GOES-R Series ABI Reprocessed L1b Product User Guide

November 2024

Version 1.1

Introduction

This document describes the improvements and enhancements to the reprocessed GOES-R series Advanced Baseline Imager (ABI) Level-1b (L1b) products. The focus is on the differences between the original, Operational L1b products ("Ops") and the reprocessed data ("Reprocessed"). Note, the Mesoscale domain products were not produced as part of the reprocessing effort. For a comprehensive resource on the Operational L1b products, including information on the GOES-R series, the ABI, product structure, and other details, users are encouraged to reference the GOES-R Product Definition and Users' Guide (PUG) Volume 3, found on the GOES-R homepage (www.goes-r.gov/resources/docs.html).

The Reprocessed L1b data addressed a number of radiometric and geometric calibration issues that were present at the time in the Operational data products:

- Ground processing discrepancies
- Anomalies discovered on-orbit
- Radiometric calibration artifacts
- Geometric image navigation and registration (INR) artifacts
- Other systematic artifacts in the data
- The Reprocessed dataset shows improvement over the Operational but may still contain data gaps or discrepancies due to the nature of the dataset

Feedback can be provided to:
Dan Lindsey (dan.lindsey@noaa.gov) and Gary Lin (guoqing.lin-1@nasa.gov)

The Reprocessed L1b products are produced in the Network Common Data Format Version-4 (NetCDF4) filetype. NetCDF4 files share many commonalities with the Hierarchical Data Format Version-5 (HDF5) file format. The Reprocessed L1b products are compatible with the majority of NetCDF4 and HDF5 software tools. For more information on these formats, as well as compatible tools and software libraries, users are encouraged to consult the homepages for NetCDF (www.unidata.ucar.edu/software/netcdf/software.html) and HDF

(https://www.hdfgroup.org/). Users who are new to GOES-R ABI data are encouraged to review the "Beginner's Guide to GOES-R Series Data" on the GOES-R homepage (www.goes-r.gov/downloads/resources/documents/Beginners_Guide_to_GOES-R_Series_Data.pdf).

Level-1b Product Improvements

The primary goal in reprocessing the ABI L1b catalogue is to improve the stability of both the radiometric and geometric calibration over the course of the entire mission life. Below is a brief summary of these improvements. For more details users are encouraged to review the Radiometric and Geometric editions of the Reprocessing Algorithm Theoretical Basis Description (rATBD) documents which can be made available upon request.

Radiometric Calibration Improvements

The absolute radiances within the Reprocessed data are based on the physics-based, long-term calibration derived from the NIST-traceable sources on board each ABI flight model. The key improvement to this long-term calibration involved recomputing the linear calibration coefficients for the six Visible/Near-Infrared (VNIR) spectral channels. Operational calibration of channels 1-6 is maintained by routine views of the on-board Solar Calibration Target (SCT). Over time, the timing of these calibration events has been optimized to specific times when the sun is at a 0º elevation angle with respect to the SCT. However early in the mission this was not the case, resulting in discontinuous jumps in the linear calibration term, with corresponding jumps in scene radiance.

New time-dependent Look-Up Tables (LUTs) were developed to provide this linear term as a smooth transition over the life of the instrument. These LUTs were derived by processing the SCT data offline to compute linear coefficients, correcting these values for errors due to improper solar angles, and trending the coefficients throughout the life of the instrument. For GOES-16 ABI, these coefficients have been computed from operational SCT data up through **April 30, 2024**.

In addition to these, a number of radiometric calibration improvements that were introduced at one point in time in operations have now applied to the entire catalogue of products. These include the channel 02 "bias fix", mitigating the channel 07 "Cold Pixels Around Fires" with an updated resampler kernel, increased saturation/undersaturation limits, and a reduction in visible striping through the use of updated quadratic terms in the calibration equations.

Geometric Calibration Improvements

The primary improvement to the reprocessed L1b Image Navigation and Registration (INR) performance comes from a new approach to handling eclipse conditions. During eclipse season, namely the Spring and Autumn months, the sun moves behind the earth as seen by ABI. For several hours before and after each eclipse the overall INR performance is degraded due to the sun moving into ABI's field of view. New algorithms were developed and implemented in the reprocessed data that greatly reduce the extent of this degradation.

A secondary improvement to the INR performance comes from removing the influence of instrument component temperatures on detector navigation. Temperatures for various parts of the ABI are reported in the raw, Level-0 (L0) data, making them available for use in reprocessing algorithms. Detecting and accounting for fluctuating temperatures results in more consistent INR performance over time.

Mitigating Image Artifacts

Due to the near-real-time nature of Operational ABI L1b production, certain image artifacts that are caused by dropped data packets or sudden on-orbit changes are unable to be mitigated. Examples of this include artifacts known as "Shark Fins", "Caterpillar Tracks", and sections of missing data. Often, reprocessing recovers and corrects the artifact. However, if the necessary raw data did not make it into the L0 input files, it is impossible to recover the artifact in the Reprocessed data. Figure 1 shows an instance of both a Caterpillar Track and a Shark Fin in the Operational L1b, both of which have been removed in the Reprocessed L1b.

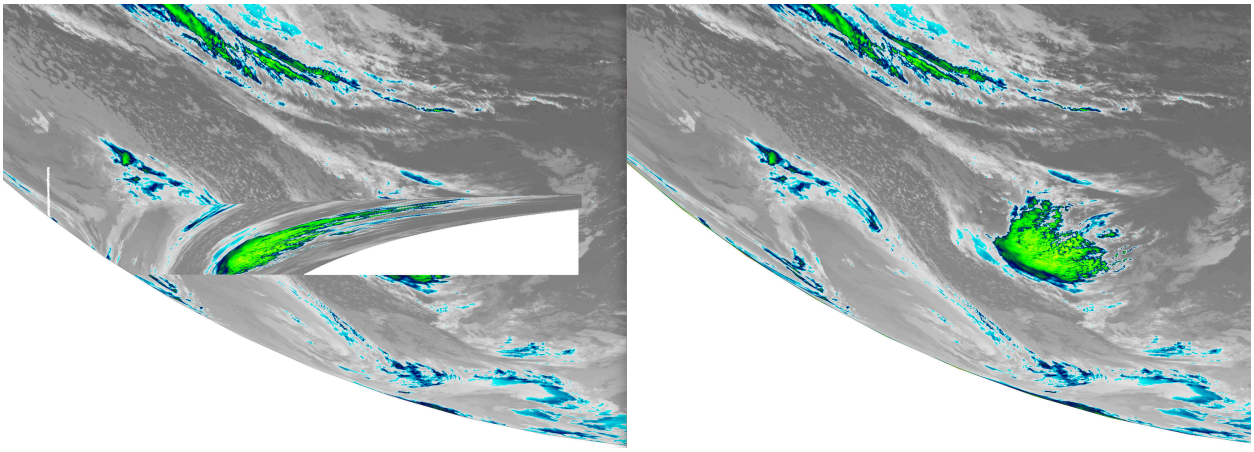

Figure 1: A subset of a GOES-16 channel 02 (0.64 µm) Full Disk image from 12/11/2019 at 12:50 UTC. A Caterpillar Track and Shark Fin are seen in the Operational product (left), while both have been removed in the Reprocessed product (right).

Production Notes and Known Issues

While the overall science content of the reprocessed L1b products has been improved, there remain instances of minor anomalies and gaps in the data record. In most cases these issues arise for one of several reasons, including gaps in the input L0 file archive, and technical issues within the L0 data.

Input L0 Data Gaps

The L0 files being used as inputs to this effort are sourced from the NOAA Comprehensive Large Array-Data Stewardship System (CLASS). CLASS is a digital archive of many types of NOAA environmental data products, including the Operational GOES-R L1b products. It More information about CLASS can be found on their homepage (https://www.class.noaa.gov).

The Operational GOES-R Ground System packages the raw ABI L0 data into NetCDF files. These files contain two minutes of L0 data, written in the order it was received by the ground station antennas. In order to maintain seamless operations, the Operational system consists of two physical sites: a primary and a backup. Both sites create L0 files and store them locally for two days. However, the exact start and end times of the two minutes of data within the files are not in sync between the two sites. For example, the primary site may package data from 11:00.00 to 11:02.00 UTC in one file, while the backup site writes a file containing data between 11:01.00 and 11:03.00.

CLASS only receives L0 files from one site at a given time; whichever site is currently the prime Operational site ("the Prime"). Over the years, operators have switched between the two sites whenever the current Prime needed to be taken offline for maintenance activities.

The result of this is the L0 archive in CLASS contains a large number of gaps and redundancies due to these "site switches". The majority of these gaps result in missing L1b files in the Reprocessed data record. Since the CLASS archive is the only source of L0 files, these gaps are unrecoverable.

L0 Data Issues

Separate from the completeness of the raw data is the issue of problems within the L0 data itself. This mainly appears in the form of raw data packets that are missing their timestamps. These timestamps are used in the reprocessing software in many ways. While the software has been written to accommodate missing timestamps from some types of data packets (e.g. swath start times), it is not within the scope of this effort to do so for every possible type of packet. The result is a gap in the reprocessed data record, or in rare cases, minor anomalies that are present in the Reprocessed data that are not in the Operational L1b.

Other Production Notes

The system architecture built for this reprocessing effort does not support real-time or near-real-time latency. Once the calibration for a given ABI model has been optimized, the data is reprocessed in large chunks, typically 1-2 months at a time, over the course of ~1 business day. As data is reprocessed it is validated using a suite of tools that assess the overall data quality and coverage. Once it is deemed ready it is made available to users. Given the large volume of data over the life of the GOES-R mission, it is possible that the Reprocessed dataset may contain errors or artifacts. Any products found during the validation stage to contain such errors are withheld from public release. However it is possible that some products are released with unidentified errors. Users who do identify such cases are encouraged to report them to Dan Lindsey (dan.lindsey@noaa.gov) and Gary Lin (guoqing.lin-1@nasa.gov).

Level-1b Product Format Changes

In addition to improvements to the data quality within the L1b NetCDFs there are a number of changes and enhancements to the product format itself. These differences between the Operational and Reprocessed NetCDF format are outlined here.

File Name Convention

GOES-R product names conform to a naming convention specified in the PUG (Volume 3, Appendix A). Operational product file names begin with the letters “OR”, indicating that the product was produced on the Operational system with Realtime data.

Reprocessed product files have been given the designation of “RP” to indicate the product was created on the Reprocessing system with Playback data.

Nominal **Operational** File Name:
OR_ABI-L1b-RadF-M6C01_G16_s20191731650587_e20191731700295_c20191731700343.nc

Nominal **Reprocessed** File Name:
RP_ABI-L1b-RadF-M6C01_G16_s20191731650587_e20191731700294_c20233110257491.nc

Product Metadata

In order to conform to the metadata standards used by Operational GOES-R products, several metadata fields have been updated to reflect the nature of the Reprocessed data and its production environment. These fields are delivered as NetCDF global attributes. The

table below outlines the differences between the Operational and Reprocessed global attributes.

Name	Value[50](...)	Value[50](...)
Conventions	CF-1.7	CF-1.7
LUT_Filenames	SpaceLookParams(FM1A_CDRL79RevP_PR_08_01_01)-61665	ABI_NavigationParameters_Band13(FM1A_CDRL79RevH_DO
Metadata_Conventions	Unidata Dataset Discovery v1.0	Unidata Dataset Discovery v1.0
cdm_data_type	Image	Image
dataset_name	OR_ABI-L1b-RadF-M6C13_G16_s20191601800499_e2019160	RP_ABI-L1b-RadF-M6C13_G16_s20191601800499_e2019160
date_created	2019-06-09T18:10:27.7Z	2024-07-18T19:51:29.4Z
id	89111021-d670-4605-b209-a3c7acb39a24	c88edbb9-21a8-7a32-98b2-e16219125e85
institution	DOC/NOAA/NESDIS > U.S. Department of Commerce, Nat	DOC/NOAA/NESDIS > U.S. Department of Commerce, Nat
instrument_ID	FM1	FM1
instrument_type	GOES R Series Advanced Baseline Imager	GOES R Series Advanced Baseline Imager
iso_series_metadata_id	a70be540-c38b-11e0-962b-0800200c9a66	a70be540-c38b-11e0-962b-0800200c9a66
keywords	SPECTRAL/ENGINEERING > INFRARED WAVELENGTHS > INFR	SPECTRAL/ENGINEERING > INFRARED WAVELENGTHS > INFR
keywords_vocabulary	NASA Global Change Master Directory (GCMD) Earth S	NASA Global Change Master Directory (GCMD) Earth S
license	Unclassified data. Access is restricted to approv	Unclassified data. Access is restricted to approv
naming_authority	gov.nesdis.noaa	gov.nesdis.noaa
orbital_slot	GOES-East	GOES-East
platform_ID	G16	G16
processing_level	National Aeronautics and Space Administration (NAS	L1b
production_data_source	Realtime	Playback
production_environment	OE	Reprocessing
production_site	WCDAS	NCCF/NCIS
project	GOES	GOES
scene_id	Full Disk	Full Disk
spatial_resolution	2km at nadir	2km at nadir
standard_name_vocabulary	CF Standard Name Table (v35, 20 July 2016)	CF Standard Name Table (v35, 20 July 2016)
summary	Single emissive band ABI L1b Radiance Products are	Single emissive band ABI L1b Radiance Products are
time_coverage_end	2019-06-09T18:10:21.8Z	2019-06-09T18:10:20.547000Z
time_coverage_start	2019-06-09T18:00:49.9Z	2019-06-09T18:00:49.911000Z
timeline_id	ABI Mode 6	ABI Mode 6
title	ABI L1b Radiances	ABI L1b Radiances

Figure 2: The global attributes of an Operational (left) and Reprocessed (right) channel 13 Full Disk image as seen in HDFView. The differences between the two datasets are highlighted.

Limb Pixels

As part of its image collection routine, the ABI instrument scans an area wider than the earth full disk. However, these overscan regions are excluded from the final L1b image by the Operational ground system algorithms. Any pixel that does not fully lie on the earth surface is set to the default fill value of 4095. The result is that atmospheric phenomenology along the limb of the earth is not visible in Operational products. The Reprocessed data retains these “limb pixels” in the final product. In order to maintain compatibility with existing software and downstream algorithms, the overall array dimensions are preserved as shown below.

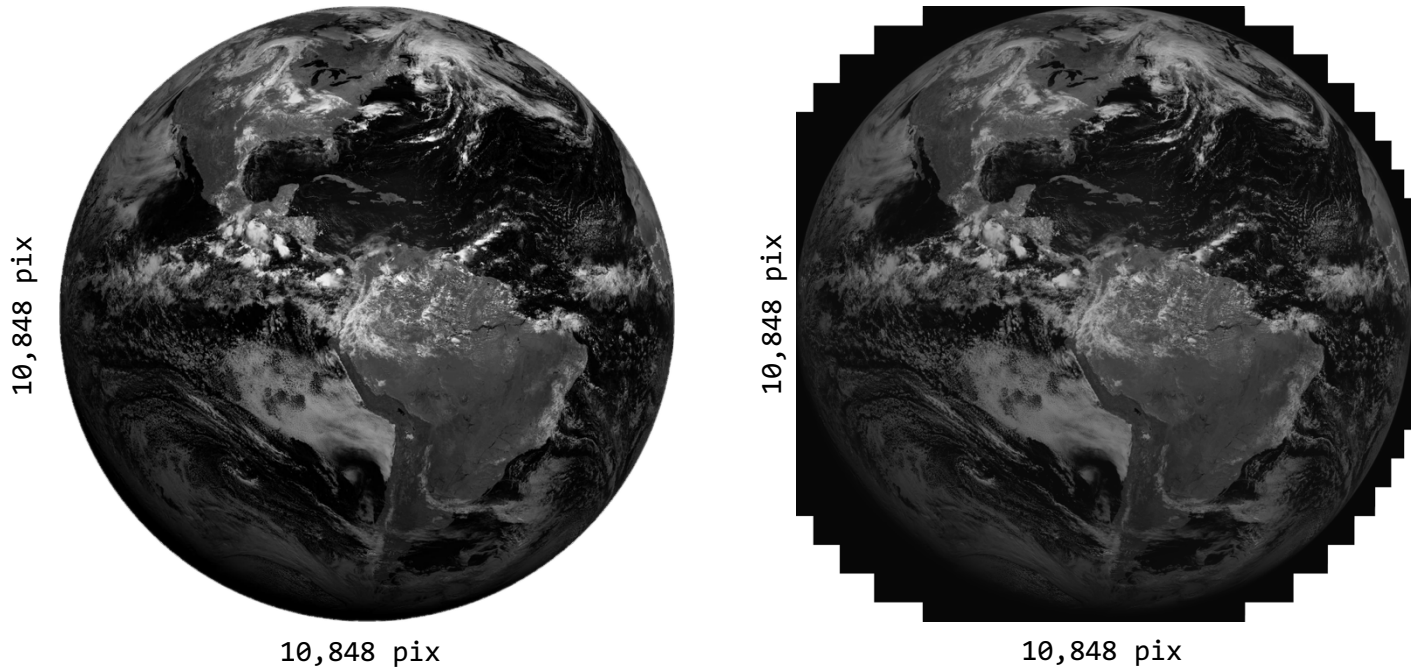

Figure 3: An Operational (left) and Reprocessed (right) channel 03 Full Disk image. The Operational image crops any pixel that is not fully on the earth surface, whereas the Reprocessed retains the full swath within the same array dimensions.

Pixel Timestamps

During routine operations, ABI scans the CONUS and Full disk domains in approximately 4 and 10 minutes, respectively. Users who identify unique phenomenology in an image may wish to determine when exactly that occurred within the image collection window. In order to accommodate this a new dataset has been included in the Reprocessed NetCDF files, *time_bounds_rows* (shown below). This dataset is 2 columns by *N* rows, where *N* corresponds to the number of rows of pixels in the image. Each row in the dataset contains the start and end time of the swath from which that row of pixels was acquired. Values are provided as the number of seconds since 01/01/2000 at 12:00:00 UTC (aka the "*J2K epoch time*"). The time at which a given pixel was acquired can then be computed by simple linear interpolation between the two times. This can be expressed as:

$$t_p = (x_p - x_0) \times \left(\frac{time\_bounds\_rows[end] - time\_bounds\_rows[start]}{x_{end} - x_{start}}\right) + time\_bounds\_rows[start],$$

where x_{start} and x_{end} are the first and last non-fill pixel positions along the row, and x_p is the position of the pixel of interest.

To illustrate, this example will determine the time, t_p, at which the pixel at row 1000, column 4000 (0-based indexing) of the channel 03 Full Disk image from June 09, 2019 at 1800 UTC was acquired. The swath Start and End times are found in row 1000 of the *time_bounds_rows* dataset: 6.1337527303529E8 and 6.1337528291721E8. The full swath width can be found from the Radiance dataset. The pixels in row 1000 change from the fill value of 1023 to non-fill values at column 769 (x_{start}), and transition back to fill at column 9389 (x_{end}), resulting in a swath width of 8620. The pixel of interest at column 4000, x_p, lies 4000 - 769 = 3231 pixels along the swath.

$$t_p = (9389 - 769) \times \left(\frac{6.1337528291721\text{E}8 - 6.1337527303529\text{E}8}{9389 - 769}\right) + 6.1337527303529\text{E}8$$

$$t_p = 613375276.739295$$

Thus, the J2K epoch time of the pixel of interest is **613375276.739295**. This can be converted to a standard calendar date and time using one of several methods. To aid users who wish to use the built-in Linux "*date*" command, the offset between the J2K epoch and the Unix epoch of January 01, 1970 (946,728,000 seconds) is provided as an attribute to the *time_bounds_rows* dataset. This can be combined with the J2K epoch computed above as:

```
TOTAL=$(echo "946728000+613375276.739295" | bc)
date -u -d @$TOTAL
Sun Jun  9 18:01:16 UTC 2019
```