Radiometric Quality Assessment of GOES-16 ABI L1b Images

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ABSTRACT

The Advanced Baseline Imager (ABI) onboard NOAA's GOES-16 satellite has been operational as GOES-East since December 18th, 2017. It is a multi-channel passive imaging radiometer with 16 spectral bands covering the visible, near infrared and infrared (IR) spectra, to captured variable area imagery and radiometric information of the Earth's surface, atmosphere and cloud cover. The Level 1B (L1b) radiance images of these channels are geometrically and radiometrically corrected to provide high quality input data to the user communities. Three series of tests are undertaken to validate the product maturity levels: Post-launch Test (PLT), Post-launch Product Test (PLPT) and Extended Validation (EV). Engineering-focused metrics reflecting the radiometric quality of ABI L1b radiance image are assessed in these tests, such as signal-to-noise ratio (SNR)/noise-equivalent-differential temperature (NEdT), background coherent noise pattern, detector dynamic range, detector linearity, etc. Direct Earth view image analysis using image processing tool such as Fourier transform can also reveal information about its quality. In this presentation, initial results of selected PLPTs undertaken by GOES-R Calibration Working Group (CWG) are provided with the focus for IR bands. The results show that the general criterion for product maturity have been largely met. Occasional artifacts still existing at smaller scale are reported. There has been continuous effort to monitor, analyze and resolve these artifacts to further improve the L1b image quality.

Keywords: GOES-R ABI, radiometric calibration, radiance image quality, noise characterization, linearity

1. INTRODUCTION

The Advanced Baseline Imager (ABI) is the main payload onboard NOAA's Geostationary Operational Environmental Satellites (GOES), known as the GOES-R Series. It remotely collects data on the Earth's land /ocean surface and atmosphere in high radiometric sensitivity and spatial resolution comparing to legacy GOES, for the prediction of weather and climate monitoring[1-2]. The first satellite in the series, GOES-R, was launched in 2016 and was renamed GOES-16 upon reaching geostationary orbit. GOES-16 became NOAA's operational GOES-East satellite in December 2017. ABI scans the Earth in three standard geographic coverage regions: Full Disk, Continental United States (CONUS), and Mesoscale[3].

ABI is a multi-spectral channel, 2 axis-scanning imaging radiometer. It has 6 visible/near-infrared (VIS/NIR) bands and 10 infrared (IR) bands, Key design specifications are listed in Table 1[4]. The ABI Level 1b (L1b) calibrated radiance product is computed from Level 0 instrument detector samples that are resampled to pixels on the ABI fixed grid, which is a projection relative to the ideal location of a satellite in geostationary orbit. Also, four types of calibration data are generated for ABI: Infrared Calibration Target (ICT) looks, space looks, Solar Calibration Target (SCT) looks, and lunar scans. ICT and associated space look observation data are used to compute detector gain coefficients M for each of the ABI IR bands. SCT and associated space look observation data are used to compute detector gain coefficients for ABI VIS/NIR bands. Lunar scans are collected when the moon is in the field of regard of the instrument.

Similar to other remote sensing instruments, intense post-launch testing has been undertaken to validate or update the calibration parameters determined pre-launch to ensure the quality of the ABI image. There are three series of tests to validate the product maturity levels: Post-launch Test (PLT), Post-launch Product Test (PLPT) and Extended Validation (EV). The PLPTs were conducted for GOES-16 from December 2016 to June 2017 after nominal L1b data products became available, in parallel to the successful completion of the PLTs. The PLPTs provide a preliminary assessment of L1b product quality by determining baseline performance at Beginning Of Life (BOL) for ABI L1b products[5]. Results

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available at the end of the PLPT period were presented at the full validation Peer Stakeholder-Product Validation Reviews (PS-PVR) in June 2018 for the determination of Provisional product validation status.

The GOES-R Calibration Working Group (CWG) and Algorithm Working Group (AWG) lead the PLPTs related to L1b and L2/L2+ products, respectively[6]. CWG also participate in certain PLT activities. Due to the large number of detectors for 16 bands, the calibration/validation of ABI during the PLT/PLPT period is particular challenging. This presentation introduced the assessment results of selected radiometric parameters, mostly for IR bands, during the PLT by CWG. In section 2, the NEdT of IR bands are assessed. In section 3, the dynamic range of IR bands are assessed. In section 4, the coherent noise of VIS/NIR bands are assessed. In section 5, the linearity of ABI bands are assessment. Section 6 documents the investigation and removal of the striping detected in the L1b images of bands 14-16. A summary is given in section 7.

Table 1. ABI bands key specification.

Band	**Center Wavelength (μm)**	**Nadir Resolution (km)**	**Detector Rows**	**Primary Function**
1	0.47	1	676	Aerosols
2	0.64	0.5	1460	Clouds
3	0.86	1	676	Vegetation
4	1.38	2	372	Cirrus
5	1.61	1	676	Snow/Ice discrimination, cloud phase
6	2.25	2	372	Cloud particle size, snow cloud phase
7	3.90	2	332	Fog, stratus, fire, volcanism
8	6.18	2	332	Atmospheric
9	6.95	2	332	Water vapor
10	7.34	2	332	Water vapor
11	8.50	2	332	Cloud-top phase
12	9.61	2	332	Total column ozone
13	10.35	2	408	Clouds
14	11.20	2	408	Clouds
15	12.30	2	408	Clouds
16	13.30	2	408	Air temperature clouds

2. NOISE CHARACTERIZATION FOR IR BANDS

Noise is random variability in electronic signals. In many scenarios, noise is the major contributor to the overall instrument uncertainty so the determination of the system noise level is critical to evaluate instrument performance. For VIS/NIR bands, the noise specification of requirement is usually defined by Signal-to-Noise (SNR) ratio. For IR bands, the noise specification of requirement is usually defined by Noise Equivalent Delta Temperature (NEdT).

The system requirement of both for ABI is documented in the GOES-R Mission Requirement Document (MRD)[7]. For IR bands, the requirement is 0.1 K in general except band 16, whose requirement is a loosened 0.3 K[7]. For this PLPT, CWG directly evaluated the NEdT value saved in the instrument calibration data INST-CAL, which are produced by the ground system (GS) every 15 minutes. The values are calculated the same way as the ground test and PLT, which is based on the statistics of the ICT view and the space look count of IR detectors. The NEdT algorithm is generic and the details can be found elsewhere.

The key results are presented in Fig. 1. For each band, its NEdT are detector dependent and vary with time. The NEdT values plotted in the Fig. 1 are the band and daily average values, calculated for the selected dates in 2017, and 2018. The NEdT are also monitored by the CWG throughout the mission to evaluate its long-term drift, as well as seasonal and diurnal variation.

As can be observed from the plot, the NEdT have been stable since June 2017 when PLPT started and remained well below the system specification of requirements. For band 16, the NEdT of a single detector (#211) is out-of-family and marginally exceed the pre-launch baseline of about 0.1 K.

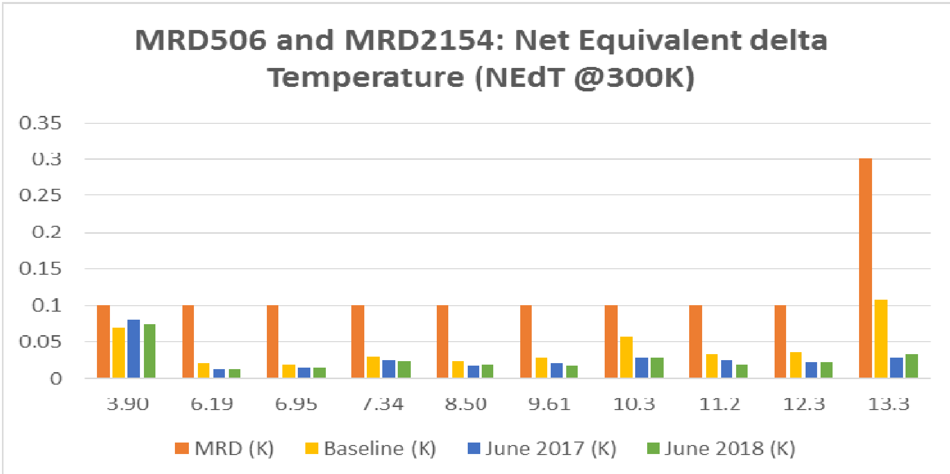


Figure 1: The NEdT characterized by PLPT is compared with results from MRD requirements, pre-launch measurements (baseline) and the start of PLPT in June 2017.

3. DYNAMIC RANGE CHARACTERIZATION FOR IR BANDS

A detector saturates when the upper limit of the dynamic range is reached. For the IR bands, the specification of requirement is defined by saturation temperature T_{max}, The maximum radiance that is allowable for a detector is

$$L_{max} = M \cdot (2^B - 1 - x_{SL}), \tag{1}$$

where the linear detector gain coefficient M is calculated by GS and provided in INST-CAL, as well as the space look count x_{SL}. B is the bit depth of the detector count. T_{max} is then derived from L_{max} with Planck equation. The space look count of a detector varies diurnally on orbit. T_{max} varies accordingly so we choose to use its daily minimum to represent the dynamic range of the detector for a given date. Also, T_{max} is also assessed on a detector basis. Figure 2 shows the PLPT T_{max} analysis results. For all these IR bands, the saturation temperatures have been stable and beyond the specification of requirement.

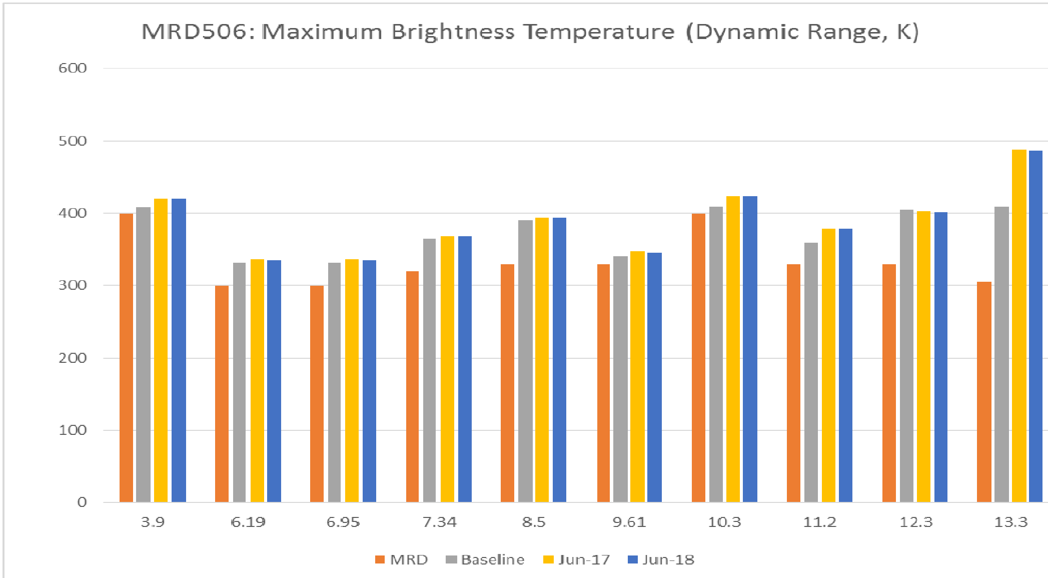


Figure 2: The saturation temperature characterized by PLPT is compared with results from MRD requirements, pre-launch measurements (baseline) and the start of PLPT in June 2017.

4. COHERENT NOISE OF VIS/NIR BANDS

Coherent noise is the undesired spatially periodic signal in the L1b image. Because of its nature, coherent noise is mostly detectible from uniform scene. During post-launch PLT, since there is no uniform Earth view scenes can be presented, the pattern of swaths for a full earth disk frame is instead executed as a series of stares at the ICT and space. Then the analysis software assigns synthetic mirror positions to these stares to "fake" an Earth view scene. Such "special-scan" data collection is not repeated for PLPT.

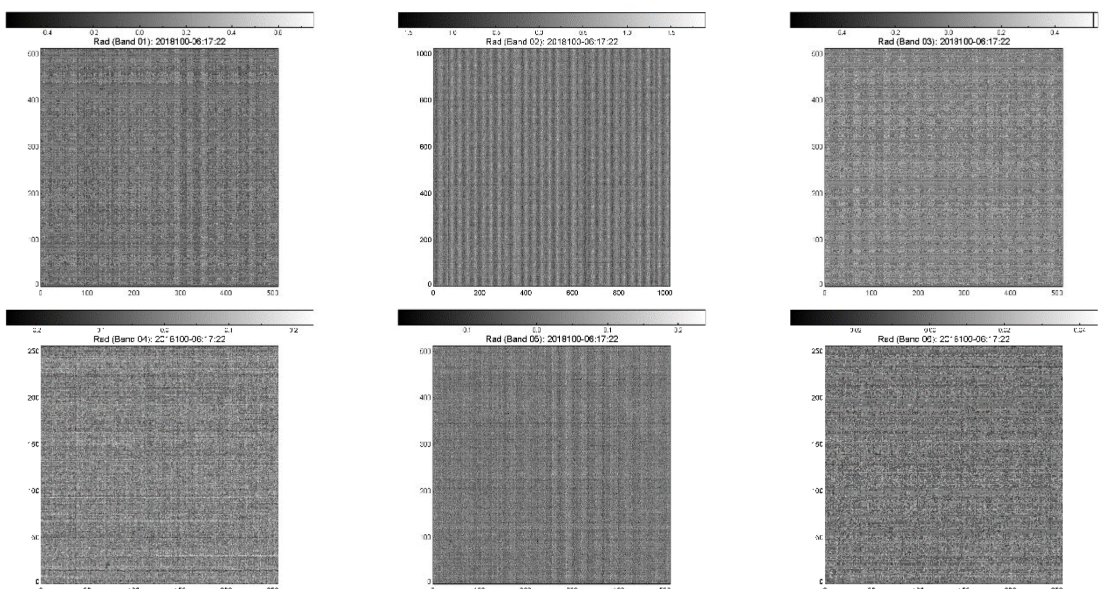


Figure 3: The L1b images of bands 1-6 with contrast enhanced for the coherent noise patterns to stand out.

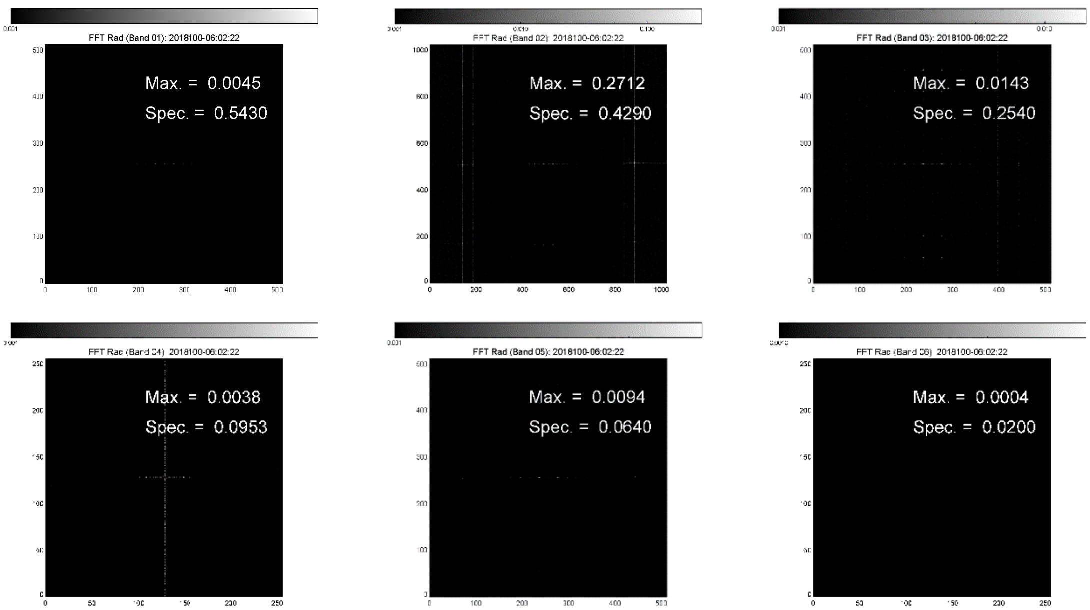


Figure 4: The Fourier transform of the L1b images of bands 1-6. (units: scaled radiance in L1b)

As a workaround, CWG analyzes the night time L1b images, which are spatially uniform for VIS/NIR bands, to check the existence of coherent noise. Two-dimensional Fourier transform is performed to detect the coherent noise:

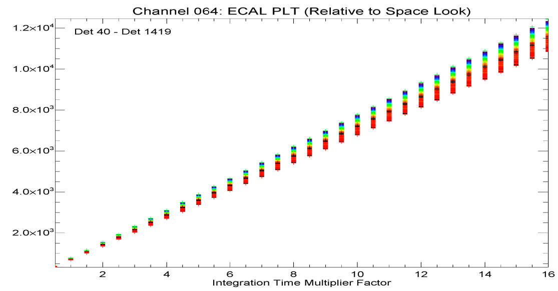
$$F(u) = \frac{1}{N}\sum_{x=0}^{N-1}(\mathrm{f}(x)exp[-j2\pi ux/]). \quad (2)$$

F(u) is the Fourier series coefficient of the l1b image f(x). Both positive components and negative Fourier components exist. Since they are generally symmetric around zero, their magnitude shall be doubled to be compared to the spec of system requirement to check any exceedance. One sample night time CONUS image is processed from 20170730 and 20180410 in the test. CWG also processed the corresponding calibrated images before re-sampling, which are plotted in Fig. 3 with contrast enhancement, to characterize the source of the coherent noise component. Vertical strips in the images are the coherent noise patterns. The Fourier transform of the l1b images are shown in Fig. 4. The numbers in the plots show the magnitude of the most significant Fourier components. The specification of requirements are met.

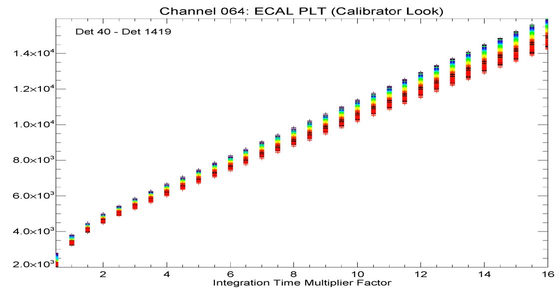
5. LINEARITY

Linearity of sensor response versus incident light over the full dynamic range can be measured in a number of different ways. During the ground test, a calibrated radiance source is used to provide multiple levels of input into the instrument which is used to verify the overall system linearity. In PLT, the linearity is characterized by assessing the linearity between the signal and the integration time. Two electronic calibration (ECAL) commands are executed so the detectors alternatively view the space and the calibration targets. When the calibration targets are viewed, the integration time multiples (ITMs) increment in pre-defined step sizes.

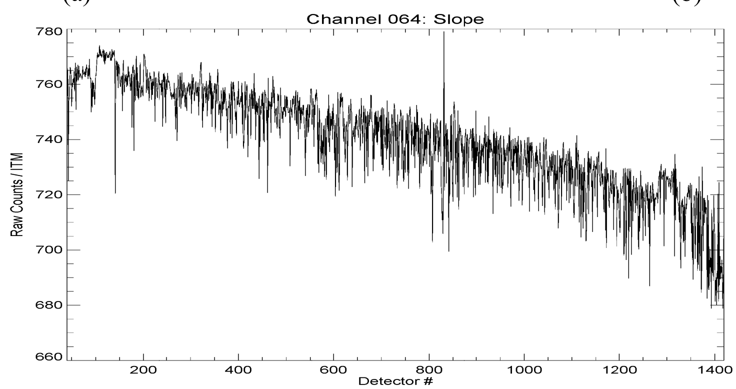
In this PLPT, we re-analyzed the ECAL data attached in PLT reports with the approaches described in the report. The data from calibration target view and the space look view are aligned and differentiated, as is shown in Fig. 5 (a)-(b). They are then fit as a linear function of the ITM. The fitting is performed on a detector basis with the slopes plotted in Fig. 5 (c). The residue of the fitting is considered as a measure of the system linearity. The maximum deviation is normalized to the signal at maximum ITM to be compared with the system requirement.



(a)



(b)



(c)

Figure 5: The (a) calibrator view of the detector, the (b) space look subtracted signal of the detector, and the slope of the linear fitting between signal and ITM.

Figure 6 shows the results of maximum deviation for band 2 as an example. The analysis approach of other bands are the same. The band maximum is then compared with the specification of requirement, also defined in MRD. The band maxima of all bands are provided in table 2. As is shown in the table, the reanalysis results are significantly lower than the MRD requirement of 1%.

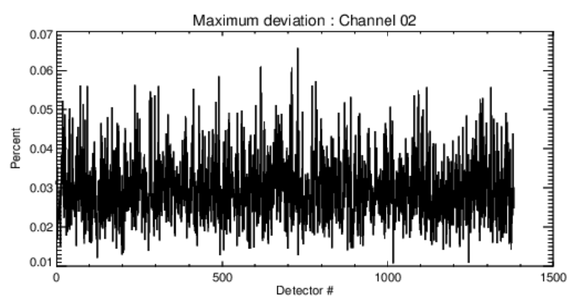


Figure 6: The normalized maximum residue of the linear fitting of ECAL data..

Table 2. ABI linearity characterized at PLPT.

Band	Maximum Deviation (%)	Band	Maximum Deviation (%)
1	0.1	9	0.22
2	0.1	10	0.08
3	0.1	11	0.08
4	0.2	12	0.18
5	0.2	13	0.10
6	0.1	14	0.10
7	0.09	15	0.12

8	0.44	16	0.12

6. STRIPING IN L1B IMAGES

As a result of the ABI's scanning mechanism and detector array layout, calibration deficiency of individual detector(s) will be reflected as stripes in the L1b image. With the tool STAR-CWG develop, striping in L1b images is regularly monitored for all ABI bands[8]. Among other bands with striping detected, band 14 at 11.20 µm is the long-wave IR window band that contributes most satellite derived products. CWG investigated the anomaly and identified the root cause of the striping as the improper non-linear gain Q coefficient for three offending detectors. We also found two other detectors, one each for band 15 and 16, cause similar striping in the L1b of these bands.

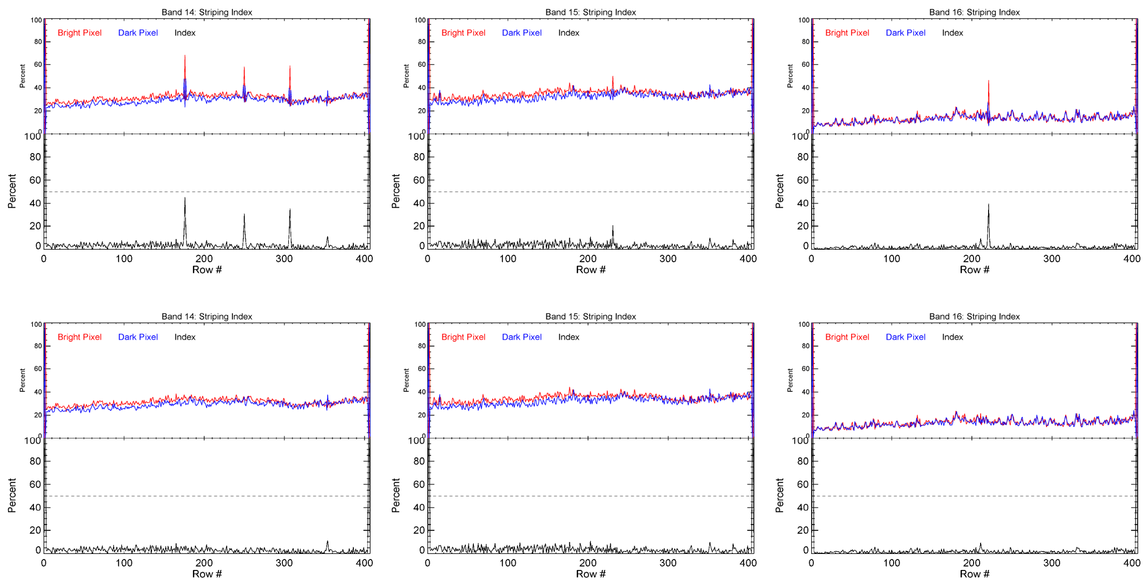


Figure 7: The striping detected in the image calibrated with current Q value (top) and the recalibrated image with $Q = 0$ (bottom) for bands 14-16. A spike in striping index is associated with an offending detector.

Offline test shows setting $Q = 0$ for these detectors remove the striping. Figure 7 is the offline test results: the top panels show the striping detected from the images calibrated with current Q values; the bottom panels show the striping detected from the images calibrated with zero Q. CWG updated Q-LUT accordingly and delivered it to GS for implementation.

7. CONCLUSION

We presented some of CWG's recent efforts on the assessment of selected radiometric performance parameters of GOES-16 ABI during the PLT/PLPT, an intensive cal/val stage. Overall, the performance meet the system requirements so the sensor's readiness for operation is verified. Future CWG work will focus on the GOES-17 ABI PLPT, as well as continuous improvement of GOES-16 ABI L1b image quality.

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