Readme for GOES-R EXIS XRS Level 1b Science-Quality Data

20 May 2021
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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 science-quality dataset is produced by NOAA's National Centers for Environmental Information (NCEI) and utilizes code provided by LASP, 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. The science-quality data have been reprocessed from the start of the mission to the present date. Both the science-quality and the operational data sets contain recovered data due to spurious dropouts. This Readme discusses the science-quality 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) and at https://www.goes-r.gov/spacesegment/exis.html.

Science-quality L2 data, which are cleaned of spikes and have better flagging, are produced from these science-quality L1b data. In general, science users are advised to use the science-quality L2 data rather than the science-quality L1b data. Links to the science-quality XRS L1b and L2 data, Readmes, a User's Guide, plots, responsivity functions and associated documentation can be found at https://www.ngdc.noaa.gov/stp/satellite/goes-r.html.

Users of the GOES-R XRS L1b Science-Quality data are responsible for inspecting the data and understanding the known caveats prior to use. Questions about this science quality data set can be sent to courtney.peck@noaa.gov or janet.machol@noaa.gov, while questions about data access should be sent to pamela.wyatt@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. A full list of variables, data type, long name, and units is provided in Appendix 1.

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. There are three L1b pointing error flags: XRS_pointing_warning_qf for a pointing error between 0.11° (7 arcmin) and 0.4°, degraded_XRS_pointing_qf for a pointing error between 0.4 and 0.8°, and invalid_XRS_pointing_qf for a pointing error greater than 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.

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”.

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 5×10^{-5} W m^{-2} peak irradiance, and an X2.5 index is defined as an irradiance level of 2.5×10^{-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://www.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.

3. Data Caveats

The following is a list of caveats for the GOES-R XRS L1b Science-Quality 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 epoch. See 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.

4. Operational XRS L1b Data

The L1b Science-Quality data product differs from the operational L1b product used in operations at SWPC in that it incorporates retrospective fixes that are not in the operational data and is reprocessed from the start of the mission. 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 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.

5. Versions

Table 1. Document versions.

Release date	Updates
15 April 2020	N/A
6 April 2021	Updates to data caveats as described in Table 2.
20 May 2021	Added caveats regarding ecef, penumbra, time, and cross_dispersion_angle.

Table 2. Science-quality L1b data versions.

Version	Release date	Updates
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

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

Appendix 1. Variables

Tables 2 and 3 list the variables in the XRS L1b data. Further attributes such as valid ranges and flag names are provided in the netCDF files.

Table 3: XRS variable dimensions.

Dimension	Value
report_number	UNLIMITED (86,400)
sps_measurement_count	4
solar_array_current_channel_index	4
number_of_time_bounds	2
solar_array_mnemonic_str_len	25

Table 4: XRS variables.

Variable	Dimension	long_name	Units
irradiance_xrsa1	report_number	irradiance at wavelengths between 0.05 and 0.4 nm calculated from XRS-A solar minimum channel (photodiode) based on a flat spectrum	W m^{-2}
irradiance_xrsa2	report_number	irradiance at wavelengths between 0.05 and 0.4 nm calculated from XRS-A solar maximum channel (quadrant photodiode) based on a flat spectrum	W m^{-2}
primary_xrsa	report_number	flags indicating which of two XRS-A channels, solar minimum channel 1 or solar maximum channel 2, provides the primary irradiance value	1
irradiance_xrsb1	report_number	irradiance at wavelengths between 0.1 and 0.8 nm calculated from XRS-B solar minimum channel (photodiode) based on a flat spectrum	W m^{-2}
irradiance_xrsb2	report_number	irradiance at wavelengths between 0.1 and 0.8 nm calculated from XRS-B solar maximum channel (quadrant photodiode) based on a flat spectrum	W m^{-2}
primary_xrsb	report_number	flags indicating which of two XRS-B channels, solar minimum channel 1 or solar maximum channel 2, provides the	1

		primary irradiance value	
xrs_ratio	report_number	ratio calculated by XRS-A primary irradiance divided by XRS-B primary irradiance	1
corrected_current_xrsa_1	report_number	corrected current for 1st quadrant of XRS-A solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsa_2	report_number	corrected current for 2nd quadrant of XRS-A solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsa_3	report_number	corrected current for 3rd quadrant of XRS-A solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsa_4	report_number	corrected current for 4th quadrant of XRS-A solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsb_1	report_number	corrected current for 1st quadrant of XRS-B solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsb_2	report_number	corrected current for 2nd quadrant of XRS-B solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsb_3	report_number	corrected current for 3rd quadrant of XRS-B solar maximum channel\'s quadrant photodiode	A
corrected_current_xrsb_4	report_number	corrected current for 4th quadrant of XRS-B solar maximum channel\'s quadrant photodiode	A
dispersion_angle	report_number	average dispersion direction pointing angle from SPS during time interval associated with observation	degree
crossdispersion_angle	report_number	average cross-dispersion direction pointing angle from SPS during time interval associated with observation	degree
sc_power_side	report_number	flags indicating which of two EXIS power boards, A or B, is active	1
exis_flight_model	report_number	flags indicating EXIS flight model. also serves as serial number of instrument	1
exis_configuration_id	report_number	EXIS configuration identifier	1
xrs_runctrlmd	report_number	flags indicating XRS internal gain calibration circuit and data retrieval	1

		indicator settings	
integration_time	report_number	XRS integration time used to collect data associated with observation	s
exs_sl_pwr_ena	report_number	flags indicating whether power to currently selected EXIS stimulus lamp is enabled	1
asic1_temperature	report_number	temperature of XRS ASIC board #1	degrees C
asic2_temperature	report_number	temperature of XRS ASIC board #2	degrees C
invalid_flags	report_number	flags indicating observation data may be invalid	1
xrs_det_chg	report_number	count of XRS detector measurements since last sensor power-on or settings change	count
xrs_mode	report_number	instrument (sensor) mode	1
sps_obs_time	report_number, sps_measurement_count	time of observation for each SPS 4 Hz measurement	seconds since 2000-01-01 12:00:00
sps_int_time	report_number, sps_measurement_count	SPS integration time for each (4 Hz) SPS measurement	s
sps_temperature	report_number, sps_measurement_count	temperature of SPS detector for (4 Hz) each SPS measurement	degrees C
sps_det_chg	report_number, sps_measurement_count	counter, which resets after SPS power-on or setting change, indicating whether to disregard observation (conditions to disregard: .lt. configurable value after power on; .lt. configurable value after internal gain calibration)	count
num_angle_pairs	report_number	number of valid SPS measurements used during XRS L1b processing	count
yaw_flip_flag	report_number	flags indicating whether spacecraft is operating in yaw flip configuration	1
au_factor	report_number	earth to sun distance multiplicative correction factor to normalize to 1-AU at time of observation. not applied in XRS L1b product processing	1

quality_flags	report_number	XRS L1b processing and data quality flags	1
time	report_number	XRS observation center time	seconds since 2000-01-01 12:00:00
packet_count	report_number	current count of XRS L0 telemetry packets received since instrument start-up or reset	count
fov_unknown	report_number	flags indicating whether instrument has received field-of-view information (eclipse, planetary and lunar transit, off-pointing calibration maneuver conditions) provided by ground system	1
fov_eclipse	report_number	flags indicating whether sun being obscured by earth is imminent or in progress as provided by ground system	1
fov_lunar_transit	report_number	flags indicating whether lunar transit across sun is imminent or in progress as provided by ground system	1
fov_planet_transit	report_number	flags indicating whether planetary transit across sun is imminent or in progress as provided by ground system	1
fov_off_point	report_number	flags indicating whether off-pointing calibration maneuver is imminent or in progress as provided by ground system	1
quaternion_Q0	report_number	spacecraft ACRF to J2000 ECI attitude quaternion Q0	1
quaternion_Q1	report_number	spacecraft ACRF to J2000 ECI attitude quaternion Q1	1
quaternion_Q2	report_number	spacecraft ACRF to J2000 ECI attitude quaternion Q2	1
quaternion_Q3	report_number	spacecraft ACRF to J2000 ECI attitude quaternion Q3	1
ecef_X	report_number	spacecraft ECEF X coordinate	m
ecef_Y	report_number	spacecraft ECEF Y coordinate	m
ecef_Z	report_number	spacecraft ECEF Z coordinate	m
solar_array_current	report_number, solar_array_current_channel_index	solar array current in DN for 4 channel groups (1-4, 5-8, 9-12, 13-16)	count
SC_eclipse_flag	report_number	flags indicating whether sun is obscured by earth as provided by spacecraft	1

product_time	input_file, number_of_time_bounds	start and end time of observations associated with product	seconds since 2000-01-01 12:00:00
solar_array_current_channel_index_label	solar_array_current_channel_index, solar_array_mnemonic_str_len	labels for four solar array current telemetry mnemonics. labels are ordered the same as applicable data variable	
SPP_to_Sun_roll_angle	input_file	angular offset of the solar north rotational pole relative to SPP with positive values measured clockwise	degree
SPP_roll_angle_time	input_file	time of SPP_to_Sun_roll_angle measurement, in seconds since J2000 epoch (2000-01-01 12:00:00 UTC)	seconds since 2000-01-01 12:00:00
percent_uncorrectable_L0_errors	input_file	(for SCI data) fraction of missing data due to missing L0 data	1