Product Performance Guide for Data Users of GOES-18 ABI Level 1b and Cloud and Moisture Imagery (CMI) Products Released for Full Validation Data Quality

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1. Introduction

The Advanced Baseline Imager (ABI, Figure 1) on the Geostationary Operational Environmental Satellite R Series (GOES-R) is an imaging radiometer with sixteen spectral channels (Table 1, Figures 2 and 3). These channels have spatial resolutions of 0.5 km, 1 km, and 2 km, covering some of the visible and infrared portion of the spectrum that allow the generation of dozens of critical weather and climate products.

Figure 1: A view of the Advanced Baseline Imager (ABI), from [1].

This Product Performance Guide summarizes the key performance and existing issues of GOES-18 ABI Level 1b (L1b) and Cloud and Moisture Imagery (CMI) products that were reported at the Full Validation Peer/Stakeholder-Product Validation Review (PS-PVR) on 1 September 2023. These product performance and issues may be carried over to the downstream Sectorized Cloud and Moisture Imagery (SCMI) products. Additional information about ABI L1b and CMI products and their quality can be found in Product Definition and User's Guide (PUG; [2] and [3]) and the presentations and supporting documents from the PS-PVR [4]. In order to obtain most satisfactory outcomes from these data products, users are also expected to utilize the embedded Data Quality Flags (DQF, [2] and [3]) and be informed of announced improvements and anomalies that occur occasionally ([5] and [6]). Users are encouraged to contact the NOAA

ABI calibration scientist and CMI developer (the authors of this document) to report anomalies or suggest improvements.

Table 1: Characteristics of ABI Channels

ABI Band	Band Central Wavelength[1] (µm)	Nominal IGFOV (km)	Sample Objective(s)
1	**0.47**	1	Daytime aerosol over land, coastal water mapping
2	**0.64**	0.5	Daytime clouds, fog, insolation, winds
3	**0.865**	1	Daytime vegetation/burn scar and aerosol over water, winds
4	**1.378**	2	Daytime cirrus cloud
5	**1.61**	1	Daytime cloud-top phase and particle size, snow
6	**2.25**	2	Daytime land/cloud properties, particle size, vegetation, snow
7	**3.90**	2	Surface and cloud, fog at night, fire, winds
8	**6.19**	2	High-level atmospheric water vapor, winds, rainfall
9	**6.95**	2	Mid-level atmospheric water vapor, winds, rainfall
10	**7.34**	2	Lower-level water vapor, winds & SO2
11	**8.50**	2	Total water for stability, cloud phase, dust, SO2, rainfall
12	**9.61**	2	Total ozone, turbulence, and winds
13	**10.35**	2	Surface and cloud
14	**11.2**	2	Imagery, SST, clouds, rainfall
15	**12.3**	2	Total water, ash, and SST
16	**13.3**	2	Air temperature, cloud heights and amounts

[1] From [7], MRD 506 with Section 3.4.8.1.4.

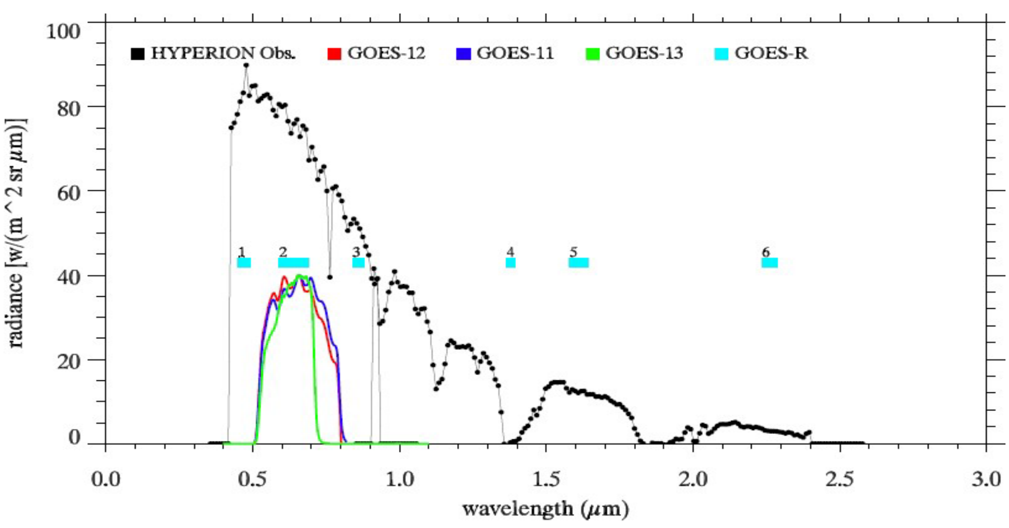

Figure 2: Spectral allocation of ABI solar channels (marked in cyan). The color curves are the spectral response function (SRF) of some of legacy GOES Imager. The black curve is the spectral radiance from a high albedo target observed by Hyperion on the Earth-Observer One (EO-1) satellite.

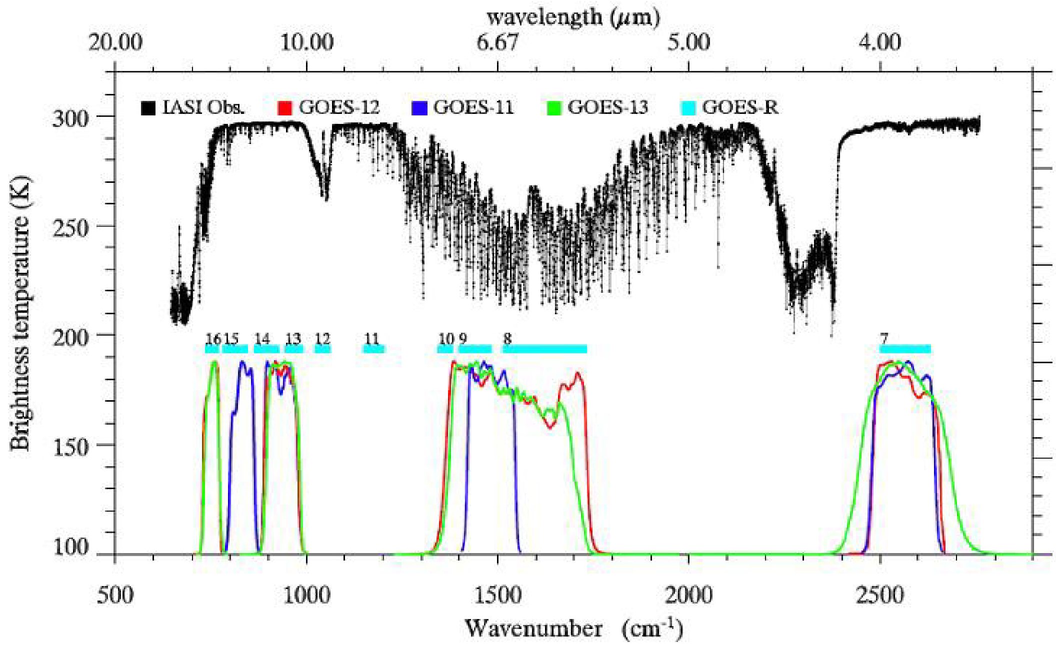

Figure 3: Spectral allocation of ABI infrared (IR) channels (marked in cyan). The color curves are the spectral response function (SRF) of some of legacy GOES Imager. The black curve is a sample spectral radiance (expressed as brightness temperature) from the Infrared Atmospheric Sounding Interferometer (IASI) on METOP-A.

The rest of Section 1 introduces some of the key characteristics of ABI and a timeline of the ABI product validation process. Section 2 provides comparison of the on-orbit ABI Level 1b (L1b) product performance to mission requirements. Section 3 and 4 contain descriptions of some remaining issues within the L1b and CMI products, respectively, and the mitigation process.

1.1 ABI Product Description

The GOES-18 ABI has several operational scanning routines or “timelines”. The Mode 6 timeline (Figure 4), also referred to as “10-Minute Flex Mode,” acquires one full disk image (FD), two PACific United States images (PACUS; the same size and cadence of the GOES East CONUS scene) of 3000 km by 50000 km, and 20 mesoscale (MESO) images of 1000 km by 1000 km in 10 minutes.

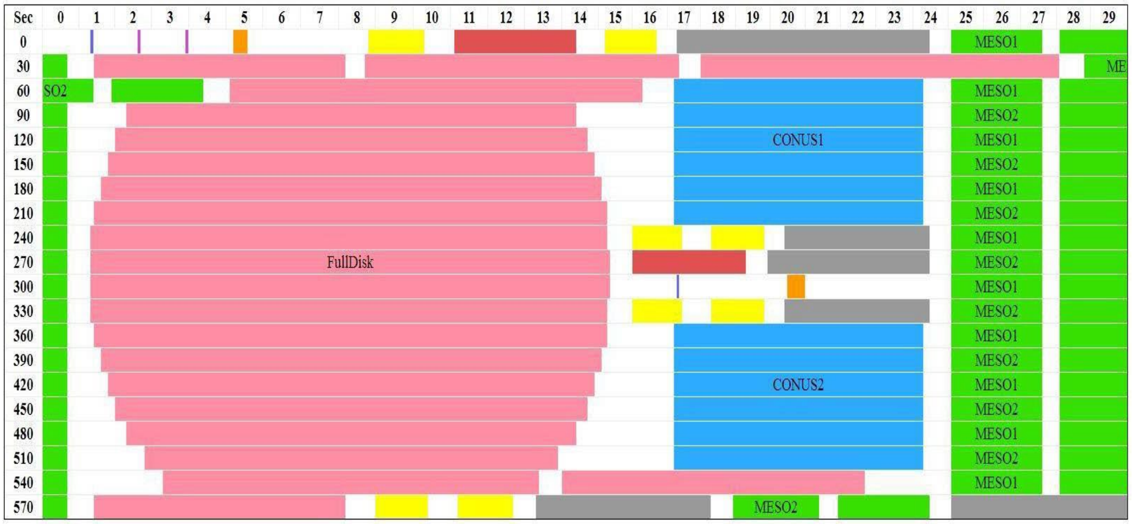

Figure 4: ABI 10-Minute Flex Mode (scan Mode 6) timeline diagram. Timeline diagrams (often called “time-time diagrams”) like this one depict the observations of ABI over 30 seconds for each line, starting at the top. The numbers along the left are the starting times of each line, in seconds, from the beginning of the timeline. This timeline, for example, covers 10 min. Pink, blue, and green represent the time scanning the FD, CONUS, and mesoscale sectors, respectively. Autonomous space looks are also included as part of each pink FD swath. White represents the time when ABI slews the line-of-sight (LOS) between observations. Gray represents the time when ABI points at nadir, collecting no data.

The Mode 4 timeline (Figure 5) acquires one FD image every five minutes and is called the “Continuous Full Disk Mode”.

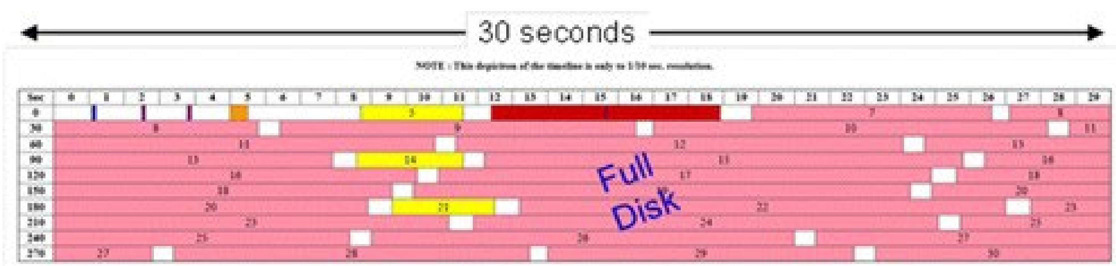

Figure 5: ABI Continuous Full Disk (scan mode 4) timeline diagram. This timeline covers 5 min. Colors same as Figure 4. There are no PACUS or mesoscale scenes in this timeline.

Besides scanning the Earth, these timelines include periodic measurements of blackbody, solar diffuser, space, and star scenes to maintain radiometric and geometric calibration accuracy. Additionally, there are other timelines for calibration and diagnosis. With its high temporal coverage capability and uninterrupted operations through eclipse, ABI provides continuous and timely monitoring of rapidly changing weather phenomena.

ABI L1b products are calibrated, geo-located, and resampled radiances of the 16 ABI channels over the FD, CONUS, and MESO regions. In addition to these Earth view data, L1b products also include certain instrument calibration and engineering data. ABI CMI products are ABI L1b Earth view data expressed in terms of reflectance factor for the solar channels (Bands 1-6) and brightness temperature for the infrared (IR) channels (Bands 7-16), and can be displayed as color-enhanced images. CMI products use L1b products as main inputs, along with metadata for the conversions. ABI Level 2+ (L2+) products include clear sky mask, cloud top properties, sea and land surface temperatures, etc. This document does not explicitly describe the quality of any L2+ products, but to the extent that all L2+ products are derived from L1b/CMI products, this document is also beneficial to users of L2+ products.

1.2 GOES-18 ABI Product Validation Timeline

GOES-T was launched on 1 March 2022, and became GOES-18 on 14 March 2022, when it was successfully inserted into the geostationary orbit. After outgassing, the ABI instrument was turned on and started a series of Post-Launch Tests (PLTs) to verify that the instrument works and the products are produced as expected.

At the end of the PLT activity for ABI, the first of a series of reviews was held to assess the status of the GOES-18 ABI L1b and CMI data products. The ABI L1b and CMI products were declared to have reached Beta Maturity on 11 May 2023. This was done without a formal Peer Stakeholder–Product Validation Review (PS-PVR) as was does for GOES-16 and -17. Instead, the Project Scientist based the declaration on the state of the PLTs completed at the time, the overall appearance of the products, and the recommendations of the cal/val leads. This process will be repeated for GOES-19. Reaching Beta Maturity means that:

- Product is made available to users to gain familiarity with data formats and parameters (via GRB)
- Product has been minimally validated and may still contain significant errors
- Product is not optimized for operational use.

GOES-18 drifted from its check-out location of 89.5° W to the GOES West orbital position of 136.8 W° in June 2022, with a later slow drift to the present orbital slot of 137.0° W where the remaining PLTs and Post-Launch Product Tests (PLPTs) were completed.

The PLPTs are used to evaluate the distributed data products generated from the ABI instrument as flowed through the GOES-R Ground System. For GOES-18 ABI L1b and CMI products, this led to the PS-PVR for the Provisional Maturity on 28 July 2022. Provisional Maturity means that:

- Product performance has been demonstrated through analysis of a small number of independent measurements obtained from select locations, periods, and associated ground truth or field campaign efforts.
- Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).
- Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.
- Product is ready for operational use and for use in comprehensive calibration/validation activities and product optimization.

GOES-18 was declared operational as GOES-West on 4 January 2023. On 1 September 2023, the final GOES-18 ABI L1b/CMI PS-PVR concluded that the ABI L1b and CMI products have reached the Full Validation Maturity per GOES-R Program, which means that:

- Product performance for all products is defined and documented over a wide range of representative conditions via ongoing ground-truth and validation efforts.
- Products are operationally optimized, as necessary, considering mission parameters of cost, schedule, and technical competence as compared to user expectations.
- All known product anomalies are documented and shared with the user community.
- Product is operational.

2. Key Performance Review

2.1. Overview

Top level GOES-18 ABI performance requirements are summarized in GOES-R Series Mission Requirements Document (MRD, [7]), some of which (from Section 3.4.8.1.2) are shown in Table 2 as a quick reference. MRD requirements are quoted here with their identification numbers. These MRD were then flowed down to Product Requirements, Instrument Requirements, and so forth, and verified and accepted at those levels before launch. Lower level requirements and verifications are not released to the public.

Table 2 summarizes requirements for ABI. For channels with central wavelengths less than 3 µm, these requirements pertain to accuracy at 100% albedo and short-term pixel-to-pixel repeatability when viewing a uniform target. For channels with center wavelengths longer than 3 µm, there are requirements for radiometric accuracy and repeatability. Meanwhile, the geometric calibration has several requirements that relate to navigation residuals, within frame registration, image-to-image registration, and channel-to-channel co-registration. There are also requirements on the lifetime of each ABI unit.

Table 2: Summary of ABI radiometric and geometric calibration and instrument lifetime requirements [7].

Spectral Bands, Radiometric Sensitivity, Dynamic Range		
Navigation		≤ 1.0 km (≤ 28 μrad)
Registration within Frame		≤ 1.0 km (≤ 28 μrad)
Line-to-Line Registration		≤ 0.25 km (at SSP) or ≤ 7 μrad
Registration Image to Image		≤ 0.75 km (at SSP) or ≤ 21 μrad for 0.5 km bands and 1.0 km bands ≤ 1.0 km (at SSP) or 28 μrad for 2.0 km bands
Band to Band Co-Registration (pre-margining)	0.5 km to 2.0 km bands	≤ 0.3 km (at SSP) or ≤ 8.4 μrad
	2.0 km to 2.0 km bands	≤ 0.3 km (at SSP) or ≤ 8.4 μrad
	0.5 km to 1.0 km bands	≤ 0.3 km (at SSP) or ≤ 7 μrad
	1.0 km to 1.0 km bands	≤ 0.25 km (at SSP) or ≤ 7 μrad
	1.0 km to 2.0 km bands	≤ 0.3 km (at SSP) or ≤ 8.4 μrad
On-Orbit Calibration	Visible and reflected solar < 3 μm	Pre-launch to ± 5% On-board to ± 3% 0.2% short-term repeatability
	Emissive IR	0.2 K repeatability 1.0 K abs. Accuracy
IR Band Linearity		± 1%
Lifetime	Ground Storage	5 years
	On-Orbit Storage	5 years is max possible
	Mean Mission Duration (MMD)	8.4 years
	Instrument On life	10 years with R=0.6

Reported in this Product Performance Guide are post-launch instrument performance, the MRD as reference. The post-launch tests are not meant to verify instrument compliance with requirements; that verification has been performed before launch with pre-defined equipment, methods, analyses, etc. Post-launch validation, on the other hand, is often subject to potential operation deficiency, instrument degradation, sub-optimal collection of test data, etc. Post-launch validation is useful in its own right, particularly for tracking the performance over time, and may supplement to the pre-launch verification. Post-launch testing also allows for the re-certification that the products fulfill the intended role while the satellite is in its intended environment. Readers of this document need to understand that while this document may contain language such as “meets requirements”, this is shorthand for more precise, but unwieldy, language that would not add to the usability of this document.

In the subsections that follow, the results provided at the Full Validation PS-PVR are reported, together with the relevant requirements in MRD. The method of validation and the related Post-Launch Test (PLT) and Post-Launch Product Test (PLPT) can be found in "Geostationary Operational Environmental Satellite (GOES) – R Series ABI L1b Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP)" [9] (for CMI, see [10]).

After the completion of GOES-17 post-launch testing, there was a review of the post-launch validation process, leading to a revised list of PLTs, PLPTs, and a new version of the RIMP. The main goal of the review is to streaming the validation process, including removing redundant, poorly-performing, or otherwise unnecessary or unfruitful test activities. Other tests were moved to reserve status, only to be utilized if initial tests indicated that one or more performance factors required deeper investigation. Therefore, some of the results found in the GOES-16 and GOES-17 versions of this guide may not be found in this document.

Additionally, for GOES-16 and GOES -17 ABI the observed on-orbit performance was compared to the Performance Baseline (PB). The Performance Baseline consists of a set of predictions for the on-orbit product performance and was compiled by a team at MIT/Lincoln Labs based on vendor reports and pre-launch test data. However, a Performance Baseline was not created for GOES-18, so the basis of comparison should be with the Full Validation results for the previous on-orbit ABI flight models. Unless noted in the text, the observed GOES-18 product performance is within family to GOES-16. Users should beware that given the GOES-17 ABI cooling issues, the observed performance of several of the metrics for that flight model may be compromised, especially those related to IR band radiometric performance.

2.2. Navigation Error

MRD522 states that "The GOES-R System **shall** navigate Radiance product observations with errors not to exceed 1.0 kilometer (3-σ) at SSP, except during eclipse."

These requirements, critical for any application of the ABI data, were evaluated by calculating the North-South (NS) and East-West (EW) components of navigation errors at various landmarks in terms of angle, finding their average μ and standard deviation σ, and reporting abs(μ) + 3σ for both the NS and EW components as error. The required Ground Sample Distances (GSD) have been converted to angles as 1 km = 28 μrad at the sub-satellite point (SSP). Full Disk images were used to achieve the best statistics. Eclipse is defined as when the Sun is eclipsed by the Earth.

For MRD522, evaluation was performed on all images (every ten minutes by default) and the

24-hour average is reported. As shown in Table 3, GOES-18 ABI L1b performance were substantially better than MRD at both the Provisional and Full Validation PS-PVRs.

Table 3. Navigation errors for selected channels not during eclipse

MRD522: Navigation Errors For Selected Channels Not During Eclipse (µrad)						
Channel	MRD		Provisional		Full	
(µm)	EW	NS	EW	NS	EW	NS
0.64	28.0	28.0	1.2	1.4	1.1	1.6
0.86	28.0	28.0	1.7	2.2	2.4	2.0
2.25	28.0	28.0	3.9	3.6	5.1	4.4
3.90	28.0	28.0	5.1	4.6	5.9	6.4
10.35	28.0	28.0	5.6	5.8	5.1	8.7

2.3. Channel-to-Channel Registration (CCR)

MRD529 states that "The GOES-R System **shall** co-register Radiance product observations between spectral channels having 2.0 km spatial resolution with 99.73% absolute error of 0.4 km at SSP."

MRD530 states that "The GOES-R System **shall** co-register Radiance product observations between spectral channels having 2.0 km and 0.5 km spatial resolution with 99.73% absolute error of 0.4 km at SSP."

MRD531 states that "The GOES-R System **shall** co-register Radiance product observations between spectral channels having 2.0 km and 1.0 km spatial resolution with 99.73% absolute error of 0.4 km at SSP."

MRD532 states that "The GOES-R System **shall** co-register Radiance product observations between spectral channels having 1.0 km spatial resolution with 99.73% absolute error of 0.25 km at SSP."

MRD533 states that "The GOES-R System **shall** co-register Radiance product observations between spectral channels having 1.0 km and 0.5 km spatial resolution with 99.73% absolute error of 0.25 km at SSP."

These requirements, critical for products using multiple channels data, were evaluated by calculating the relative differences of navigation errors for the pair of participating channels in both the NS and EW directions. The required ground distances have been converted to angles as 1 km = 28 µrad at SSP. As shown in Table 4, GOES-18 ABI L1b performance at the Provisional and Full Validation PS-PVRs met the MRD.

Table 4 . Channel-to-channel registration errors

MRD529-533: Channel-to-Channel Registration (CCR) Errors (µrad)						
Channels	MRD		Provisional		Full	
(µm)	EW	NS	EW	NS	EW	NS
0.64-3.90	11.2	11.2	5.6	3.9	4.7	6.0
0.86-1.61	7.0	7.0	5.3	2.5	1.4	3.2
3.90-13.30	11.2	11.2	5.6	4.5	4.6	3.9
9.61-10.35	11.2	11.2	5.5	2.1	1.7	1.4

2.4. Pixel-to-Pixel Registration Within Frame (WIFR)

MRD535 states that "The GOES-R System **shall** separate two Radiance product navigated data samples in the same channel by a known fixed distance not to exceed 1.0 km at SSP (28 µrad)."

This requirement prevents the existence of regions with large local navigation errors, which may vary in time to remain invisible in the average measures of the image. This requirement is evaluated by the standard deviation of a large number of navigation errors in FD images to homogeneity of image navigation. As shown in Table 5, GOES-18 ABI L1b performance at the Provisional and Full Validation PS-PVRs met the MRD.

Table 5: Pixel-to-pixel registration errors

MRD 535: Pixel-to-Pixel Registration Error Within Frame (µrad)						
Channels	MRD		Provisional		Full	
(µm)	EW	NS	EW	NS	EW	NS
0.64	28.0	28.0	10.6	7.8	8.2	9.2
0.86	28.0	28.0	10.1	8.5	10.8	9.6
2.25	28.0	28.0	10.4	8.7	10.6	9.6
3.90	28.0	28.0	12.6	12.3	12.2	14.6
10.35	28.0	28.0	11.9	12.6	13.6	18.5

2.5. Swath-to-Swath Registration (SSR)

MRD536 states that "The GOES-R System **shall** register to 99.73% absolute error two adjacent Radiance product lines/swaths of navigated data samples by a known fixed distance of 0.28 km at SSP."

This requirement is to ensure homogeneity of image navigation, specifically near the scan swath boundaries. It is of particular concern for ABI because of unprecedented large separation in time between swaths (up to 30 seconds, compared to 2.2 seconds or less previously) at higher spatial resolution, and the less-restrictive requirement that the adjacent swaths be in parallel. SSR errors also provide a fine temporal resolution to monitor and diagnose complex navigation processes. As a fine and delicate instrument, ABI may be subject to subtle external disturbance.

These requirements were evaluated by calculating the relative differences of navigation errors for adjacent swaths in both the NS and EW directions. The required ground distances have been converted to angles as 1 km = 28 μrad at SSP. As shown in Table 6, GOES-18 ABI L1b performance at the Provisional and Full Validation PS-PVRs met the MRD.

Table 6: Swath-to-swath registration

MRD 536: Pixel-to-Pixel Registration Error Within Frame – Register Two Adjacent Lines/Swaths (SSR; μrad)						
Channels	MRD		Provisional		Full	
(μm)	EW	NS	EW	NS	EW	NS
0.64	7.8	7.8	1.5	1.1	1.6	1.4
0.86	7.8	7.8	1.6	1.3	0.8	1.4
2.25	7.8	7.8	3.6	1.7	2.3	6.4
3.9	7.8	7.8	7.2	7.7	6.4	7.7
10.35	7.8	7.8	3.1	4.4	6.4	5.0

2.6. Frame-to-Frame Registration (FFR)

MRD538 states that "The GOES-R System **shall** register the same Radiance product sample location in two consecutive products ("frame-to-frame registration") within 0.75 km at SSP (21 μrad) for spectral channels with 0.5 km and 1.0 km spatial resolution."

MRD539 states that "The GOES-R System **shall** register the same Radiance product sample location in two consecutive products ("frame-to-frame registration") within 1.0 km at SSP (28 μrad) for spectral channels with 2.0 km spatial resolution."

These requirements are critical for products using radiance in time sequence, for example the atmospheric motion vectors (AMV). These MRD's were evaluated by calculating the relative differences of navigation errors for two consecutive images of the channel in question, in both the NS and EW directions. Only window channels were evaluated. The required ground distances have been converted to angles as 1 km = 28 μrad at SSP. As shown in Table, GOES-18 ABI L1b performance at the Provisional and Full Validation PS-PVRs met the MRD.

Table 7: Frame-to-frame registration

MRD 538 and 539: Frame-to-Frame Registration (µrad)						
Channels	MRD		Provisional		Full	
(µm)	EW	NS	EW	NS	EW	NS
0.64	21	21	0.9	0.7	0.7	0.9
0.86	21	21	1.7	1.6	1.9	5.2
2.25	28	28	3.8	3.1	5.2	4.1
3.9	28	28	4.4	3.8	6.0	5.8
10.35	28	28	4.0	4.8	6.8	9.1

2.7. Solar Channel Noise

MRD506 sets noise requirements for ABI. For solar channels, these requirements are expressed in terms of signal-to-noise ratio (SNR). It is evaluated by calculating, for individual detectors, the mean μ and standard deviation σ of radiances from on-orbit measurements of the Solar Calibration Target (SCT), and reporting μ/σ as detector SNR. The requirement applies to the minimum SNR of ABI pixels, which is a weighted average (by "resample kernel") of 16 neighboring detectors. As shown in Table 8, the minimum detector SNR for all solar channels of GOES-18 ABI are higher (better) than the MRD at the Provisional and Full Validation PS-PVRs; the pixel SNR must be even better.

Table 8: Minimum Signal-to-Noise Ratio (SNR) for all detectors of a channel

MRD506: Signal-to-Noise Ratio – 100% Albedo			
Channel (µm)	MRD	Provisional	Full Validation
0.47	**300**	**978**	**984**
0.64	**150**	**399**	**373**
0.64 for 99% Det.	**300**	**418**	**402**
0.64 for 5% Alb.	**20**	**49**	**Not Tested**
0.86	**300**	**664**	**682**
1.38	**300**	**929**	**922**
1.61	**300**	**355**	**368**
2.25	**300**	**1016**	**1013**

Channel 2 deserves extra attention for two reasons. First, this SNR requirement was waived for a previous Flight Module to be "300:1, except < 1% smaller than 300:1 and greater than 150:1". This waiver is no longer needed for GOES-18 ABI, but the result of similar evaluation is reported as "SNR for 99% det" in case a comparison is desired.

Second, MRD 506 has an additional requirement for Band 2 that the SNR for scenes of 5% albedo (dark scenes) **shall** be larger than 20. This test requires special data that were collected only once before Provisional validation, however this performance is not expected to change significantly over time. And this is a representative pixel SNR, not the minimum detector SNR reported in other cells.

2.8. IR Channel Noise

MRD506 also sets noise requirements for ABI infrared channels in terms of Noise Equivalent differential Temperature (NEdT) at 300K. This requirement is evaluated by calculating, for individual detectors, the standard deviation σ of radiances from the Internal Calibration Target (ICT) as measured by ABI, and converting the σ as δR to brightness temperature perturbation δT at the specified scene temperature using $\partial B^{-1}/\partial R$, the partial differentiation of reverse Planck's function B^{-1}. The requirement applies to the maximum NEdT of ABI pixels, which is a weighted average (by "resample kernel") of 16 neighboring detectors. As shown in Table 9, the maximum detector NEdT for Channels 8-18 of GOES-18 ABI are well below (much better) than the MRD at the Provisional and Full Validation PS-PVRs; the pixel SNR must be even better.

Table 9: Maximum Noise Equivalent differential Temperature (NEdT) at 300 K for all detectors of a channel

MRD506: Noise Equivalent differential Temperature (NEdT, mK @300°K)			
Channel (µm)	MRD	Provisional	Full Validation
3.90	100	157/86	126/72
6.19	100	17	17
6.95	100	24	23
7.34	100	33	36
8.50	100	33	32
9.61	100	24	62
10.3	100	38	40
11.2	100	28	25
12.3	100	37	32
13.3	300	80	118

For the 3.9 µm channel, the detector NEdT is 57% higher than pixel NEdT [8]. Both NEdT are reported in Table 9 as detector/pixel NEdT. While the noise of this channel is higher (worse) than all IR channels of GOES-16/18 ABI and GOES-17 ABI 3.9 µm channel, it is in compliance with the MRD.

2.9. Radiometric Calibration Accuracy

MRD2120 states that “The GOES-R System **shall** provide calibrated Radiances product measurements for the solar reflective channels to within an absolute accuracy of 5%.”

A partial list of ABI performance summary in 3.4.8.1.2 of MRD requires that the absolute accuracy of on-orbit calibration for emissive IR channels be 1.0 K.

Radiometric accuracy is critical for all applications of ABI measurements. Accuracy in this context measures the proximity of ABI radiance to truth. In reality, since truth is often unknown, lacks consensus of acceptance, or not readily available, these requirements are evaluated using comparable measurements by a well-calibrated radiometer.

For solar channels, the primary method of evaluation is direct comparison with the Visible and Infrared Imaging Radiometer Suite (VIIRS) onboard the NOAA-20 satellite. Additional references include radiances from Sonora Desert, Uyuni Desert, Deep Convective Clouds, and the Moon. As shown in Table 10, GOES-18 ABI solar channel bias is less (better) than the MRD requirement for all channels at the Full Validation PS-PVR.

Table 10: Radiometric calibration accuracy for solar channels.

MRD2120: Radiometric Accuracy – Solar Channels (Percent Difference)					
Channel (µm)	MRD	Provisional Mean	Provisional Stdev	Full Mean	Full Stdev
0.47	5	2.2	3.6	2.7	3.4
0.64	5	6.7/3.2	4.9	2.9	3.7
0.86	5	3.4	3.9	1.7	3.3
1.38	5	-2.4	2.1	-4.7	1.7
1.61	5	5.8	5.1	3.2	3.9
2.25	5	-0.1	2.3	0.3	2.6

Bias for two channels at the Provisional PS-PVR requires further explanation. The 0.64 µm channel has a known bias at launch. The correction was derived before the Provisional PS-PVR and was implemented the day before, however the data were not available to update the evaluation. Instead, the evaluation based on the old data and estimate of updated bias were reported. For the 1.61 µm channel, there was reason to suspect that the bias at the Provisional PS-PVR was not realistic. Indeed, the bias was reduced at the Full Validation PS-PVR after a new release of instrument alignment coefficient.

For IR channels, the primary reference is the Infrared Atmospheric Sounding Interferometer (IASI) onboard the METOP-B satellite. Additional references include the IASI on METOP-C satellite, and the Cross-track Infrared Sounder (CrIS) on S-NPP and NOAA-20. As shown in Table 11, GOES-18 ABI IR channels agree very well with references; the differences are much smaller than the MRD requirement for all channels at the Provisional and Full Validation PS-PVRs.

Table 11: Radiometric calibration accuracy for IR channels

Table 12MRD 1493, 1503 and 1513: Radiometric Accuracy – Infrared (mK)					
Channel (µm)	MRD	Provisional Mean	Provisional Stdev	Full Mean	Full Stdv
3.9	1000	-28	159	-29	163
6.19	1000	-23	57	-15	62
6.95	1000	-102	96	-87	100
7.34	1000	37	120	31	126
8.5	1000	-43	333	-53	341
9.61	1000	-3	268	2	267
10.3	1000	-38	446	-42	456
11.2	1000	-17	499	-21	493
12.3	1000	39	513	34	496
13.3	1000	134	412	128	430

3. Existing Issues and Product Changes in ABI L1b Products for User Awareness

3.1. Existing Issues in the L1b Products

Users are advised of following existing issues:

1) Barcode Artifact: There was a moderate anomaly of vertically oriented artifacts in the image of 3.9 µm channel that may spread to several products using that channel. This anomaly was later named Barcode Artifact (BA). For unknown reason, BA was substantially subdued after 22 September 2022. While detectable, it is considered unnoticeable for most users. Further information, including history, characteristics, related investigation, and mitigation plan of BA, can be found in [11]. Monitoring of the amplitude of the barcode artifact can be found at [12] and [13].
2) Stray light:
   a) Significant stray light can be found for solar channels (1-6) approximately one hour before

and after satellite local midnight for approximately forty days before and after the vernal (spring) and autumnal (fall) equinox, and may exist in other days of the year. Unlimited straylight for solar channels at night is allowed.

b) Straylight may be detected in Channel 7 approximately one hour before and after satellite local midnight for approximately forty days before and after the vernal (spring) and autumnal (fall) equinox within the Zone of Reduced Data Quality (ZRDQ). This is to be expected; the straylight intensity complies with the requirement.

3) Calibration error due to lunar intrusion: A software deficiency may lead to the failure of rejecting the space views contaminated by the Moon. Usually, this compromises the calibration of one swath of all sectors (up to 30 second). Occasionally, it may compromise the space view used for IR channel calibrations, ruining the calibration for the entire timeline (up to ten minutes). This may affect multiple (not all) detectors of several (not all) channels, and occur more than once a month on average.
4) Calibration error resulting in missing swath(s): A software deficiency may lead to the loss of valid space counts for a channel. Usually, this compromises the calibration of one swath of all sectors (up to 30 second). Occasionally, it may compromise the space view used for IR channel calibrations, ruining the calibration for the entire timeline (up to ten minutes). This may happen to any IR channel, but more often to the 3.9 μm channel. This happens about twice a week on average, although it could happen multiple times a day.

3.2. ABI L1b, CMI, and SCMI Product Changes

For GOES-17 several changes were made to the ABI L1b and CMI product files to help users identify when the increased focal plane temperatures may be degrading the products. These new flags and temperatures values are retained in the GOES-18 ABI radiances and CMI files. For more details, please consult the Product Users Guide (PUG). More about prior ABI artifacts can be found in [14].

4. Existing Issues for ABI CMI

For CMI, all the issues noted above in Section 3 for the radiances are valid, in addition to the following:

4.1. Inconsistent Spatial Coverage

ABI utilizes on-board flight software to avoid direct observations of the Sun. The software prevents the ABI mirrors to direct light from within a specified angular region around the Sun onto the detectors. Due to the physical layout of the detectors for each channel on the multiple focal planes, the region of the field of regard seen by each channel is different for a fixed set of mirror angles. When a swath is truncated to avoid pointing too close to the Sun, the actual position seen on the Earth at the swath truncation point is different for every channel, shifted East-West depending on the channel detector position on the focal planes. That is, the “chunk” of the Earth not scanned during BOA varies channel-by-channel.

Early in the design of the ground processing algorithms it was decided to process each channel independently and set data quality flags (DQFs) for the BOA region for each channel. Developers of products that use multiple channels need to carefully scrub their input data to ensure they are not missing one or more channels around the BOA region, resulting in degraded or misleading products.

4.2. Missing Data

For yet-unknown reasons, the GOES-18 ABI data processing suffers from slightly more frequent occurrences of small amounts of missing L0 data. As far as known, this is not a problem with the on-orbit instrument, but is confined to the ground processing system. These events are rare, but are more frequent than is seen with GOES-16 or GOES-17 ABI. These data drop-outs are manifest by small blocks of missing data within the L1b and CMI products. Occasionally, if multiple space looks or other calibration data are missed, there can be full swaths of ABI scanning that do not make it into the L1b product. Missing swaths are most common for Band 7. The investigation for the cause of this anomaly is ongoing.

4.3. Metadata Timing

When the metadata arrives for an ABI file via GOES-R ReBroadcast (GRB), that is supposed to be the indicator that the entire file has been delivered. Yet, in some cases this metadata is sent too soon. To address this issue, some users have inserted a “sleep” command to wait for extra time. In general, this is effective, but adds latency, for example 10 sec. Yet, there are infrequent situations where the added time isn’t enough and hence part of an image is missed. Most of the time the latency is less than 4 sec, but it can be larger as well.

4.4. T_B(3.9 μm) for Cold Targets

Cold targets (< 230 K) produce very little light at 3.9 μm (Band 7). Due to the nature of the Planck relationship each step in the quantized radiance values for cold targets converts into large brightness temperature steps (see Figure 6). Care should be taken for enhanced visual representation of cold clouds, so that the noise in these low light levels is not amplified. For example, during the nighttime a high cloud can be very cold, resulting in small (near zero) radiance values observed by the satellite. Hence, if a color mapping is applied that varies over many colors on the cold end, the image may appear noisier. More on this issue can be found on the CIMSS Satellite Blog: http://cimss.ssec.wisc.edu/goes/blog/archives/28030.

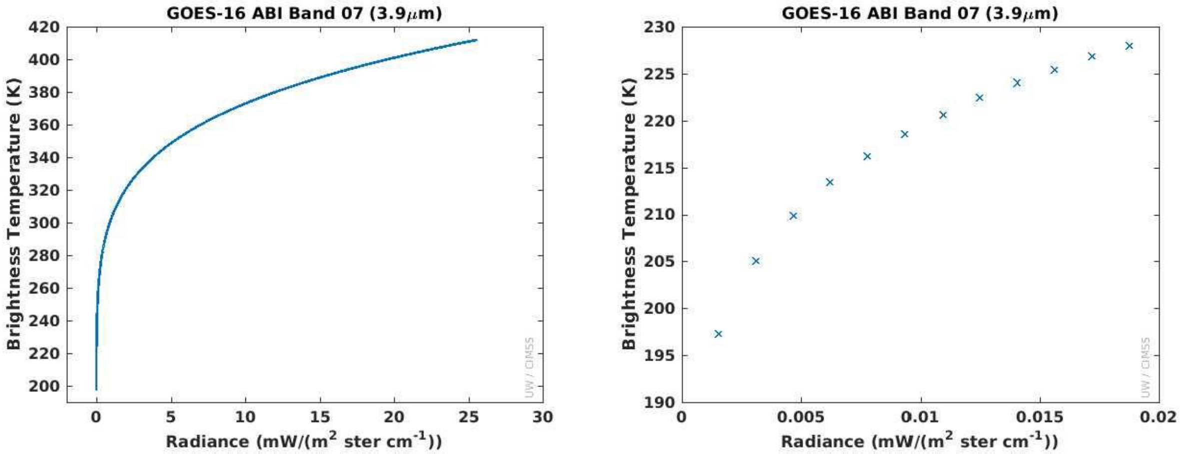

Figure 6: Planck relationship between brightness temperature and radiance for GOES-16 Band 7 (3.90 μm), displayed over the full dynamic range of the ABI band (left) and zoomed in (right) to show the large discrete steps in brightness temperature at the cold (low radiance) end of the ABI L1b radiance range. A small amount of noise in the radiance values can be exaggerated into very large brightness temperature noise (plots courtesy UW/CIMSS Satellite Blog linked in the text). The Planck relationships for all ABI Flight models show this phenomenon at low radiance for Band 7.

5. <u>Summary</u>

GOES-18 ABI instrument and the ground processing work well to create high quality L1b and CMI products. The performance and existing issues have been described, including how users could be affected. Results from the testing of ABI L1b performance and mitigation plans have been presented. More information on the calibration and navigation performance can be found at: https://www.star.nesdis.noaa.gov/GOESCal/

Contact for further information: OSPO User Services at SPSD.UserServices@noaa.gov

Contacts for specific information on the ABI L1b and CMI products:

- ABI L1b CWG Team Lead: Fred Wu (xiangqian.wu@noaa.gov)
- ABI CMI AWG Team Lead: Tim Schmit (tim.j.schmit@noaa.gov)

6. References

[1] GOES-R Series Data Book: https://www.goes-r.gov/downloads/resources/documents/GOES-RSeriesDataBook.pdf

[2] GOES-R Product Definition and Users Guide (PUG), Volume 3 (L1b Product): https://www.goes-r.gov/users/docs/PUG-L1b-vol3.pdf.

[3] GOES-R Product Definition and Users Guide (PUG), Volume 5 (L2+ Product): https://www.goes-r.gov/products/docs/PUG-L2+-vol5.pdf

[4] ABI L1b/CMI PS-PVR Materials: https://www.noaasis.noaa.gov/GOES/PS_PVR_GOES18.html

[5] CWG Event Log: https://www.star.nesdis.noaa.gov/GOESCal/goes_SatelliteAnomalies.php

[6] ESPC Notifications for satellite operations: https://www.ospo.noaa.gov/Operations/messages.html

[7] Mission Requirements Document: https://www.goes-r.gov/syseng/docs/MRD.pdf

[8] The MRD requirements are levied against the final, resampled pixel-level values.

[9] Geostationary Operational Environmental Satellite (GOES) – R Series ABI L1b Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP).

[10] Geostationary Operational Environmental Satellite (GOES) – R Series ABI L2 Cloud and Moisture Imagery Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP): https://www.goes-r.gov/products/RIMPs/RIMP_ABI-L2_CMI.pdf

[11] GOES-18 Post-launch Testing and Transition to Operations (barcode section near end): https://www.goes-r.gov/users/transitionToOperations18.html. See also a presentation describing the barcode artifact: https://www.goes-r.gov/downloads/users/transitionToOperations18/GOES-18_Band07BarcodeArtifactRev2.pptx

[12] STAR Barcode Artifact Monitoring web site: https://www.star.nesdis.noaa.gov/GOESCal/G18_ABI_Barcode_Artifact.php

[13] AWG/CIMSS Website for Barcode Anomaly: https://data.ssec.wisc.edu/abi/?action=view_data&params=satellite,date,region,parameter&param_values=GOES-18,20231024,conus,1paneltimediff_b7

[14] Gunshor, M. M.;Schmit, T. J.;Pogorzala, D.;Lindstrom, S.;Nelson, J. P., 2020: GOES-R series ABI Imagery artifacts, J. of Applied Remote Sensing, 14(3), 032411 (2020), DOI: https://doi.org/10.1117/1.JRS.14.032411