GOES X-ray Sensor (XRS) Measurements

Janet Machol, NOAA National Centers for Environmental Information (NCEI)
and University of Colorado, Cooperative Institute for Research in Environmental Science (CIRES)
Rodney Viereck, NOAA Space Weather Prediction Center (SWPC)
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Important notes for users

Scaling factors: For GOES 8-15, the archived fluxes have had SWPC scaling factors applied. To get true fluxes, these factors must be removed. To get true fluxes from the archived data, users must divide short channel fluxes by 0.85 and divide the long channel fluxes by 0.7. Similarly, to get true fluxes for pre-GOES-8 data, users should divide the archived fluxes by the scale factors. No adjustments are needed to use the GOES 8-15 fluxes to get the traditional C, M, and X alert levels. (See Section 2.)

Time stamps: The raw data time stamps are offset 1.024 s after the integration periods. The timestamps for averaged data have a 1-3 s offset from the start of the data. (See Section 3.)

Version	Date	Description of major changes	author
1.4.1	9 June 2016	3 s data for GOES 8-12 added to archive. Revised table of chronology of primary and secondary satellites. Added references and discussion of digitization.	Machol
1.4	4 March 2015	original	Machol

Contents

1. GOES X-ray Sensor (XRS)

On each GOES satellite there are two X-ray Sensors (XRS) which provide solar X-ray fluxes 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 data comes from the NOAA Space Weather Prediction Center (SWPC) and is archived at the NOAA National Center for Environmental Information (NCEI) which was formerly the National Geophysical Data Center (NGDC). Figure 1 shows primary and secondary GOES satellites for XRS data since 1986.

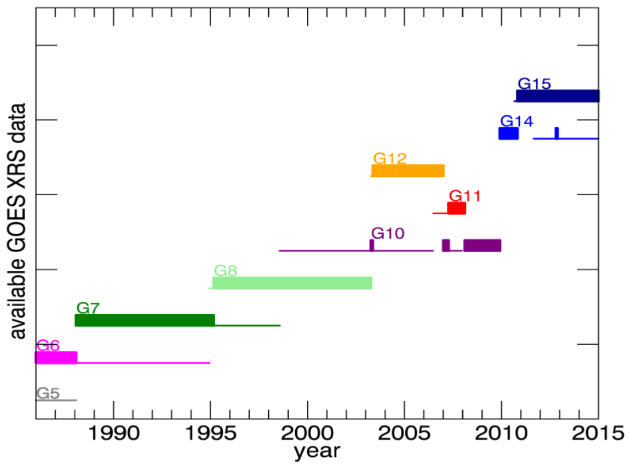

Figure 1. Primary (thick lines) and secondary (thin lines) GOES satellites for XRS data since 1986. GOES-13 measurements were unstable for many years, but have been been stable since 2014. However GOES 13 is not considered a primary or secondary satellite at this time. XRS data goes back to 1974, but the designation of primary and secondary satellites prior to 1986 is not known.

The measurements are obtained from 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. The instruments are not thought to degrade. 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]. Although electronics are very different for the two series, the measurements agree across the full dynamic ranges except at the very lowest signal levels. 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 2 shows the normalized detector responses for the short and long wavelength bands. The relative spectral contributions measured by the detectors are shown in Figure 3.

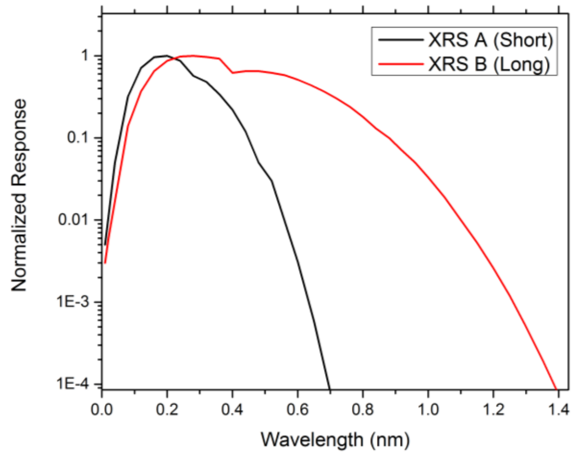

Figure 2. XRS detector responses.

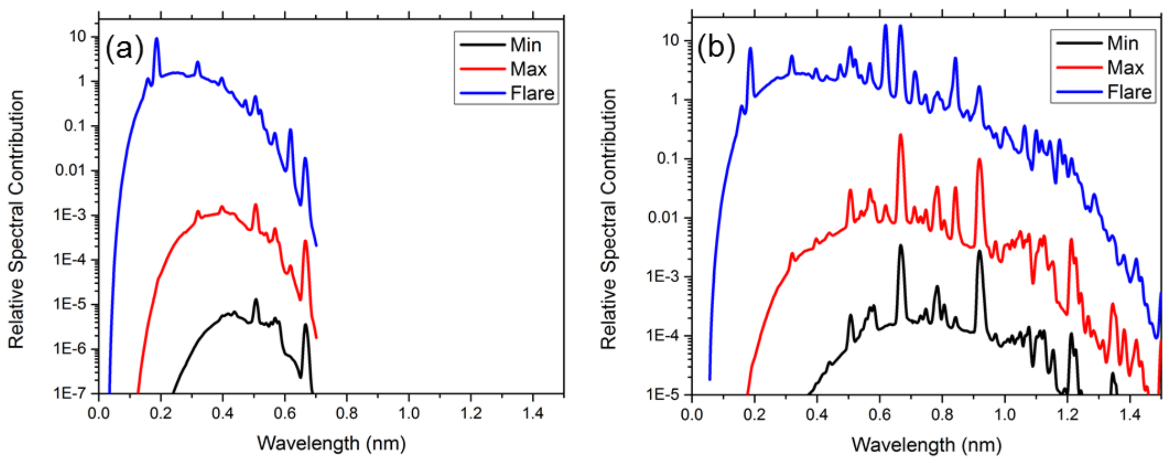

Figure 3. Relative spectral contributions for the XRS (a) short and (b) long channels. These are the detector responses multiplied by smoothed solar spectra for solar minimum, maximum, and flare conditions obtained from CHIANTI.

2. Data issues

2.1 Scaling factors and calibration

The archived XRS fluxes include scaling factors that were initially implemented by SWPC to get GOES-8 to agree with GOES-7. GOES 7 was the last of the spinning GOES satellites while GOES 8 was the first of the 3-axis-stabilized satellites. The scaling factors were retained by SWPC so that flare warning levels correspond to consistent flux values; e.g., an M5 X-ray alert from SWPC is based on a flux level of $5x10^{-5}$ W/m^2 for all satellites. Some rocket launches have confirmed that the new sensors are accurate and that the use of scaling factors to match the old spinner satellites is not correct. SWPC has not removed the scaling factors from the data, however, because (1) there has been no actual calibration, (2) the XRS is operational, and (3) there are many procedures and customers that require consistency more than accuracy. The next generation of satellites, GOES-R (to launch in 2016) will have well calibrated detectors and will provide the confirmation needed to finally remove the scaling factors.

To get true fluxes for GOES 8-15 XRS, users must remove the SWPC scaling factors from the data. To get the true fluxes, divide the short band flux by 0.85 and divide the long band flux by 0.7.

Similarly, **to get true fluxes for pre-GOES-8 data**, users should divide the archived fluxes by the scale factors. No adjustments are needed to use the GOES 8-15 fluxes to get the traditional C, M, and X alert levels.

Calibration issues are discussed by Neupert [2011]. A comparison of XRS data with Thermosphere Ionosphere Mesosphere Energetics Dynamics– Solar Extreme Ultraviolet Experiment (TIMED-SEE) measurements is given by Rodgers et al. [2006].

2.2. Time stamps

For GOES XRS, the data sampling rate depends on the satellite generation. For GOES 13-15, the data accumulation time is 2.048 s, and both the A and B channels take data simultaneously [Data and calibration handbook, 2009, Section 9.3]. The location of the time stamps is ***offset*** relative to the integration periods. As can be seen in Figure 4, for the raw data, the time stamps are 1.024 s ***after the end of the integration period***.

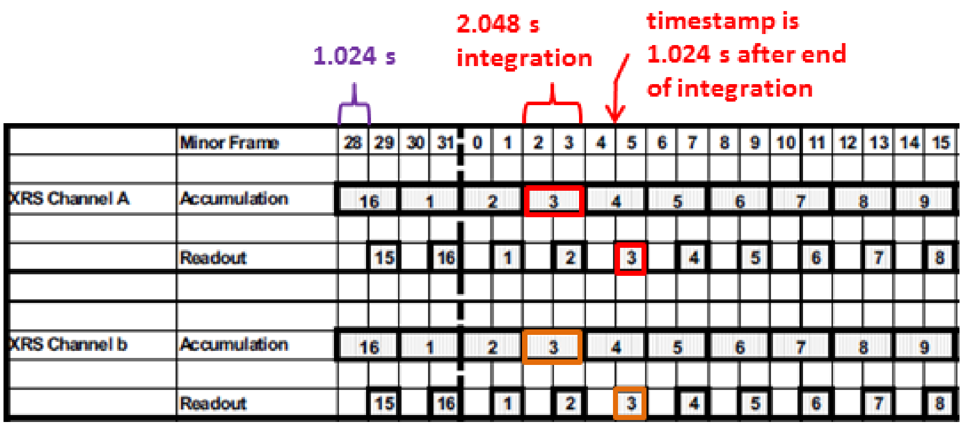

Figure 4. Sketch of XRS data integration and readout from the instrument. Telemetry minor frames are 1.024 s. As an example, the relative times for integration period '3' and its delayed timestamp are indicated.

For GOES 13-15, one minute averages are created by including all raw data with time stamps within a 1 minute window. The time stamp is set to the beginning of the 1 minute window. Five minute averages are created from averages of 1-min averages, and time stamped at the beginning of the average. Because the raw data time stamps are offset after the data, the time stamps for the averaged data are 1.024-3.072 s after the start of the included data. This is sketched in Figure 5.

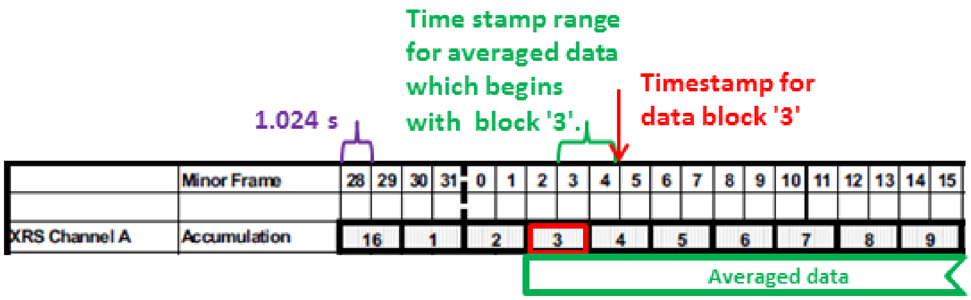

Figure 5. Sketch shows that timestamp for averaged data is offset 1.024-3.072 s after the start of the included data.

For satellites prior to GOES-13, the data accumulation time was 3 s. The time stamps are <3 s after the end of the accumulation period; the offset is not defined exactly because there was no on-board satellite clock. The actual sampling rate is 0.512 according to the GOES I-M DataBook [1996], but this raw data is only available by reprocessing the raw telemetry . The averages are created in the same way as for GOES 13-15.

2.3 Digitization

As described by Simões et al. [2015], the digitization of the GOES XRS data is larger than the Poisson noise from photon counting statistics. This can be problematic when differencing or taking derivatives of the flux data. GOES 8-12 had three different gain ranges and the digitization is apparent at the edges of these ranges. For GOES 10, the contractor changed the electronics to reduce the noise level of the XRS. This had the unintended consequence of enhancing the digital steps or quantization at low levels for the 1 and 5 minute averaged data.

2.4 Contamination

On rare occasions, when the X-ray sun is very quiet, bremsstrahlung contamination can be observed. This contamination is caused by energetic particles in the outer radiation belts and depends on satellite local time, time of year, and the local particle pitch-angle distribution. The X-ray sensors are also sensitive to background contamination due to energetic electrons that either deposit their energy directly in the telescope or strike the external structure and produce bremsstrahlung X-rays inside the ion chambers.

2.5. Saturation

During the most extreme flare events, the GOES XRS channels can saturate. As shown in Figure 6, during the 2003 Halloween storms, on GOES-12, the XRS long channel saturated at X-17 and the short channel saturated at X-5.   On GOES 13-15, there has not been a solar flare that has saturated the XRS channels (as of February 2015), but it is expected that they will saturate at about the same flux levels.

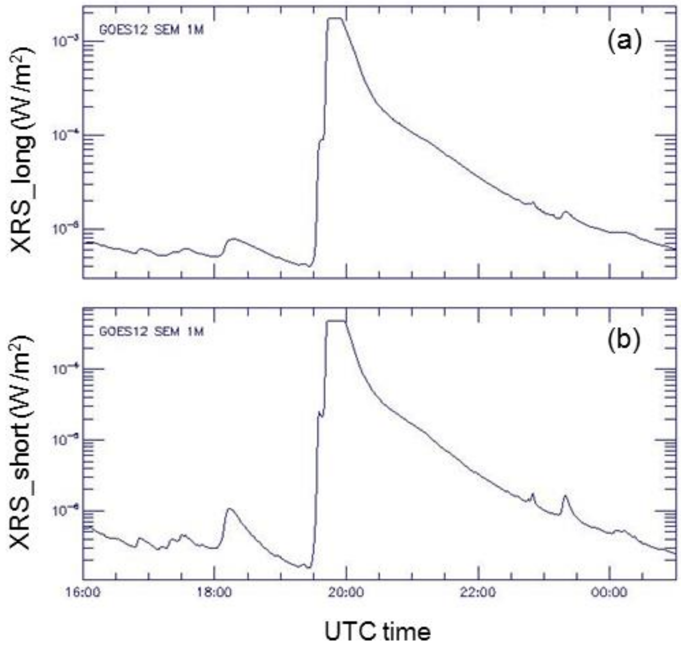

Figure 6. Saturation of the long (a) and short (b) channels on GOES-12 during a flare on 4 November 2003.

3. Data Access

Real time GOES XRS data is available from SWPC under "Instrument Measurements" at
http://www.swpc.noaa.gov/Data/
The archived GOES XRS data is available from the NOAA National Geophysical Data Center (NGDC) at
https://www.ngdc.noaa.gov/stp/satellite/goes/index.html
Click "Data Access" on the left side of this page. There are two parts of the archive, a newer and an older part. XRS data from older satellites is also accessible at the bottom of the page.

The newer part of the archive contains data from 1986 onward and is available for GOES 6-15 satellites. The data includes raw data, averaged data, and plots. The data is in both .csv and netcdf (.nc) formats.

The older part of the archive contains data files with .csv and .FIT formats for both 3-s raw and some 1-minute averaged data as well as summary plots. An associated file explains the file naming convention. Details of dates of the satellites and archive locations of the data are given in the Section 5.

In the archived .csv files of averaged XRS fluxes, the flux columns are labeled correctly, but their order changes for the different satellite series. The order of the columns for the different satellite series is:

GOES 6-7	xl(long)	xs(short)
GOES 8-12	xs(short)	xl(long)
GOES 13-15	A(short)	B(long)

4. Dates of GOES satellites with XRS sensors

Table 1 shows the approximate times of the different satellites in the NGDC archive. At any time, one GOES satellite is designated as the primary and one satellite is the secondary. Secondary satellite measurements are used when the primary satellite cannot provide data due to eclipses or maintenance. Table 2 shows the chronology of primary and secondary GOES satellites for XRS measurements since 1986.

The GOES13 XRS had an electronics problem early in the mission -- it is suspected that a capacitor failed. This resulted in a changing calibration and period of data inversion (where flares appear as dips). GOES-13 measurements were unstable for many years, but have been stable since late 2013.

Table 1. Approximate dates of GOES XRS sensors data in the NGDC archive. (Launch dates from http://www.osd.noaa.gov/download/JRS012504-GD.pdf and http://www.goes-r.gov/mission/history.html)

Satellite	***Launch Date***	***XRS data start date***	***XRS data end date***	***NCEI Archive name***	***Full res.***	***Averaged data***	***Remarks***
GOES-15	2010-03-04	2010	present	new	2s	1min	
GOES-14	2009-06-27	2009	present	new	2s	1min	satellite in storage during some years
GOES-13	2006-05-24	2015***	present	new	2s	1 min	unstable until ~2014***
GOES-12	2001-07-23	2003	2007	new	3s	1, 5 min	3s data for 2003-2010
GOES-11	2000-05-03	2000	2008	new	3s	1, 5 min	3s data for 2006-2010
GOES-10	1997-04-25	1998	2009	new	3s	1, 5 min	3s data for 2001-2009
GOES-9	1995-05-23	1996	1998	new	3s	1, 5 min	no 3s data available
GOES-8	1994-04-13	1995	2002	new	3s	1, 5 min	3s data for 2001-2002
GOES-7	1987-02-26	1987	1996	old, new*	3s	1, 5 min	
GOES-6	1983-04-28	1983	1994	old, new*	3s	1, 5 min**	
GOES-5	1981-05-22	1983	1987	old	3s	1, 5 min**	
GOES-4	1980-09-09	-	-	-	-	-	no data
GOES-3	1978-06-15	1978	1980	old	3s	-	
GOES-2	1977-06-16	1977	1983	old	3s	-	
GOES-1	1975-10-16	1976	1977	old	3s	-	
SMS-2	1975-02-06	1974	1976	old	3s	-	
SMS-1	1974-05-17	1975	1975	old	3s	-	

*For GOES 6 and 7, the averaged data is available in the new archive while the raw data is in the old archive.

** Averaged data for GOES 5 and 6 available beginning in 1986.

*** GOES-13 data for the early part of 2014 may become available later.

Table 2. Chronology of designation of primary and secondary satellites for XRS measurements since 1986. Designations are unknown for period 1974-1986. (Table revised 7 June 2016)

Start Date	*Time*	*Primary*	*Secondary*	*Remarks*
2016-06-09	17:30	15	13	
2016-05-16	17:00	14	15	
2016-05-12	17:30	14	13	
2016-05-03	13:00	13	14	
2015-06-09	16:25	15	13	
2015-05-21	18:00	14	13	
2015-01-26	16:01	15	13	
2012-11-19	16:31	15	None	
2012-10-23	16:00	14	15	
2011-09-01	0:00	15	GOES-14	
2010-10-28	0:00	15	None	
2010-09-01	0:00	14	15	
2009-12-01	0:00	14	None	GOES-10 decommissioned
2008-02-10	16:30	10	None	GOES-11 XRS failure
2007-12-18	0:00	11	None	GOES-10 not tracked due to antenna problems
2007-12-05	0:00	11	10	
2007-11-21	0:00	11	None	GOES-10 not tracked due to antenna problems
2007-04-12	0:00	11	10	
2007-01-01	0:00	10	11	
2006-06-28	0:00	12	11	
2006-06-28	14:00	12	11	
2003-05-15	15:00	12	10	
2003-04-08	15:00	10	12	
1998-07-27	0:00	8	10	
1995-03-01	0:00	8	7	
1994-12-11	0:00	7	8	
1988-01-26	0:00	7	6	
1986-01-01	0:00	6	5	

5. Contacts

XRS data archive/access: sem.goes@noaa.gov

XRS calibrations: janet.machol@noaa.gov, rodney.viereck@noaa.gov

Please contact janet.machol@noaa.gov *to provide comments on this document or if you wish to be added to a mailing list for updates on the GOES XRS data set.*

6. Status flags for GOES 8-12

The definitions for the two status flags in the XRS 8-12 data are given in Table 3 and Table 4.

Table 3. Status word 1. AOCS is the Attitude and Orbit Control System. [Bornmann code, p.24]

bit	value	definition	likely XRS impact
0	1	No torquer current sign. (AOCS-Attitude and Orbit Control System)	
1	2	Torquer current sign change.	
2	4	0.256 s Torquer 1 update	
3	8	20 minute Torquer 1 change	
4	16	AOCS anomaly	
5	32	AOCS, torquer, or patch status change	
6	64	Single bit error (corrected)	
7	128	Telemetry noise (more than 1 bit)	
8	216	Bad or wrong satellite identification	
9	532	goeslave restart	
10	1064	(unused)	
11	2048	Time jump	x
12	4096	Time reverse	x
13	8192	Frame count jump	x
14	16384	(unused)	
15	32768	EPS/HEPAD off	
16	65536	HEPAD off	
17	131072	EPS/HEPAD calibration on	
18	262144	EPS transient	
19	524288	S4, S3 ratio bad	

Table 4. Status word 2.

bit	value	definition	likely XRS impact
0	1	X ray off	x
1	2	X ray calibration	x
2	4	X ray transient	x
3	8	X ray Long saturation	x
4	16	X ray Short saturation	x
5	32	Long channel range change	x
6	64	Short channel range change	x
7	128	XRS elevation angle change	x
8	216	XRS pointing error (SADA, CASS, yoke)	x
9	532	Eclipse	x
10	1064	(unused)	
11	2048	Magnetometer 2 on	
12	4096	Magnetometer off	
13	8192	Magnetometer calibration	
14	16384	Magnetometer transient	
15	32768	Minor mag disturbance	
16	65536	(unused)	
17	131072	Timing suspect	x
18	262144	Dwell	
19	524288	(unused)	

7. Calibration tables for GOES 13-15

For GOES 13-15, the NOAA SWPC gets raw count data with a cadence of 2.048 s from the GOES satellites. The counts are converted to calibrated fluxes with the equation:

$$X\text{-}ray\ flux[\mathrm{W/m^2}] = S * ((\mathrm{Counts} - B\ [\mathrm{counts}]) * G\ [\mathrm{A/count}]) / C\ [\mathrm{A/(W/m^2)}] \quad \text{(Eq. 1)}$$

where *S* is the SWPC scaling factor, *B* is the background, *G* is the gain and *C* is a units conversion factor. Values for all three satellites are given in Table 3. The values for the *G* and *C* come from the GOES Data and Calibration Handbooks. The background values, *B*, are really electronic offsets, and are measured when the satellite is pointed away from the Sun.

Table 5. Counts to flux conversion factors for GOES 14 and 15 XRS.

GOES sat	XRS channel	SWPC scaling factor	Background [counts]	Gain [A/counts]	Flux conversion [A/(W/m^2)]
15	A	0.85	17840	1.87e-15	1.141e-5
15	B	0.70	17700	1.87e-15	3.992e-6
14	A	0.85	16020	1.90e-15	1.117e-5
14	B	0.70	17200	1.91e-15	4.168e-6
13	A	0.85	15900	1.88e-15	1.171e-5
13	B	0.70	16000	1.88e-15	3.100e-6

As examples of the XRS response curves, the following two tables and figures are spectral response calibration data for GOES-13. The tables and figures are from the XRS/EUV Data and Calibration Handbook for F1(SN003).

Table 6. Calibration data for GOES-13 Channel A.

Wavelength (nm)	Mu(Be) (cm^2/g)	Mu(Xe) (cm^2/g)	G(wavelength) ($A\text{-}m^2/W$)	Wavelength (nm)	Mu(Be) (cm^2/g)	Mu(Xe) (cm^2/g)	G(wavelength) ($A\text{-}m^2/W$)
0.01	0.1	1.16	1.167E-07	0.25	4.4	625	1.359E-05
0.02	0.1	7.23	5.798E-07	0.25899	4.8	660	1.310E-05
0.03	0.1	21	1.244E-06	0.25901	4.8	231	1.020E-05
0.035799	0.1	33.1	1.564E-06	0.26	4.9	232	1.012E-05
0.035801	0.1	5.94	6.948E-07	0.27	5.5	255	1.000E-05
0.04	0.1	8	9.296E-07	0.28	6.2	275	9.660E-06
0.05	0.1	14.7	1.674E-06	0.29	6.9	303	9.398E-06
0.06	0.1	24.3	2.694E-06	0.3	7.6	328	9.045E-06
0.07	0.1	37	3.963E-06	0.31	8.4	357	8.613E-06
0.08	0.13	53.2	5.443E-06	0.32	9.3	388	8.092E-06
0.09	0.19	73.1	7.065E-06	0.33	10.2	421	7.578E-06
0.1	0.26	97.1	8.780E-06	0.34	11.2	454	6.995E-06
0.11	0.35	126	1.053E-05	0.35	12.2	491	6.446E-06
0.12	0.46	159	1.217E-05	0.36	13.4	529	5.804E-06
0.13	0.59	197	1.367E-05	0.38	15.8	609	4.671E-06
0.14	0.74	239	1.493E-05	0.4	18.5	694	3.619E-06
0.15	0.91	275	1.566E-05	0.42	21.5	791	2.708E-06
0.16	1.1	327	1.649E-05	0.44	24.8	885	1.957E-06
0.17	1.3	383	1.705E-05	0.46	28.5	991	1.355E-06
0.18	1.6	447	1.725E-05	0.48	32.5	1090	9.081E-07
0.19	1.9	518	1.727E-05	0.5	36.9	1190	5.841E-07
0.2	2.2	592	1.711E-05	0.55	49.6	1500	1.630E-07
0.21	2.6	673	1.667E-05	0.6	65	1860	3.461E-08
0.22	2.9	762	1.632E-05	0.7	104	2740	6.831E-10
0.23	3.4	725	1.540E-05	0.8	157	3710	3.294E-12
0.24	3.8	792	1.485E-05				

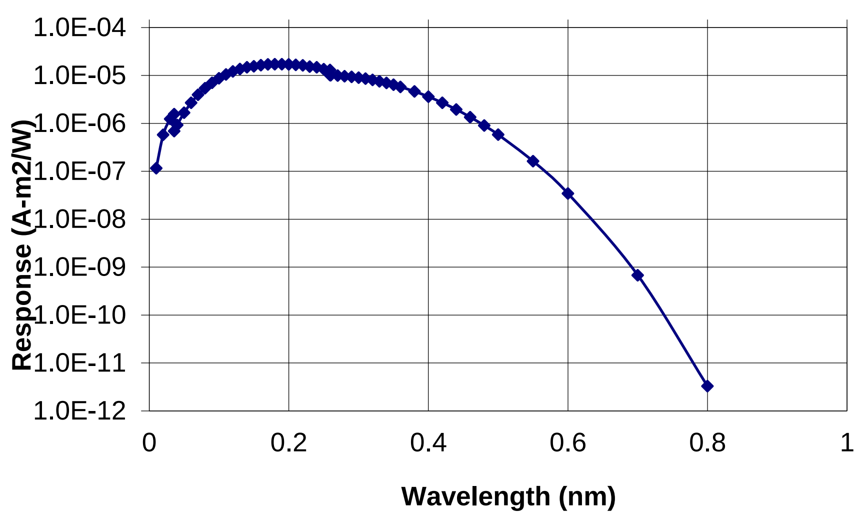

Figure 7. Calibrated response for GOES-13 Channel A.

Table 7. Calibration data for GOES-13 Channel B.

Wavelength (nm)	Mu(Be) (cm^2/g)	Mu(Ar) (cm^2/g)	G(wavelength) ($A\text{-}m^2/W$)	Wavelength (nm)	Mu(Be) (cm^2/g)	Mu(Ar) (cm^2/g)	G(wavelength) ($A\text{-}m^2/W$)
0.02	0.1	0.4	1.864E-08	0.5	36.9	296	4.036E-06
0.04	0.1	2.9	1.336E-07	0.52	41.7	328	3.952E-06
0.06	0.1	8.9	4.004E-07	0.54	46.9	363	3.836E-06
0.08	0.13	20	8.640E-07	0.56	52.5	399	3.689E-06
0.1	0.26	36	1.469E-06	0.58	58.5	438	3.520E-06
0.12	0.46	59	2.223E-06	0.6	65	479	3.330E-06
0.14	0.74	90	3.059E-06	0.62	72	522	3.124E-06
0.16	1.1	130	3.894E-06	0.64	79	568	2.925E-06
0.18	1.6	180	4.643E-06	0.68	95	667	2.498E-06
0.2	2.2	240	5.238E-06	0.72	113	778	2.078E-06
0.22	2.9	311	5.664E-06	0.76	134	903	1.671E-06
0.24	3.8	393	5.918E-06	0.8	157	1040	1.314E-06
0.26	4.9	489	6.038E-06	0.84	183	1187	9.998E-07
0.28	6.2	597	6.051E-06	0.88	211	1346	7.448E-07
0.3	7.6	720	6.002E-06	0.92	242	1516	5.376E-07
0.32	9.3	858	5.903E-06	0.96	275	1696	3.799E-07
0.34	11.2	1011	5.779E-06	1	311	1890	2.601E-07
0.36	13.4	1180	5.633E-06	1.04	351	2099	1.708E-07
0.38	15.8	1366	5.476E-06	1.08	393	2323	1.098E-07
0.38699	16.7	1435	5.419E-06	1.12	439	2561	6.766E-08
0.38701	16.7	153	3.730E-06	1.16	488	2813	4.040E-08
0.4	18.5	167	3.841E-06	1.2	540	3080	2.338E-08
0.42	21.5	189	3.966E-06	1.3	690	3800	4.824E-09
0.44	24.8	213	4.050E-06	1.4	860	4600	8.066E-10
0.46	28.5	239	4.088E-06	1.5	1050	5500	1.093E-10
0.48	32.5	267	4.086E-06	1.6	1270	6500	1.080E-11

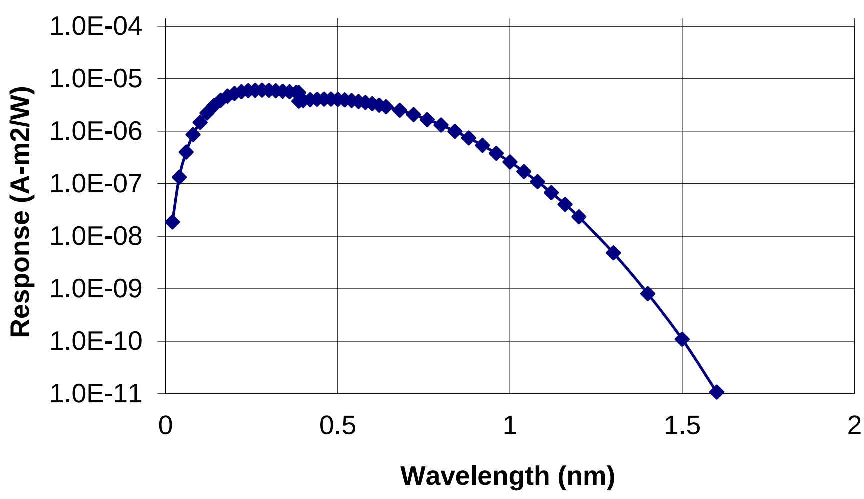

Figure 8. Calibrated response for GOES-13 Channel B.

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