

Readme for GOES-R EXIS XRS Level 1b Operational Data

8 March 2023

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WARNING - THE USE OF SCIENCE-QUALITY DATA INSTEAD OF OPERATIONAL DATA IS STRONGLY RECOMMENDED.

Science users are advised to use the science-quality L2 data rather than the operational L1b data. The operational data is intended for archiving and for analyses that require “SWPC operational-like” data. Persons desiring to use the XRS Operational L1b products are advised to involve the responsible NOAA scientists before proceeding.

Links to the science-quality XRS data, Readmes, a User's Guide, plots, responsivity functions and other the associated documentation can be found at <https://www.ngdc.noaa.gov/stp/satellite/goes-r.html>.

1. Summary

The GOES-R Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS) X-Ray Sensor (XRS) Level 1b (L1b) science-quality 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 is for the XRS L1b product used in operations at SWPC. This Readme discusses the data and data caveats. Further details on the XRS instrument can be found in the article by Chamberlin et al. (2009) and at <https://www.goes-r.gov/spacesegment/exis.html>.

Users of the GOES-R XRS L1b operational 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 or josh.riley@noaa.gov.

2. Use of Science-Quality Data instead of Operational Data

The operational L1b data, especially from the earlier dates, contain significant issues that are not retroactively corrected, and therefore this data should be used with great caution and not for scientific analysis. While major issues in the operational processing code have been resolved, minor issues remain to be fixed.

In general, users are advised to use the reprocessed science-quality XRS L1b and L2 data instead of the operational data. The science-quality dataset is produced by NOAA's National Center for Environmental Information (NCEI), and 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. Both operational and science-quality data contain recovered data due to spurious dropouts. The science-quality data have been reprocessed from the start of the mission to the present date.

Links to the science-quality XRS data, Readmes, a User's Guide, plots, responsivity data, and associated documentation can be found at <https://www.ngdc.noaa.gov/stp/satellite/goes-r.html>. The science-quality data directories have names which end in "_science" and the file names have prefixes of "sci_". 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.

3. 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.

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). 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 sensor, which is a quad photodiode. 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. Since the GOES instruments operate in geostationary orbit, they experience two eclipse seasons per year around the equinox. The flag "SC_eclipse_flag" indicates these events. There are three L1b pointing error flags (Table 1); the flag names will be simplified in the summer of 2021.

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".

Table 2. L1b pointing error flags for operational XRS data

Pointing error range	Original flag name	Revised flag name (starting summer 2021)
(7 arcmin) 0.11° to 0.4° degrees	degraded_due_to_calibrated_but_exceeds_requirements _XRS_pointing_qf	XRS_pointing_warning_qf
0.4 to 0.8°	degraded_due_to_uncalibrated_range_XRS_pointing_qf	degraded_XRS_pointing_qf
>0.8°	invalid_due_to_out_of_range_XRS_pointing_qf	invalid_XRS_pointing_qf

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 $5 \times 10^{-5} W m^{-2}$ peak irradiance, and an X2.5 index is defined as an irradiance level of $2.5 \times 10^{-4} W m^{-2}$ 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 data are now available from the GOES 8-15 tab at <https://ngdc.noaa.gov/stp/satellite/goes-r.html>. In this GOES 13-15 science-quality data, the irradiances are provided in physical units (i.e., without the SWPC scaling factors) to match the GOES-R data.

4. Data Caveats

The following is a list of caveats for the GOES-R XRS L1b operational data *at this time*. Earlier operational data has more significant errors which are not described here. Some of the errors

below will be corrected in future operational data, and most of these errors are corrected in the science-quality data.

1. The XRS-A irradiance is approximately 41% larger for GOES-R than GOES-15; i.e., $XRS-A_{GOES-R}/XRS-A_{GOES-15} \approx 1.41$ (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. 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. The fov_eclipse flag is not set during Earth eclipses. The SC_eclipse_flag should be used to identify eclipses.
6. The spacecraft eclipse flag, yaw_flip_flag, the alg_container, packet_count variables and roll angle values are incorrect early in the missions. GOES-16 has had no yaw flips prior to the date of this document.
7. The solar array currents are incorrect in all GOES 17 data.
8. 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.
9. Prior to February 2019 the lunar_transit_flag variable was not set during lunar transits.
10. During lunar transits, eclipses, and off-points, the sps variables, dispersion angle variables and fov_planet_transit are set incorrectly.
11. The SPS observation times have a small error of 0.125 s.
12. 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.
13. 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 will be renamed SPP_roll_angle in the future.
14. The ecef values are bad for most of 2017.
15. Penumbra without an adjacent eclipse are not flagged.
16. 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 epoch. See <https://www.nist.gov/pml/time-and-frequency-division/time-realization/leap-seconds>
17. There are small discrepancies in the cross_dispersion_angle of about 0.003° (1 arcsec) for about an hour after eclipses.

4. Document Versions

Table 2. Document versions.

Release date	Updates
8 March 2023	Minor updates.
20 May 2021	Added caveats regarding ecef, penumbra, time, and cross_dispersion_angle.
6 April 2021	Added mention of errors in SPP_to_Sun_roll_angle, pointing flags, and during eclipses and off-points. Other minor changes.
15 April 2020	First version

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>