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GOES-17 ADVANCED BASELINE IMAGER (ABI) POST LAUNCH TEST PERFORMANCE COMPARISON TO GOES-16

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Abstract

The 17th Geostationary Operational Environmental Satellite (GOES-17) will be taking over the GOES-West slot in late 2018, completing the upgrade of the active U.S. geostationary weather satellites to the GOES-R series. The Advanced Baseline Imager (ABI) is the primary instrument on the GOES-R series for weather and environmental monitoring. With three times the spectral bands, four times the spatial resolution, and five times the image collection rate, ABI significantly improves the quality and frequency of existing data products and provides many new weather and environmental products.

The GOES-16 ABI (flight model 1), currently active as GOES-East, has already demonstrated these improvements during on-orbit operations. This paper describes the unique difficulties experienced on GOES-17 due to an anomaly with the ABI thermal system, some of the optimization process that went into recovering a significant amount of ABI performance, and finally preliminary post-launch test results for the GOES-17 ABI (flight model 2) in its final optimized configuration. Though some compromises were made to balance data availability versus performance, the GOES-17 ABI is still providing high-quality imagery and will be a valuable asset once put into operation as GOES-West.

INTRODUCTION

GOES-17 was launched on March 1, 2018, and inserted into geostationary orbit at the GOES test location of 89.5 W. After launch, the ABI was configured for outgas mode, where it remained for approximately 30 days. While remaining in outgas mode, the Optical Port Cover was deployed on April 13, 2018, so that visible imagery collection could begin. ABI's three visible bands are capable of uncooled operation. Assessments of early visible imagery indicated performance on par with GOES-16.

On April 29, outgas was declared complete, and the ABI thermal system was configured for operation: outgas heaters were disabled, loop heat pipes (LHPs) were started, and cryocoolers were configured to cool the focal plane arrays (FPAs). During the initial cooldown attempt, FPA temperatures were not dropping as expected. It became evident that the LHPs were not carrying the expected amount of heat from ABI's subsystems to the radiator. Initial investigations indicated the LHPs were not operating at full capacity. Without the ability to shed excess heat to the radiator and ultimately into space, heat builds up in the system and puts ABI at risk of exceeding safe temperature limits.

THERMAL ANOMALY

ABI's two largest thermal loads are the cryocoolers and incoming solar energy. During the day, when the sun is behind the spacecraft and illuminating Earth, the solar load on ABI is close to zero. The GOES-17 ABI thermal system can handle the internally generated heat (primarily produced by the cryocooler), even with the degraded LHP performance. For a few hours each side of midnight, however, the sun is behind the earth and shining directly into ABI's optical aperture. The substantial heat load from the sun overwhelms the limited heat-carrying capacity of the GOES-17 ABI LHPs. To reduce the overall heat load and maintain safe operating temperatures, the cryocooler power must be reduced.

Reducing the power to the cryocoolers has an immediate impact to the temperature of the focal plane arrays. ABI nominally maintains its infrared (IR) focal planes at 60 K, and its visible and near-infrared

(VNIR) focal plane at 170 K. These temperatures are controlled to tight stability (<0.1 K) to maintain radiometric accuracy. When the cryocooler power is reduced to compensate for incoming solar heat, the focal plane temperatures rise. They continue to rise until the cryocooler power is ramped back up a few hours after midnight, when the solar heat load is reduced.

NASA and Harris assembled a team to investigate root cause and a second team to work in parallel on maximizing the performance of the ABI instrument.

OPTIMIZED THERMAL PERFORMANCE

The engagement of a parallel team to investigate an optimization strategy proved to be a fruitful endeavor. Utilizing the operational flexibility of the ABI payload, an optimal configuration was developed and validated with on-orbit testing.

One of the strategies employed to improve the situation was increasing the nominal operating setpoint of the IR focal planes from 60 K to 81 K. This new nominal temperature was determined to be the best compromise between unburdened performance during the day and limiting overall cryocooler heat load to minimize the solar impact at night.

It was found that when the sun is near its summer solstice position ($\beta = +23.5°$), the high angle of solar incidence reduces the heat load into the ABI aperture. The total heat load is low enough that reduction of cryocooler power is unnecessary to maintain safe operating temperatures, and the thermal system can maintain the IR focal plane temperatures at 81 K for the entire day. As time progresses past the solstice, the sun appears lower in the sky every day and shines more directly into ABI's aperture, which increases the total heat load on the system. To compensate, the cryocooler power must be reduced earlier in the day and remain off for a longer time; thus, the focal plane temperatures will rise slightly higher than the day before, with the worst case expected to be when the sun is just above the northern limb of Earth.

A new model was developed to predict the peak daily focal plane temperature based on the beta angle of the sun for any given day. *Figure 1* contains a comparison of the measured peak temperature versus that predicted temperature from the new model, which performs well in its prediction of the peak daily temperature.

There are several notable deviations from the predicted value, where continued testing perturbed the thermal conditions. One critical test was a late-July spacecraft maneuver that mimicked the worst-case orbit conditions that would be experienced in late August. The good early match between model and measured performance further bolstered by this tested verification of worst-case conditions provided enough confidence to declare optimization complete. On July 30, ABI was configured in its new operational configuration, and the Post-Launch Test (PLT) phase officially began.

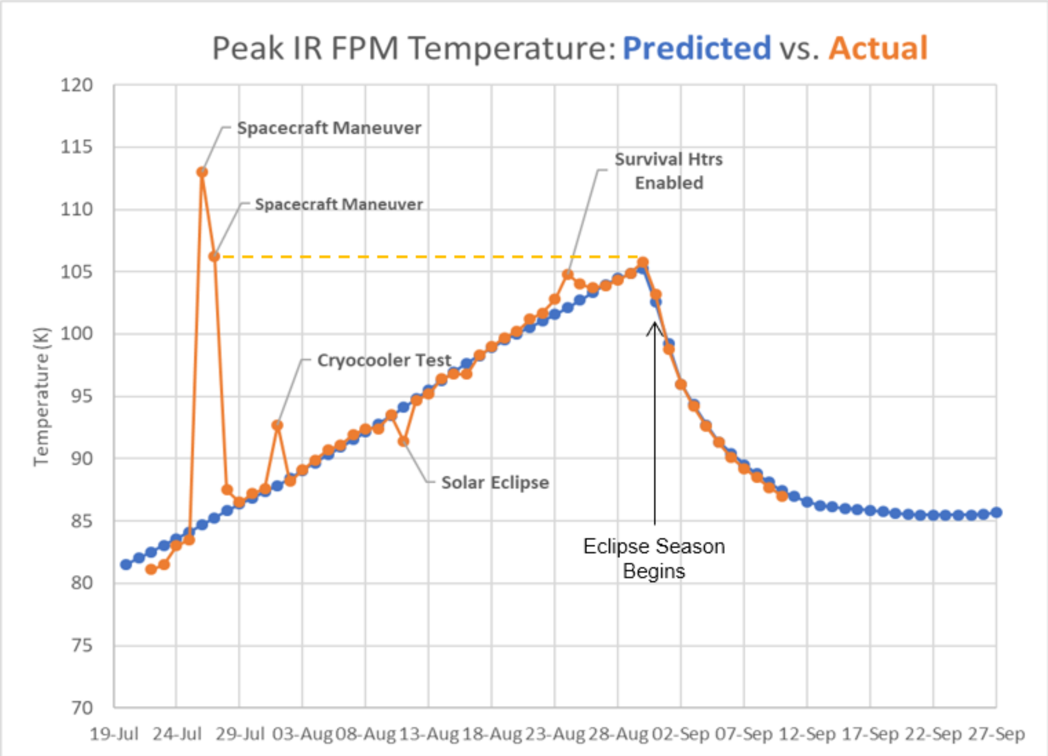

Figure 1: **Comparison of Measured Peak Diurnal Focal Plane Module Temperature to Model Prediction**

ANNUAL THERMAL PERFORMANCE AND CHANNEL AVAILABILITY

As the focal plane temperature is critical to the performance of ABI's individual bands, it was critical to have a model that could predict how hot the focal plane arrays would get each day so that expectations could be set for operational performance. *Figure 2* shows the peak daily focal plane temperature as predicted by the new model. The model predicts that for 109 days/year, ABI maintains its infrared detectors at the optimized setpoint of 81 K. For the remaining 256 days/year, the IR focal planes rise above their temperature setpoint near local midnight as the cryocooler power is reduced to balance incoming solar energy.

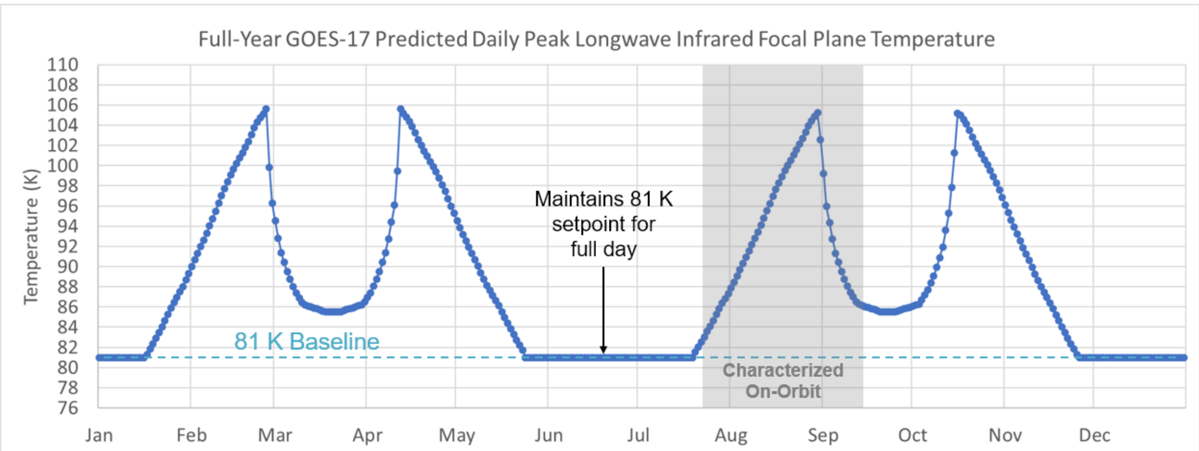

Figure 2: **Full Year of Predicted Peak Daily IR Focal Plane Temperature**

While *Figure 2* shows only the predicted peak daily focal plane temperature, the model also predicts the shape of the temperature rise versus time throughout the day. This level of information combined with knowledge about how individual bands perform versus focal plane temperature enables predictions to be made about channel performance for any date and time of year. *Figure 3* represents a snapshot of that prediction. It contains a single square for each of ABI's 16 spectral bands with time of year on the y-axis and time of day (local spacecraft time) on the x-axis.

The color code represents an assessment of data quality made with inputs from NASA and NOAA science teams. Factors used in this determination were noise performance, presence of image artifacts, suitability for downstream algorithms, and loss of imagery from digital saturation. Data was qualified into one of three categories as described in *Table 1*.

Data Quality	Annual Availability	Qualifiers
Good (Green)	97 %	Imagery is free of artifacts; noise is low
Marginal (Yellow)	2 %	Imagery may have some artifacts, have increased noise, and may not be suitable for downstream algorithms
Unusable (Orange)	1 %	Image artifacts are too significant; band has reached digital saturation

Table 1: **Data Quality Category Details**

As evident in *Figure 3*, eight of the 16 bands experience no significant impact to data quality. The remaining eight bands will see reduction in data quality, primarily in the four regions of the year just prior to and after eclipse season. Also note that the daily peak temperature occurs near 03:30 spacecraft local time, which is a few hours after peak solar load at midnight. Early morning imagery will be most impacted.

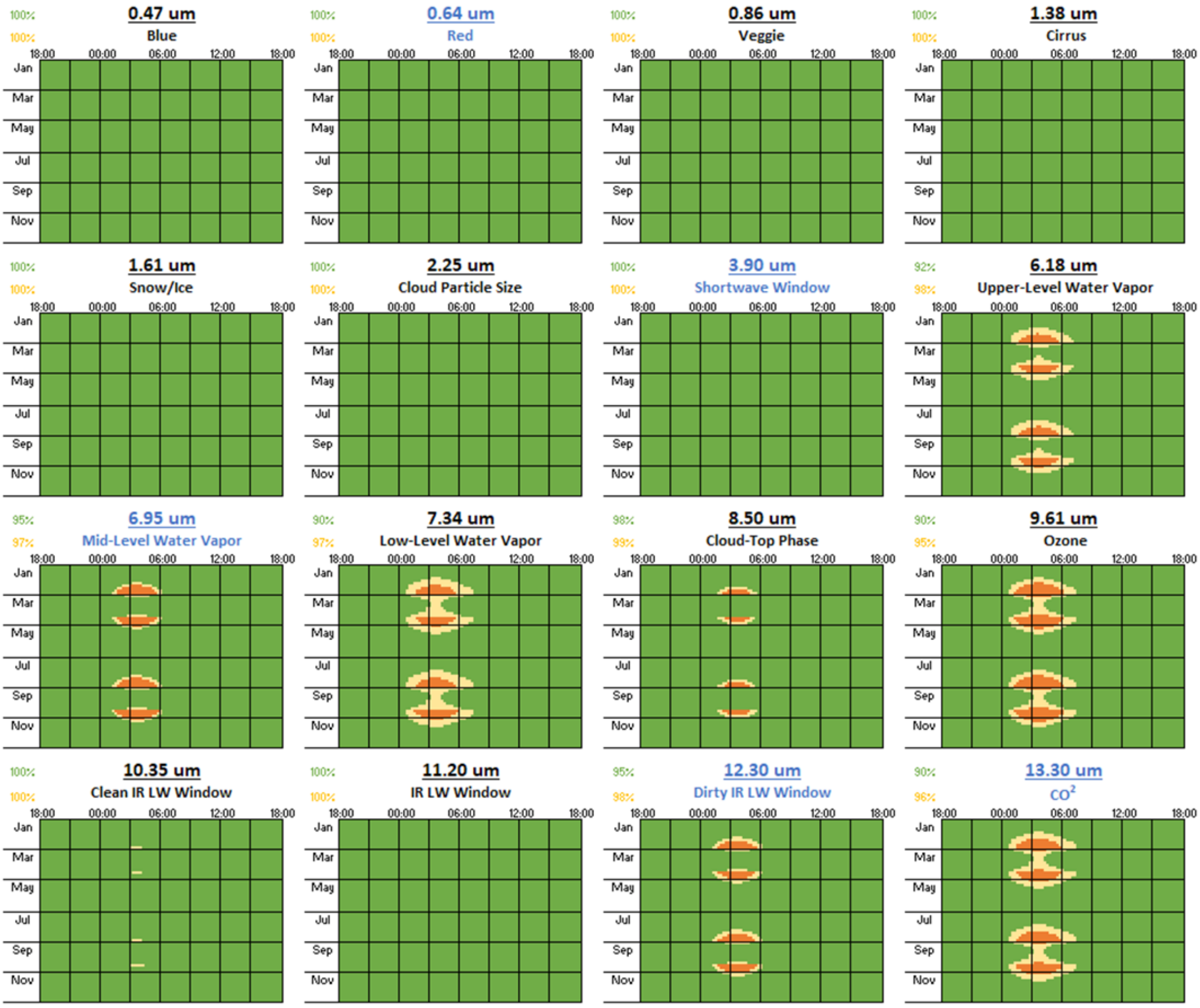

Figure 3: **Estimated Annual Channel Availabililty (Blue Bands Are Heritage GOES)**

PERFORMANCE

Though much emphasis has been put on the ramifications of ABI's thermal anomaly, the overall performance of GOES-17 ABI is excellent. The six VNIR bands are unaffected by changes in operation due to the thermal anomaly. The first visible image shown in *Figure 4* was released to the public in late May and qualitatively shows the type of high-quality imagery produced by GOES-17. *Figure 5* contains a more quantitative assessment, showing that signal-to-noise and dynamic range are exceeding their specifications. The performance compares well to pre-launch expectations and is on par with GOES-16.

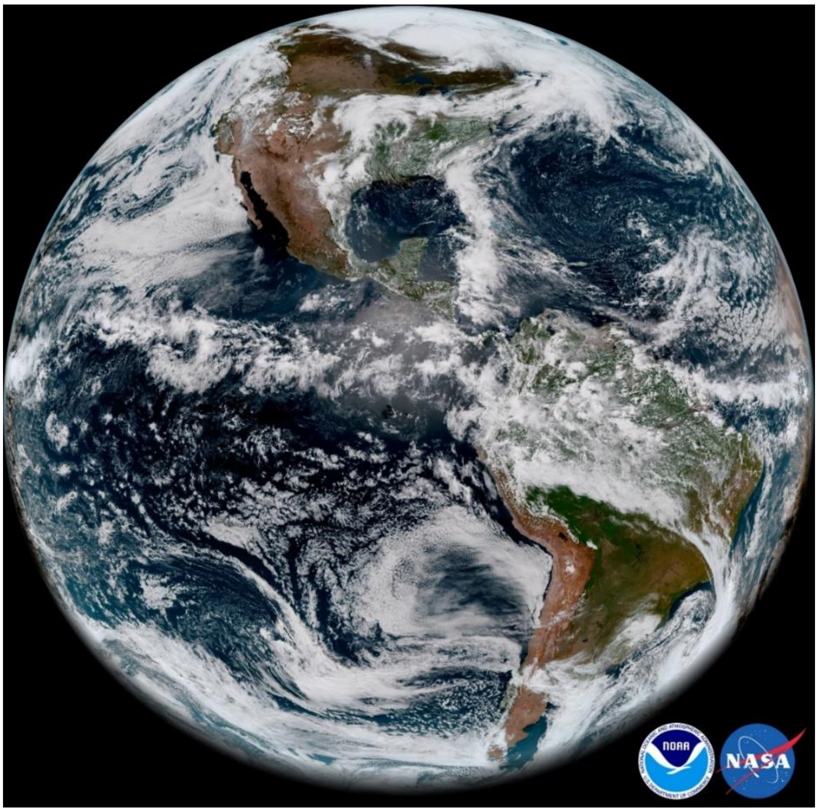

Figure 4: **GOES-17 First Public Visible Image (Collected May 20, 2018)**

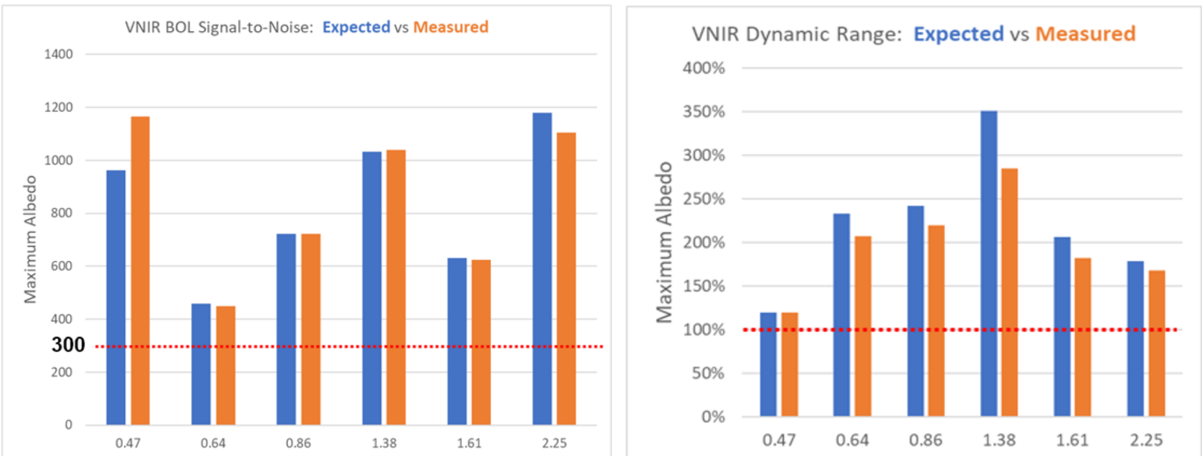

Figure 5: **VNIR Channel Signal-to-Noise and Dynamic Range Compared to Pre-Launch Expectations**

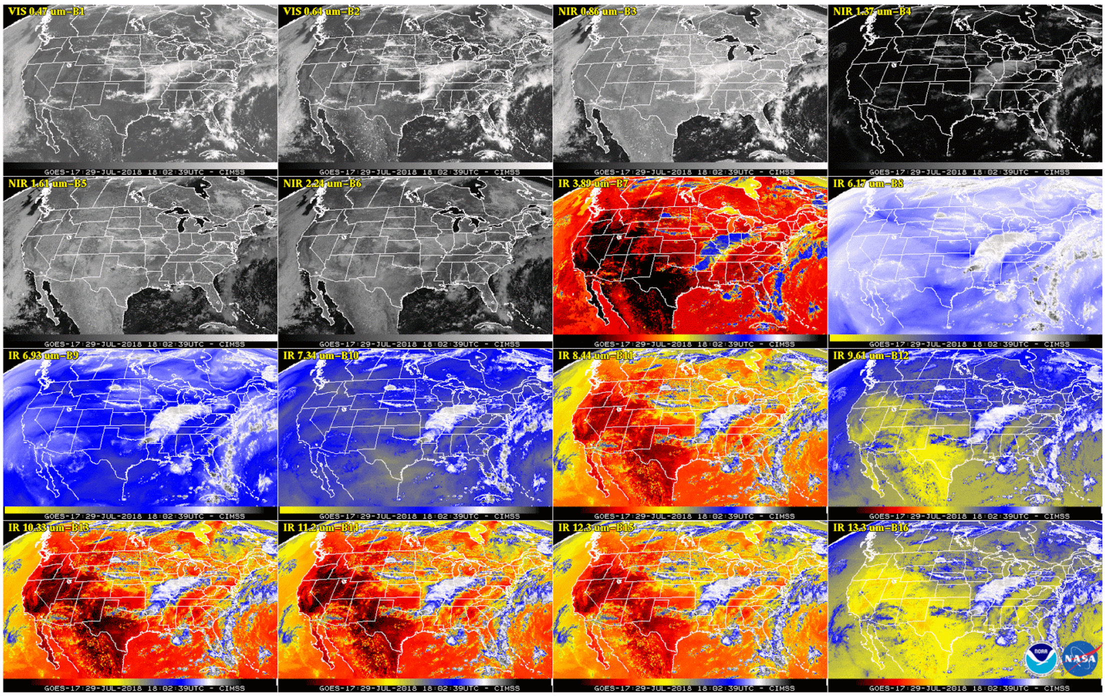

Figure 6: **GOES-17 First Public Release of IR Imagery (Collected July 29, 2018)**

Performance of GOES-17 IR bands is expectedly different from pre-launch expectations and GOES-16. The successful strategies put in place to operate with limited thermal capacity are a compromise between having bands with no useable data versus accepting slightly less performance to maintain usability.

Figure 6 contains the first public IR imagery (a 16-panel image collected July 29) released on August 8. It qualitatively illustrated the capability for all 16 bands when controlled at the elevated 81 K baseline focal plane temperature. *Figure 7* summarizes the Noise Equivalent Delta Temperature (NEdT) performance at the new baseline. Although operating the detectors a full 21 K warmer than the nominal design and with compromises made to other operating parameters, eight of the 10 IR bands still meet the noise specification with the remaining two exhibiting modest outages.

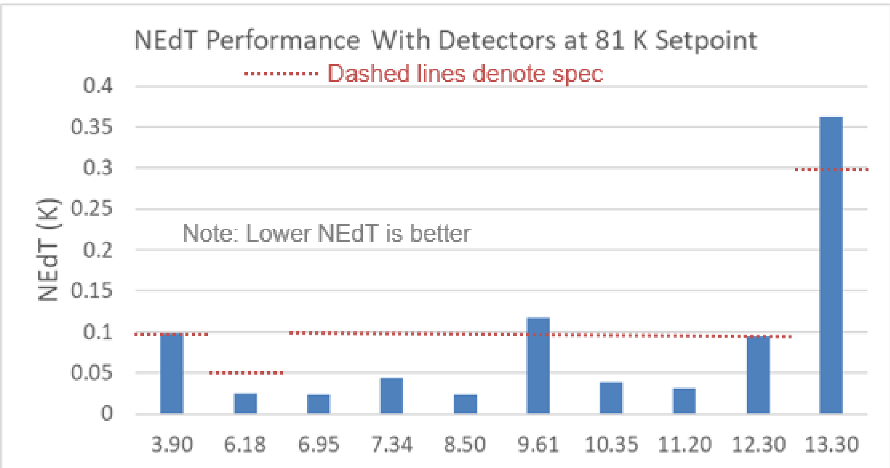

Figure 7: **NEdT for IR Bands and Nominal 81 K Focal Plane Temperature**

Figure 8 and *Figure 9* provide a summary of NEdT performance versus focal plane temperature. These measurements were made under worst-case thermal conditions on August 30, 2018, and thus encompass performance for any day of the year during which the temperature rises above the 81 K set point. There are a couple key features to note in these plots. For all bands but 3.9 μm, a steep jump can be seen at 81 K followed by a gentler rise. The initial jump occurs due to deliberate reduction in gain made to keep the bands out of digital saturation as the focal plane temperatures rise.

A second feature to note is that not all bands extend the full range of focal plane temperatures, but rather are only plotted up to point where they remain out of saturation. As evident in *Figure 8*, the noise performance of the midwave infrared (MWIR) bands remains quite low throughout the entire range. While the data remains out of saturation and useable, all NEdT values remain below 0.14 K. The impact is greater on longwave infrared (LWIR) bands as shown in *Figure 9*. Four of the bands show limited increases in NEdT up to 0.6 K, while the 13.30 μm band is a clear outlier. It was notably the most difficult band to wrest back performance.

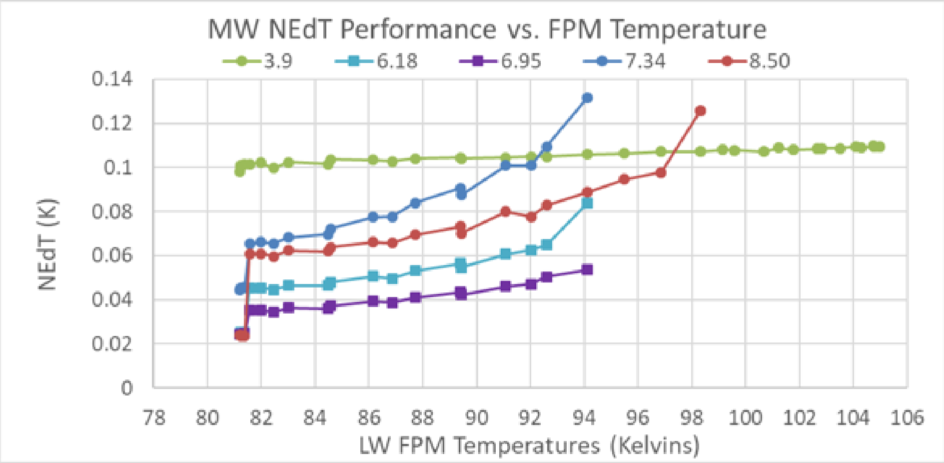

Figure 8: **MWIR NEdT vs. Focal Plane Temperature**

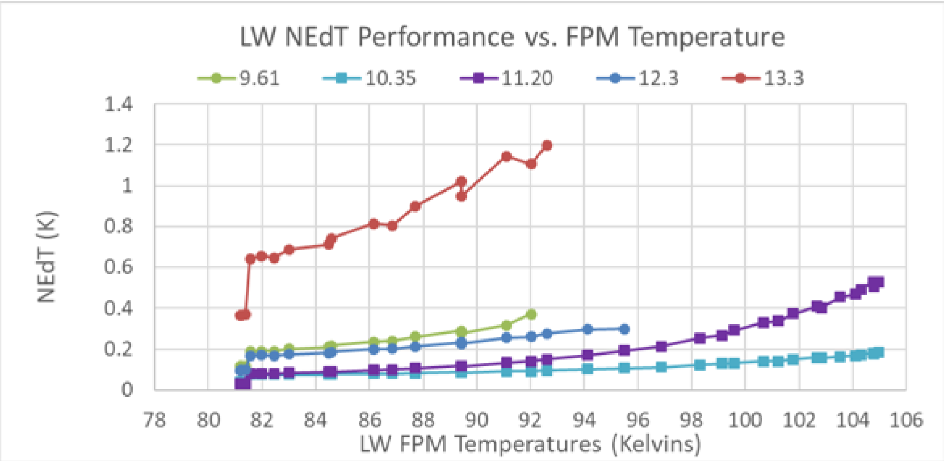

Figure 9: **LWIR NEdT vs. Focal Plane Temperature**

Figure 10 contains an assessment of the maximum measurable scene temperature for each of the IR bands. For most bands, the results indicate minor change in the maximum temperature compared to pre-launch expectations. However, three of the bands show considerable increases in dynamic range directly related to changes made in the gain configuration for those bands. These three bands required the most significant gain changes. They are also unique in that image artifacts become the dominant factor in non-usability before reaching digital saturation.

Direct measurements of spatial response performance were not available, but all indications point to excellent image quality. Although ABI is equipped with the ability for on-orbit focus adjustments, there appears to be no need for such an adjustment. *Figure 11* presents a comparison of Hurricane Florence collected simultaneously with GOES-16 and GOES-17 and shows the incredible level of fine detail produced by both spacecraft.

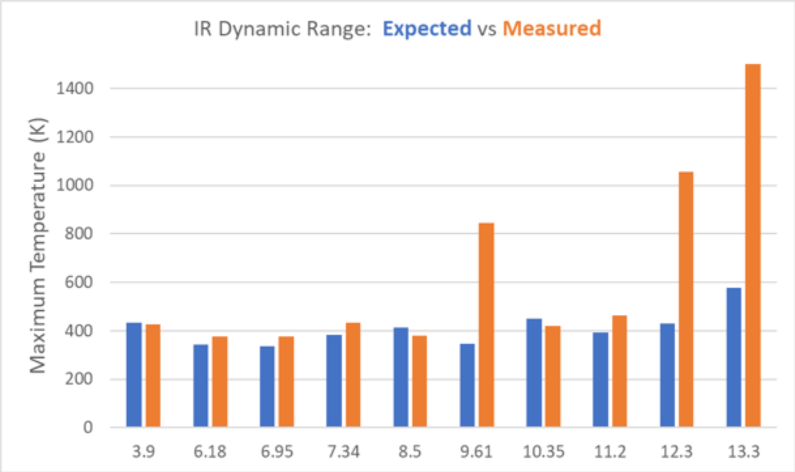

Figure 10: **Maximum Measurable Scene Temperature**

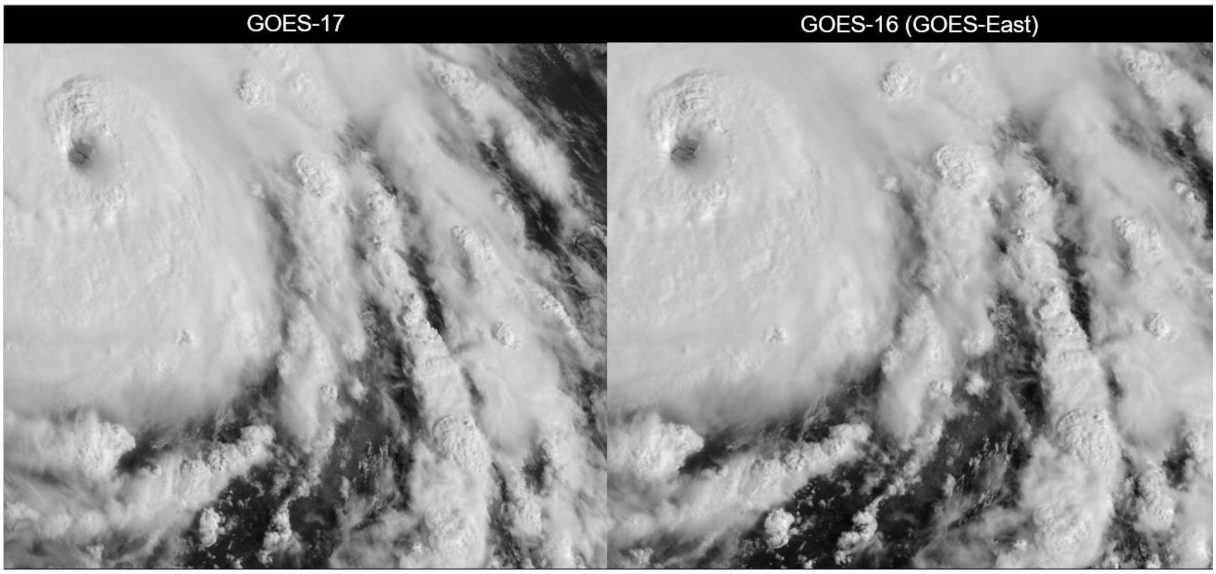

Figure 11: **Hurricane Florence Comparison Between GOES-16 and GOES-17 Shows Good Spatial Peformance**