# GOES-17 ABI L1B PRODUCT PERFORMANCE WITH PREDICTIVE CALIBRATION

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## ABSTRACT

The ABI instrument on GOES-17 suffers from insufficient cooling, resulting in degradation in the L1b radiance products during times of excessive solar heating, partially due to the original calibration algorithm assuming only a slowly-varying thermal state. In 2019 a modification of the calibration algorithm (named “Predictive Calibration”) was introduced as part of the mitigation strategy. We summarize the early evaluation of L1b products created with this modified algorithm. We also describe some of the imagery artifacts sometimes introduced into the GOES-17 ABI L1b data by the Predictive Calibration or other mitigation steps.

***Index Terms—*** GOES-17, ABI, Advanced Baseline Imager, calibration, on-orbit sensor optimization

## 1. INTRODUCTION

The Advanced Baseline Imager (ABI) is the prime Earth-observing instrument aboard the GOES-R Series spacecraft. It is a 16 channel imaging radiometer designed to have increased spatial, temporal, and wavelength coverage compared to legacy GOES imagers. Ten of the 16 channels are dedicated to thermal infrared (IR) wavebands in the 3.9 to 13.3 µm range [1].

The launch of GOES-17 (now GOES West) on March 1, 2018 sent the second flight model of ABI into orbit. In May 2018, it was determined that the instrument cryocooler had suffered an anomaly, and it would not be possible to cool the IR focal plane module (FPM) temperatures down to the nominal operating temperature of 60 K. This anomaly and the mitigation steps taken to improve the situation have been described previously [2, 3]. After extensive work by the instrument vendor (L3Harris), GOES-R Flight Team, and others, a mitigation plan was implemented that allows the IR focal plane temperatures to stay around 81 K for most of the year. However, under intense solar heating around satellite midnight on certain days of year, these FPM temperatures can rise up to over 105 K, peaking around 1300 UT (0400 satellite local time).

The original ABI calibration algorithm [4] performs well for the GOES-17 ABI when the FPM temperatures are stable [5]. However, during times of rapidly-changing focal plane temperatures (on the order of 2 mK/s) assumptions held by this calibration algorithm fails. For example, the original algorithm assumes that the space look values (used for the dark correction) changes less than 0.025% in 30 seconds. From GOES-16 ABI IR channel on-orbit data, the mean diurnal trend in space look count values has a maximum slope of less 0.01% per 30 seconds. For GOES-17 ABI in a worse-case scenario (during a rapidly-warming time of day for a day with the seasonal highest maximum temperatures), the space look values increased by about 60 counts (or about 0.4%) over the 30 seconds [6].

Similarly, the original calibration algorithm assumes the detector gain changes are small for up to 15 minutes (the duration of the operational Mode 3 timeline) between scheduled observations of the on-board blackbody calibrator (designated the Internal Calibration Target, or ICT). This is to ensure that the difference due to gain change, when converted to brightness temperature at 300 K, is less than 0.1 K. For GOES-17 IR bands, the contribution to the bias in brightness temperatures induced by rapidly-changing FPM temperatures can be up to ± 0.5 K over 5 minutes. The primary contributor (space look change vs. gain change) to bias per band-dependent. For Band 14, the gain change dominates the bias. For all other channels except Band 13, the space look change dominates. For Band 13, both contribute about equally, but each affects the brightness temperature bias with opposite sign. An additional contribution to the bias is that at higher (near-saturation) FPM temperatures the detectors for some bands begin to manifest an uncorrected non-linear response [7].

In this paper, we will summarize some of the early results on the improvements to the L1b product performance due to the implementation of the Predictive Calibration in Section 2. In section 3 we will also discuss some of the other phenomena seen in the data products as a result of the implementation of the Predictive Calibration and other mitigation steps. Most of these results are from of the work of the Calibration Working Group (CWG) at NOAA/STAR.

## 2. PREDICTIVE CALIBRATION AND PRELIMINARY PRODUCT PERFORMANCE

As described in [2], the Predictive Calibration algorithm works by extrapolating both the dark current and detector gains forward in time linearly based on the last two observations of each quantity. The dark current is measured by space look observations. During normal operations, these measurements take place at a cadence of about 30 seconds. For Full Disk swaths during the time of day with elevated temperatures, the observation takes place at the beginning of the swath off the western limb of the Earth as seen by the spacecraft. A dedicated space look scene is used with some specific scenes, including the ICT blackbody calibration.

The gains of the IR channels are determined by the observations of the ICT. As part of the mitigation, these observations are taken about every 5 minutes. Even though the ICT observations take place a few seconds after a dedicated space look scene, the space look values are extrapolated to the time of the ICT observations when the dark current correction is applied.

The correction for both dark current and detector gains are applied at the detector level [4]. Each detector of each of the IR bands reacts differently to the dynamic thermal environment. As the FPM temperatures rise, individual detectors will begin falling out of calibration and create stripes across the final L1b product, but the remaining detectors should be correctable.

### 2.1 Installation and Initial Performance Test Results

The Predictive Calibration algorithm update was installed on the test environment of the GOES-R Series ground system on June 15, 2019. The daily maximum FPM temperatures are minimized near both solstices, so only in July could the performance improvement be measured. An example from this period is given in Figure 1 taken from [7] showing the difference in brightness temperature (Tb) computed for an equatorial inter-comparison region midway between the satellite subpoints of GOES-16 and GOES-17 on July 24, 2019, the last day before the Predictive Calibration algorithm was placed in to operations.. Once in operations, nominal ability to directly compare to GOES-17 data with Predictive Calibration on and off went away. The peak FPM temperatures on this day were about 89 K, which is about 20 K lower than the seasonal maximum, but this date is also the last day before Predictive Calibration went into operation use, limiting the availability of this kind of test data. The original algorithm results ("OE data") show the effect of the elevated FPM temperatures, including the reversal of the calibration difference once the FPM temperatures begin to drop. The products produced with the Predictive Calibration algorithm ("pCal data") show a near-total removal of the brightness temperature offset.

The Predictive Calibration algorithm cannot improve data when either the space look or ICT look measurements are saturated. Depending on the IR band, the amount of time in full saturation ranges up to about 6% for Band 12 (Band 7 and 14 never saturate, while Band 13 almost never saturates). The FPM temperatures are stable near 81 K for about 71% of the year [2]. Prior to Predictive Calibration, the data for the remainder of the time (~23-29%, depending on band) was considered marginal quality, but at the time of writing it is believed that the algorithm has improved nearly all this marginal quality data to within specifications or nearly-so [7].

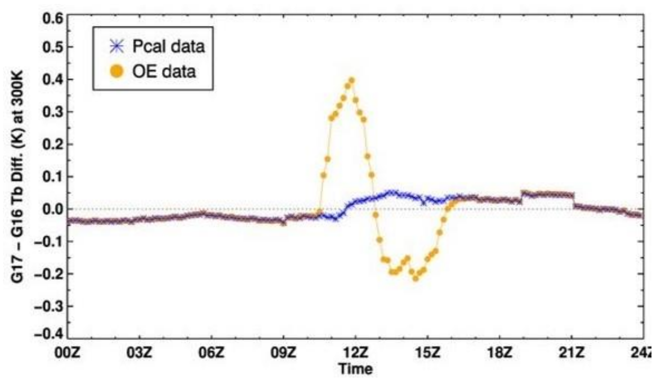


**Fig. 1.** Difference in brightness temperatures over a common area observed by both GOES-16 and GOES-17 ABI instruments in Band 10 (7.3 µm) for July 24, 2019. The original calibration algorithm (Tb differences marked as "OE data") cannot accurately calibrate the GOES-17 data during the hot part of its orbit, while the Predictive Calibration algorithm ("Pcal data") follows the GOES-16 data.

## 3. ADDITIONAL ABI L1B PRODUCT PHENOMENA DUE TO ELEVATED FPM TEMPERATURES

There have been other modifications to the original calibration algorithm and operational plan to help mitigate the dynamic FPM temperatures for GOES-17 ABI. One example is the need to disable the rejection of lunar contamination to the space look measurements. The pre-launch assumption is if the FPM temperatures were stable, a threshold may be set to detect and reject contaminated measurements.

This kind of filtering became impossible because the nominal space look values for GOES-17 can range up to saturation. The filter thresholds are set at saturation, which means when the Moon does end up in a space look observation, the dark current correction for the affected detectors is wrong and the Earth-view data for those detectors is bad (Figure 2). A few times per year, the Moon can even land in the space look region used for an ICT look. When that happens, the computed gains for the affected detectors are wrong until the next ICT look (Figure 3). When Predictive Calibration is not operating, the affected data should return to normal as soon as a space look or ICT look is conducted with the Moon out of the way (about 30 seconds or 5 minutes later, respectively). Predictive Calibration uses the last two measurements, so the recovery time is doubled. An algorithm fix is in the works to eliminate this lunar intrusion problem.

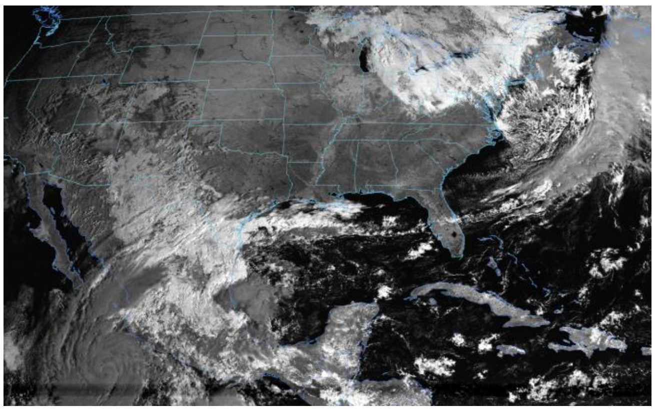

**Fig. 2.** GOES-17 ABI Band 5 (1.6 µm) CONUS image from 1522 UT on Oct. 24, 2018 showing the effects of a lunar intrusion into an individual swath space look. The effect is especially evident through the tropical system in the lower left.

Another special consideration of Predictive Calibration is when it should or should not be operating. An early mitigation step has been the utilization of an alternative detector settings (effective integration time and detector bias levels) to prevent detector saturation until higher FPM temperatures. These detector settings are colloquially called “gain sets”. At this time, two gain sets are employed for all days when the maximum FPM temperatures are expected to rise over 85 K: a nominal set for when the FPM temperatures stay near 81 K, and another set for the hotter part of days. For operational simplicity, the time of the two gain set switches are fixed in time depending on the satellite orientation.

This is relevant to the Predictive Calibration algorithm because any extrapolation utilizing measurements from two different gain sets would be invalid. Therefore, Predictive Calibration algorithm must be off at the time of the gain set switches. An example of what happens if Predictive Calibration is on during a gain set switch is given in Figure 4.

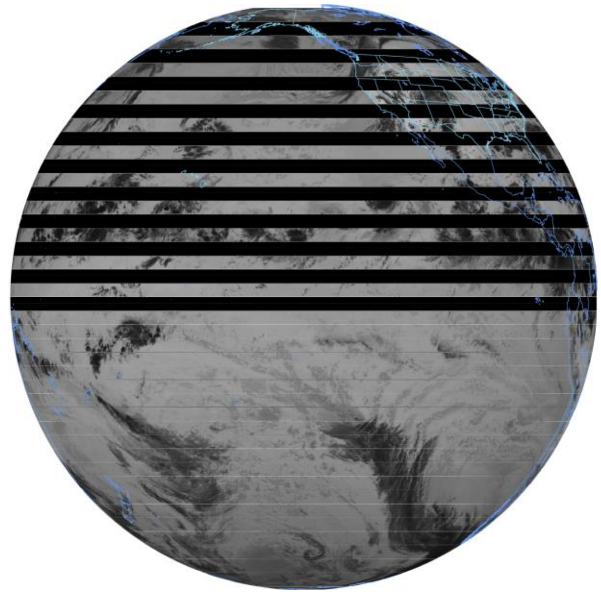

**Fig. 3.** GOES-17 ABI Band 13 (10.3 µm) Full Disk image from 2310 UT on Sept. 15, 2019 affected by a lunar intrusion in the space look used for the ICT gain calibration. The scanning of the Earth occurs north to south, and the affected ICT look occurred immediately before the scanning of the Earth. A second ICT gain calibration takes place halfway through the Full Disk scanning.

The on/off control of Predictive Calibration algorithm is done by per-band FPM temperature thresholds: FPM temperatures above the threshold trigger the operation of the algorithm. The challenge discovered during testing was that the FPM temperature at the gain set switch varied seasonally and a fixed threshold would not work unless it was set so high the Predictive calibration algorithm would be forced off during some of the times of rapid temperature change when it is most effective, which would lead to large jumps in the radiance or brightness temperatures and therefore negatively affect downstream L2+ products.

Attempts to change the threshold parameters to keep up with the drifting daily temperatures became logistically difficult. However, starting on October 3, 2019, a solution was employed that will force the Predictive Calibration on 10 minutes (one full timeline—the algorithm should not be turning on halfway through a Full Disk measurement) after changing into the hot-period gain set and turn the calibration off 10 minutes before switching back into the cool-period gain set. This is only a short term fix, but the expectation is that it will be performed until an algorithm update prevents the degradation shown in Figure 4.

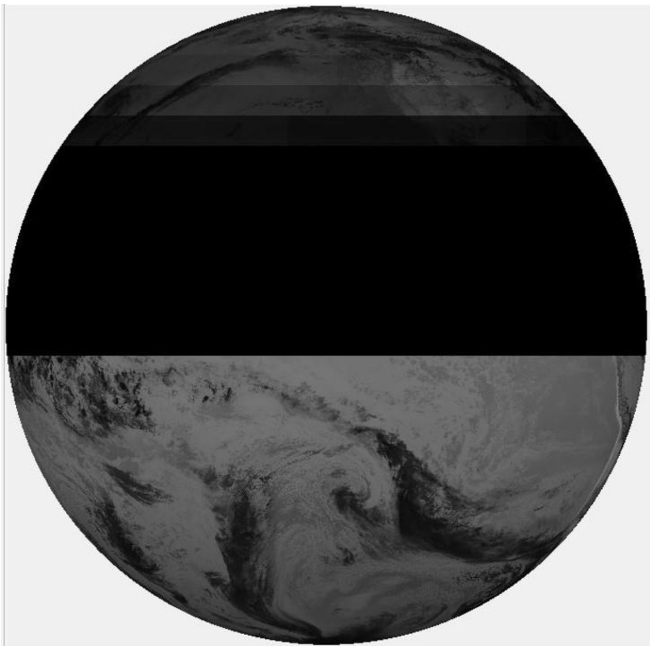

**Fig. 4.** A GOES-17 ABI L1b Full Disk image from July 18, 2019 at 1900 UT produced on the test processing environment showing what happens in the processing when the Predictive Calibration algorithm is active during a gain set switch. The applied detector gain extrapolation divergence continues until the ICT look that occurs halfway through the Full Disk. At that point the two ICT gain calibrations used for the extraploation are utilizing the same gain set information.

## 4. SUMMARY

In this proceeding, we have summarized the initial performance results from the Predictive Calibration algorithm implemented for GOES-17 ABI. These initial evaluations show a large improvement in the radiances during the period when the FPM temperatures are moving between the stable time of day and saturation temperatures. The GOES-17 ABI IR band L1b products also show increased noise at higher temperatures, but this is the result of basic detector physics and the increased quantization noise of the alternative gain set. Finally, users of GOES-17 ABI data should be aware of a few types of degraded data that are due to the mitigation strategies. These include lunar intrusion into space look measurements and erroneous Predictive Calibration utilization during a gain set switch.

## 5. ACKNOWLEGEMENTS

We are grateful to the Flight and vendor team developers of the Predictive Calibration algorithm and to those involved with the implementation of the algorithm onto the ground processing system. The evaluation of the algorithm is ongoing and has involved contributions from many members of the GOES-R community.

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