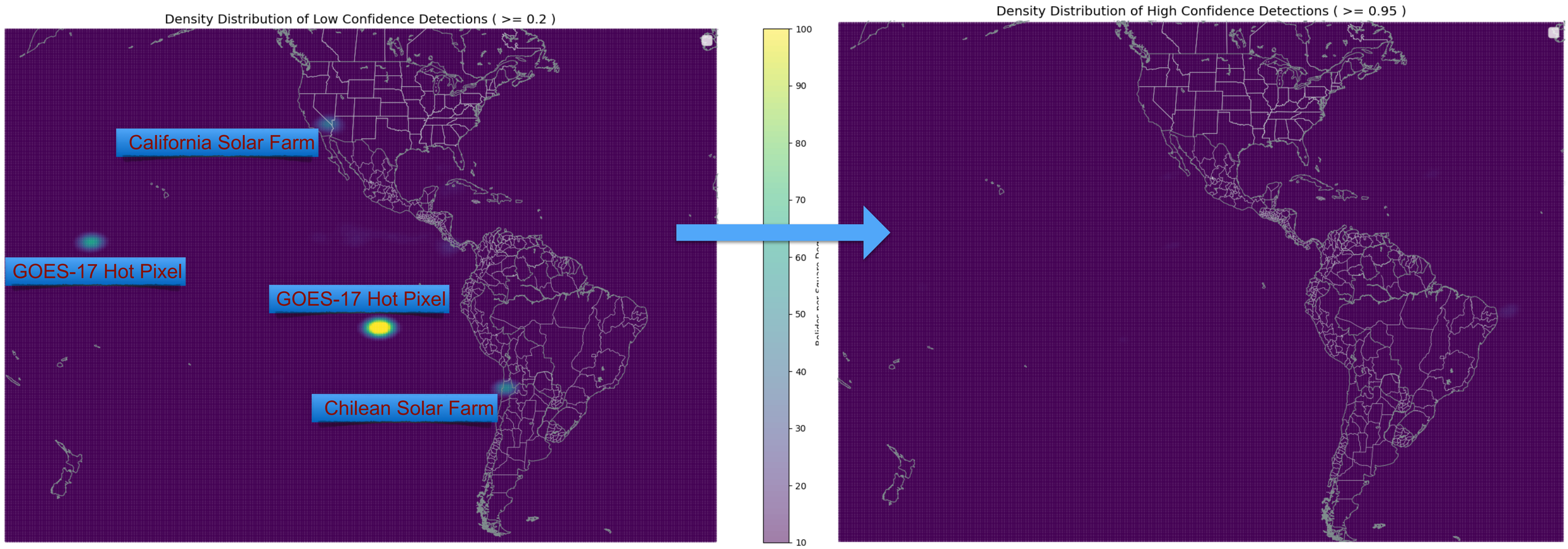
- GLM ground segment processing and L2 data products are designed for lightning studies
  - Assumes non-traveling objects
    - Flashes and groups not ideal event grouping methodology
  - Assumes brief flashes
    - Background subtraction increases for static sources
  - Does not record full extent of bolide flash (I.e. missing pixels)
    - Only downlinks brightest pixels
- We have developed our own light curve reconstruction pipeline for bolides
  1. Re-cluster events for bolides
  2. Correct background
  3. Use PRF modeling to fill missing pixels





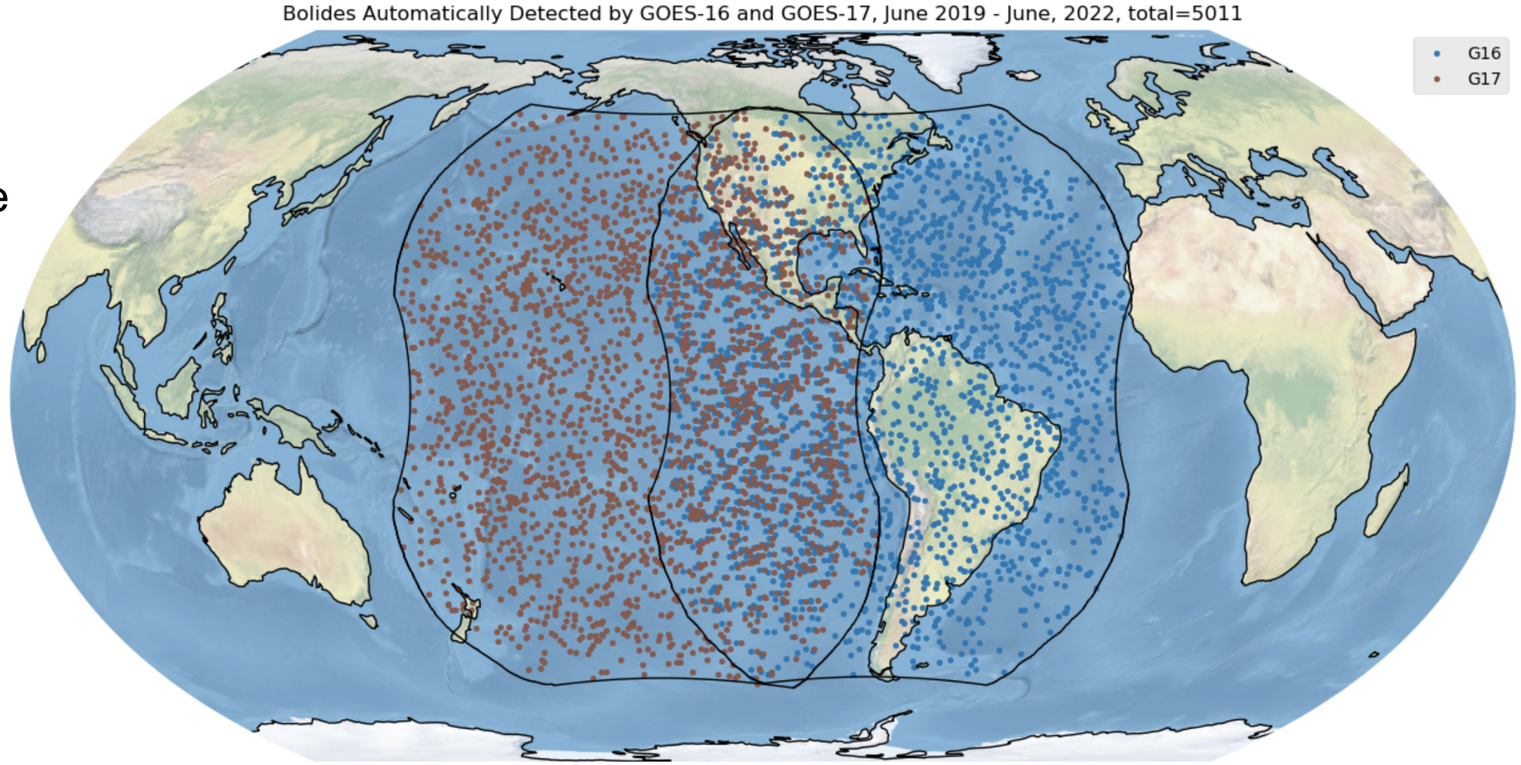
Detection Biases

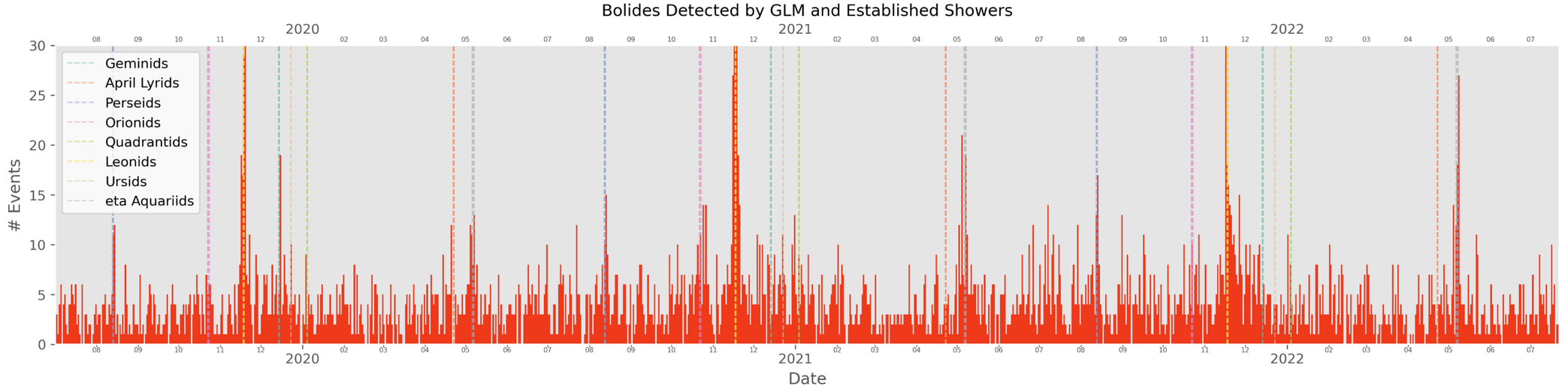
- In order to study the distribution of bolides impacting the Earth, we need to remove all detection biases in the instrument and detection algorithms.



Performance

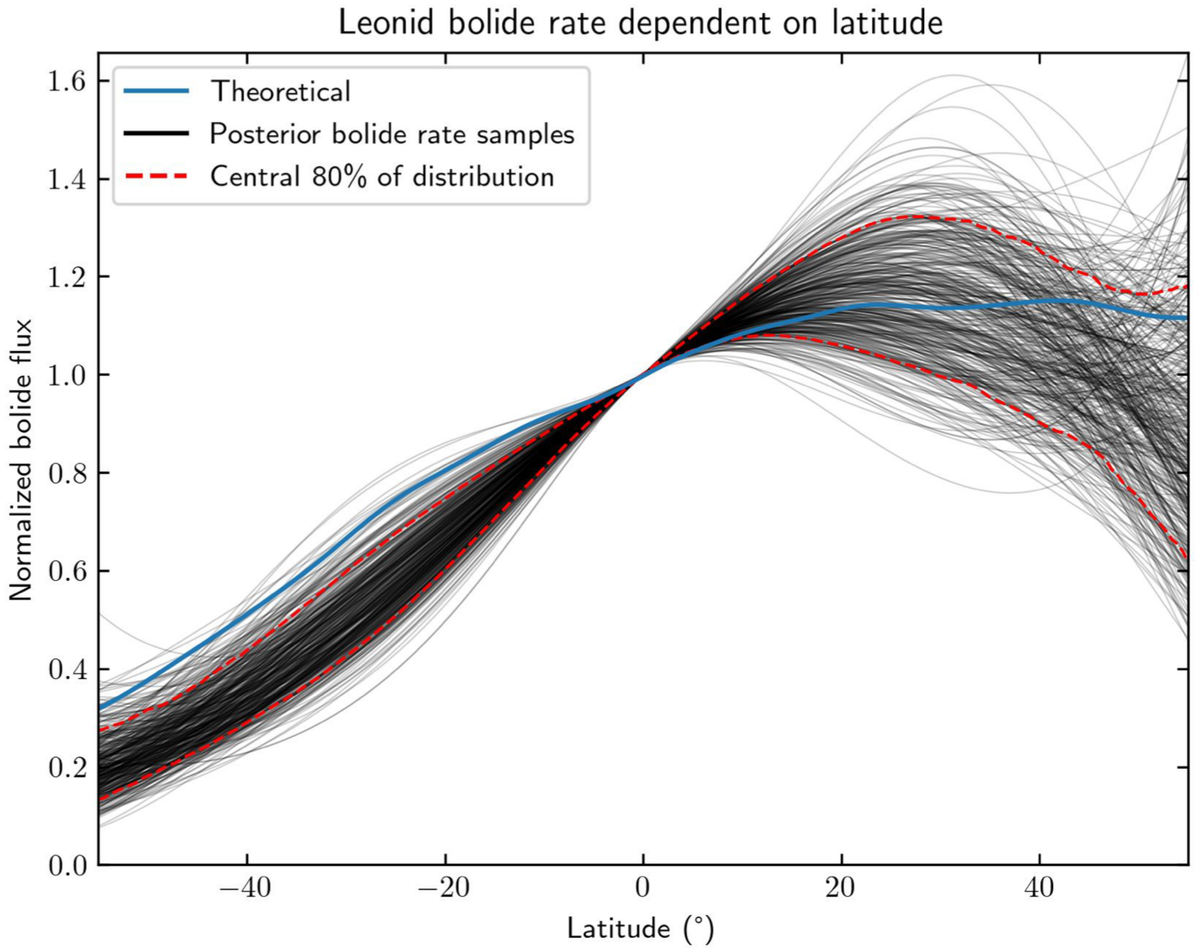
- Current detection precision before manual vetting is 88% and increasing.
- Goal is to be fully automated; no human vetting necessary. Also to report bolides within a minute of the impact.
- Can rapidly reprocess all data for statistically consistent data analysis
- **4079 Bolides** currently published on website (https://neo-bolide.ndc.nasa.gov)
  - Each bolide detection confidence rated (low, median, high).
  - Number detected is huge compared to all previously published bolides.

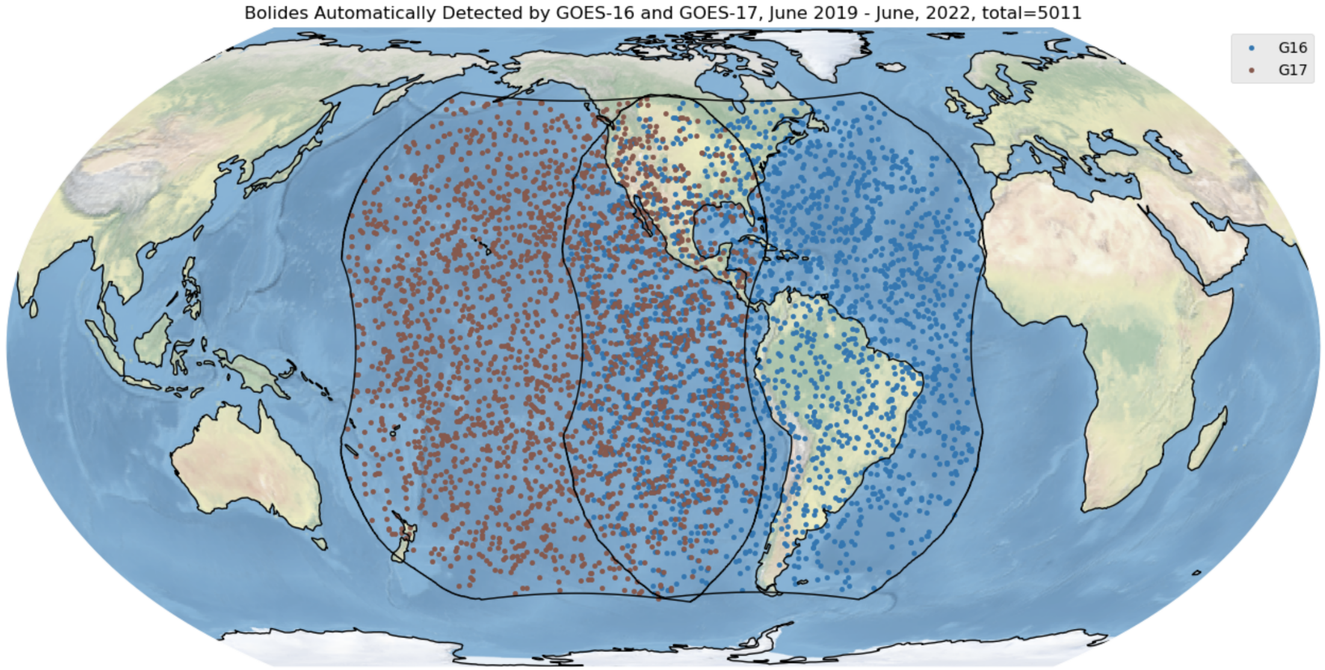




Distribution of Bolides Over Globe

- Want to assess accuracy of theoretical models of bolide impact distribution.
- Developed Markov Chain Monte Carlo Poisson model of bolide impacts.

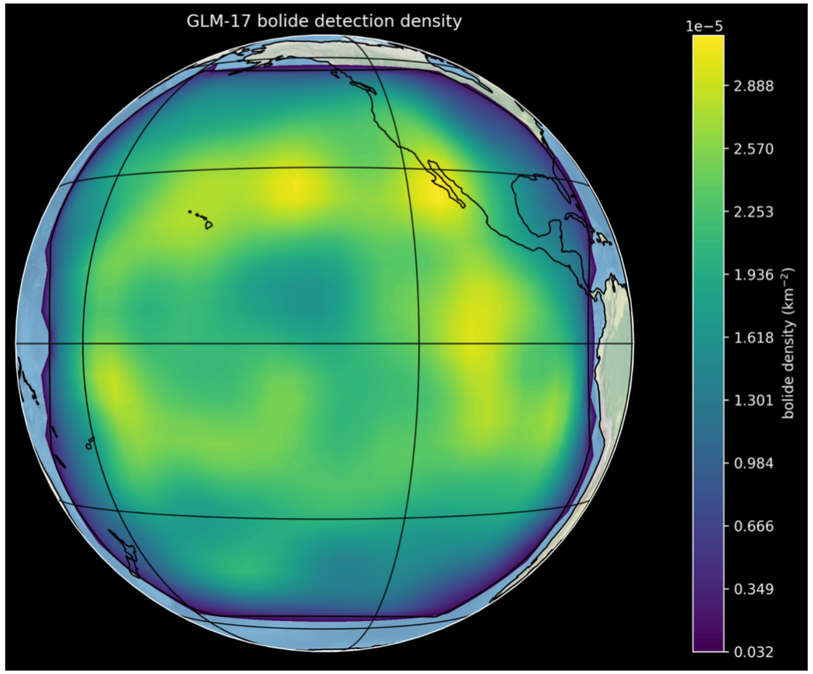


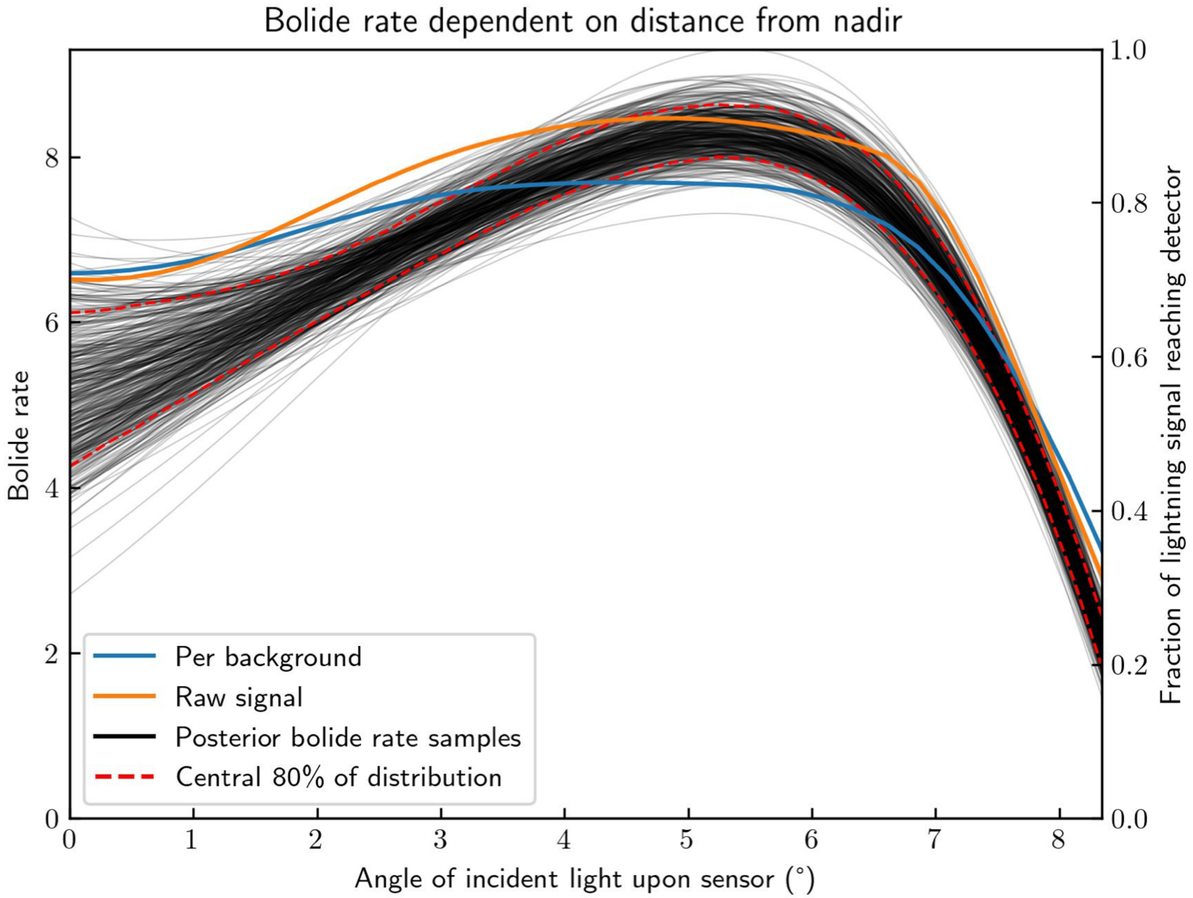


- Account for instrumental biases
  - Non-global FOV
  - More massive and faster bolides expected to be easier to detect
  - Angle of incidence onto CCD will impact detection bandpass
    - A systematic bias in measured energy when using L2 data
- Good agreement with theoretical models

Bolide Detection Efficiency Over GLM FOV

- Bolide detection efficiency varies over field of view.
  - Alignment of bolide flash spectra and GLM bandpass varies with angle of incidence, hence location on globe.
  - GLM ground segment applies a gain correction to account for angle of incidence, we can measure this dependence.

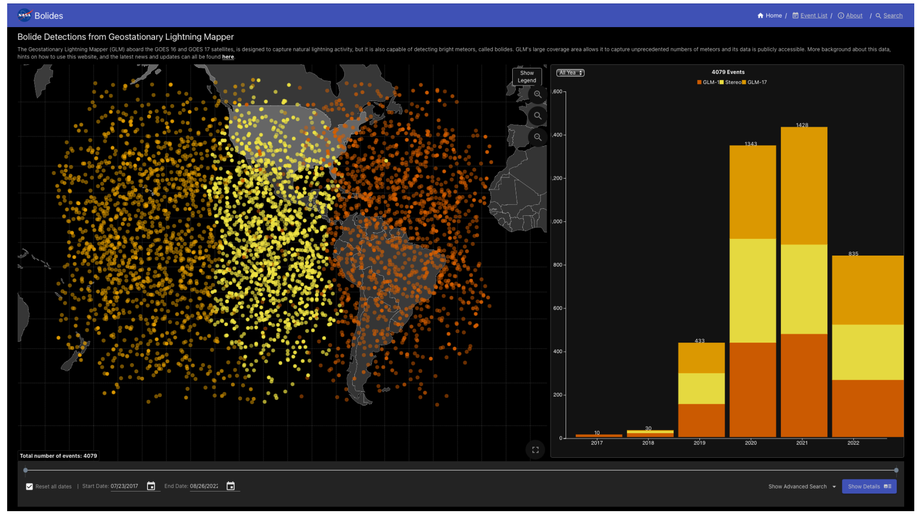




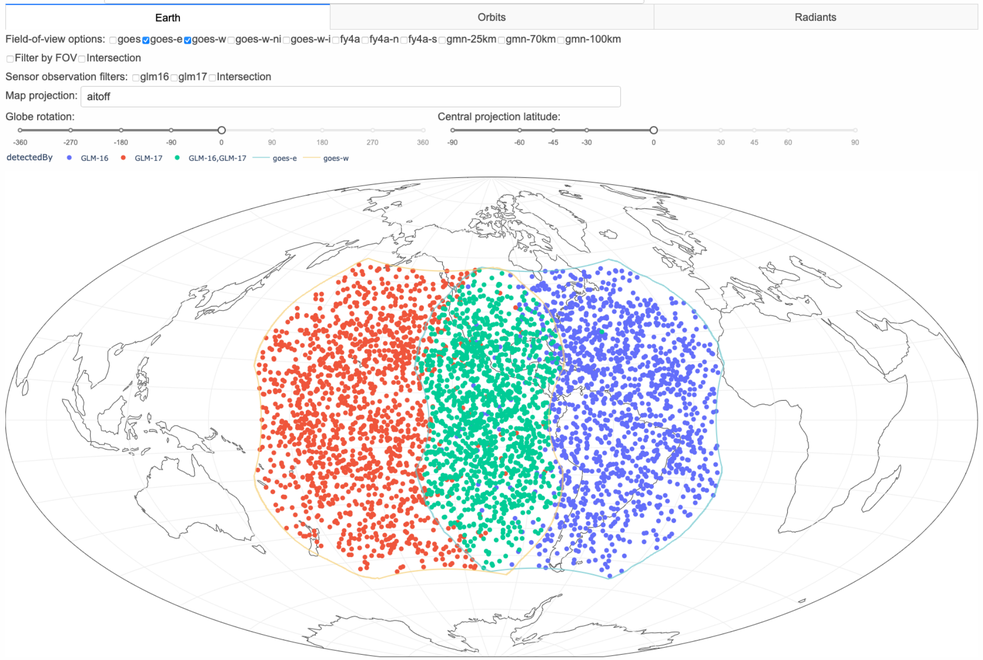
- Bolide models indicate that the ratio of continuum to line emission flux is dependent on the brightness of the bolide, hence, the GLM gain factor is not entirely correct for bolides and we can measure a change in detection efficiency with distance to nadir.
- Our measured dependence with distance from nadir agrees with the gain ratio curve.

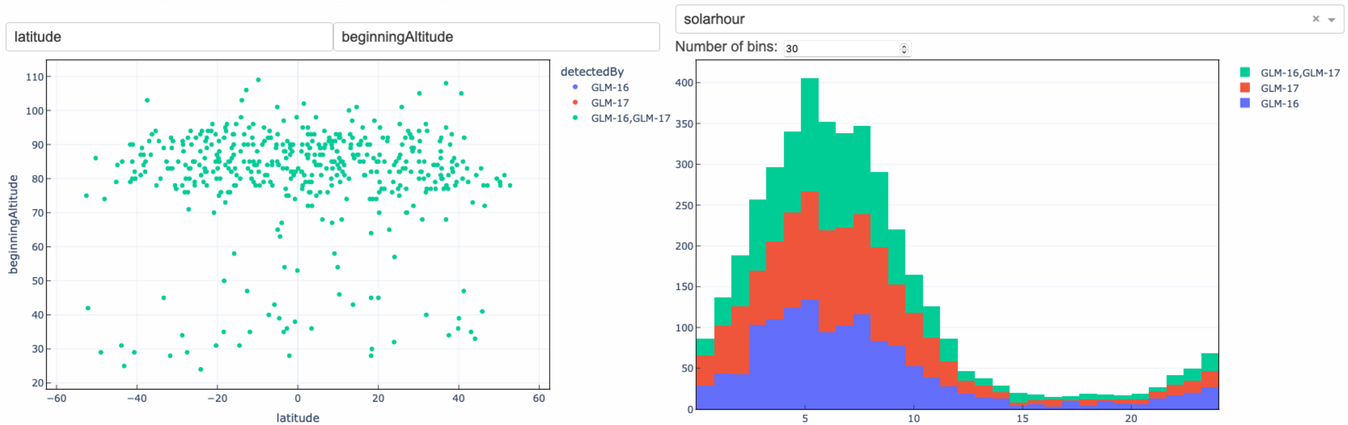
Available Resources

- A now slightly outdated paper:
  - J.C. Smith et al. “An Automated Bolide Detection Pipeline for GOES GLM,” Icarus, Vol 368, 2021
- Official NASA website for fully vetted bolides:
  - **https://neo-bolide.ndc.nasa.gov**



- Experimental Interactive Bolide Data Visualizer:
  - **https://bolides.seti.org**
  - Can view data from:
    1. GLM,
    2. U.S. Government sensors,
    3. Global Meteor Network
    4. IAU Meteor Data Center





- We also have fully automatic data sets which are statistically consistent (versus manually vetted data, but statistically inconsistent, on NASA website)

Thank You

Smith, J. C., et al., An automated bolide detection pipeline for GOES GLM, Icarus, p. 114576. (2021)

https://neo-bolide.ndc.nasa.gov

https://bolides.seti.org