Mitigating the GOES-17 ABI Thermal Anomaly Using Predictive Calibration

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ABSTRACT

The GOES-17 Advanced Baseline Imager (ABI) has an anomaly with its on-board cooling system that prevents it from maintaining its Focal Plane Modules (FPMs) at cold, optimal temperatures. Because of this, during certain times of the year the FPMs and their detectors warm and cool throughout the day. Changing the detectors' temperature changes their response to incoming radiance, which leads to calibration errors over time and degrades the imagery.

Numerous mitigation strategies have been implemented to reduce the solar insolation on the instrument and to mitigate image degradation, including semi-annual yaw flips and changing the integration time of the detectors twice daily. These and other mitigations all work with the baseline calibration algorithms currently in place on the GOES-R Ground System. In an attempt to reduce the image degradation even further, the ABI vendor designed a new calibration scheme that predicts key parameters forward in time to account for the drifting FPM temperatures. These parameters, the linear gain term and dark current scene, are nominally updated on orbit every 5 minutes and 30 seconds, respectively. However, even at these relatively short cadences the detectors can change temperature, thereby rendering the parameters invalid for accurate calibration. By projecting these parameters forward in time the radiometric bias is reduced and image quality improves.

This Predictive Calibration modification was deployed to operations on July 25, 2019, following several months of extensive testing and optimization by the GOES-R science teams. During this time several parameters and thresholds were tuned to ensure Predictive Calibration was turning on and off at the optimal times. Since going into operations users have seen noticeable improvement to the imagery and its calibration. This paper will discuss the fundamental assumptions behind the baseline equations and highlight the changes introduced by Predictive Calibration. Results will show the improvements to the calibration of the operational L1b products and reduction in image degradation.

Keywords: GOES-R, GOES-17, ABI, Advanced Baseline Imager, calibration, image quality

1. INTRODUCTION

The Advanced Baseline Imager (ABI) flown aboard the Geostationary Operational Environmental Satellites (GOES)-R Series provides enhanced spatial, spectral and temporal imaging capabilities compared to the legacy GOES-N Series. Channels 1-6 span the visible/near-infrared (VNIR) portion of the electromagnetic spectrum (0.47 – 2.25 µm), while the remaining 10 channels (7-16) span the mid- to long-wave infrared (MWIR, LWIR)[1]. Collectively these latter 10 channels are known as the infrared (IR) channels. ABI acquires radiometrically calibrated imagery of the Full Disk (FD), Continental Unites States (CONUS), and Mesoscale regions (MESO). During nominal, "10-minute Flex Mode" operations, ABI images the FD every 10 minutes, CONUS every 5 minutes, and one of two MESO regions every 30 seconds (each MESO region is imaged once per minute)[2].

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The second ABI was launched aboard GOES-17 on March 1, 2018. During the post-launch checkout phase an anomaly was discovered with the cooling system. The cryocoolers and loop heat pipes were unable to effectively transfer heat to the radiator. This meant the instrument could not maintain the focal plane arrays at the optimal operating temperature of 60 K. Numerous mitigation strategies were developed by the GOES-R Flight Project and the ABI instrument vendor[3, 4], L3Harris. Together, these actions successfully allowed ABI to collect imagery with its focal planes at a baseline temperature of 81 K and produce quality products[5]. ABI can maintain this baseline temperature for most of the year except for the times of day and days of the year when sunlight directly illuminates the entrance optical port. During those periods, the weeks before and after both equinoxes, the sun shines directly into the optical port for several hours of the day about satellite midnight. This sunlight overloads the cooling systems causing the focal planes to warm. As each detector warms and cools, its response to incoming light falls out of family with its neighbors leading to image degradation. When the focal planes warm too much the detectors saturate. This lasts until the cooling system recovers and cools the focal planes back to the nominal operating temperature of 81 K.

The nominal calibration algorithms[1] are predicated on the fundamental assumption that the detectors are "cold and stable". This validates the principle of updating calibration parameters periodically, then using them forward in time to calibrate earth data as it is acquired. When the detectors are cooled to their optimal operating temperature any drift in the calibration parameters is small compared to the uncertainty requirements of the instrument and algorithms. For the cold dark signal, ABI acquires views of space, ("Spacelooks") every 30 seconds. For the linear gain term ("gain"), ABI images its internal blackbody (the Internal Calibration Target, ICT) once per "10-Minute Flex Mode" (termed "Mode 6", one of the operational Timelines ABI uses to acquire imagery)[1]. As part of the GOES-17 thermal anomaly mitigation, a second view of the ICT was added midway through the 10-minute Timeline[2].

To even further mitigate the impacts of the cooling system anomaly the ABI vendor and the Flight Project designed the Predictive Calibration algorithm. This algorithm was to be used only with GOES-17 during the times when the detector temperatures were rapidly rising or falling. This paper will detail how the nominal calibration algorithms fail when the detectors are warming and cooling[4], how Predictive Calibration helps mitigate this, and results showing the improvement to the L1b products due to Predictive Calibration.

2. THE PREDICTIVE CALIBRATION ALGORITHM

2.1 Nominal calibration when detector temperatures are changing

When ABI's IR detectors are no longer "cold and stable" the calibration parameters rapidly lose validity during the time in-between calibration views. This is best illustrated in Figures Figure 1 and Figure 2 which depicts the raw counts acquired by ABI during a nominal Full Disk swath for both GOES-16 and 17.

For GOES-16, where the cooling systems are able to maintain the focal planes at the ideal temperature of ~60 K, the counts recorded by ABI when viewing space on each side of earth are within family (Figure 1a). For GOES-17 the space counts rise by 0.4% (up to 30 counts) over the course of the swath (Figure 2a).

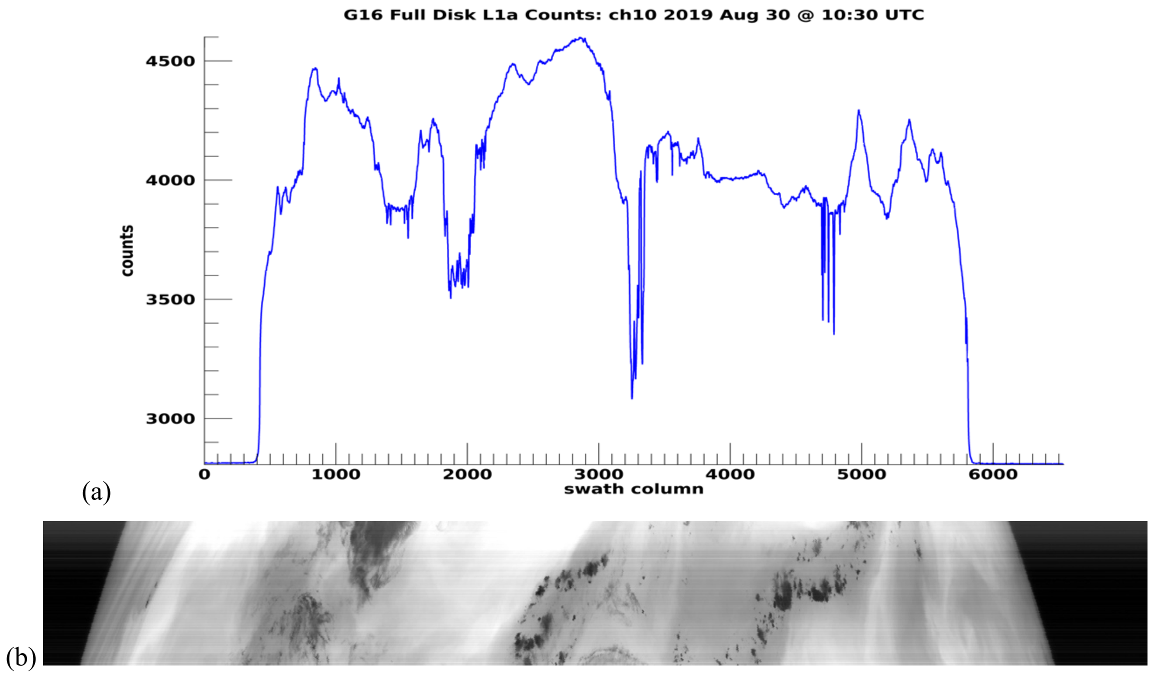

Figure 1. (a) Plot of raw counts from detector 100 across a single GOES-16 channel 10 (7.34 µm) Full Disk swath. Note that the counts recorded while viewing space on either side of earth are in family (~2800 counts). (b) Corresponding swath (width and height not to scale) of raw counts displayed as an image. In each Full Disk scan ABI views space on both the west (left) and east (right) sides of the Full Disk.

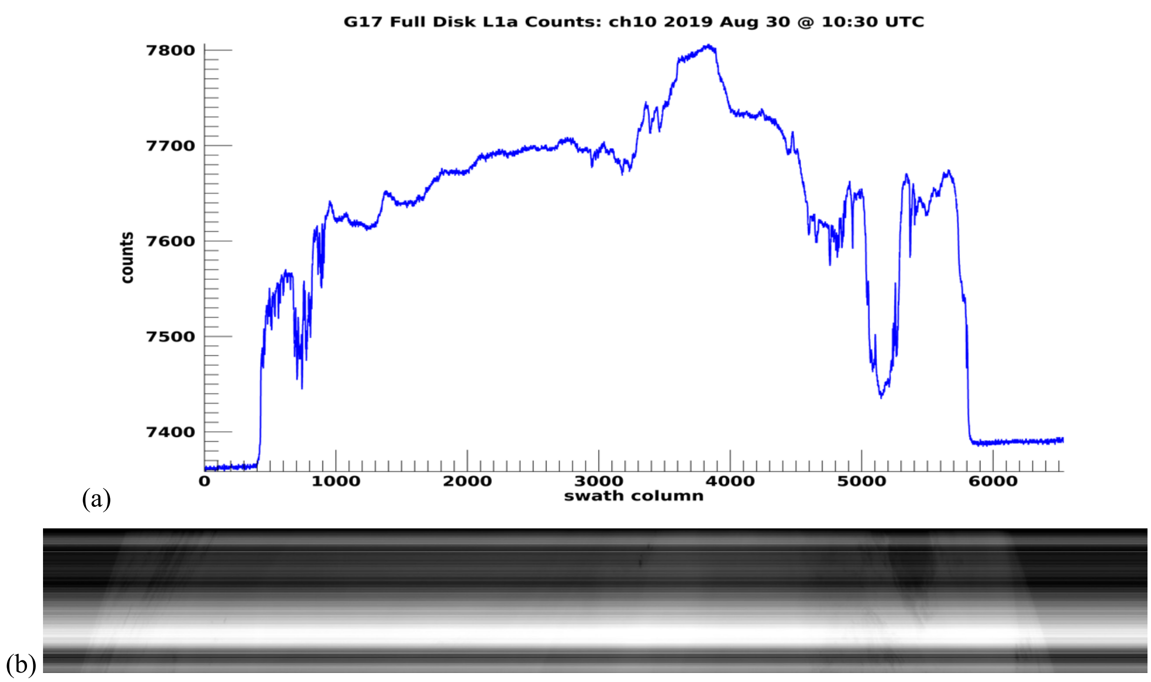

Figure 2. (a) Plot of raw counts from detector 100 across a single GOES-17 channel 10 (7.34 µm) Full Disk swath. Note that during the course of scanning this swath the counts recorded while viewing space rose by ~30 counts (0.4%). (b) Corresponding swath (width and height not to scale) of raw counts displayed as an image. Also noticeable in (b) is a wide bright region across the swath resulting from a cluster of detectors whose response had drifted out-of-family due to heating.

Under the nominal calibration algorithms[1], the Spacelook recorded from the beginning of the swath (western side of earth) would be applied to all earth samples across the swath. As Figure 2 shows, the fundamental physical property for which the Spacelook compensates, the dark counts, continues to rise across the swath due to the increasing focal plane temperatures. For samples on the eastern side of the swath the space counts should be higher. The "delta counts", the difference between the earth and Spacelook counts, therefore grows artificially larger across the swath, resulting in a positive radiance bias. In the example shown in Figure 2 this bias was as large as 3 K. This is compounded by the fact that the gain terms, computed once every 5 minutes, are also drifting in time.

It is important to note that the rising space counts described above were observed over the course of a single Full Disk swath, lasting ~12 seconds for the wider swaths near the equator. ABI acquires the next Spacelook 18 seconds later (a 30-second cadence). During those 18 seconds ABI is imaging a portion of the CONUS as well as an entire MESO scene. The dark noise continues to rise during this time, further increasing the radiometric bias for those scenes. Additionally, after the cooling system recovers and the detectors begin to cool, the forementioned Spacelook drift occurs in reverse leading to negative brightness temperature biases. Finally, whenever the focal plane temperatures are warm enough to saturate the detectors no algorithm modifications would be able to recover that data. Predictive Calibration is only effective when the detectors are warming or cooling but below saturation.

2.2 Predictive calibration algorithm description

The warming and cooling of the focal planes cause a similar rise and fall in the counts recorded while viewing the ICT, which then cause a subsequent change in the computed gains. Since the heating and cooling of the detectors follows a predictable, gradual pattern, it becomes possible to compensate for this by projecting the calibration parameters forward in time.

The Predictive Calibration algorithm deviates from the baseline algorithm by holding the previous two sets of Spacelooks and gains in memory. The algorithm uses these two datapoints to linearly extrapolate the Spacelook and gain parameters forward in time. This ensures that each Earth view sample is calibrated using parameters relevant to that moment in time. This extrapolation is performed for each detector individually since each respond differently to warming and cooling.

During the times of day and days of the year when the IR detectors are stable at their nominal operating temperature of ~80 K Predictive Calibration is not needed. In fact, using Predictive Calibration in these instances would introduce slight, but unnecessary, radiometric errors. Therefore, Predictive Calibration is toggled on/off based on the MWIR and LWIR focal plane module temperatures. When the temperatures rise above a given "on" threshold, which is configured per-channel in a look-up table, Predictive Calibration is turned on. It remains on until the temperatures fall and remain below the "off" threshold (which can differ from the "on" threshold).

2.3 Deployment to Operations

The Predictive Calibration algorithm was installed in the test environment of the GOES-R Ground System on June 15, 2019. Over the following six weeks the GOES-R Calibration Working Group, along with scientists from MIT-Lincoln Laboratory and the GOES-R Program Office, worked to validate and optimize the algorithm performance. The on/off temperature thresholds were carefully chosen to optimize image quality and minimize radiometric error. Following the intensive checkout and optimization period Predictive Calibration was promoted to the operational environment on July 25, 2019. The teams continually monitor the data and adjust the thresholds throughout the year to accommodate the seasonal drift in diurnal temperatures.

3. PRODUCT PERFORMANCE USING PREDICTIVE CALIBRATION

The impact Predictive Calibration has on the L1b products can be seen both quantitatively and qualitatively. Figure 3 shows a comparison between GOES-16 and GOES-17 with and without Predictive Calibration over a common spatial region. A common 401x1001 region of interest was identified in imagery from both satellites. The GOES-16 data was then reprojected to the GOES-17 perspective, and the mean brightness temperature bias was computed between the two. Before Predictive Calibration was in use the bias was on the order of 2 K. With Predictive Calibration in place this bias was reduced to ~0.1 K. Also shown in the figure is the temperature of the LWIR focal plane. Without Predictive Calibration the brightness temperature bias is positive while the detectors warm, then negative while they cool.

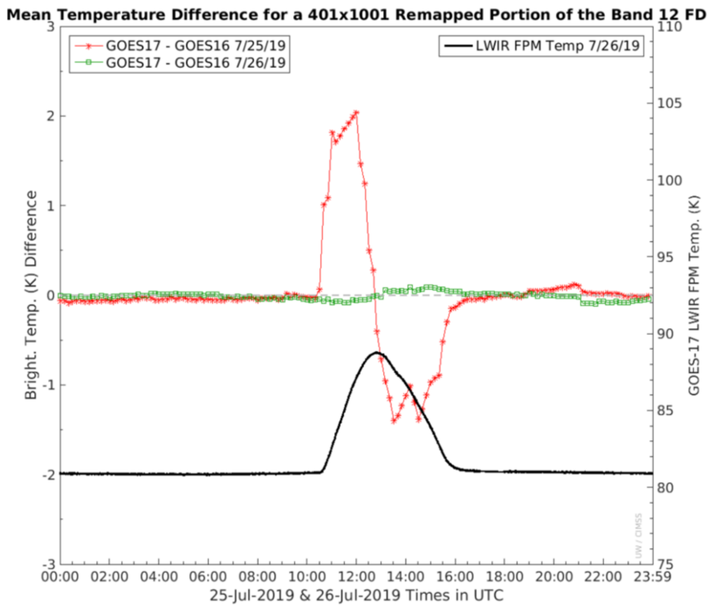

Figure 3. Mean brightness temperature difference over time for a common region of interest viewed by GOES-17 and GOES-16 (reprojected to the GOES-17 perspective). Data from July 25, 2019 (red stars) show the difference between the two satellites when Predictive Calibration was not in use, data from July 26, 2019 (green squares) is the difference when Predictive Calibration was used. Also plotted is the LWIR focal plane module temperatures over time for July 26, 2019. Figure courtesy UW/CIMSS.

Figures 4 and 5 show qualitative assessments of Predictive Calibration's effectiveness. Figure 4 shows a common region of interest as seen from both GOES-17 and GOES-16 (reprojected to the GOES-17 perspective). By displaying brightness temperatures with a fixed color table one can see that the imagery generated using Predictive Calibration, middle panel, more closely resembles that of GOES-16. The warm airmass in southern California and the Baja Peninsula is not as warm as is depicted without Predictive Calibration. The brightness temperatures in the cloud formations to the north are also closer to those seen by GOES-16.

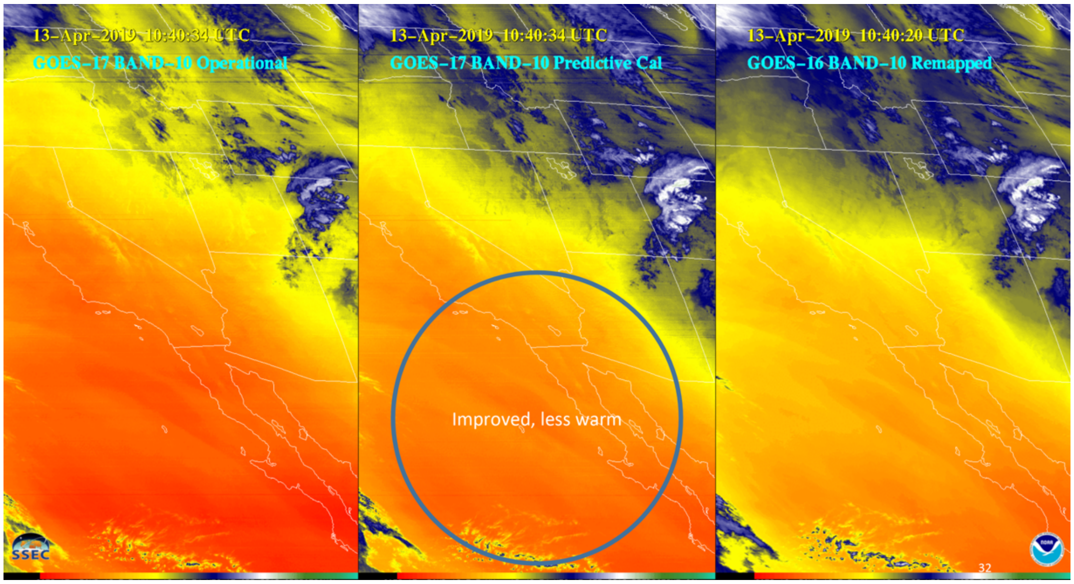

Figure 4. ABI channel 10 (7.34 µm) Full Disk image subsets from April 13, 2019 at 10:40 UTC. The three panels show GOES-17 without Predictive Calibration (left), with Predictive Calibration (center), and from GOES-16 reprojected to the GOES-17 perspective (right). Figure courtesy UW/CIMSS.

Figure 5 shows a Full Disk acquired at 1240 UTC on March 02, 2020 both without (left) and with (right) Predictive Calibration. Here it is apparent that Predictive Calibration mitigates striping in the imagery due to the warming detectors. In addition, without Predictive Calibration certain cloud formations are artificially warm. One such example is the small yellow feature in the Pacific Ocean west of southern Mexico. Note how in the Predictive Calibration image this feature is cooler, appearing as salmon instead of yellow.

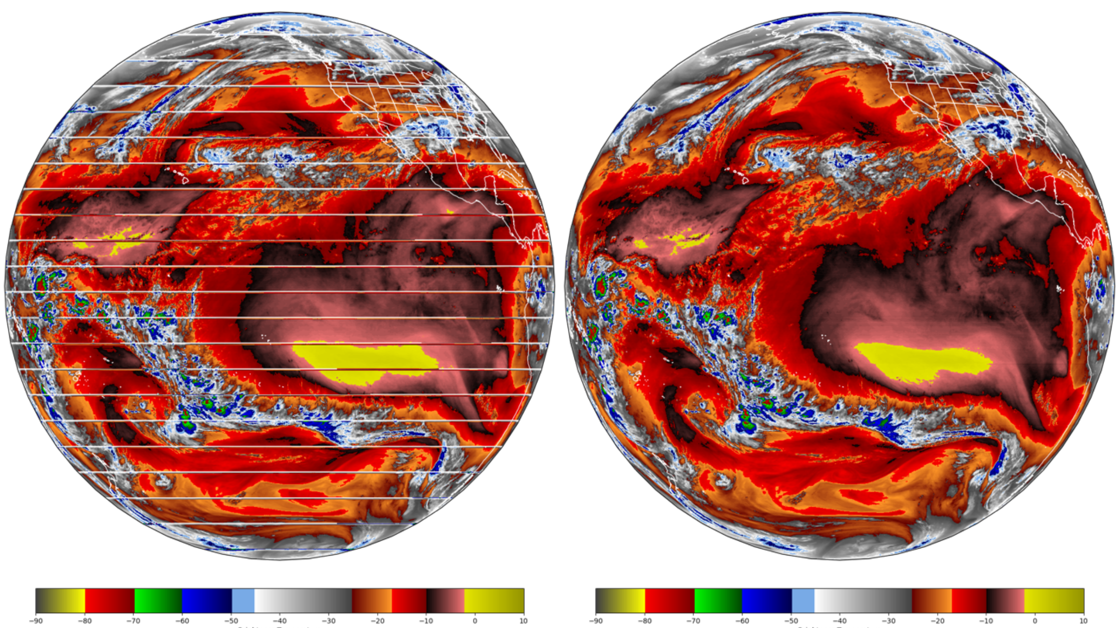

Figure 5. ABI channel 10 (7.34 µm) Full Disk images from March 02, 2020 at 12:40 UTC using the nominal calibration algorithms (left) and using Predictive Calibration (right).

4. SUMMARY

The above examples illustrate both the quantitative and qualitative improvements to the L1b products due to Predictive Calibration. The quantitative improvements help ensure the validity and utility of derived products, while qualitative improvements aid forecasters in visual identification of weather phenomena. In both senses Predictive Calibration has been shown to greatly mitigate the GOES-17 thermal anomaly. Users can expect that the relevant science teams will continue to monitor the performance of Predictive Calibration and tune the parameters as-needed to maintain product quality.

REFERENCES

[1] Kalluri, S., Alcala, C., Carr, J., Griffith, P., Lebair, W., Lindsey, D., Race, R., Wu, X. and Zierk, S., "From Photons to Pixels: Processing Data from the Advanced Baseline Imager", Remote Sensing 10, 177 (2018), https://doi.org/10.3390/rs10020177

[2] Smith, M., "Advanced Baseline Imager Scan Mode Information", https://www.goes-r.gov/users/abiScanModeInfo.html (2020).

[3] McCorkel, J., Van Naarden, J., Lindsey, D., Efremova, B., Coakley, M., Black, M. and Krimchansky, A., "GOES-17 Advanced Baseline Imager Performance Recovery Summary," Proc. IGARSS 2019 - IEEE International Geoscience and Remote Sensing Symp., 4511 (July 28, 2019).

[4] Van Naarden, J. and Lindsey, D., "Saving GOES-17", Aerospace America, 4, https://aerospaceamerica.aiaa.org/departments/saving-goes-17/ (April 2019).

[5] Wu, X., Yu, F., Kondratovich, V., Yoo, H., Qian, H., Wang, Z. and Guo, S., "GOES-17 ABI L1b Provisional Product Maturity PS-PVR Report," https://www.noaasis.noaa.gov/GOES/PS_PVR_GOES17.html (28 November 2018).