Evaluation of Geostationary Lightning Mapper (GLM) Navigation Performance with the INR Performance Assessment Toolset (IPATS)

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September 26, 2018

SPIE Asia-Pacific Remote Sensing Symposium
Earth Observing Missions and Sensors: Development, Implementation, and Characterization V
Outline

• GOES/Geospatial Lightning Mapper overview
• IPATS and INR evaluation overview
  – General overview
  – GLM-specific challenges and optimizations
• Post-processing quality filtering
• Example results and conclusions

Image from NASA SPORT (Short-term Prediction Research and Transition Center; https://weather.msfc.nasa.gov/cgi-bin/sportPublishData.pl?dataset=goeastglm&product=group&loc=conus
GOES-R series earth-observing payloads overview

<table>
<thead>
<tr>
<th>ABI – Level 1B</th>
<th>GLM – Level 1β</th>
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<tbody>
<tr>
<td><strong>Spectral</strong></td>
<td></td>
</tr>
<tr>
<td>16 bands, 0.4 μm to 14 μm</td>
<td>Single band (777 nm)</td>
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<tr>
<td><strong>Spatial Resolution</strong></td>
<td></td>
</tr>
<tr>
<td>Fixed Grid (FG) coordinate system with sample spacing of 14, 28, or 56 μrad (0.5, 1, or 2 km at nadir)</td>
<td>8 km at nadir, 14 km at edge of field</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td></td>
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<tr>
<td>• Full Disk (FD): 17.4 deg diameter centered at nadir</td>
<td>Near full disk</td>
</tr>
<tr>
<td>• CONUS: Rectangular, 5000 km EW x 3000 km NS</td>
<td></td>
</tr>
<tr>
<td>• Mesoscale: Rectangular, 1000 km EW x 1000 km NS</td>
<td></td>
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<tr>
<td><strong>Temporal</strong></td>
<td></td>
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<tr>
<td>FD: 5 or 15 min; CONUS: 5 min; Mesoscale: 30 sec</td>
<td>150 sec</td>
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<tr>
<td><strong>Acquisition</strong></td>
<td></td>
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<tr>
<td>Scan</td>
<td>Stare</td>
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</table>

ABI “GeoColor” image with GLM overlay from 6/14/18; Animation from NOAA/NESDIS Regional and Mesoscale Meteorology Branch (RAMMB): http://rammb.cira.colostate.edu/ramsdis/
**GLM INR Assessment**

- The formal GLM level 1B product is navigated lightning events
- Camera alignment errors are assessed using coastline matching (coastline identification in GLM background images, misregistration assessment between detected coastlines and coastline database)

- Background images themselves do not have formal image navigation and registration (INR) requirements
- The GOES-R flight project performs independent verification and validation of the INR performance of ABI and GLM
  - GLM INR is assessed via the background images after “downsampling” by the ground system
  - While the background images do not have formal INR requirements, their navigation accuracy is generally considered to be a helpful proxy for event navigation accuracy (i.e., background image INR accuracy is suggestive of event navigation accuracy but does not constitute a formal navigation accuracy validation)
IPATS evaluation modes

• Navigation (NAV) error (ABI & GLM)
  – *Difference between location of pixel in data product and true location*

• Frame-to-frame registration (FFR) error (ABI)
  – *Relative navigation error of corresponding pixels of same band in consecutive images*

• Swath-to-swath registration (SSR) error (ABI)
  – *Relative navigation error of two neighboring pixels on opposite sides of image swath boundary*

• Channel-to-channel registration (CCR) error (ABI)
  – *Relative navigation error of corresponding pixels of different bands in the same frame*

• Within-frame registration (WIFR) error (ABI)
  – *Difference between radial separation of two pixels on the FG and their true angular separation*
  – *Computed from ABI NAV measurements*
**IPATS image registration by correlation**

For NAV, shifted sub-image is cropped from ABI or GLM image, stationary sub-image is truth map:
- High contrast Landsat 8 derived chip projected to FG for ABI NAV
- **ABI image for GLM NAV**, with GLM background image resampled to fixed grid

For more detail on IPATS, see De Luccia et al., 2016, SPIE Asia Pacific Remote Sensing

*Common error estimation concept for all evaluation modes except ABI WIFR*
GLM-specific optimizations

• Downsampled GLM background images:
  – *Have very coarse resolution w.r.t. ABI images (~224 µrad vs 28 µrad for ABI B3)*
  – *Lack regular pixel spacing*
• To perform navigation w.r.t. ABI data, the images must be on a common pixel grid
• IPATS has incorporated an irregular grid resampling algorithm
  – GLM and ABI images are resampled to a common (“ABI-like”) pixel grid at user-specified sampling; GLM NAV baseline resamples to native ABI resolution
  – Careful optimization of resampling factors and evaluation window size has been performed

Irregular grid resampler concept: GLM grid (every 10 pixels illustrated)
GLM-specific optimizations

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Irregular grid resampler concept: ABI-like (regular) grid
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Irregular grid resampler concept. Solid blue lines represent GLM pixels, dotted black lines the regular ABI-like grid. A local search algorithm assigns GLM pixels to resampled pixels.
Distribution of IPATS correlation windows

- IPATS correlations are performed for a number of small image subsets ("windows") across the image extents
- Windows drawn from the location of the Landsat-based chips used for ABI NAV and a regular grid of windows
- Windows are enabled and disabled for various evaluation modes
- GLM-specific optimizations included tailored window sizes, and disabling of windows over water and close to the edge of the disk/GLM field of regard
**GLM Datasets**

- 2 3-day sets, full 24 hours, denser sampling during illuminated periods
  - 28 Sep 2017: 2017, DOY 260-262 (9/17-9/19)
- Processed to downsampled background image format via offline process (Adam Milstein, MIT/LL, Donald Chu, NASA GSFC)
- 28 Sep 2017 is the training set for quality filter threshold tuning

![Diagram showing time spacing]
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IPATS results quality filtering

• Correlation results from all windows span a range of “quality” levels
• Many windows exhibit reduced performance due to factors such as varied illumination conditions, variable scene content or cloud motion, errors in the correlation process, etc.
• Filtering in post-processing attempts to emphasize correlation results where misregistration is due to real navigation offsets as opposed to such other competing factors
• GLM NAV uses four parameters to perform quality filtering. The baseline configuration includes carefully tuned thresholds for each parameter; since GLM NAV is a relative assessment (no absolute truth), optimization trades reduced dispersion against sample size
  – Solar zenith angle (reject low sun conditions); SZA
  – Analytic measurement uncertainty: parameterization of false misregistration resulting from noise sources described above for otherwise perfectly registered images; aMU
  – Clear sky ratio: Ratio of clear/probably clear to cloudy/probably cloudy pixels based on ABI level 2 cloud mask product; CSR
  – 9*median absolute deviation extreme outlier rejection; MAD
Progressive application of quality filtering: Unfiltered

- Scatterplot of $x$ vs $y$ errors for the 28 Sep 2017 (training) set
- All correlations in the dataset surviving the indicated filter are illustrated
- Error indicates the relative NAV error for the GLM window w.r.t. ABI “truth”

![Unfiltered Scatterplot](image)

$n = 94949$
Progressive application of quality filtering: SZA

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Progressive application of quality filtering: SZA + AMU

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SZA < 75°, AMU < 2.52 µrad
Progressive application of quality filtering: SZA + AMU + CSR

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*Bimodal distribution results from a known artifact of the GLM focal plane*
### Results for example datasets

Summary results capturing properties of error distributions, as illustrated in previous charts

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<tbody>
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<td></td>
<td>N Hem</td>
<td>N Hem</td>
<td>S Hem</td>
<td>S Hem</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>11.2</td>
<td>10.0</td>
<td>11.3</td>
<td>12.1</td>
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<tr>
<td>$\sigma_y$</td>
<td>9.5</td>
<td>9.5</td>
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<tr>
<td>Mean X</td>
<td>-18.1</td>
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<td>$</td>
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<tr>
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<td>10322</td>
<td>5764</td>
<td>2062</td>
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<tr>
<td># images</td>
<td>186</td>
<td>166</td>
<td>175</td>
<td>141</td>
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All shaded rows in units of microradians (µrad)

Results are after quality filtering and hemisphere stratification
Temporal trends
One point per GLM background image

- NAV estimates are relatively stable over the analysis period
- Expected trend in dispersion with sample size
- General correlation in sample size with illumination (time)
  - Irregular nature likely due to variable temporal offset (inter- and intra-image) between ABI and GLM images
**Discussion**

- Error “metric” of mean + 3σ is ~40-50 µrad (~100 µrad NS in S Hem)
- Navigation accuracy requirement for navigated lightning events is 112 µrad
- IPATS NAV results for GLM background images are suggestive of NAV accuracy of lightning events
- Results suggest GLM NAV compliance with L1B requirement
- Sample size issues (note discrepancy between 28 Sep and 31 Oct sets) are likely due to cloud cover differences; sample size issues are a focus of ongoing research

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Sample size issues

- Bars indicate total number of correlations per 24 hour period (ending 23:59 UTC) after quality filtering.
- Fewer samples in S Hem are observed consistently.
- Sample size issues are under active research; may be linked to cloud cover/distribution in this case.

**Insufficient sample size leads to poor statistical INR assessment**
Conclusions

• Functional independent GLM NAV evaluation with IPATS has been demonstrated.

• Baseline quality filtering is effective at clarifying true INR performance.

• Filtered results from the two datasets considered herein suggest compliance with GLM NAV requirements.

• Sample size issues are the focus of ongoing research efforts.

• Analysis of GOES-17 GLM are forthcoming.
Backup Materials
CSR Histograms

CSR, 092817 Set, 12/22/17 Baseline

CSR, 103117 Set, 12/22/17 Baseline
CSR Histograms, N Hem

CSR, 092817 Set N Hem, 12/22/17 Baseline

CSR, 103117 Set N Hem, 12/22/17 Baseline
CSR Histograms, S Hem

CSR, 092817 Set S Hem, 12/22/17 Baseline

CSR, 103117 Set S Hem, 12/22/17 Baseline