GLM Instrument Performance Verification

GLM Science Meeting
September 27-29, 2016

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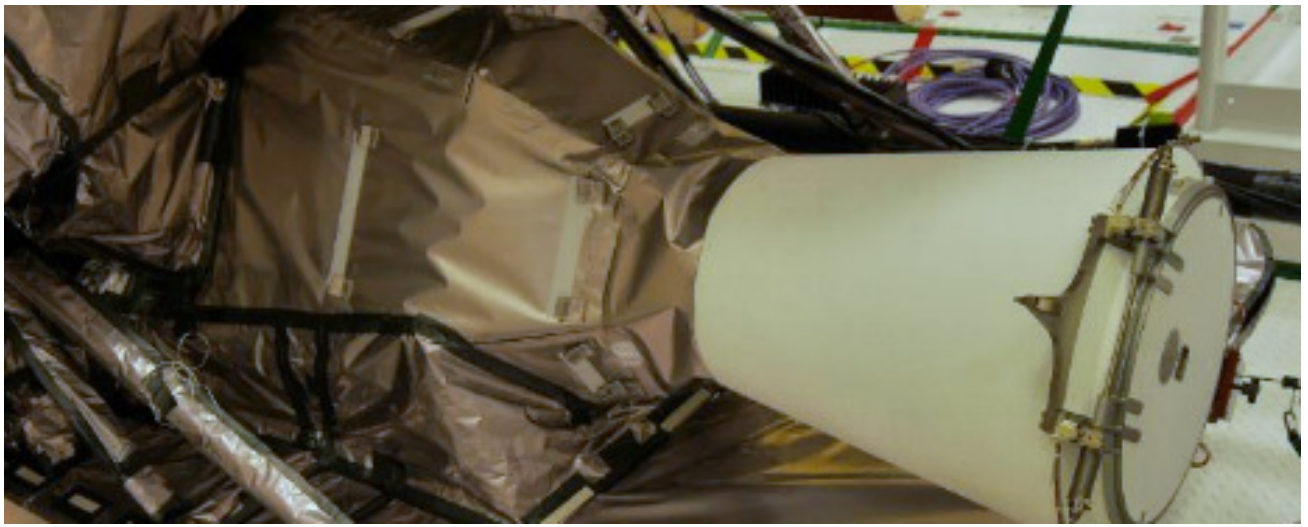
GLM Key Performance Requirements

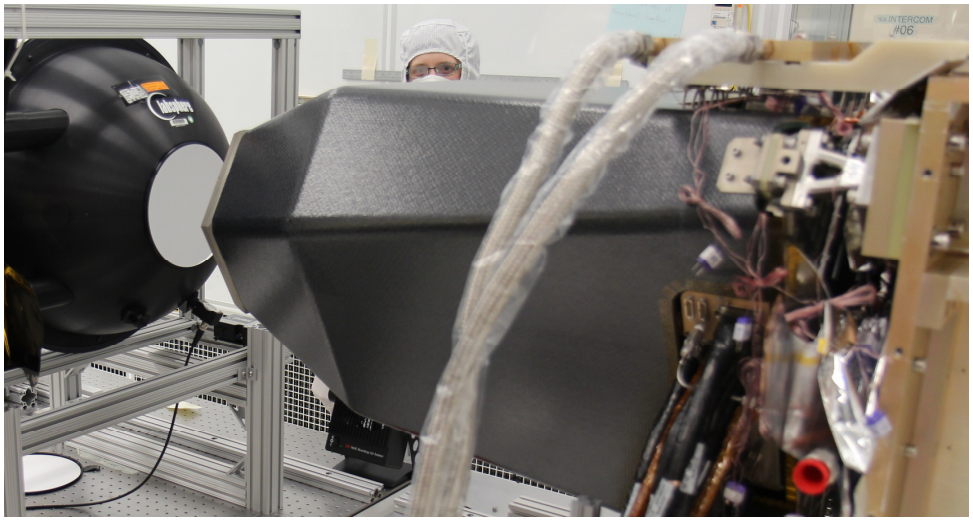
Performance Requirement	GOES-R Capability
Detection efficiency > 70%, averaged over full disk and 24 hours.	> 70%
Coverage required over full disk	Meets coverage requirements
Flash false alarm rate shall be less than 5%, averaged over 24 hours	< 5%
Dynamic range greater than 100 at all times everywhere in FOV	< 100
Navigation error within ±112 microradians (~1/2 pixel or ~4 km)	< 112 µrad

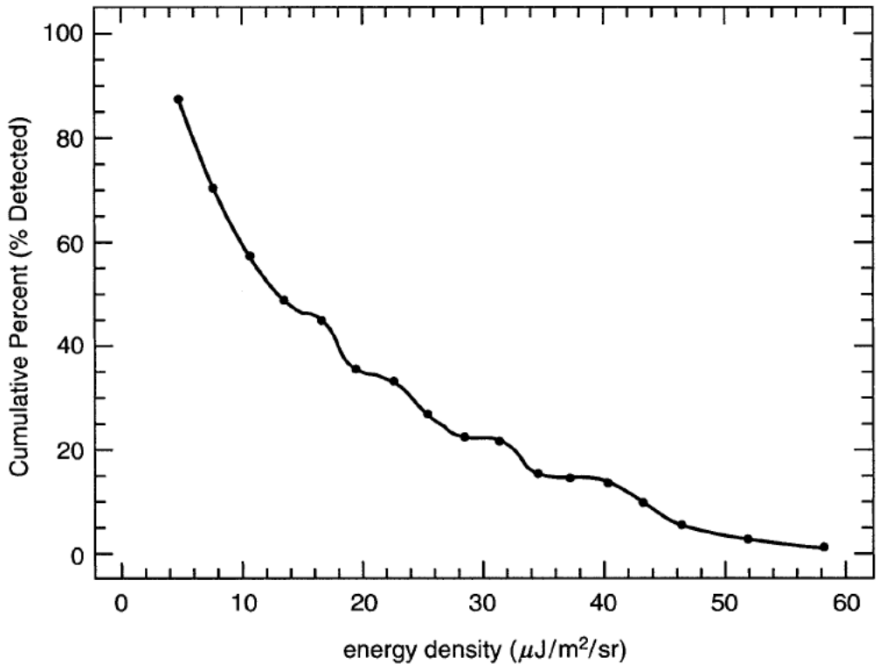


GLM Flight Model 1 Installed on GOES-R

Detection Efficiency

- Verification followed the example set by TRMM LIS
- Static and transient response of the instrument was measured using a calibrated source
- RTEP thresholds were set with a conservative false event rate
- Threshold levels were compared to U2 lightning radiance data to determine detection efficiency
- Final operational detection efficiency will depend on RTEP thresholds selected during PLT

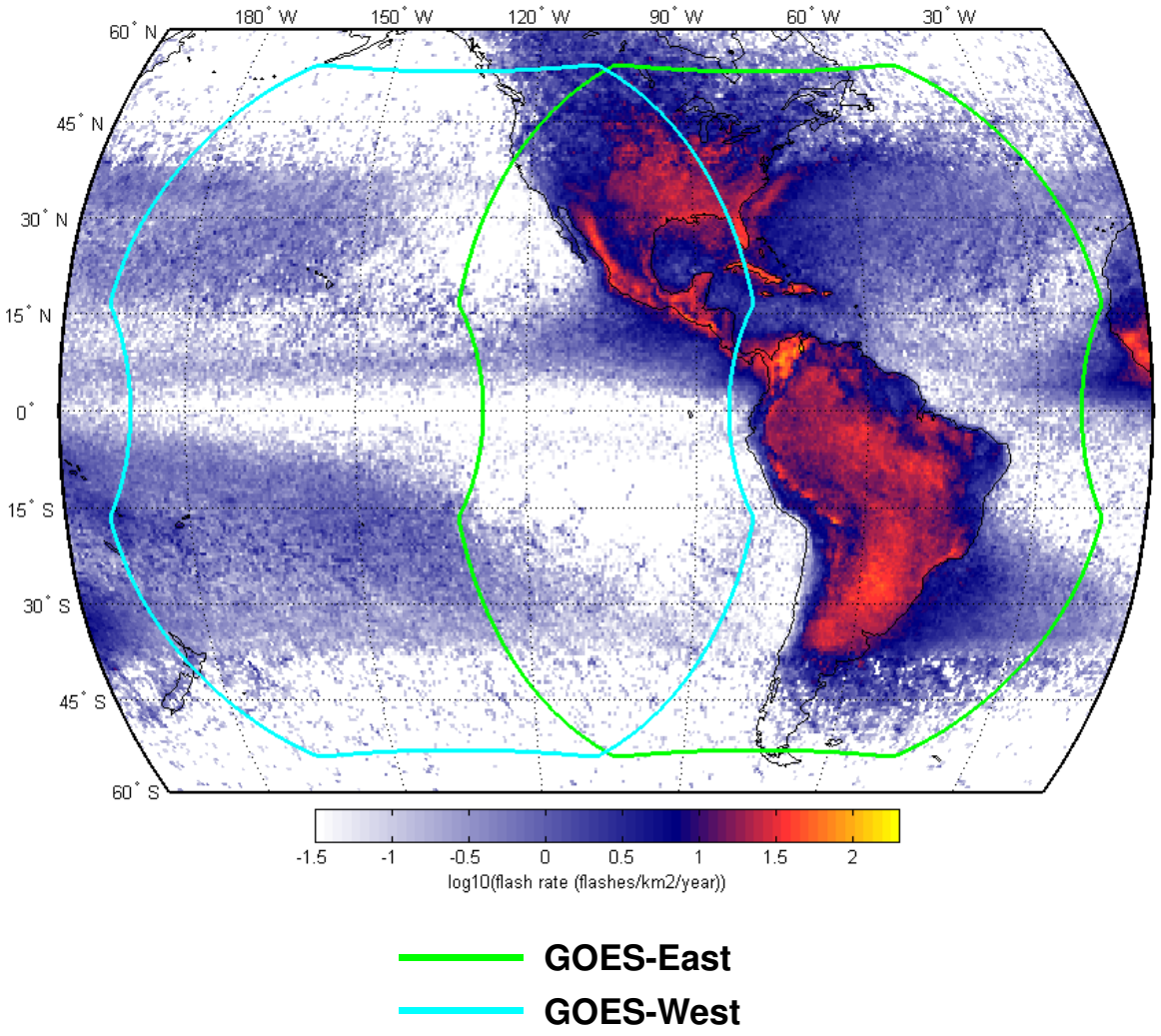




Cumulative distribution of lightning optical energies, derived from U2 aircraft measurements. Used to determine DE for LIS and GLM.

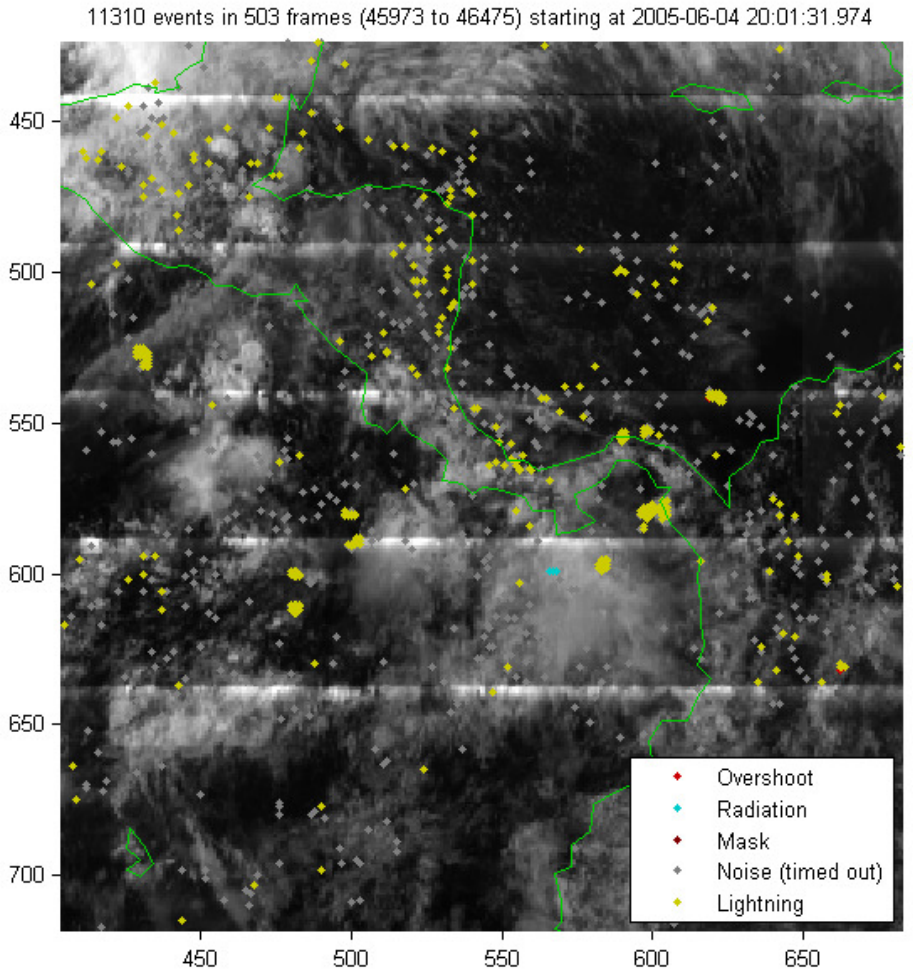
Coverage

- Coverage is verified with a combination of:
  - Measured instrument placement on the spacecraft Earth Pointing Platform
  - Measured internal instrument alignment
  - Measured instrument Field of View



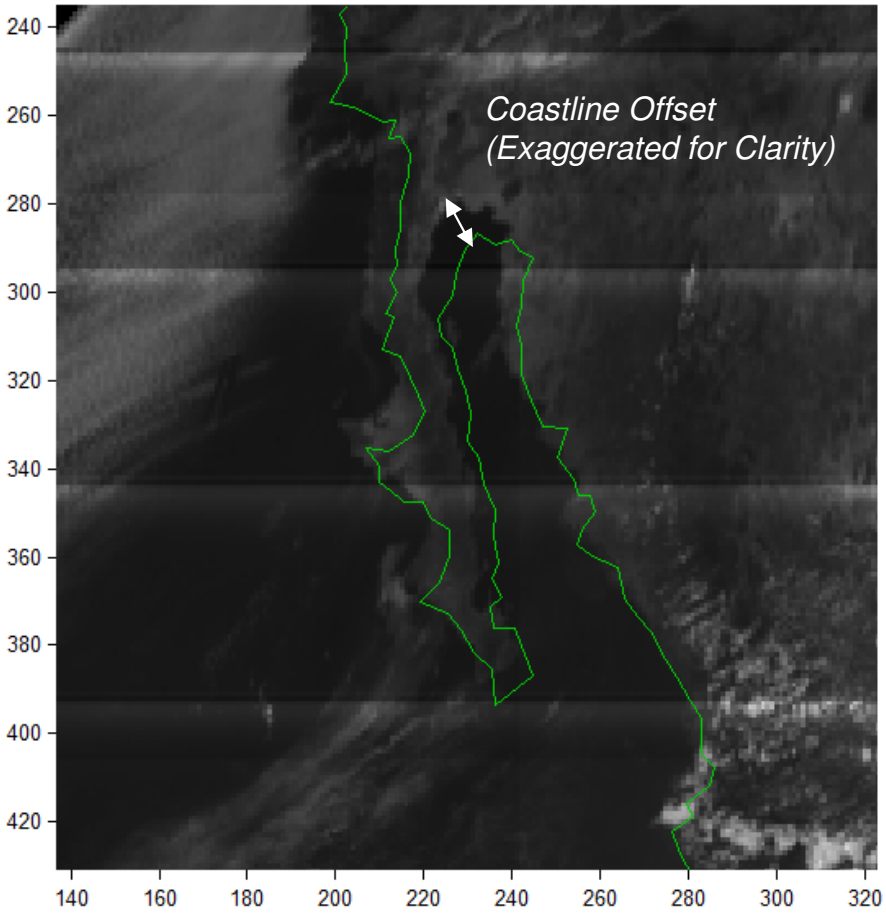
False Alarm Rate

- False alarm rate is defined as the number of false flash detections divided by the average true flash rate
- Verification is by analysis
  - LM implementation of the GPAs is run on simulated and test data sets



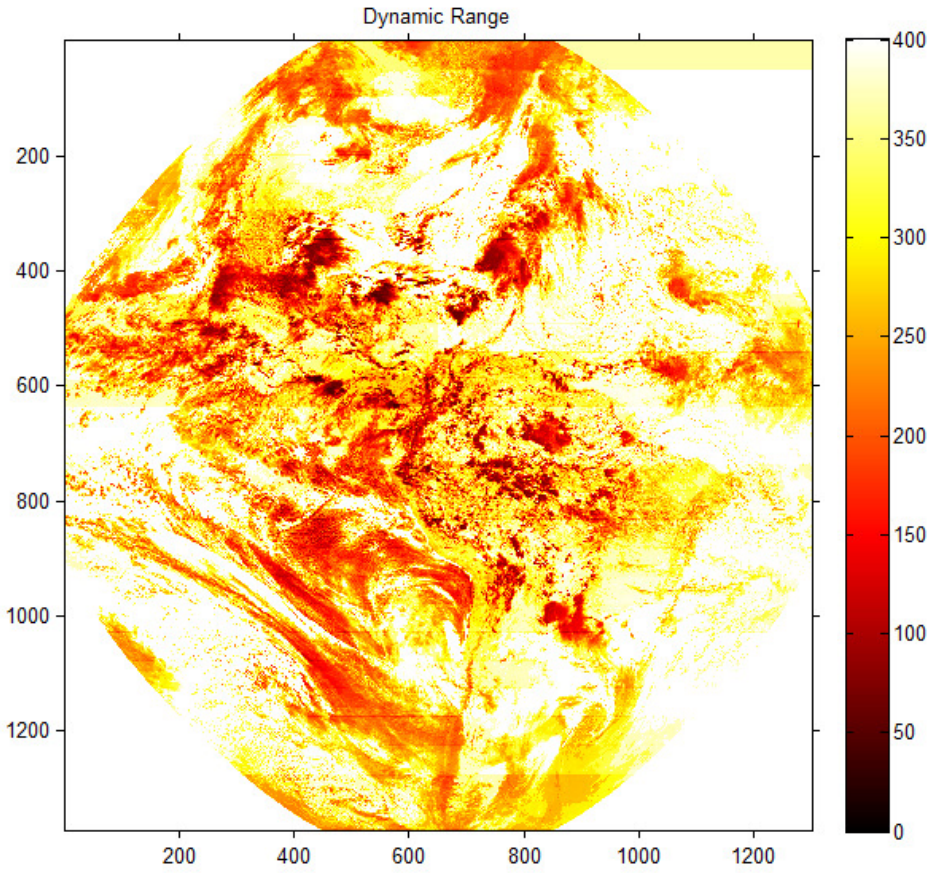
Navigation

- GLM has no internal pointing mechanisms, and relies wholly on the spacecraft for pointing
- We register background images to the coastline database to determine offset between GLM boresight and spacecraft pointing
- We measure the optical distortion to determine pixel to pointing vector transformation
- We use analysis and test to predict internal GLM pointing response to expected temperature distributions



Dynamic Range

- Dynamic Range is defined as the ratio of available headroom above background (under worst case illumination conditions) to the lowest detectable signal (RTEP threshold)
- Due to higher than designed responsivity of the instrument, GLM does not meet the dynamic range requirement at certain times of the day and regions of the FOV
- Impact on Detection Efficiency and False Alarm Rate is expected to be minor, based on simulation of typical cloud background scenes (based on current GOES images)
  - Small percentage of events may be saturated, a condition that is readily detectable



GLM Post Launch Test (PLT) "Vendor" Tools

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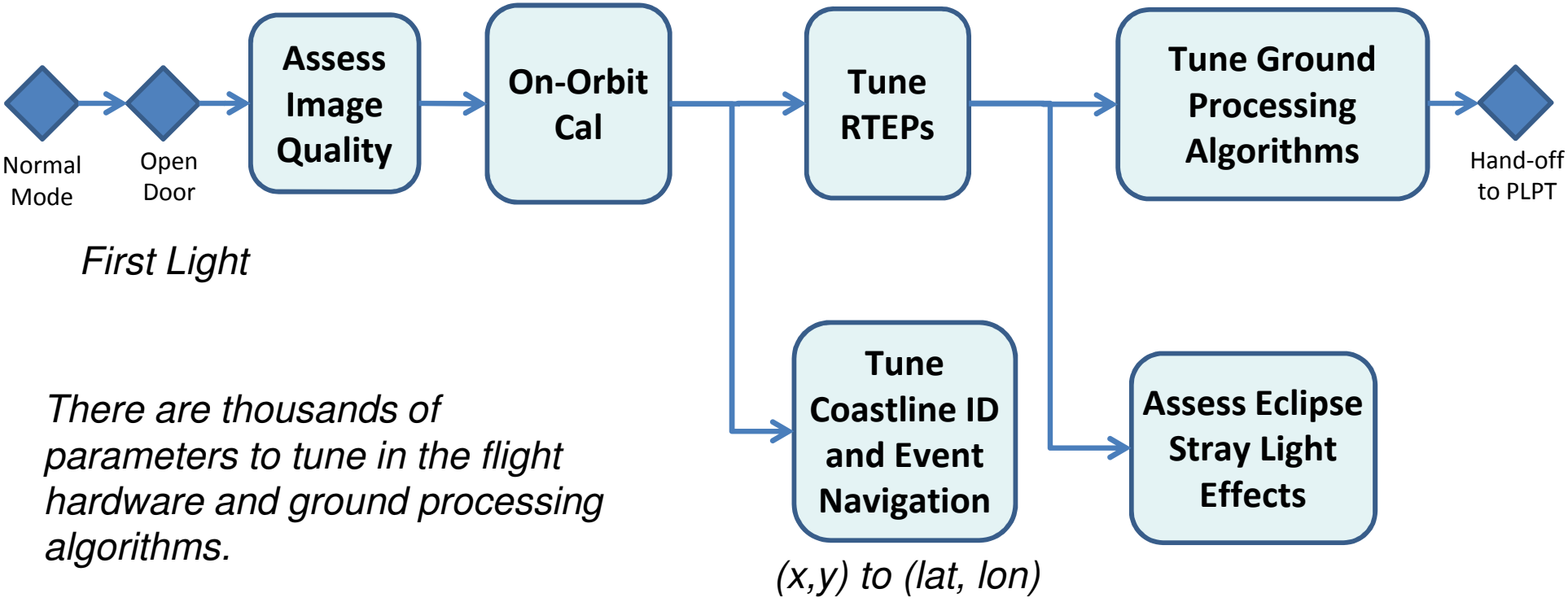
GLM Post Launch Test Flow

Follows Signal Chain: *Electrons → DN* *DN → Events (downlink)* *Events → Level 1b Lightning*



First Light

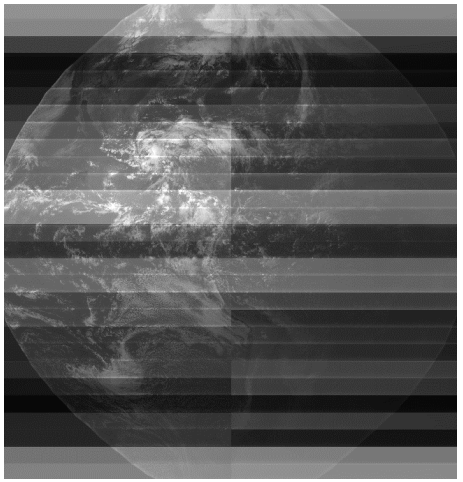
(x,y) to (lat, lon)

There are thousands of parameters to tune in the flight hardware and ground processing algorithms.

Good tools are essential.

Image Quality

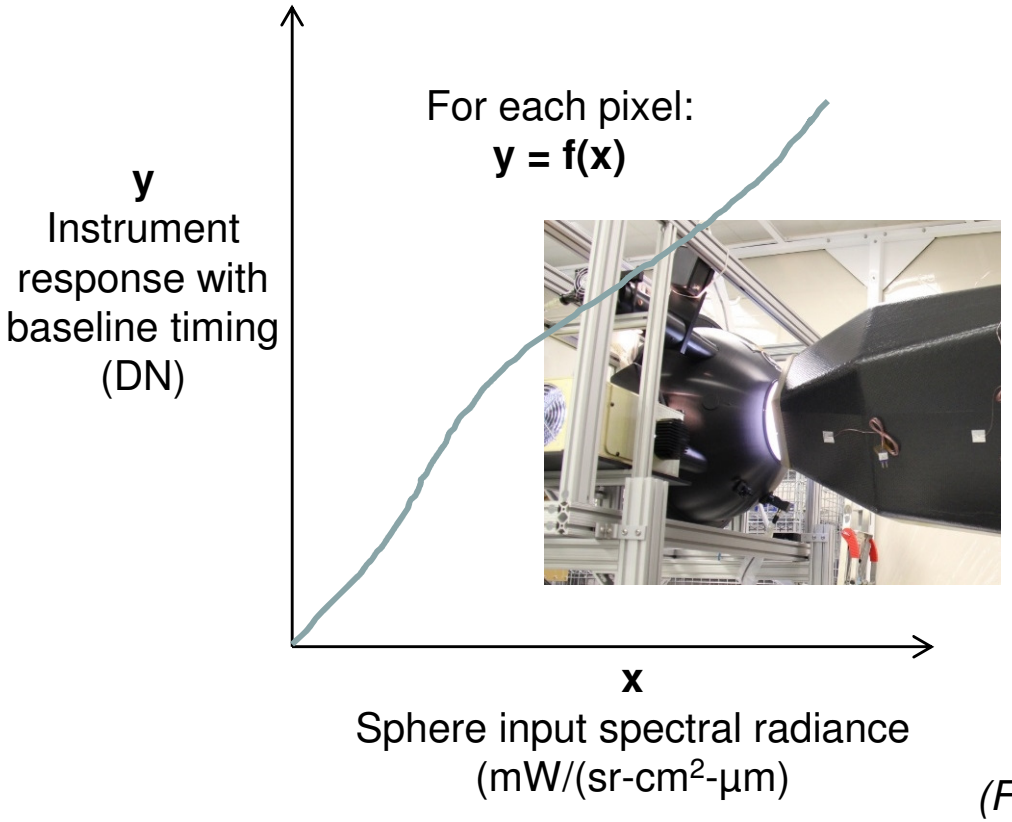
- Video is acquired at 503 fps
- RTEPs maintain an exponential average of the value of each pixel
- Periodically, GLM collects a “snapshot” of this background average
  - In normal mode, this occurs every 150 seconds
  - In “fast background” mode (with the entire science telemetry stream dedicated to background, and no events) this occurs every 12 seconds
- Matlab PLT tool is used to extract image metrics, such as…
  - Cross-cuts, Headroom to ADC saturation, Contrast, Overshoot, Dynamic Range, Estimated gain (DN/(mW/cm^2-sr-µm)), Max, Min, Zones of Reduced Data Quality, Down-sampled images, Histograms, etc.



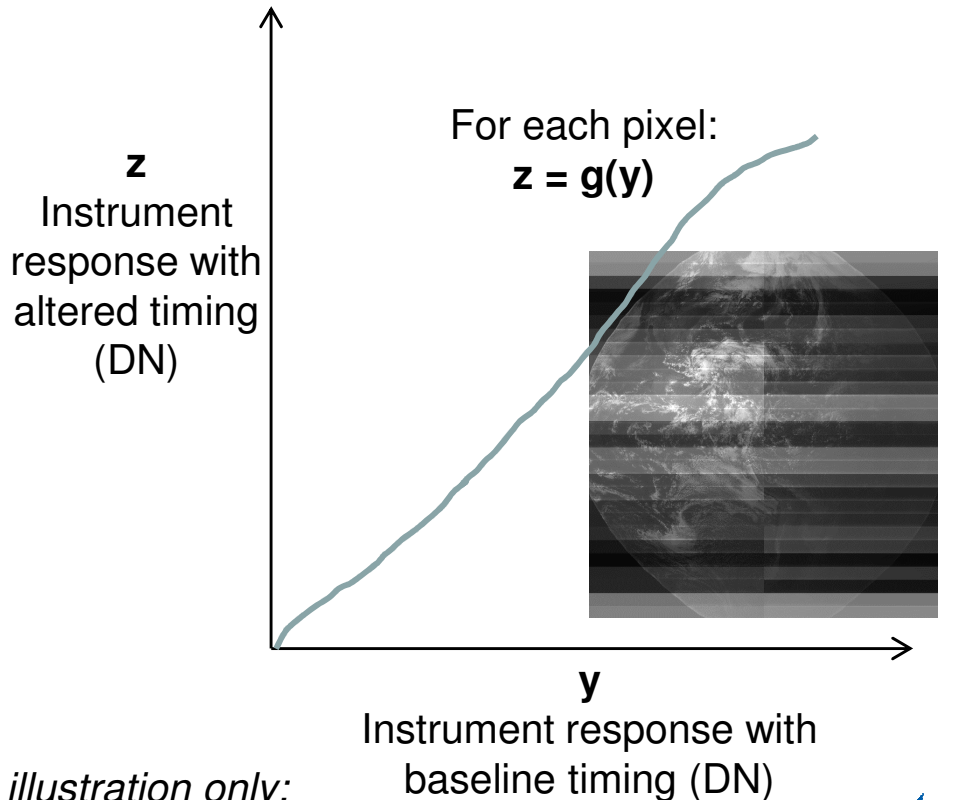
On-Orbit Calibration

- GLM flight software contains a register sweep macro that can "turn knobs" for the on-board camera timing, without ground commanding
- PLT tool extracts a "delta" calibration: **z = g(f(x))**

Ground Calibration



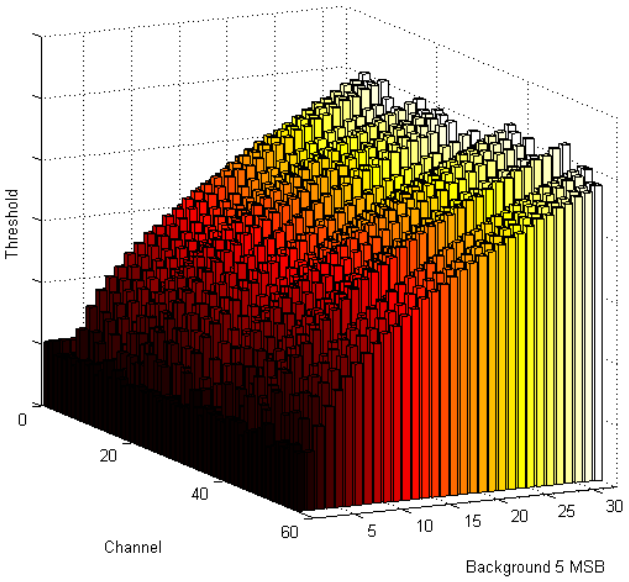
PLT On-Orbit Calibration



(For illustration only; Not real data)

RTEP Detection Thresholds

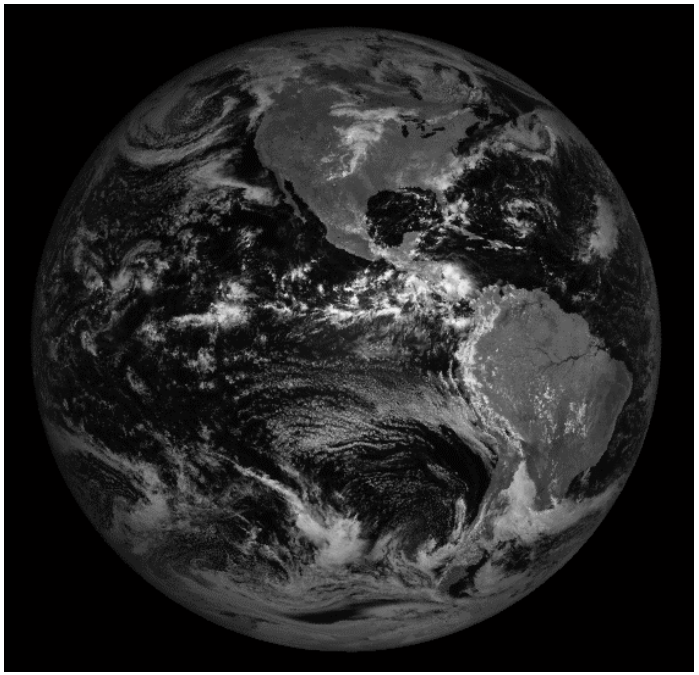
- RTEP = Real Time Event Processor
  - Picks out any positive change in the value of a pixel that exceeds a programmable detection threshold, effectively compressing raw video by ~2000x. The RTEP discards data, so must be tuned carefully!
- RTEPs are like lawn mowers
  - Blade too high → low sensitivity to dim lightning
  - Blade too low → jam the downlink with false events
- 56 channels * 32 BG levels = 1792 thresholds
  - TNR or Threshold-to-Noise Ratio is related to the FER
  - For each threshold, $TNR = \sqrt{2}\, erfc^{-1}(2 \cdot FER/(503))$
  - Initial TNR ~ 5, with a target after RTEP tuning ~4.3
- For RTEP tuning, lightning is a distraction!
  - Can use GPAs to collect only the noise events, and throw out lightning



Example Threshold Table

Coastline ID and Navigation

- GLM reports events in pixel coordinates (x,y)
- Need to translate (x,y) to (longitude, latitude) for L1b lightning data
- Coastline ID is a ground image processing algorithm applied to daytime background images from GLM that identifies coastlines and matches them to known database
  - Result is a boresight offset measurement
- Before PLPT and independent navigation assessment, GLM will perform sanity check on navigation GPA parameters that were determined in ground testing
  - Optical distortion map
  - Temperature sensitivities



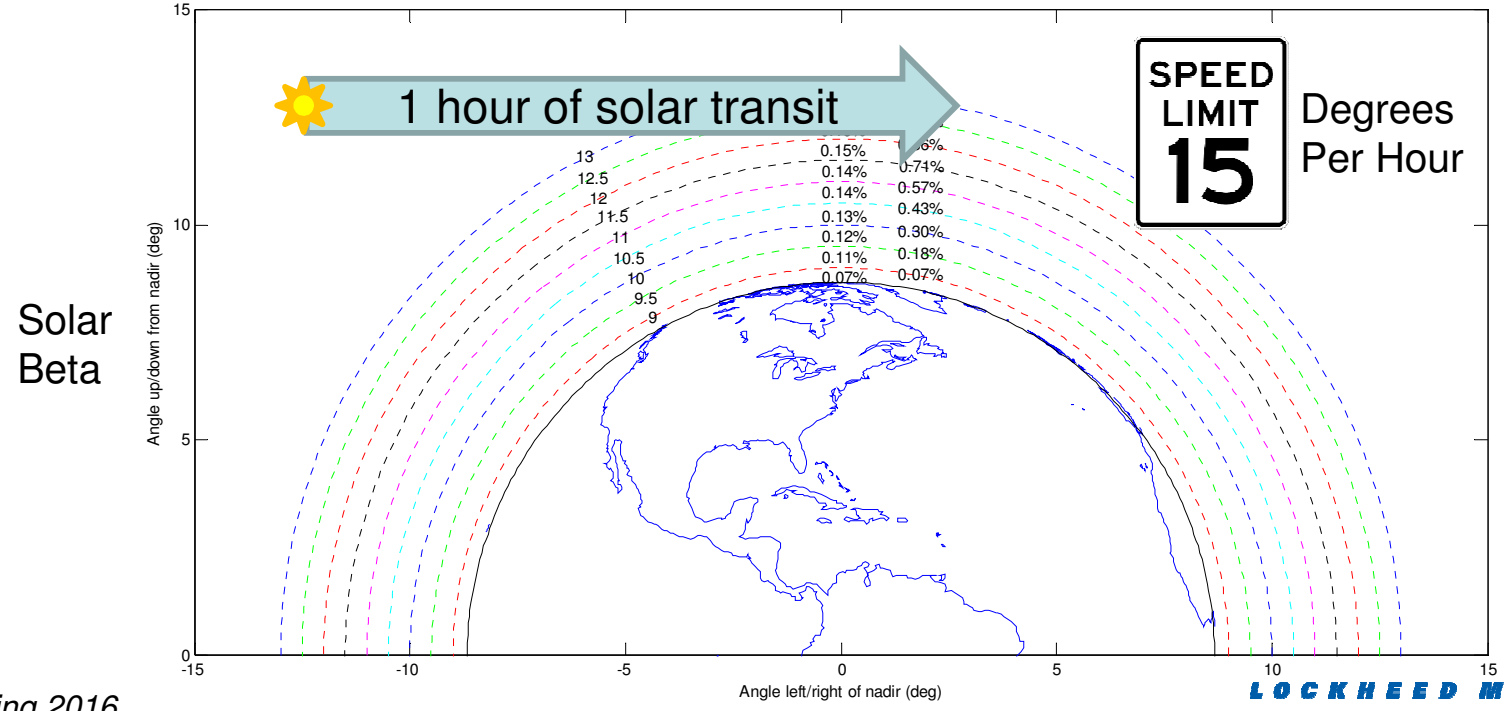
Earth viewed at 780 nm by DSCOVR / EPIC

GPA Filter Tuning

- Ground Processing Algorithms delivered to NASA by GLM vendor
- GPAs are implemented into software by the GS vendor, Harris Corp.
- Ground Processing Algorithm event filters sift out lightning events from other events due to noise, radiation, etc.
  - All event data processing is done on the ground except (by necessity, due to downlink limit) the event detection process.
  - The GPA filters discard data, so must be tuned carefully!
- PLT is performed in Palo Alto on GLM vendor's GPA implementation
  - Does not use GS operational or development environments
  - Requires tight coordination / validation to ensure agreement between GS vendor implementation and GLM vendor implementation
- Matlab PLT tool allows slicing and displaying event data in time and space
  - Regions of interest, selection of filters, etc.
  - This is a Big Data problem (many gigabytes of data per day)

Solar Intrusion Assessment

- The solar disk is ~50000x brighter than a 100% albedo cloud
- During eclipse season, direct solar illumination enters the GLM optics and reaches almost all the way to the focal plane
- The GLM optics are designed to reject (absorb) this direct solar illumination, using geometrical features and coatings
- We will assess impact to lightning detection within the extent of ZRDQ (Zones of Reduced Data Quality). Data quality product is in development.



PLT Outputs and PLPT Handoff

- The output of PLT is a parameter file
  - CDRL079 Calibration Data Books, containing an HDF5 file with the thousands of on-board and ground processing parameters
- PLT may also result in changes to algorithms, or new algorithms
  - This is a new instrument, and current GPAs are only our highly educated guess for what will work best to detect lightning
- In practice, PLPT will overlap with PLT
  - Requires incorporation of PLT results into GS development environment, since PLPT will rely on GS L1b product

```
HDF5 GLM_FM1.h5
GLM_CalibrationParameters
  |-- EventFilters
  |     |-- 2ndLevelThreshold
  |     |-- Burst
  |     |-- Coherency
  |     |-- ContrastLeakage
  |     |-- Crosstalk
  |     |-- FrameTransfer
  |     |-- Glint
  |     |-- Mask
  |     |-- Overshoot
  |     \-- Radiation
  |-- INR
  |     |-- Coastline
  |     |-- Navigation
  |     \-- UniversalParameters
  |-- InstrumentParameters
  |-- RadiometricCalibration
  \-- SpacecraftParameters
```