README FOR SCIENCE-QUALITY GOES 13–15 XRS DATA V. 1.0

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1 Summary

On each GOES satellite there are two X-ray Sensors (XRS) which provide solar X-ray irradiances for the wavelength bands of 0.5 to 4 Å (short channel) and 1 to 8 Å (long channel). Measurements in these bands have been made by NOAA satellites since 1974 and the design has changed little during that time period [Garcia, 1994]. The operational (real time) data comes from the NOAA Space Weather Prediction Center (SWPC). This document discusses GOES 13–15 XRS data which has been reprocessed to be science-quality. Both operational and science-quality data are provided by the NOAA National Centers for Environmental Information (NCEI).

Users of the GOES 13–15 XRS 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 janet.machol@noaa.gov or erika.zetterlund@noaa.gov, while questions about data access should be sent to pamela.wyatt@noaa.gov.

2 GOES X-Ray Sensor (XRS)

XRS consists of two gas-filled ion chambers, one for each band. Sweeper magnets deflect incoming electrons away from the assemblies so that only X-rays are measured. GOES 8–12 (GOES I–M series) and 13–15 (GOES NOP series) have ion cell detectors and the detector/filter combinations that make the spectral bandpasses nearly identical between both satellite series (and to earlier XRS detectors). A description of the GOES-8 instrument is given by Hanser and Sellers [1996]. For each sensor, the short wavelength cutoff is defined by the ion cell, while the long wavelength cutoff is defined by the thickness of the beryllium (Be) filter. Figure 1 shows the normalized detector responses for the short and long wavelength bands. Response functions are provided with the irradiance data. The GOES 13–15 irradiance measurements have a 2-s cadence.

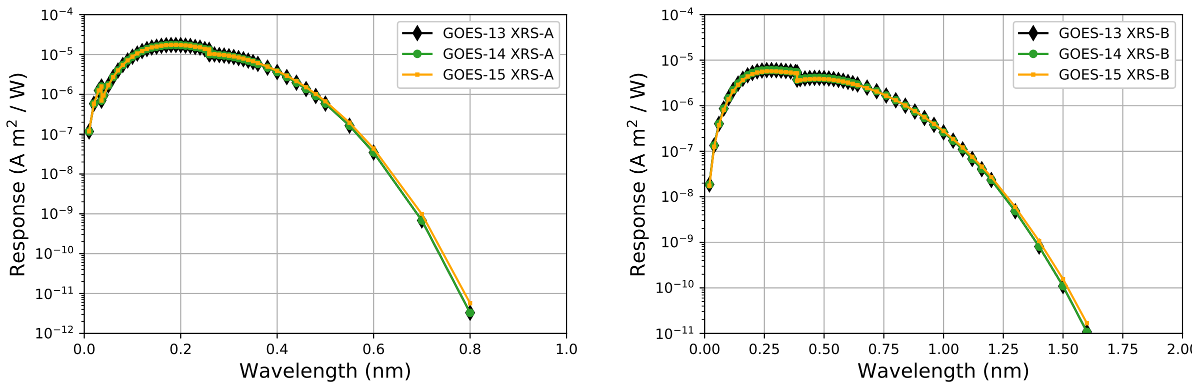

Figure 1: Response functions for XRS-A (left) and XRS-B (right). There are only minor differences between the three satellites.

Table 1 lists the launch dates of the three satellites, along with the date ranges for the science-quality data. While GOES-13 took data for years before our start date, it was unstable until June 2013. Figure 2 shows primary and secondary GOES satellites for the XRS data.

Table 1: Operational Dates

		Science-Quality Data	
Satellite	**Launch**	**Start**	**End**
GOES-13	2006/05	2013/06	2017/12
GOES-14	2009/06	2009/09	2020/03
GOES-15	2010/03	2010/03	2020/03

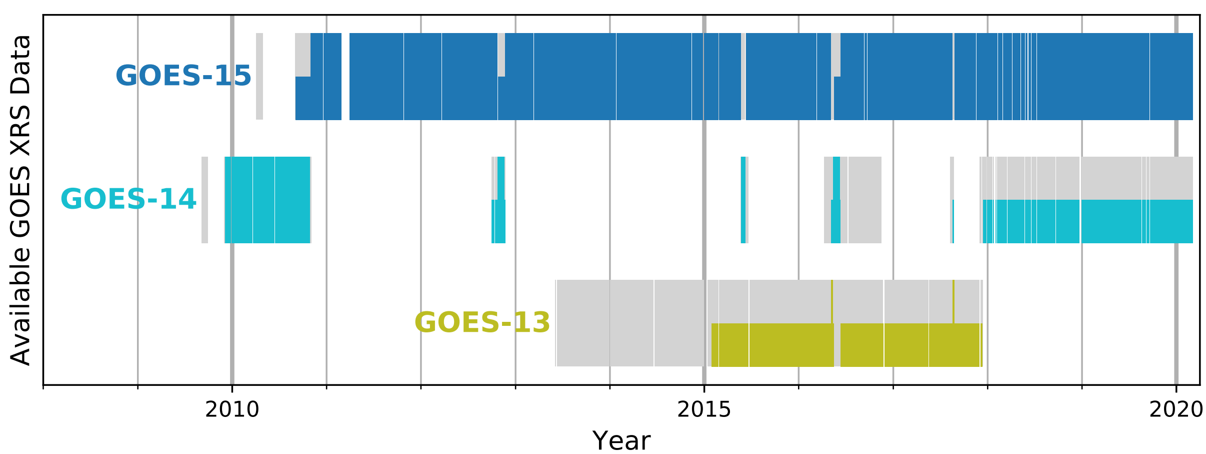

Figure 2: Grey indicates that science-quality data exists. A full color bar indicates that the satellite is the primary XRS satellite at the time. A half color bar indicates it is the secondary XRS satellite.

The GOES 13 XRS had an electronics problem early in the mission – it is suspected that a capacitor failed. This resulted in a changing calibration and periods of data inversion (where flares appear as dips). We refer to these periods as "anomalous mode." While this mode is obvious during flares, when the signal is low, the anomalous and normal modes are indistinguishable. The science-quality data for GOES-13 begins in June 2013 when GOES-13 XRS ceased to go into anomalous mode.

3 Science-Quality Irradiances

The science-quality data differs from the operational data in several ways. In the retrospective science data, the calibration coefficients are determined as smoothly varying values, while the coefficients were updated occasionally in operational data were updated occasionally which resulted in step functions in the irradiances. One of these background adjustments occurred in April 2019, and the fix in the science-quality data is apparent in Figure 3. Also, as described in Section 3.1, the science-quality data does not contain the SWPC scaling factors. The X-ray irradiance in each channel is calculated as

$$\text{Irradiance [W/m}^2] = (\text{Counts} - B) \times G/C \tag{1}$$

where B is the background, G is the gain, and C is the units conversion factor. Background and gain are determined from in-flight calibrations, while the conversion factor is determined pre-launch. The terms irradiance and flux are used interchangeably in this document.

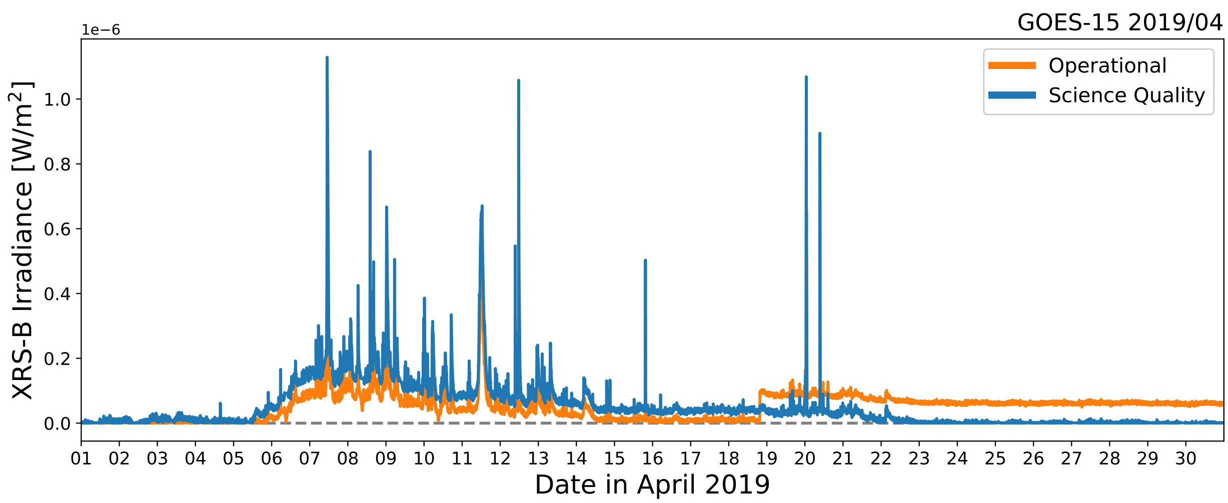

Figure 3: Comparison of operational (orange) and science-quality XRS-B data for the month of April 2019. A discontinuity in the operational data due to an adjustment of the background value occurred on 18 April. Both datasets are 1-minute averages.

3.1 Flare Magnitudes

A notable change between the GOES 13-15 science-quality data and the operational data is that the science 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 those from GOES-7. The flare index was based on the operational irradiances, but to get true irradiances from the operational data, it was necessary to remove the SWPC scaling factors of 0.85 (for XRS-A) and 0.7 (for XRS-B). The scaling factors have been removed in the science-quality GOES 13–15 data and are also not used in the data for the new GOES-R series (GOES 16–19) data.

The magnitude of a flare (i.e., the flare index) is defined by SWPC based on the 1-minute average of the GOES operational irradiance in the XRS-B channel at the peak of the flare. Flare indices, denoted by a letter and a number based on the $\log_{10}$ peak irradiance of the flare, are 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 2.4×10^{-4} W/m^2 peak irradiance. Because of the SWPC scaling factors in the operational data, flare indices for the operational data were reported as 42% (1.0/0.7) smaller than for the science GOES 13-15 and GOES-R data (e.g., an X2.5 class flare reported operationally for GOES-15 will be an X3.6 class flare for the GOES-15 science data and for

GOES-16). An XRS Level 2 (L2) product useful for flare detection is the flare summary product which provide flare peak irradiances, indices, and times.

4 Data Flags

The quality flags for the irradiances are listed in Table 2. The majority of the flags are the same as in the SWPC operational data, with minor corrections to the flag timing. Flags that are specific to the science-quality data are described in the following subsections. The unknown eclipse, saturation, and gain state change flags were never set for GOES 13 – 15; they are used for earlier GOES series datasets.

Table 2: Flag Dictionary

Bit #	**Value**	**Definition**
0	1	Calibration
1	2	Off-pointed
2	4	Eclipsed by Earth
3	8	Eclipsed by Moon
4	16	Eclipsed by Unknown
5	32	Temperature Recovery
6	64	Spike
7	128	Unknown Bad Data
8	256	Saturated
9	512	Gain State Change

4.1 Temperature Recovery Flag

XRS cools during eclipses, resulting in decreasing background counts over the course of the eclipse. After the eclipse ends, the instrument slowly warms back up to its pre-eclipse temperature. Depending on the level of solar activity, this post-eclipse warming may have a major impact on the count rate in which case the temperature recovery flag is set.

The relative importance of temperature on counts is determined by comparing the effect of the cooling on the background counts during the eclipse to the counts above the background after XRS has warmed for 70 minutes. This algorithm to set the temperature flag is demonstrated in Figure 4. It should be noted that while these short-term temperature effects caused by eclipses are flagged and left uncorrected, long-term temperature effects are corrected in the background measurements.

An additional minor temperature effect that appears on the ends of many eclipses occurs when an on-board heater tries to partially compensate for the eclipse cooling. The heater often starts too early or stops too late, causing a small increase in the counts on either or both ends of the eclipse. The eclipse flags are set to include these bumps. Figure 5 shows examples of these bumps.

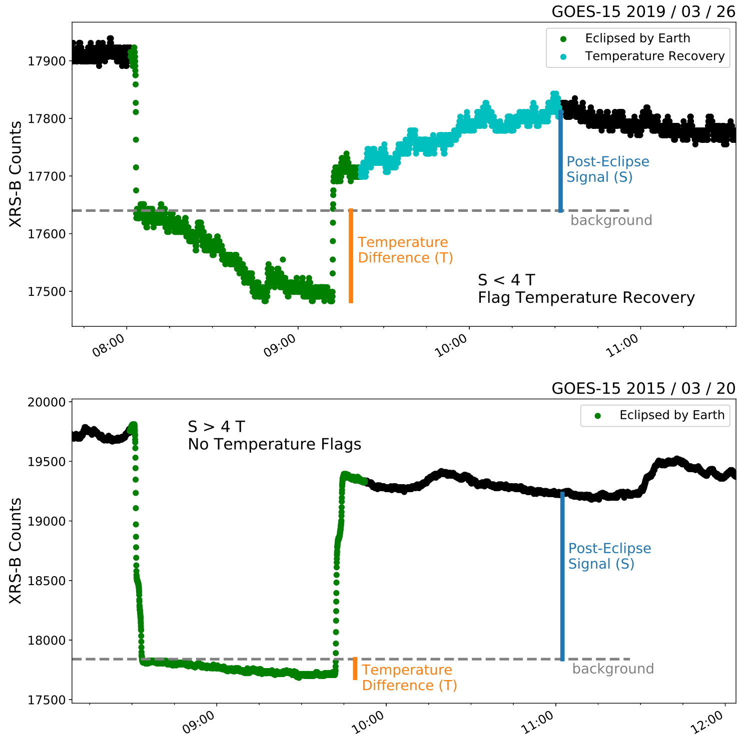

Figure 4: The need to set the temperature recovery flag is determined by comparing the post-eclipse signal to the signal difference due to cooling during the eclipse. If the post-eclipse signal (at 70-mins after the eclipse) is less than four times the counts change during the eclipse, the temperature effects are considered significant, and the recovery period is flagged. The upper plot demonstrates an instance were the temperature effects were significant, and the lower plot demonstrates an instance of when they were unimportant.

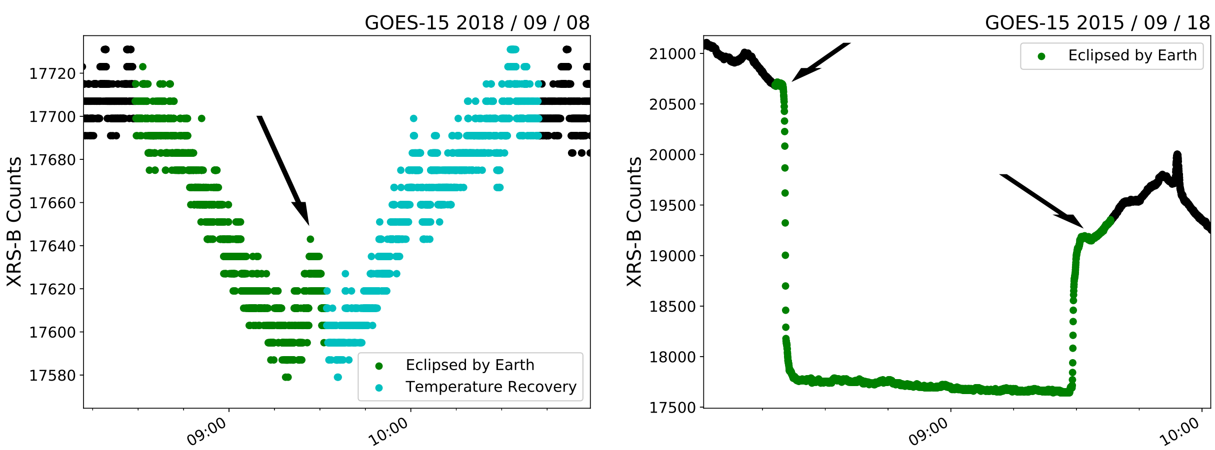

Figure 5: Two examples of bumps (indicated by arrows) in the counts on one or both ends of an eclipse due to overcompensation by the on-board heaters. The left plot shows one of these bumps as an eclipse ends while the Sun is quiet. The right plot shows an eclipse during greater solar activity, with bumps both at the start and end.

4.2 Spike Flag

Single-point spikes, significantly above the local noise level, are likely due to galactic cosmic rays. We identify these spikes via a lightly-modified Hampel filter. The Hampel filter is a type of median filter particularly suited for removing single-point outliers from time-series data with large signal variance such as the XRS data. The rate of these spikes increases dramatically during solar energetic particle (SEP) events.

4.3 Unknown Bad Data

The bad data flag is set during periods when the counts are zero or near-zero or there are other unexplained problems with the data. Such low counts cannot be physical because the counts have a large electronic offset.

5 Data Caveats

The following are known issues with the data.

1. GOES-13 XRS-B scaling

   Presumably due to the anomalous mode issues, GOES-13 XRS-B irradiances are 26% lower than GOES-15 when the pre-launch conversion factor, C, is used. Due to the size of this discrepancy, we revised C so that it scales GOES-13 XRS-B to GOES-15 XRS-B for all measurements which overlap in time. For XRS-A it was not necessary to change C from the pre-launch value. Due to the anomalous mode and the XRS-B scaling, we recommend using GOES-13 only as necessary for gap-filling.

2. Electron contamination

   XRS is sensitive to background contamination due to energetic electrons. In the future, a correction may be applied to remove this electron contamination.

3. Lunar eclipse flags

   The timing of the lunar eclipse flag is sometimes misaligned by up to approximately 15 minutes.

6 Higher Level XRS Products

The highest resolution 2-s irradiance measurements and the Level 2 (L2) products for XRS are listed in Table 3. Details of these products can be found in the User's Guide for GOES-R XRS L2 Products.

Table 3: Summary of XRS Products

Product	Name	Description
2-sec fluxes	irrad	XRS irradiances at a 2-s cadence
1-min fluxes	avg1m	XRS irradiances at a 1-min cadence
flare summary	flsum	flare detection flags such as start and peak
flare detection*	fldet	flare detection status for every minute
daily background	bkd1d	daily X-ray irradiance background

* Most users should use the the flare summary instead of the flare detection product. See warning in GOES-R XRS L2 Readme.

We note that there are several major differences between the GOES 13–15 data and the GOES-R that will be apparent in the L2 Readme.

1. The GOES-R L2 User's Guide lists two products, 1-second irradiances and flare location, that are not available for GOES 13–15 data.

2. Flagging for the GOES 13–15 data is slightly different than for GOES-R. It follows the flagging described in this document and is also defined in the file metadata.

3. The L2 User's Guide will mention additional XRS detectors.While GOES 13-15 has a detector for each channel, called XRS-A and XRS-B, XRS on GOES-R has two sets of detectors for each channel resulting in XRS-A1, XRS-A2, XRS-B1 and XRS-B2. Primary detectors for the two channels are identified at each time, and they are named as XRS-A and XRS-B, just as for GOES 13–15.

7 Data Access

The reprocessed science quality GOES 13-15 XRS irradiances, flare detection files, daily backgrounds, responsivity functions, and associated documentation can be accessed from the GOES 8–15 tab at `https://www.ngdc.noaa.gov/stp/satellite/goes-r.html`. Daily files are available for all data products, with the exception of daily backgrounds. Mission-length aggregations are also available for all data products, with the exception of 2-s fluxes, which are instead available in monthly aggregations. These mission-length files are located in the main directories for each product.

The original operational data can be accessed from `https://www.ngdc.noaa.gov/stp/satellite/goes/index.html`.

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