Readme for GOES-R XRS L2 Data

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1 Summary

The GOES-R Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS) X-Ray Sensor (XRS) Level 2 (L2) data is based on 1-second cadence soft X-Ray irradiance measurements covering 0.05-0.4 nm and 0.1-0.8 nm integrated passbands. EXIS was designed and built by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder. The L2 products are available in netCDF format as science-quality data produced by NOAA's National Center for Environmental Information (NCEI) and as real-time operational data used at the NOAA Space Weather Prediction Center (SWPC). The science-quality dataset differs from the operational product in that it incorporates retrospective fixes for issues in the operational product and updated calibrations, and the data have been reprocessed since the start of the mission (See Section 4).

This Readme gives brief descriptions of the L2 products and discusses the data caveats for the XRS L2 data. More details about the XRS L2 algorithms can be found in the GOES-R XRS L2 User's Guide. Links to the science-quality XRS data, Readme's, a User's Guide, plots, responsivity data, and associated documentation can be found at `https://www.ngdc.noaa.gov/stp/satellite/goes-r.html`.

Users of the GOES-R XRS L2 data are responsible for inspecting the data and understanding the known caveats prior to use. Technical questions about this data can be sent to janet.machol@noaa.gov, while questions about data access should be sent to pamela.wyatt@noaa.gov or josh.riley@noaa.gov.

2 XRS L2 Products Overview

XRS measures soft X-ray fluxes at 1-second cadence in the historical bandpasses of 0.05 to 0.4 nm (Channel A) and 0.1 to 0.8 nm (Channel B). Each channel has two irradiance sensors to capture the full dynamic range of the solar X-ray irradiance, where "1" denotes the low-irradiance sensor and "2" denotes the high-irradiance sensor. This numbering is utilized in the variable naming convention where, for example, "xrsa2_flux" corresponds to the irradiance in Channel A on the high irradiance sensor. The flag "xrsa_primary_chan" indicates whether XRS-A1 or XRS-A2 provides the primary irradiance values. Time series for primary detectors, designated "xrsa" and "xrsb", consist of low- and high-irradiance sensor values merged into a single time series based on the primary_chan flags. The current thresholds for switching the primary channels are $10^{-5}\,\mathrm{W\,m^{-2}}$ for Channel A and $10^{-4}\,\mathrm{W\,m^{-2}}$ for Channel B.

The six L2 products for XRS are listed in Table 1.

Table 1: Summary of XRS L2 Products

Product	Name	Description
1s fluxes	flx1s	XRS irradiances at 1-s cadence
1-min fluxes	avg1m	XRS irradiances at 1-min cadence
flare summary	flsum	flare detection flags such as start and peak
flare detection*	fldet	flare detection status for every minute
flare location	flloc	flare location on solar disk
daily background	bkd1d	daily background and daily averages

* The flare summary should be used instead of the flare detection product as noted in Section 3.4.

2.1 Flare Magnitudes

A notable change between the GOES-R and previous GOES data is that the GOES-R XRS irradiances are provided in true physical units of $\mathrm{W\,m^{-2}}$. The operational data prior to GOES-16 had scaling factors applied by SWPC so as to adjust the GOES 8-15 irradiances to match fluxes from GOES-7. The flare index was based on the operational irradiances, but to get true irradiances from the operational data, the scaling factors of 0.85 (for the XRS-A channel) and 0.7 (for the XRS-B channel) applied to GOES 8-15 had to be removed. There are no such scaling factors in the GOES-R XRS data; the provided irradiances are in true physical units.

The magnitude of a flare is defined by SWPC with a flare index that is based on the 1-minute average of the GOES operational irradiance in the XRS-B channel at the peak of the flare. Flare indices are denoted by a letter and a number based on the log 10 peak irradiance of the flare , (X: 10^{-4} W m^{-2}, M: 10^{-5} W m^{-2}, C: 10^{-6} W m^{-2}, B: 10^{-7} W m^{-2}, and A: 10^{-8} W m^{-2}). For instance, an M5 index is defined for a $5x10^{-5}$ W m^{-2} peak irradiance, and an X2.5 index is defined as an irradiance level of $2.5x10^{-4}$ W m^{-2} peak irradiance. Because of the SWPC scaling factors in the pre-GOES-R data, flare indices for the earlier satellites were based on irradiances that were reported as 42% (1.0/0.7) smaller than for GOES-R (e.g., an X2.5 class flare reported operationally for GOES-15 will be an X3.6 class flare for GOES-R). Two XRS Level 2 (L2) products useful for flare detection are the event detection and event summary which provide flare peak irradiances, indices, and times.

A related note is that reprocessed science-quality GOES 13-15 XRS L1b and L2 data are now available. In this GOES 13-15 reprocessed data, the irradiances are provided in physical units (i.e., without the SWPC scaling factors) to match the GOES-R data. This earlier data is available from the GOES 8-15 tab at `https://www.ngdc.noaa.gov/stp/satellite/goes-r.html`.

2.2 Data Caveats

The following is a list of caveats for the GOES-R XRS L2 data.

1. The XRS-A irradiance is approximately 41% larger for GOES-R than GOES-15; i.e., $\text{XRS-A}_{\text{GOES-R}}$ / $\text{XRS-A}_{\text{GOES-15}} \approx 1.41$ (for GOES-15 data without SWPC scaling factors). The GOES-R XRS instrument was carefully calibrated at NIST and the source of this discrepancy is currently unknown and under investigation.

2. The flare classifications have changed somewhat, as discussed in Section 2.1.

3. The XRS irradiances are noticeably contaminated by electrons during periods where X-ray fluxes are low and electron fluxes are high. The impact is negligible in other conditions. In the L2 1-min cadence data, a correction is applied which removes much of the electron contamination. The method for removing electron contamination is currently being improved and revised data will be provided at a later date.

4. The dark radiation coefficient is not applied to the XRS irradiances. This coefficient corrects the irradiances for proton contamination during SEP events. Until this is applied, signals will be artificially high during SEP events, especially in the A2 and B2 channels. Analysis to determine this term is in progress.

5. The spacecraft eclipse flag and the roll angle values are incorrect early in the mission. The solar array current for all GOES 17 data is bad for all days. Future versions of the science-quality data will correctly derive these values from the telemetry data.

6. GOES-17 has done twice-yearly yaw flips since 2019 and several before that. The yaw_flip_flag variable is briefly set incorrectly to 0 (instead of 2) on 2018-10-24 in ops, but not sci. GOES-16 has had no yaw flips prior to the date of this document and the yaw_flip_flag variable is set properly for all times.

7. Mercury transits are not flagged. There are only two Mercury transits in the GOES mission lifetimes (11 November 2019 and 13 November 2032) and they cause no noticeable decrease in XRS irradiance.

8. Users of the XRS L2 operational data are advised to read the Readme for the GOES-R XRS L1b Operational Data for additional caveats.

3 Product Descriptions

This section provides brief descriptions of the XRS L2 products.

3.1 1-second Fluxes Product

This product provides the highest resolution XRS irradiances for the A and B channels along with a condensed set of quality flags. Time series of irradiance values are provided for each detector (XRS-A1, XRS-A2, XRS-B1 and XRS-B2) and for the primary detectors (XRS-A and XRS-B). Additional variables include corrected currents for XRS-A2 and -B2, the roll angle, and a yaw flip flag. Particle spikes, probably due to galactic cosmic rays, are flagged in the data.

3.2 1-minute Averages Product

This product contains the 1-minute averages of the 1-s cadence data. Flags are provided which state the status of the averaged irradiances. Additionally, the number of 1-s data points included in the average and the union of flags set for data points that were excluded from the averages are provided.

Electron contamination is approximated and removed in the L2 1-min averaged data with the use of a linear function of electron flux measurements as a function of angle and energy from the GOES-R SEISS MPS-HI. Further improvements to the method for doing the electron contamination removal are being evaluated. Three values are reported for each channel: the averaged flux (e.g., xrsb_flux_observed), the estimated electron contamination (e.g., xrsb_flux_electrons), and the flux corrected for the electron contamination (e.g., xrsb_flux). The flux is constrained with a minimum threshold of $10^{-9}\,\mathrm{W\,m^{-2}}$.

3.3 Flare Summary Product

This product provides information on the flares, including flare class, start and end times, integrated flux, and background flux. Flare detection uses 1-minute averaged data. Status flags are listed in Table 2.

Table 2: Status Flags for Flare Summary Product

Flag	Description
EVENT_START	start of flare
EVENT_PEAK	peak of flare
EVENT_END	flare declined by 1/2
POST_EVENT	flare declined to background

3.4 Flare Detection Product

This product has a status flags every minute. The time stamps represent the time that the algorithm detected an event such as the peak of the flare, rather than when the actual peak occurred. For some types of events such flare peak, this is later than the actual event time. *Therefore, for most users, the flare summary product should be used* because it has the correct event times and consists of shorter files which exclude unnecessary monitoring status flags. The flare detection product is provided for users who wish to examine the algorithm behavior.

3.5 Flare Location Product

Flare location on the solar disk is determined based on the measurements from the high flux XRS-B2 quad diode detector. This product is the result of a center-of-mass calculation of the flare intensity on the quad diode. Flare location is provided in four coordinate systems: Stonyhurst/heliographic (lon, lat), Carrington (lon, lat), heliocentric-radial (R, θ) and heliocentric Cartesian (x,y) coordinates. The solar P-angle and apparent solar angular radius are also provided.

3.6 Daily Background Product

This product provides daily averages irradiances and daily backgrounds for XRS-A and -B. The algorithm uses hourly and 8-hour minima of the 1-minute averages to determine the daily background values.

4 Science-Quality Versus Operational XRS Data

The science-quality L2 data products differ from the operational L2 products used in operations at SWPC in completeness and quality. The science-quality data incorporate the most up-to-date calibrations and algorithm fixes and they are reprocessed since the start of the mission. The science-quality L2 data products are created from the science-quality L1b data. Both the science-quality and the operational data include some recovered data that was missing in the real-time operational products. The operational L1b and L2 data, especially from the earlier dates, contain significant issues that are not retroactively corrected, and therefore should be used with great caution and not for scientific analysis.

The start dates for the science-quality L1b and L2 XRS data are 7 February 2017 for GOES-16 and 1 June 2018 for GOES-17. The official transitions at SWPC to use GOES-R XRS operational data occurred considerably later. SWPC transitioned to GOES-16 XRS operational L2 products on 20 December 2019 and to GOES-17 on 24 August 2021.

The science-quality data directories have names which end in "_science" and the file names have prefixes of "sci_". The science-quality data has a latency of three days.

The operational data are in directories without the "_science" suffixes, and the operational filenames have prefixes of "ops_" for L1b data and 'dn-' for L2 data. The operational data can be accessed from the parent directories of the science-quality data. This data has a latency of one day.

5 Versions of Science-Quality Data

Version numbers for the science-quality L2 XRS data are listed in Table 3. For each new version, the version numbers are updated for all of the L2 products. The products impacted by the specific changes are listed parenthetically in the table.

Table 3: Science-quality L2 data versions

Version	Release date	Revisions
2-1-0	6 April 2021	Uses v0.0.1 science L1b data. (all) Spike detection on all data, not just good quality. (flx1s) New flare location product. (flloc) Variable flare_counter renamed to flare_id with new format. (fldet, flsum, flloc) New flag meaning marks times of significant electron contam. (avg1m) New electron correction coefficients and account for yaw flip. (avg1m) pointing_degraded flag meaning removed. (all) Fixed incorrect au_factor averages. (avg1m)
2-0-1	15 June 2020	Corrected timestamp in 1-sec fluxes by 0.516 s. (all) Integrated fluxes set to fill value in monitor state. (fldet)
$\leq$ 2-0-0	21 May 2020	Initial public data release.