Readme for GOES-R EXIS XRS Level 1b Data

26 March 2024
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1. Summary

The GOES-R Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS) X-Ray Sensor (XRS) Level 1b (L1b) data contains 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. This Readme discusses the XRS L1b data products, as well as current and future improvements to the dataset. Further details on the XRS instrument can be found in the article by Chamberlin et al. (2009).

NOAA's National Centers for Environmental Information (NCEI) provides both science-quality and operational data, and at two levels, L1b and Level 2 (L2). **Users are advised to use the science-quality data**, preferably the L2 data, instead of the L1b or L2 operational data.

The science-quality data set differs from the L1b operational product used at the NOAA Space Weather Prediction Center (SWPC) in that it incorporates retrospective fixes for issues in the operational product and uses the most recent calibrations. The science-quality data have been reprocessed from the start of the mission to the present date. The operational L1b 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. While major issues have been resolved in the operational processing code, more minor issues remain to be fixed. The GOES-R XRS L1b Science-Quality data were validated against the GOES-R XRS L1b operational data. The science quality data directory names end in "_science" and the file names have prefixes of "sci_". The operational data are in directories without the "_science" suffixes, and have filename prefixes of 'ops_' for L1b data and 'dn-' for L2 data. Both the science-quality and the operational data sets contain recovered data due to spurious dropouts.

The L2 data, which are cleaned of spikes and have better flagging, are produced from the L1b data and include a variety of higher level L2 products such as averages, flare detection and flare location. Links to the XRS L1b and L2 data, plots, and associated documentation are at https://www.ngdc.noaa.gov/stp/satellite/goes-r.html.

Users of the GOES-R XRS L1b data are responsible for inspecting the data and understanding the known caveats prior to use. Questions about this data set can be sent to janet.machol@noaa.gov, while questions about data access should be sent to pamela.wyatt@noaa.gov and josh.riley@noaa.gov.

2. Data Overview

This section briefly describes the main L1b variables from the XRS instrument. The data is stored in netCDF format, and can be readily accessed via pre-packaged routines in many programming languages, including IDL and Python. The start dates for the L1b and L2 XRS data are 7 February 2017 for GOES-16, 1 June 2018 for GOES-17, and 17 June 2022 for GOES-18, although temporarily, the GOES-18 data is only available starting in September 2022.. Operational XRS data provided by NCEI begins on these same dates. The official transitions at SWPC to use GOES-R XRS operational data occurred considerably later.

XRS measures soft X-ray fluxes at 1-second cadence in the historical bandpasses 0.05 to 0.4 nm (Channel A)and 0.1 to 0.8 nm (Channel B)respectively. 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" is for the high-irradiance quad photodiode sensor. This numbering is utilized in the variable naming convention where, for example, “irradiance_xrsa2” corresponds to the irradiance in Channel A on the high irradiance sensor. The flags “primary_xrsa” and “primary_xrsb” indicate whether the low or high irradiance sensors for Channel A and B provide the primary irradiance value. The current thresholds for switching the primary channels are 10^{-5} W m^{-2} for Channel A and 10^{-4} W m^{-2} for Channel B.

Flags are provided to indicate data outages and reliability. XRS data quality is indicated in the variable “quality_flags” which have individual bits regarding the reliability of pointing, temperature, irradiance, and other issues. An overall flag value of 0 indicates good quality data. The Sun Pointing Sensor (SPS) on EXIS utilizes a quadrant photodiode to provide pointing information. SPS operates at 4 Hz, and the average pointing is provided by the variables “dispersion_angle” and “crossdispersion_angle” and the time is provided by “sps_obs_time”. The three L1b pointing error quality flags and their associated error ranges are: XRS_pointing_warning_qf (7 arcmin; 0.11° to 0.4°), degraded_XRS_pointing_qf (0.4° to 0.8°), and invalid_XRS_pointing_qf (>0.8°). Since the GOES instruments operate in geostationary orbit, they experience two eclipse seasons per year around the equinox. The flags “fov_eclipse” and “SC_eclipse_flag” indicate these events.

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 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, 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. The flare index is defined by the truncated (not rounded) irradiance; e.g., a flare with peak irradiance of $4.19x10^{-5}$ W/m^2 is an M4.1 flare, not an M4.2 flare.

A related note is that reprocessed science-quality GOES 8-15 XRS data are now available from the GOES 1-15 tab at https://ngdc.noaa.gov/stp/satellite/goes-r.html. In this science-quality data, the irradiances are provided in physical units (i.e., without the SWPC scaling factors) so as to match the GOES-R data.

3. Data Caveats

The following is a list of caveats for the GOES-R XRS L1b science-quality data. No list of caveats is provided here for the extensive set of errors in the operational data.

1. The XRS-A irradiance is approximately 41% larger for GOES-R than GOES-15; i.e., $XRS\text{-}A_{GOES\text{-}R}/XRS\text{-}A_{GOES\text{-}15} \approx 1.41$ (for GOES-15 data without the SWPC scaling factors). The GOES-R XRS instrument was carefully calibrated at NIST, and the source of this discrepancy is unknown but under investigation. There is no such discrepancy for the XRS-B irradiance.
2. The XRS irradiances are noticeably contaminated by electrons during periods where X-ray fluxes are low and electron irradiances are high. The impact is negligible in other conditions. The electron contamination is flagged and removed in the L2 data.
3. The irradiances contain spikes which are probably due to galactic cosmic rays. These spikes are flagged and removed in the L2 data.
4. The dark radiation coefficient is not applied. 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. Currently, some variables related to spacecraft information are filled using operational data, which contain some errors. The spacecraft eclipse flag and the roll angle values are incorrect early in the mission. The fov_eclipse_flag should be used to identify eclipses. The solar array current is bad for all GOES-17 data. Future versions of the data will correctly derive these values from the telemetry data.
6. SPS has four values per time index. For the first time index of the day (i.e., the first second of the day) there may be up to 2 missing SPS values which will be replaced with

fill values. This has a negligible impact on the data product. This will be corrected in future data versions.

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. The ecef values are bad for most of 2017.
9. Penumbra without an adjacent eclipse are not flagged.
10. Time is defined as seconds since 2000-01-01 12:00:00 UTC, neglecting leap seconds. To convert the time variables to UTC time (which does include leap seconds), the user must add the leap seconds that have passed since the base time. See the GOES-R XRS L2 Data User's Guide or https://www.nist.gov/pml/time-and-frequency-division/time-realization/leap-seconds
11. There are small discrepancies in the cross_dispersion_angle of about 0.003° (1 arcsec) for about an hour after eclipses.
12. Here are some of the errors in the early operational data.
    a. ECEF_Z range is incorrectly defined.
    b. The SPP_to_Sun_roll_angle is misnamed and has an incorrect description. The value is the angular offset of SPP relative to the celestial north rotational pole measured counterclockwise. This variable was renamed SPP_roll_angle in the later data.
    a. The lunar_transit_flag variable is not set during lunar transits (prior to February 2019).
    b. During lunar transits, eclipses, and off-points, the sps variables, dispersion angle variables and fov_planet_transit are set incorrectly.
    c. The SPS observation times have a small error of 0.125 s.
    d. The pointing error flags are not set properly during eclipses and lunar transits. Only one pointing flag should be set at a time, but often multiple flags are set.
    e. The three pointing quality flags had different names.
    f. All irradiances were set to fill values when any channel saturated.

4. Versions

Tables 1 and 2 provide the changes for the science-quality L1b data versions and the versions of this Readme. The version number for the XRS L1b operational data never changes.

Table 1. Science-quality L1b data versions.

Version	Release date	Updates
v.0.0.2	26 March 2024	Updated responsivities for GOES-16 (XRS-B2), GOES-17 (-A2, -B2), GOES-18 (-A1, -A2, -B1, -B2). Updated GOES-18 XRS-A1 and -A2 dark coefficients.
v0.0.1	6 April 2021	Data reprocessed with updated calibration tables. Fixed minor error in SPS pointing flags.

		Dispersion and cross-dispersion angles are now set to fill values if pointing is below a pre-defined low signal threshold. Fixed minor yaw_flip_flag error causing fill_values for some dates, and resolved all known yaw_flip_flag errors Updated dark values in calculations. Corrected au_factor calculation
v0.0.0	15 April 2020	N/A

Table 2. Document versions.

Release date	Updates
26 March 2024	Minor updates. Combined science-quality and operational L1b Readmes.
8 March 2023	Minor updates.
20 May 2021	Added caveats regarding ecef, penumbra, time, and cross_dispersion_angle.
6 April 2021	Updates to data caveats as described in Table 2.
15 April 2020	First version.

Acknowledgements

We acknowledge contributions from S. Codrescu, T. Eden, F. Eparvier, K. Hallock, A. Jones, A. Mahon, J. Riley, A. Wilson, D. Woodraska, T. Woods, and P. Wyatt.

References

Chamberlin, P. C., F. G. Eparvier, A. R. Jones, and T. N. Woods (2009), Next Generation X-Ray Sensors (XRS) for the NOAA GOES-R Satellite Series, SPIE Proc., 7438-23. https://doi.org/10.1117/12.826807