GOES-19 CCOR-1 Data Release
Provisional Data Quality
Read-Me for Data Users

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Version 1.2

Contents

List of Acronyms

API - Application Programming Interface
CCOR-1 – Compact Coronagraph-1
CME – Coronal Mass Ejection
DN – Data Number
ECEF – Earth-Centered Earth-Fixed
FITS – Flexible Image Transport System
FOV – Field of View
GPA – Ground Processing Algorithm
GOES – Geostationary Operational Environmental Satellite
HDU – Header Data Unit
HEE – Heliocentric Earth Ecliptic
MSB – Mean Solar Brightness
NCEI – National Centers for Environmental Information
NOAA – National Oceanic and Atmospheric Administration
OSPO – Office of Satellite and Product Operations
PQF – Pixel Quality Flag
PS-PVR – Peer Stakeholder Product Validation Review
SUVI – Solar Ultraviolet Imager
SWPC – Space Weather Prediction Center

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1 Introduction

The GOES-R Peer Stakeholder Product Validation Review (PS-PVR) for GOES-19 Compact Coronagraph-1 (CCOR-1) Provisional Maturity was held on February 24, 2025. As a result of this review, the PS-PVR panel chair recommended that the CCOR-1 data be promoted to Provisional Validation Maturity.

The NCEI will host both operational and retrospective data streams (fits files) for all product levels here: https://noaa-nesdis-swfo-ccor-1-pds.s3.amazonaws.com/index.html

- For a more detailed explanation on using an application programing interface (API) for accessing data from the NOAA cloud please read the information here.
- Please note that NCEI provided operational files can have latency as large as 24 hrs due to how data is passed between SWPC and NCEI.

To access images for real-time space weather forecasts, the SPWC provides an operational data stream with `level 1B` (fits) and `level 2` (JPEG) files in a rolling 60 day window:

- https://services.swpc.noaa.gov/products/ccor1/

2 Product Overview

CCOR-1 data consist of white-light coronal images designed to capture coronal mass ejections (CMEs) and other solar coronal structures. The instrument images the Sun's corona in the visible wavelength range from 480 nm to 730 nm, utilizing an occulting disk to block direct sunlight and reveal the fainter corona. The full resolution image size is 2048 x 1920 pixels with the platescale varying from ~ 19.33 arcsec near the inner field of view (FOV) to 19.10 arcsec towards the outer edge of the FOV. The usable field of view spans from approximately 4.5 to 22.5 solar radii (1.2 deg to 6 deg in elongation), with a spatial resolution of ~2 pixels = 38 arcsec. Similarly to past coronagraphs the corner regions and the central pylon of each image are obscured due to instrumental vignetting.

All CCOR-1 products are presently stored using the Flexible Image Transport System (FITS) file format. The FITS standard format is independent of the hardware platform and software environment. A data file in the FITS format consists of a series of Header Data Units (HDUs), each composed of two components: a text header and the binary data (Figure 1)[1]. Each header contains a series of header keywords (metadata) that describe the data that immediately follows the header inside that HDU. The first header in a FITS file is known as the primary header, and any number of extensions can follow the primary HDU. We plan to release example Python Jupyter notebooks for interacting with the CCOR-1 data. For now users can also gain familiarity with accessing and handling FITS files using image data from the NOAA Solar Ultraviolet Imager (SUVI) which is available here.

The products contain image metadata that provide the necessary navigation information to locate and orient the Sun with respect to known astronomical coordinate systems. These

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[1]https://www.stsci.edu/hst/wfpc2/Wfpc2_dhb/intro_ch23.html#:~:text=A%20data%20file%20in%20FITS,component%20immediately%20follows%20the%20header.

metadata adhere to the World Coordinate System conventions used for FITS files (e.g. Thompson et al., 2006).

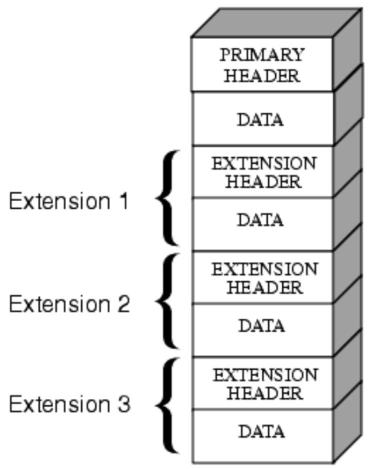

Figure 1. Adapted schematic diagram[1] to visualize the structure of the header data units (HDUs) inside a file that follows the FITS format.

3 Provisional Validation

Provisional validation of GOES-19 CCOR-1 data indicates:

- Validation activities of the data are ongoing and we encourage participation and feedback from the broader research community.
- Severe anomalies have been identified and are under analysis; solutions are in development.
- Incremental product improvements may still occur
- Product performance has been validated through comparisons with independent coronal observations.
- Analysis establishes performance relative to the official Performance Baseline.
- Documentation includes some recommended remediation strategies for known anomalies but work is still ongoing for some issues like eartshine mitigation.
- All testing procedures are fully documented.
- The product is ready for operational use and comprehensive calibration/validation activities.

4 Known Caveats

Users of GOES-19 CCOR-1 data are responsible for inspecting the data and understanding the following known caveats, which are under active investigation.

- Data validity start date: CCOR-1 data are provisionally valid beginning with observations on February 24, 2025. Observations prior to this date may have incorrect or incomplete navigation metadata. The National Centers for Environmental Information (NCEI) will reprocess and release early mission data using the Provisional Maturity algorithms and updated look-up tables.
- Issues reading products using IDL: Because the files use internal compression the typical IDL fits reader programs (readfits.pro, mreadfits.pro) may not work. A number of workarounds have been found so far:
    - Use mreadfits_tiecomp.pro (or read_sdo.pro) with the keyword /USE_SHARED enabled.
    - Use a Python-to-IDL bridge. One can then use the Python astropy package to read in the compressed FITS data from IDL.
    - Use a simple Python script to open the compressed file and save it to an uncompressed FITS file before reading it in using IDL.
- Image data gaps: Since we are still under Provisional maturity until 2026, calibration data will sometimes still be collected over longer periods of time. This may cause hours-long

outages in higher level operational and retrospective products especially near equinoxes.
    - Data gaps may also appear during periods when eclipses take place as images are not downlinked when the Earth fully obscures the FOV.
- Image dimensions: The majority of the data generated will be full resolution 2048 x 1920 pixels.
    - As part of the ongoing commission work during Provisional some images will be taken at faster cadence (5 min) but with reduced resolution 1024 x 960.
- Different filename conventions: Due to differences in data processing systems, operational and retrospective products follow distinct filenaming conventions. Detailed explanations of these conventions can be found in Sections 6.1.1 and 6.2.1.
- Backgrounds: As in previous space coronagraphs, images are dominated by light from instrumental straylight. Another important component of the background is a contribution from light scattered by solar system dust (F-corona). To compute an estimate of the contributions from these backgrounds CCOR-1 computes a pixel wise minimum over images taken over a long enough period of time.
    - Operational products use a 7-day lookback period to compute the background. These background images will not be made publicly available.
    - Retrospective products use a 29-day window centered on the date for which the background is generated. These products will be available for download.
- Image rotation: Because the GOES-19 spacecraft is in a geostationary orbit which jointly hosts both Earth and Sun facing instruments, the stellar background and F-corona slowly rotate by ± 23 deg over the course of the year, essentially following the inclination of the Earth's orbit with respect to the solar equator. This effect can be observed in other Sun facing instruments located on the GOES platforms, like the Solar Ultraviolet Imager (SUVI). For CCOR this effect is visible in the slowly rotating orientation of stellar tracks across images.
    - Additionally, long-term background images tend to develop an enhanced bright line through the center, aligned with the stellar background's rotation. Efforts are underway to mitigate this issue, either by shortening the background averaging window or identifying a more effective background subtraction method.
- Yaw flips: Twice a year, near each equinox the GOES-19 spacecraft performs a 180 deg roll about the yaw axis to avoid increasing reflected straylight from the solar panels. The keyword `YAWFLIP` will record the state of the flip. Full impacts and effects on the data from this maneuver are only partially known at this time, since no flip has occurred yet with the door open. Knows effect on the images:
    - The occulter pylon shadow changes position in the rectified images which align solar North to the top edge of the image.
    - The quality of the retrospective and operational background files will be impacted around each flip date. This is because the backgrounds are created from images with the same `YAWFLIP`. As such expect retrospective monthly minimum backgrounds produced around the yawflip date to be marked as degraded since fewer than the nominal number of daily median images (28) can be aggregated together.

- Instrumental straylight: As with previous coronagraphs some amount of sunlight gets scattered or refracted into the image. This effect tends to be strongest around the central occulter where diffraction ring artifacts may be observed. Other features of the instrumental straylight are large circular patterns where the images are brighter.
    - These artifacts dominate total image signal and are observed at all product levels that do not have a background image subtracted.
    - Particularly prominent features are the “whiskers/eyebrows” features located around the neck of the occulter pylon. Due to the increased straylight there the signal areas are saturated. In each retrospective product we include a pixel quality flag (PQF) mask that flags the coordinates for saturated pixels (see Section 6.2.2.3).
- Earthshine (a form of straylight) and eclipses: CCOR-1 is the first coronagraph to be placed in a geostationary orbit and as such there are periods during each day/orbit when scattered light from the Earth’s atmosphere (earthshine) increases the image background.
    - The duration during each day that eclipses happen varies (predictably) as the Earth approaches and departs each equinox.
    - Around 20 days before and after each equinox for at least one frame each day more than half the image is eclipsed by the Earth.
    - Around 40 days before and after each equinox, the Earth limb partially obscures some portion of the FOV.
    - Quality flags are included in the image metadata which indicate the presence of these eclipses (see Section 7).
- Transient features due to stars, comets, planets, satellites and debris coming off the spacecraft itself:
    - CCOR-1 images contain on average hundreds of stars transiting the FOV in any single image. The direction in which the stars transit changes slowly over the year due to the geosynchronous orbit.
    - Comets can transit the FOV for both short and long periods of time. Over the first 5 months since the CCOR-1 camera has been collecting data, at least 3 bright comets transited the FOV. The brightest one (C/2023 A3) impacted a large portion of the FOV for 6 days, while smaller ones were only present for a few hours. Cometary appearance is similar to what is observed from the ground, with a bright cometary body (often saturated) with an elongated tail.
    - The Moon enters the field of view (FOV) on a monthly basis and is one of the largest observed transiting objects. It appears as an approximately 80-pixel-wide disk, taking up to 24 hours to pass through the FOV. Unlike some other bright objects, the Moon does not saturate the images, and recognizable surface features can be matched with those visible from Earth.
    - Other satellites will appear as bright steaks in the images, typically only observed in a few frames.
    - Debris or dust falling off the spacecraft may traverse the telescope entrance and cause extra scattered light and streaks in the images.

    - Optical “ghosts” appear when debris scatters light causing multiple reflections to appear in the image. These can appear as groups of bright sources moving across the image.
- Optical distortions of sources: Because the telescope has a varying point spread function (PSF) across the image point sources change shape as they traverse different regions of the image plane.
    - For unsaturated sources like faint stars the effect is small enough to occur below resolution and noise thresholds.
    - Saturated sources like the planet Mercury, other satellites or very bright stars show a change in their shape as they traverse the image from circular near the edge to more elongated in the inner region.
- Metadata accuracy: Some metadata entries in CCOR-1 files may be incomplete or preliminary. Updates will be provided to reprocessed retrospective data.
    - Some FITS header comments may be truncated as we continue to adjust the headers.
- Spikes and bad pixels: CCOR-1 uses onboard scrubbing to remove cosmic-ray hits and images on the ground will be generally free of spikes. Defective pixels are currently not corrected in CCOR-1 images and users may encounter negative pixel values or NaNs in the image arrays. Each retrospective CCOR-1 product contains a corresponding pixel quality flag mask added as an extra header data unit. Users should consult these masks before detailed analyses.
- Missing data blocks: The image is segmented into 64 x 64 pixel blocks before it is downlinked to the ground station.
    - Intentional: To converse bandwidth when processing/downlinking data some of these blocks are discarded. The missing blocks are in the corners and at the center of the image array, which roughly corresponds to the area right behind the central occulter. These areas would contain no signal anyway due to vignetting from the occulter and edges of the aperture.
    - Accidental: Sometimes the data packet containing a block gets corrupted and may appear as missing squares in the image.
        - The presence of these missing blocks is recorded by the data quality flags `IMGBLK_Q`, `BADBLK_N` and `MISBLK_N` (see Section 7).
- Platform location: The metadata contains information about the GOES-19 platform location specified in the Heliocentric Earth Ecliptic (HEE) system within the header metadata: `HEEX_OBS`, `HEEY_OBS`, `HEEZ_OBS`.
    - The products also include placeholder values (still under analysis) for the Earth-Centered Earth-Fixed (ECEF) coordinate system within the following metadata: `OBSGEO-X`, `OBSGEO-Y`, and `OBSGEO-Z`.
    - Users requiring heliocentric coordinates should consult references like Hapgood (1992) for conversion details.
- Additional information from SWPC: We encourage users to also read complementary documentation that is available now and will likely be continuously updated by SWPC:
    - https://www.spaceweather.gov/products/ccor-1-coronagraph-experimental

5 Ground Processing Algorithm (GPA)

The schematic in Figure 2 summarizes the GPA actions and products generated by two parallel but separate data processing flows running on the SWPC and NCEI systems.

The operational data processing flow is run by SWPC and combines telemetry and data CCSDS packet information into images and metadata that can be stored in FITS files. The most important driver for operational products is achieving low latency so forecasters can make space weather predictions. The current latency on these products is around 20 minutes and SWPC is making publicly available real-time `level 1B` data over the past 30 days at: https://services.swpc.noaa.gov/experimental/products/swfol1/ccor-1/fits/.

NCEI will be responsible for storing and disseminating operational products older than this time window. Operational data through NCEI will be available with at most at 24 hr delay due to how data is flowed internally between SWPC and NCEI.

Retrospective data products are produced by NCEI. The retrospective algorithm takes as input the operational `level 0B` products made by SWPC, delivered to NCEI after the end of every UTC day. SWPC and NCEI products at equivalent levels are generated by similar but distinct algorithms with key differences found in how backgrounds are produced. NCEI data may be reprocessed to take advantage of instrument trending work throughout the mission lifetime, which should not be expected of SWPC operational products.

In time we plan to make available a Python library that contains the GPA code along with auxiliary routines that can be used to perform data analysis and visualization.

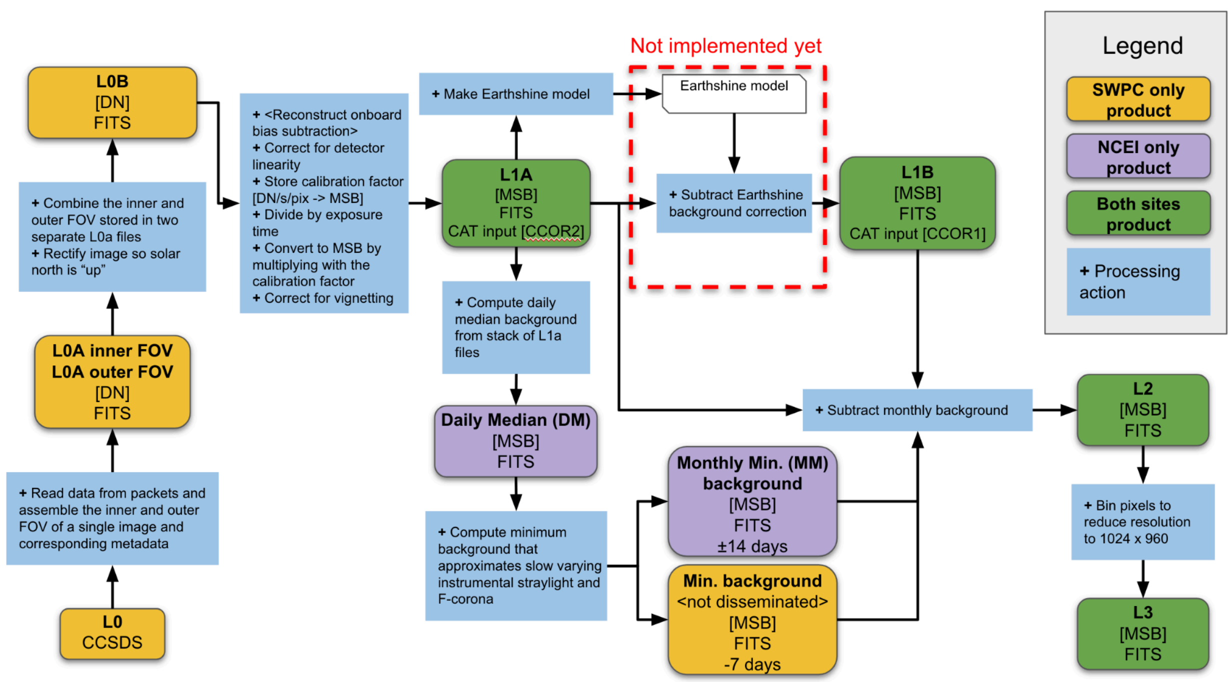

Figure 2. Schematic overview of the SWPC and NCEI GPA processing and product levels. Inside each product shape we also indicate the units for each product level.

6 Product descriptions

As indicated in Figure 2, SWPC and NCEI generate data products that are very closely related, with the main differences related to product latency and reprocessing to include results from long term instrument trending and updates. One key difference that drives the difference in latency is the time window used to compute the background estimate for the scattered light + F-corona background (the monthly minimum). The SWPC operational backgrounds are produced using data looking backwards 7 days from the present date of the observations. As such operational `level 2` and `level 3` files can be made available at nearly the same latency as lower level products.

Following past experience and literature on coronagraphs, the retrospective backgrounds utilize a longer 29 day time window that is centered on the day when a file is processed. As such there is a 14 day delay in producing `ccor1-l2` and `ccor1-l3` retrospective products. The benefit is that images will have improved backgrounds subtracted from them. Due to the noted (CCOR-1 specific) periodic but varying image rotation, ongoing work is being done to understand and mitigate the impacts on the retrospective background quality.

Another difference between operational and retrospective products is that operational products will not be reprocessed once created. Thus, while the operational products are much more suitable for space weather forecasting purposes due to their low latency (~20 min), the retrospective products are more suitable for later detailed scientific analysis. The plan is to make available products at all processing levels to allow community members to use the data most suitable for their specific analysis needs.

6.1 Operational products

6.1.1 Filenaming convention

```
[instrument]_[prod_level]_[date_obs]_[version]_[sucode].[extension]
```

Example operational CCOR filenames:

```
CCOR1_0A_20211109T054518_V00_T1.fits
CCOR1_0A_20211109T054518_V00_N2.fits
CCOR1_0B_20211109T054518_V00_NC.fits
CCOR1_1A_20211109T054518_V00_0C.fits
CCOR1_1B_20211109T054518_V00_0C.fits
```

Table 1: Detailed filename field descriptions for the operational products.

Field	Description	Allowed (or example) values

instrument	The instrument from where the data came from. The GOES-19 spacecraft contains the CCOR-1 instrument.	CCOR1
prod_level	The operational data product levels names.	0A, 0B, 1A, 1B, 2, 3 See Table 2 below for a full description of each product level.
date_obs	Start datetime (UTC) indicating the start of the first exposure (DATE-OBS metadata). Format is: [yyyy][mm][dd]T[hh][mm][ss]	Example: 20211109T054518
version	GPA software version number. Format is: V[version]	Examples: V00, V01
sucode	Combination code that indicates the image type. It is used to clasify images taken at different cadences or as part of calibration maneuvers.	T1 : Present in the 0A products. Indicates the first (inner) portion of the image. N2 : Present in the 0A products. Indicates the second (outer) portion of the image. NC : Present in 0B and higher products. Indicates a nominal 15 minute cadence image. EC : Present in 0B and higher products. Indicates an eclipse mode 5 minute cadence image. These will only appear in periods around equinox when the Earth limb obscures a large part of the FOV. 0C : Present in 0B and higher products. Indicates a full resolution image taken at an irregular cadence, typically as part of eclipse cadence sequences or long term

		instrument trending. `0B` : Present in 0A products. Indicates a bias image frame which is only 64x2048 pixels in size. Other examples that may appear in `0A` products: `R2, L1, 01, 00`.
`extension`	The data file extension.	`fits`

6.1.2 Product structure

All operational products use the astropy.io.fits module to internally compress the images using GZIP_1. Using internal compression enforces that the written files contain at least two header data units (HDUs) with the primary containing an empty data portion and the compressed image being located in the first extension. All the operational products contain exactly two HDUs.

6.1.2.1 Primary HDU

The header only contains information about the SWPC operational GPA version and a `HISTORY` keyword describing the structure of the file.
The binary data portion of the primary HDU is empty.

6.1.2.2 First extension HDU

This HDU contains the operational metadata and image data. Table 2 provides a summary description of the data. Currently only a small subset of metadata items in the headers contain comments. A fuller description of what the header metadata entries mean can be found in a separate document called Operational Product Metadata Definitions. We note this document continues to be updated so may not always contain a complete list of the keywords found in the products. Incremental processing applied to each image is tracked through the HISTORY keyword.

Table 2: Description of the operational data stored in the first extension HDU.

Product level	Image dimensions (pixels)	Units	Processing applied
`0A`	2048 x 1920	DN	Constructed from lowest level CCSDS packets. Contains the inner or outer portion of the image.

`0B`	2048 x 1920	DN	Contains the combined inner and outer portions of the image. Rotated/reflected so that Solar N points towards the top edge of the image.
`1A`	2048 x 1920	MSB	Time normalized. Flat field corrected by division through the vignetting function. Converted from DN to MSB units through multiplication with the photometric calibration factor stored under the keyword `CALFAC`. Detector nonlinearity correction is currently NOT applied pending more testing. Bias subtraction reconstruction is currently NOT applied pending more testing.
`1B`	2048 x 1920	MSB	Currently identical to the 1A products. The correction for earthshine is currently NOT applied since more data needs to be collected in order to create a suitable earthshine model.
`2`	2048 x 1920	MSB	A background image that approximates the instrumental straylight + F-corona background is subtracted from the 1B products. The background is computed as a minimum over daily median images computed from `level 1B` files over the past 7 days.
`3`	1024 x 960	MSB	Image resolution is downsampled by a factor of 2 along each image axis. This product level is more suitable for making animations that are smaller in size.

6.2 Retrospective products

6.2.1 Filenaming convention

```
[env]_[dsn]_[satellite]_[startDate]_[endDate]_[processDate]_[access].[extension]
```

Example retrospective CCOR filenames:

```
sci_ccor1-l1a_g19_s20230401T000000Z_e20230401T235959Z_p20230402T143300Z_pub.fits
```

sci_ccor1-mm_g19_s20230401T000000Z_e20230401T235959Z_p20230402T143300Z_pub.fits
sci_ccor1-l2_g19_s20230401T000000Z_e20230401T235959Z_p20230402T143302Z_pub.fits

Table 3: Detailed filename field descriptions for the operational products.

Field	Description	Allowed (or example) values
env	The ground system environment where the product was created and/or the type of data.	sci
dsn	The product Data Short Name.	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3, ccor1-dm, ccor1-mm See Section 6.2.2 for a full description of each product level.
satellite	The platform/satellite from which the product came.	g19
startDate	The coverage start datetime of the data. For ccor1-l1a, ccor1-l1b, ccor1-l2 and ccor1-l3 products this time refers to the start of the first exposure time (DATE-BEG metadata). For ccor1-dm, ccor1-mm products this time refers to the start of the UTC day for which the files are valid. Format is: s[yyyy][mm][dd]T[hh][mm][ss]Z	Example: s20241103T071520Z s20230817T000000Z
endDate	The coverage end datetime of the data. For ccor1-l1a, ccor1-l1b, ccor1-l2 and ccor1-l3 products this time refers to the end time of exposures used in the image average (DATE-END header keyword). For ccor1-dm, ccor1-mm products this time refers to the end of the UTC day for which the files are valid. Format is: e[yyyy][mm][dd]T[hh][mm][ss]Z	Example: e20241103T071548Z e20230817T235959Z
processDate	The product file creation datetime. Format is:	Example: p20230818T022130Z

	`p[yyyy][mm][dd]T[hh][mm][ss]Z`	
`access`	Public access level. Either "pub" for public release or "emb" for embargoed (no public release).	`pub, emb`
`extension`	The data file extension.	`fits`

6.2.2 Product structure

All retrospective products use the astropy.io.fits module to internally compress the images using RICE_ONE. Using internal compression enforces that the written files contain at least two header data units (HDUs) with the primary containing an empty data portion and the compressed image being located in the first extension. As detailed below, retrospective products contain extra HDUs to store the pixel quality flag (PQF) mask and lists of files used to generate the aggregate daily median and monthly minimum data.

6.2.2.1 Primary HDU

The header contains a set of keywords summarizing the information in the extension HDUs. The `HISTORY` keyword is used to transmit details about the type of compression used to make the retrospective product.

The binary data portion of the primary HDU is empty.

6.2.2.2 First extension HDU

This HDU contains the main science and telemetry metadata in the header and the image data itself (Table 4). The metadata entries contain comments to summarize the meaning of each keyword but the users should also consult the document on [Operational Product Metadata Definitions](). To improve readability some of the engineering keywords that are included in the operational products will not be included in the retrospective products. More detailed documentation for the retrospective product metadata will be made available in the future.

Incremental processing applied to each image is also tracked through the `HISTORY` keyword. Retrospective versions of products corresponding to the operational `level 0A` and `level 0B` are currently not being produced but may become available in the future.

Table 4: Overview of the image data stored in the retrospective products stored in the first extension HDU.

Data Short Name	**Image dimensions (pixels)**	**Units**	**Processing applied**
`ccor1-l1a`	2048 x 1920	MSB	The input data is the operational `level 0B` product which is then: ● Time normalized.

			• Flat field corrected by division through the vignetting function. • Converted from DN to MSB units through multiplication with the photometric calibration factor stored under the metadata keyword CALFAC. Detector nonlinearity correction is currently NOT applied pending more testing. Bias subtraction reconstruction is currently NOT applied pending more testing.
`ccor1-l1b`	2048 x 1920	MSB	Currently identical to the `ccor1-l1b` products. The correction for earthshine is NOT applied yet since more data needs to be collected in order to create a suitable earthshine model.
`ccor1-dm`	2048 x 1920	MSB	Daily medians are aggregate images that are computed as a median over `ccor1-l1b` images that are not impacted by earthshine. The SN_ANGLE keyword records the elongation angle between the instrument boresight and the Earth disc center. The `ccor1-dm` products are currently computed only from images with SN_ANGLE > 40 deg which do not contain any measurable earthshine. As earthshine is better understood the number of excluded images may improve.
`ccor1-mm`	2048 x 1920	MSB	Monthly minimums are aggregate images that are computed as a pixel-wise minimum over `ccor1-dm` images. The files are picked to span a 29 day window centered on the day for which the `ccor1-mm` file is valid. Only images with the same yaw flip orientation are used.
`ccor1-l2`	2048 x 1920	MSB	A `ccor1-mm` background image that approximates the instrumental straylight + F-corona background is subtracted from the `ccor1-l1b` products.
`ccor1-l3`	1024 x 960	MSB	Image resolution is degraded by a factor of 2 along each image axis. This product level is more suitable for making animations that are smaller in size.

6.2.2.3 Second extension HDU

The data portion of the HDU stores a pixel quality flag (PQF) mask which is an array of the same dimensions as the image stored in the first extension HDU (e.g. 2048 x 1920 or 1024 x 960 pix). The values stored for each pixel are integer values that are sums of powers of 2 which encode different flags. This type of scheme allows a pixel to have several flags “raised on it” simultaneously.

The flag types are recorded in the header portion of the HDU and summarized Table 5 for each product. Many of the flags are set based on the `level 0B` product pixel values which are measured in DN.
For the binned `ccor1-l3` products, a bitwise OR is performed on the pixels that are being binned such that all the flags from the pixels that get binned are preserved in the lower resolution pixel.

To extract pixels from the PQF data pertaining to single or multiple flags, bitwise comparative operators must be used. This is because the powers of 2 flag values ensure that the bits corresponding to each flag do not overlap. We plan to release more detailed usage examples as well as include routines in the Python libraries to decode the flags and make masks. The simple example below is meant to illustrate a simple way the users could use the PQF mask.

Example:

For Flag0: flag_value = 0,   the 8bit binary representation is 00000000
For Flag1: flag_value = 1,   the 8bit binary representation is 00000001
For Flag2: flag_value = 2,   the 8bit binary representation is 00000010
For Flag6: flag_value = 32, the 8bit binary representation is 00100000

If several pixels fall within a region of overlapping flags (e.g., where Flag1 and Flag2 are TRUE), the pixel value in the PQF data where both flags are TRUE is:

```
     Flag1: 00000001
|    Flag2: 00000010 ( | = bitwise OR operator)
--------------------
            00000011 (integer representation = 3)
```

Thus, this pixel corresponds to both flag values, and the information for each flag is preserved. Now, to extract the pixels that only correspond to Flag1, we find where Flag1 (00000001) is in 00000011. To do this, the bitwise AND (&) operator is used.

```python
# pqf_data = data from second extension HDU

# Extract single flag:
# -----
# Flag to extract:
```

```
extract_flag_value = 16
# Mask:
flag_mask = (pqf_data & extract_flag_value)

# Extract multiple flags:
# -----
# Flags to extract:
extract_flag_values = (8, 16)
# Mask:
flag_mask = (pqf_data & (extract_flag_values[0] | extract_flag_values[1]))
```

Table 5: Definitions for the flags used by the retrospective products to compute the PQF data array stored in the second extension HDU.

Flag name	Flag value	Flag meaning	Products that include this flag.
FLAG0	0	Level 0B pixel value in linear range (1000 ≤ I(DN) ≤ 11580)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3, ccor1-dm, ccor1-mm
FLAG1	1	Vignetting function value < 0.1	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3, ccor1-dm, ccor1-mm
FLAG2	2	Vignetting function value < 0.01	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3, ccor1-dm, ccor1-mm
FLAG3	4	Level 0B pixel value below linear range (I(DN) < 1000)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3
FLAG4	8	Level 0B pixel value in correctable nonlinear range (11580 < I(DN) < 15300)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3
FLAG5	16	Level 0B pixel value is saturated (I(DN) > 15300)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3
FLAG6	32	Pixels with unreliable photometry (still being defined - not applied yet)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3
FLAG7	64	Dead pixels or no data being downlinked intentionally or due to failure (I(DN) = 0)	ccor1-l1a, ccor1-l1b, ccor1-l2, ccor1-l3

FLAG8	128	Pixel value is equal to 0/NaN/Inf in the background. This flag is fundamentally a way to flag pixels that get affected by the image aggregation when the ccor1-dm, ccor1-mm products are created.	ccor1-dm, ccor1-mm, ccor1-l2, ccor1-l3

6.2.2.4 Third extension HDU

This HDU is only included in the daily median and monthly minimum (ccor1-dm, ccor1-mm) products. The data portion stores a list of filenames used to generate the daily median and monthly minimum aggregate products. For the daily median products this list may be as long as 96 entries but will usually have fewer entries due to exclusion of earthshine affected 1B images.

7 Data quality flags

In addition to the PQF mask (see Section 6.2.2.3) both operational and retrospective products have a number of data quality flags that are used to automatically identify images with anomalies in them based on the information available in the telemetry. A summary of the flags is included in Table 6.

Table 6: Summary of the data quality flag metadata included in the operational and retrospective products.

Keyword	Value type	FITS comment
ISVIABLE	bool	T = image is nominal -- no degraded inputs
ISNORMAL	bool	T = full resolution and taken with regular mask
DCMPRS_Q	bool	T = decompress. alg. was successfully applied
IMGBLK_Q	bool	T = no bad/missing blocks
BADBLK_N	int	No. of bad blocks (valid only for NORMAL images)
MISBLK_N	int	No. of missing blocks (valid only for NORMAL images)
TRACMD_Q	bool	T = Tracking mode time within 60s of image acq. time
TRACMD_N	int	[s] Tracking mode data/image acq. time difference
GTTRAC_Q	bool	T = GT fine tracking the Sun is good
GTTIME_Q	bool	T = GT time(APID 151) within 60s of image acq. time
GTTIME_N	int	[s] GT-image acq. time difference
YWTIME_Q	bool	T = Yaw flip (APID 164) time within 60s of image acq. time
YWTIME_N	int	[s] Yaw flip-image acq. time difference
TMTIME_Q	bool	T = Temperature (APID 982) time within 60s of image acq. time

TMTIME_N	int	[s] Temperature-image acq. time difference
SPRFTM_Q	bool	T = SPRF Sun vector (APID 167) time within 60s of image acq. time
SPRFTM_N	int	[s] SPRF Sun vector acq. time difference
ECTIME_Q	bool	T = Eclipse (APID 173) time within 60s of image acq. time
ECTIME_N	int	[s] Eclipse data-image acq. time difference
SATIME_Q	bool	T = S-M, S-E nadir (APID 176) time within 60s of image acq. time
SATIME_N	int	[s] S-M, S-E (nadir) data-image acq. time difference
EPTIME_Q	bool	T = Ephemeris (APID 255) time within 60s of image acq. time
EPTIME_N	int	[s] Ephemeris data-image acq. time difference
BORSGT_Q	bool	T = Earth is NOT within 20 deg of boresight
EARFOV_Q	bool	T = Earth limb is NOT inside the CCOR field of view
MONFOV_Q	bool	T = Moon is NOT inside the CCOR field of view

8 Contact for Further Information

For general inquiries, contact:
swx.coronagraph@noaa.gov
SPSD.UserServices@noaa.gov (OSPO User Services)

Users are also encouraged to contact the NCEI GOES-R CCOR team for further assistance, questions, or to report any issues with CCOR files. Additional data access information is available on the NCEI website:
https://www.ncei.noaa.gov/products/space-weather/swfo