On-Orbit Verification of GLM Navigation on GOES-16

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Abstract

The GOES-R flight project has developed the Image Navigation and Registration (INR) Performance Assessment Tool Set (IPATS) to perform independent INR evaluations of the optical instruments on the GOES-R series spacecraft. In this presentation, we document the development of navigation (NAV) evaluation capabilities within IPATS for the Geostationary Lightning Mapper (GLM). We also discuss the post-processing quality filtering developed for GLM NAV, and present example results for several GLM background image datasets. Initial results suggest that GOES-16 GLM is compliant with navigation requirements.

Introduction

The Geostationary Operational Environmental Satellite-R Series (GOES-R) is the next generation of geostationary weather satellites for the United States [1], the first of which was launched on November 19, renamed "GOES-16" upon reaching geostationary orbit, and designated "GOES-East" upon reaching its operational position over the western Atlantic.

The primary optical payload on GOES-16 is the Advanced Baseline Imager (ABI), a scanning multispectral imaging radiometer [2].

GOES-16 also includes a newly-developed instrument – the Geospatial Lightning Mapper (GLM). The first operational lightning mapper flown in geostationary orbit, GLM measures total lightning activity continuously over the Americas and adjacent ocean regions, enabling forecasters to focus on developing severe storms much earlier, before they produce damaging winds, hail, or tornadoes [3].

The GLM level 1b product is near real-time optical lightning events that have been calibrated, navigated and time tagged.

GLM also generates regular snapshot "background images" of its field of view. These images are not a formal product and thus do not have formal navigation requirements, but are considered a proxy for approximate INR performance [4].

The GOES flight project performs independent assessments of the GLM INR performance by evaluating the background images with IPATS [5].

IPATS Overview

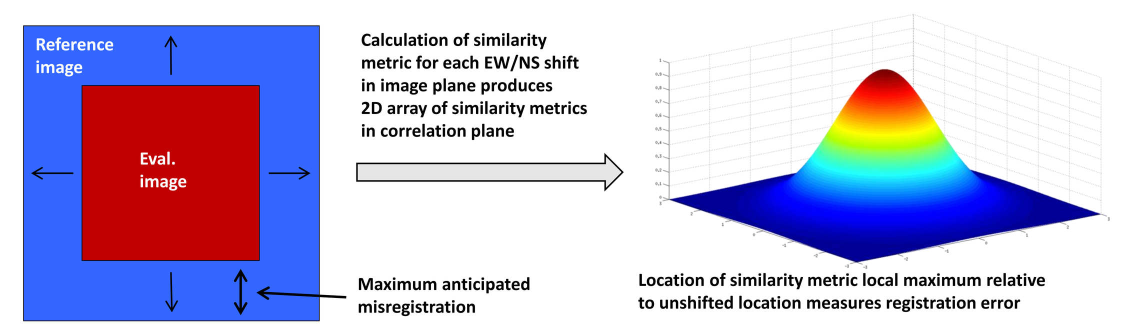

Figure 1: Cross correlation approach to INR evaluation using image registration. The evaluation image is shifted within the reference image, and the misregistration is determined from the offset between the similarity metric maximum and the unshifted location. Modified from [5].

- The Image Navigation and Registration (INR) Performance Assessment Tool Set (IPATS) was developed by the GOES-R Flight Project to facilitate evaluation of INR performance of the ABI and the GLM.
- IPATS is comprised of two related tools, the Image Pair Selector and Evaluator (IPSE) and the Output Database Analysis Tool (ODAT).
- IPSE determines the misregistration in pixels between two input images. IPSE can perform this analysis using a variety of image correlation algorithms and pre-processing optimizations. ODAT is used for post-processing of IPSE output and generating reports. More detail is provided in [5].
- For relative assessments, images are compared to other images of the same type (e.g., ABI image to ABI image).
- For absolute assessments, images are compared to truth images.

IPATS approach to GLM Navigation (NAV)

- IPATS computes the misregistration between navigated GLM background images and well-calibrated ABI level-1b imagery. ABI band 3 (0.86 µm, 28 µrad/pixel) has been found to offer the best performance as a reference band.

GLM Background Images & Resampling

- GLM mitigates parallax effects at large off-nadir angles using a non-traditional irregular focal plane pitch (pixel size) [3].
- While typical geostationary imagers (e.g. ABI) collect data that is regularly sampled in angular (fixed grid) space [6], the GLM background images have non-uniform angular spacing because of the novel focal plane design [4].
- IPATS includes a special irregular image resampler that enables GLM background images to be treated as if they had a regular grid. This resampler is illustrated in Figure 2.
- The current baseline configuration resamples both ABI and GLM images to an intermediate resolution of 56 µrad/pixel.

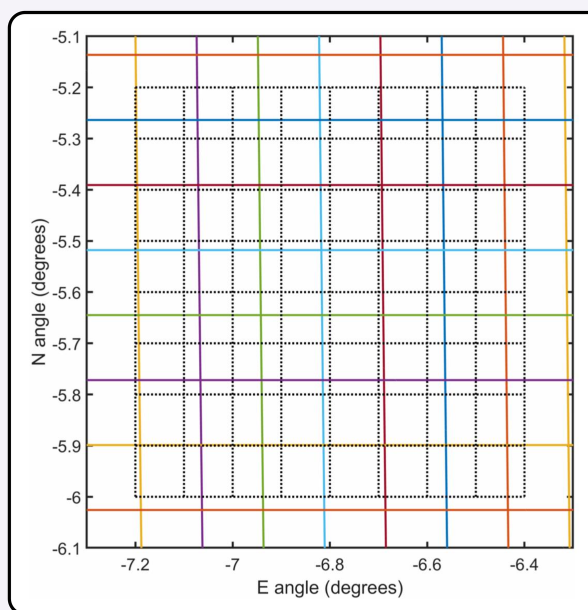

Figure 2: Conceptual illustration of GLM irregular angle resampler algorithm. Solid colored lines indicate the angular coordinates of the GLM pixels (lines are plotted every 10 pixels), and the regular "ABI-like" grid is shown in dotted black lines. A local search algorithm is employed to assign GLM pixel values to resampled pixels.

GLM NAV evaluation locations

- IPATS performs correlation analyses at a series of geographic locations defined a priori; an example is provided in Figure 3.
- Locations (called "windows") are defined by the IPSE input location database file.
- For GLM NAV, windows are excluded from analysis if their center is over water, as the dominant error in such locations tends to be driven by cloud motion.
- Windows are also excluded if they are close to the edge of either the earth limb or of the GLM field of regard.

Figure 3: Illustration of GLM evaluation locations for the 89.5° W longitude checkout orbit. Points illustrate the centers of the evaluation location "windows". Locations are defined based on the locations of the Landsat chip truth images used for ABI NAV evaluations plus a set of regular grid locations. Windows near the edge of the limb of GLM field of view are excluded and not shown in this figure. Background image source: NASA.

IPATS results quality filtering

- IPATS evaluates INR performance for an image by analyzing statistically a set of localized correlations.
- Many of the local correlations suffer from reduced accuracy for a variety of reasons (clouds/cloud motion, illumination conditions, scene content differences from truth image, errors in the correlation process, etc.).
- Judicious filtering of results to exclude such correlations dramatically improves the INR assessment. Appropriate quality filtering is of particular importance to GLM NAV, because of the temporal offset between a GLM background image and the temporally-closest ABI image (cloud motion is a major concern).
- Significant effort has been expended to optimize the filtering for GLM NAV.
- The parameters used for quality filtering of GLM NAV results are analytic measurement uncertainty (AMU), solar zenith angle (reject extreme low sun angles), extreme outlier rejection using the median absolute deviation (MAD), and the "clear sky ratio" (fraction of cloudy to clear pixels based on the ABI clear sky mask product). The progressive application of these filters is illustrated in Figure 4.
  - AMU is a mathematical construct that parameterizes the level of false misregistration derived, for images that are perfectly navigated and registered, resulting from noise sources such as variation in illumination conditions, scene content differences, and error in the correlation process.
  - AMU incorporates image contrast, image size (number of pixels) and the typical magnitude of image perturbations not associated with image translations. For more detail, please see [5].
- GLM NAV is a relative assessment (no absolute truth), so filtering thresholds are evaluated by trading reduced dispersion against maintaining sufficient sample size for reliable statistics.
- Baseline quality filtering thresholds were selected from analysis of multiple full days of GLM background images collected in fall, 2017.
- The illustrated filtering is considered the baseline configuration for processing other GLM background image datasets. The thresholds are revisited as-needed to ensure that they are tuned appropriately for newer background images.

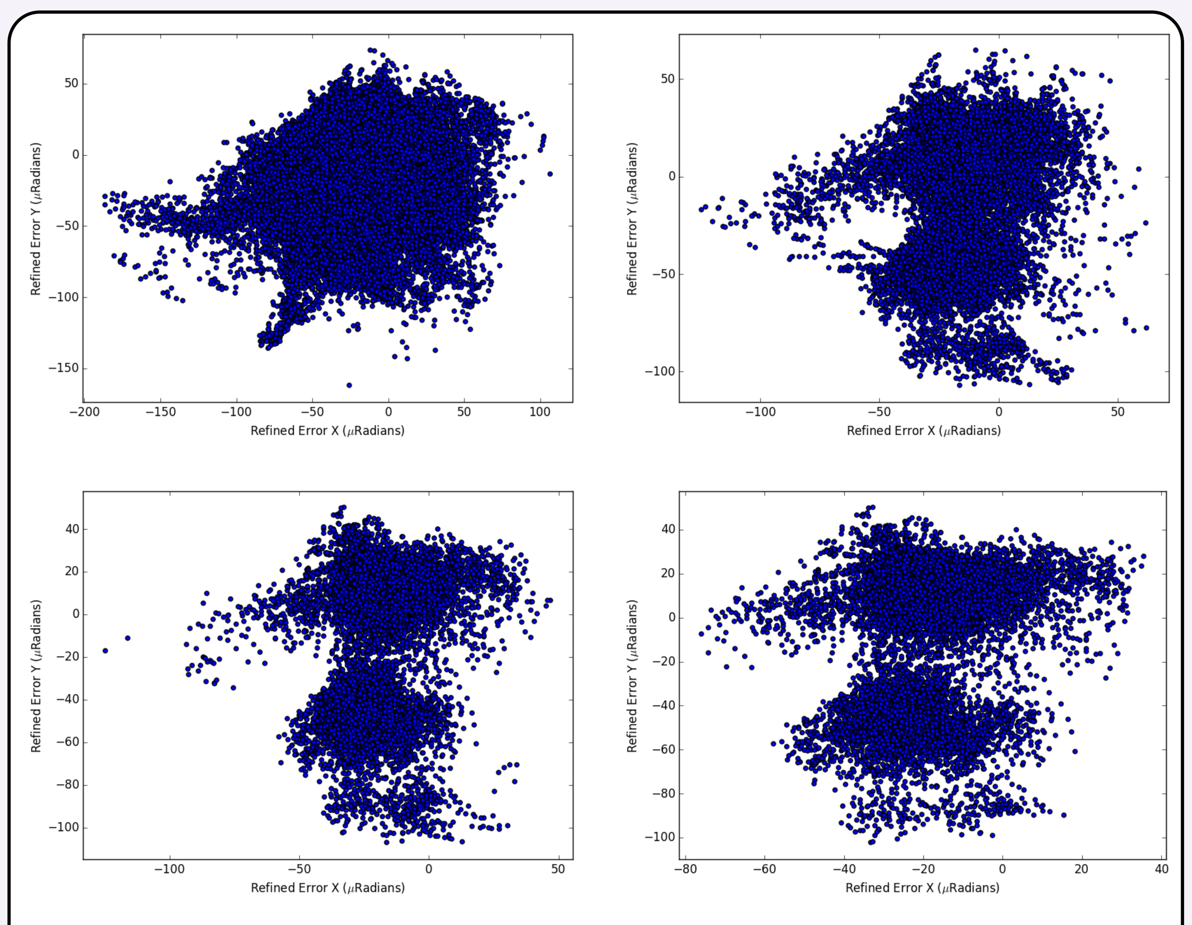

Figure 4: Progressive application of quality filtering thresholds to the filter training dataset. Plots show Y (NS) error vs. X (EW) error in microradians (µrad). UL: SZA<75°; UR: AMU<2.52 µrad; LL: CSR>250 (25%); LR: Addition of 9*MAD extreme outlier rejection. The bimodal N/S behavior is an artifact of a GLM focal plane anomaly and is addressed via hemispheric stratification of results.

Example GLM NAV results

Table 1: GLM NAV results for two datasets collected in fall 2017. The results are presented as means compiled across the full multi-day span and stratified by hemisphere in each case. The 092817 (MMDDYY) set is the quality filter "training set", and these results are illustrated in Figure 4 (LR). The 103117 set was evaluated using the filtering thresholds derived from the 092817 set. While the number of individual correlations (n) is smaller in the 103117 results, in both cases the metric of mean X or Y error plus 3σ suggests compliance with the GLM NAV specification of 112 µrad [7]. Systematic NAV error between N and S hemispheres is a known artifact that is not currently addressed by the GLM NAV algorithm.

	092817, N	103117, N	092817, S	103117, S
σ_x	11.246	10.047	11.328	12.092
σ_y	9.499	9.474	15.394	14.261
Mean X	-18.090	-14.047	-22.438	-27.196
Mean Y	12.709	11.369	-49.847	-54.095
$\lvert\bar{X}\rvert + 3\sigma_x$	51.828	44.188	56.422	63.472
$\lvert\bar{Y}\rvert + 3\sigma_y$	41.206	39.791	96.029	96.878
n	15420	10322	5764	2062
# images	186	166	175	141

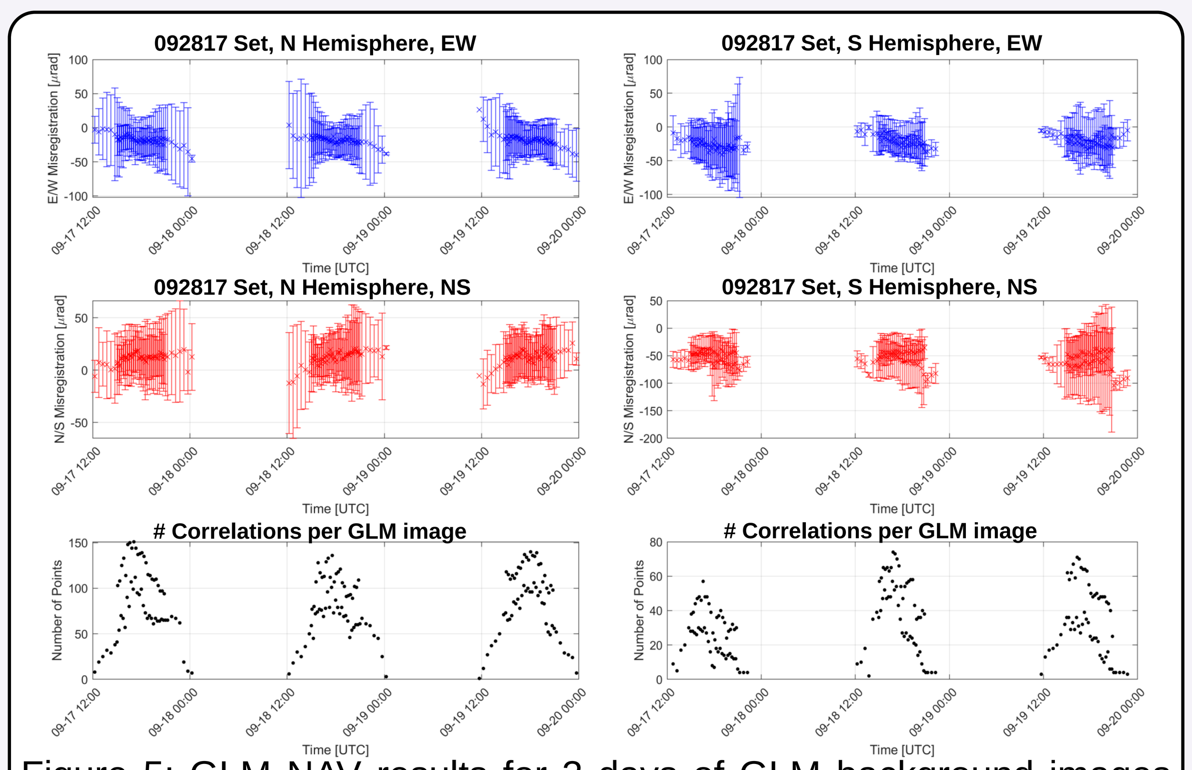

Figure 5: GLM NAV results for 3 days of GLM background images from September 2017. Quality filtering has been applied as described above. Results are shown as a function of GLM background image acquisition time, on a per-image basis. Error bars on the EW and NS plots are ±3σ.

- In both datasets presented above (Table 1, Figure 5), results suggest compliance with the GLM NAV spec of 112 µrad [7].
  - While GLM background images are not a formal GOES product and thus do not have navigation requirements, they are navigated with the same algorithm as the lightning events (which are the formal level 1b product), and thus the navigation performance (NAV) of the background images can be considered a proxy for the NAV of the lightning events.
  - Recall that IPATS is the GOES flight project's tool for performing independent evaluation of NAV performance. IPATS results are suggestive of the formal GLM NAV performance, but the IPATS assessment is not a formal validation of GLM NAV w.r.t. the requirement.
- The 103117 set has a smaller number of correlations remaining after filtering. This is likely due to increased cloud cover over a few key areas of the disc during those collections.
- Sample size roughly follows the expected trend with time of day, with maxima near local noon (Figure 5, bottom). The somewhat irregular nature of this correlation is likely due to the discrete spatial sampling of the disc (Figure 3) and variable temporal offset between the ABI and GLM images.

Summary/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.

References

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