Readme for Science-Quality GOES 13-15 EUVS Channels A and B Irradiance Data

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Table 1: Document Versions

Date	Version	Change Description
15 Sep 2023	3.2	Moved Channel E/Lyman alpha information to separate Readme. Reformatted documents in latex.
30 Sep 2016	3.1.3	Added references.
30 Sep 2015	3.1.2	Fixed equation in Figure 13 caption.
12 Aug 2015	3.1.1	Corrected Equation 2.
4 Mar 2015	3.1	Original

Contents

1 Summary

The geostationary orbiting GOES-13, -14 and -15 satellites were launched in 2006, 2009 and 2010, respectively. They each carried an Extreme Ultraviolet Sensor (EUVS) which measured the EUV in 5 wavelength bands (A-E) from about 5-127 nm as shown in Figure 1. The raw data units are counts with a 10.24 cadence and a requirement of <15% uncertainty. GOES-14 is unique in that it measures duplicate A and B bands (with A' and B' channels) instead of C and D bands.

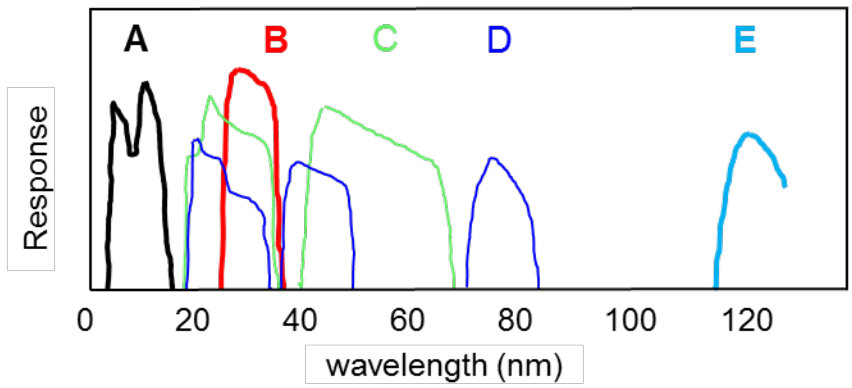

Figure 1: The wavelength responses of Channels A-E for GOES EUVS.

The operational (raw) data came from the NOAA Space Weather Prediction Center (SWPC) and was further processed and archived by the NOAA National Centers for Environmental Information (NCEI). NCEI currently provides calibrated data for the A, B, and E bands for all three satellites from 2006 through March 2020. Figure 2 shows measurement time periods for the three GOES satellites into 2016. This document covers primarily covers reprocessed science-quality data for Channels A and B. Channel A includes wavelengths near 15 nm, while Channel B includes the 30.4-nm He II solar line. Channel E includes the Lyman alpha solar line (121.6 nm) data and is processed until 2020 as discussed in a separate Readme at .

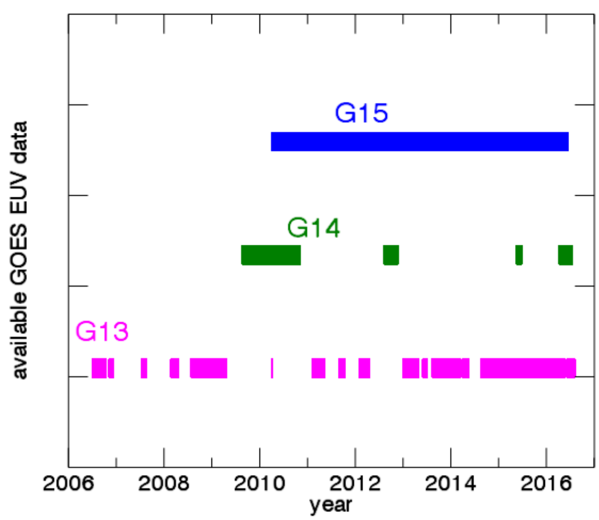

Figure 2: EUVS measurements for GOES satellites shown until 2016. Science-quality data is currently only available until mid-2014 for Channels A and B.

This Readme gives details of the EUVS Channels A and B science-quality data for GOES 13-15. A separate Readme about the Lyman-alpha (Channel E) science-quality data, is provided at `https://www.`

ncei.noaa.gov/data/goes-space-environment-monitor/access/science/euvs/GOES_13-15_EUVS_Lyman_alpha_Science-Quality_Data_Readme.pdf. Users of the GOES data are responsible for inspecting the data and understanding the known caveats prior to use. Please contact janet.machol@noaa.gov if you have technical questions about the EUVS data or if you wish to be added to a mailing list for updates on the GOES EUVS data sets. Please contact kim.baugh@noaa.gov or josh.riley@noaa.gov for questions about data access.

2 Data Products Overview

2.1 Science-Quality Data

Science-quality datasets are produced by NOAA's National Center for Environmental Information (NCEI), and differ from the operational products used at SWPC in that the data have been reprocessed from the start of the mission and incorporate retrospective fixes for issues and outages in the operational product. When available, users are advised to use the science-quality data instead of the operational data.

The latest science-quality data for the GOES 13-15 EUVS-A and -B bands is Version 2 and it has been processed from 2006 through April 2014 for EUVS-A and through October 2014 for EUVS-B. The available raw counts data is provided into 2016. Eventually, a new science-quality data version of Channel B data through 2020 with more modern netcdf formats will be available. Links to the counts and science-quality data, plots, responsivity data, and other associated documentation are accessible from https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/euvs/. For the next satellite series (GOES 16-19), EUVS data is available since 2017 from https://www.ngdc.noaa.gov/stp/satellite/goes-r.html.

The EUVS raw count data is converted into irradiances using measured detector response curves and quiet Sun reference spectra. Responsivity values are provided at https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/euvs/responsivity/. In general, measurements of the A and B bands agree well with other instruments and there has been no noticeable degradation. Figures 3 and 4 show the measured irradiances for the A and B bands.

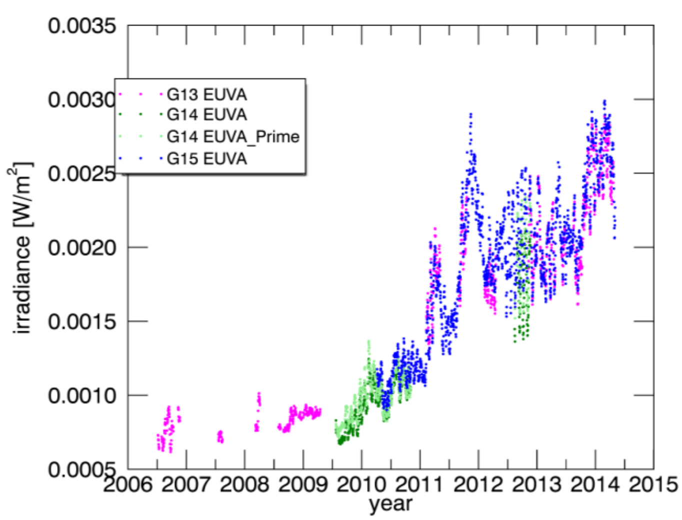

Figure 3: Irradiances for Channel A of GOES-13, -14 and -15. Irradiances for GOES-14 Channel A' are also shown.

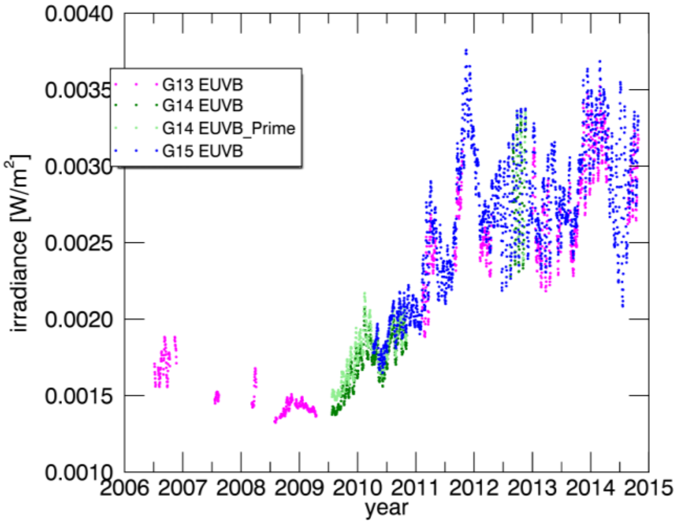

Figure 4: Irradiances for Channel B of GOES-13, -14 and -15. Irradiances for GOES-14 Channel A' are also shown.

For EUVS-A and -B NCEI archive provides annual ASCII files of raw (10.24 s) counts and flags, and calibrated ASCII data files with 1-minute and daily averaged counts, irradiances, and flags. Column and format information is in the file headers. Table 2 lists the main types of available data files. There are yearly and mission length aggregations. Count and irradiance data is not adjusted to 1 AU. Files with daily factors to adjust the irradiances to 1 AU are provided separately and the factors in them can be interpolated for use with the 10-s and 1 minute data. The daily irradiances files contain a column with 1 AU correction factors. Ephemeris data for the GOES satellites is also available.

Table 2: Version 2 science-quality files for Channels A and B.

File Type	Cadence	Description	Subdirectory*
1-min	1 min	counts, irradiances, and flags	GOES_V2
_daily	daily	counts, irradiances, and flags	GOES_V2
_Cnts	10.24 s	raw counts	raw_10s
_Corrected_Cnts	10.24 s	Chan A, corrected for heater noise	raw_10s
_Flags	10.24 s	flags	raw_10s
plots	1 min, daily	annual irradiance plots	plots_V2
1 AU factors	daily	factors to convert irradiance to 1 AU	AU_correction
responsivity	–	detector response functions	responsivity
ephemeris	1 min	satellite location	**

* Main directory is `https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/euvs/`.

** Ephemeris data is at `https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/sat_locations/`.

The data archive includes annual "quick look" plots. An example of one of these quick look plots is shown in 5. Currently, version 2 data (channels A and B) are available up to October 2014.

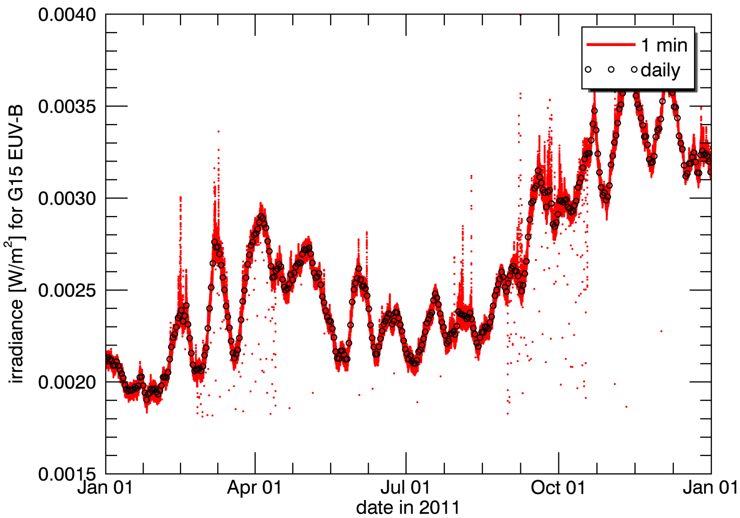

Figure 5: GOES-15 Channel B 1-min and daily averaged irradiances for 2011.

3 Data Calibration and Product Details

3.1 Calibration

Count data is converted to calibrated channel irradiances with the equation:

$$Irradiance[W/m^2] = ((Counts - B[counts]) \cdot G[A/count] - V[A])/C[A/(W/m^2]) \tag{1}$$

where for each channel, B is the background, G is the gain, V is the visible light contamination, and C is a units conversion factor. Calibration factors are given in the tables of Appendix A. The values for the G and V come from the GOES Data and Calibration Handbooks. The temperature-dependent background values, B, are really electronic offsets, and are determined from the measurements when the satellite is pointed away from the Sun. The conversion factors are determined from a convolution of the measured detector spectral responses with a quiet sun spectrum and change with solar activity level.

3.2 10-s Raw Data

The EUVS detectors accumulate counts for 10.24 s. The 10-s cadence data uses the SWPC data quality flags as defined in Table 3.

Table 3: Flags for 10-s data.

Flag	Definition
0	good data
-99999	bad or missing data
1048576	in-flight calibration (only 2009-2010)
2097152	off-pointed
3145728	off-pointed and in-flight calibrations
4194304	Sun is eclipsed by the Moon
8388608	Sun is eclipsed by the Earth
12582912	Sun is eclipsed by the Moon and the Earth
14680064	Sun has unknown eclipsed (Moon or Earth)

3.3 1-Min Data

The 1-min averaged data is created from averages of the raw 10-s count data excluding spikes, dropouts, and other bad data. The A channel counts are also (partially) cleaned of noise from the Solar X-ray Imager (SXI) heater as described in Appendix A.5. The averaged irradiances are created from the averaged counts with Eq. 1.

The flags for the 1 minute data are shown in Table 4. The 'partial eclipse flag' is set for data near eclipse periods to indicate that the counts are reduced by thermal effects. The number of minutes of partial eclipse flags set on either side of an eclipse depends empirically on the eclipse duration. Partial eclipse flags are set for 8 mins before and 5 mins after eclipse periods longer than 30 mins, and for 12 mins before and 10 mins after eclipse periods shorter than 30 mins.

Table 4: Flags for 1-min data

Flag	Definition
0	good data
1	possible bad data
2	partial eclipse
5	eclipse
8	off-pointed or in-flight calibrations
-999	bad or missing data

Each 10-s record with good data is averaged into the 1-min period in which its midpoint lies. Timestamps for 1-min data are in middle of the period. The raw data spacing is 10.24 s, and 97% of the 1-min averages contain 5 or 6 raw records while approximately 3% of the 1-min records have no data (flags 5, 8 or -999). The timestamps for the 1-min averaged Version 2 data (Channels A and B) are late by 11-12 s, as explained in A.4.

3.4 Daily Averages

The daily averages are based on averages of the 1 min data. There are only three flags options for the daily averages as shown in 5. Timestamps are the middle of the integrated period.

Table 5: Flags for daily averages

Flag	Definition
0	good data
1	possible bad data
2	partial eclipse
-999	bad or missing data

4 Acknowledgements

We thank Pamela Wyatt, Kim Baugh and Josh Riley for data management assistance.

5 References

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Warren, H.P. (2005), Astrophys. J. Suppl. Ser. 157, 147. https://doi.org/10.1086/427171

Appendix A Calibrations

A.1 Calibration Tables

The conversion from count rates into irradiances is made with Eq. 1 and using the calibration factors given in Tables 6 and 7. Flux conversion factors are provided for both solar minimum and solar maximum. The scale factors in the tables can be used to scale the irradiances of the GOES channels to match the bandpasses of other instruments.

Table 6: Calibration factors.

Satellite	Channel**	Background* [counts]	Gain* [A/counts]	Visible Light Contamination [A]	Bandpass [nm]
13	A	25198	1.91E-15	2.13E-14	2.8-20.6
13	B	15970	1.89E-15	1.21E-14	2.8-36.4
13	C	16229	1.90E-15	4.79E-14	—
13	D	24387	1.89E-15	1.20E-15	—
14	A	26571	1.92E-15	1.04E-14	2.8-19.0
14	B(A’)	23948	1.93E-15	7.18E-14	2.8-19.0
14	C(B)	14207	1.93E-15	2.96E-13	6.0-36.6
14	D(B’)	24856	1.95E-15	5.47E-15	6.0-36.6
15	A	49454	1.91E-15	1.78E-14	3.6-20.8
15	B	49797	1.90E-15	2.71E-14	3.6-38.5
15	C	55451	1.90E-15	2.03E-15	—
15	D	51218	1.90E-15	4.37E-14	—

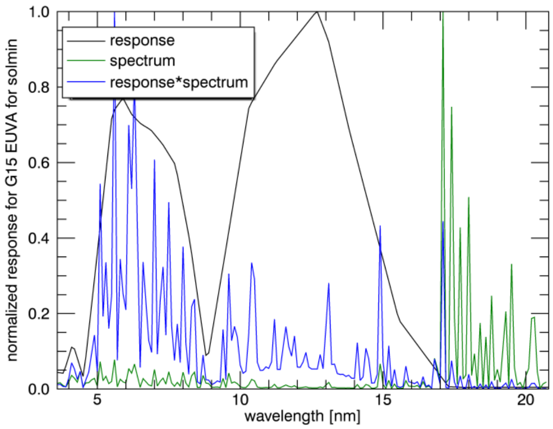
* Assumes a telescope temperature of 12C.
** GOES-13 and -15 Channel C and D values are included for future reference.

Table 7: Flux conversion factors (C) and instrument scale factors (f).

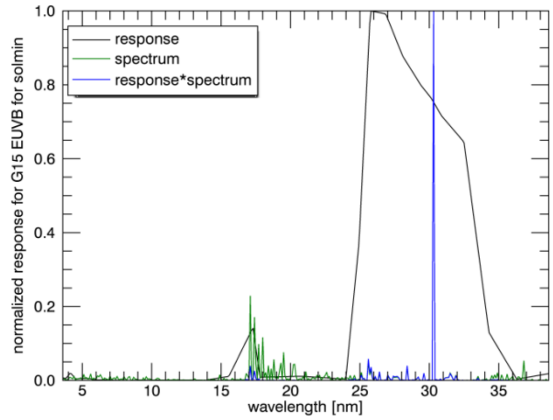
Satellite	Channel	Solar Activity	C [A/(W/m^2)]	f_{EVE} 5-15 nm	f_{EVE} 25-34 nm	f_{SOHO} 26-34 nm
13	A	minimum	8.918e-10	0.21	—	—
13	A	maximum	8.065e-10	0.19	—	—
13	B	minimum	6.615e-09	—	0.406	0.368
13	B	maximum	6.034e-09	—	0.381	0.335
14	A	minimum	8.718e-10	0.256	—	—
14	A	maximum	8.691e-10	0.248	—	—
14	A’	minimum	8.744e-10	0.256	—	—
14	A’	maximum	8.628e-10	0.248	—	—
14	B	minimum	4.841e-09	—	0.424	0.385
14	B	maximum	4.441e-09	—	0.406	0.357
15	A	minimum	1.100e-09	0.213	—	—
15	A	maximum	1.006e-09	0.193	—	—
15	B	minimum	3.786e-09	—	0.399	0.363
15	B	maximum	3.594e-09	—	0.379	0.333

A.2 Response curves

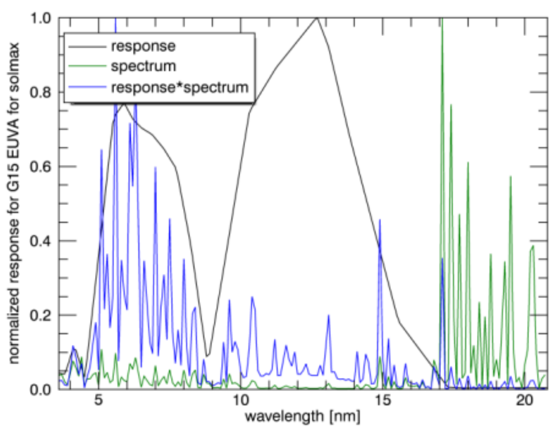
The Version 2 calibrations for the shorter wavelengths (channels A-D) used a quiet sun spectra, the NRLEUV 2 updated Model Quiet Sun Irradiance Spectrum (Warren, 2005), and a flare spectrum (Meier et al., 2002). Response curves for Channels A and B for GOES-15 are shown in Figure 6 along with reference spectra for a quiet sun during solar minimum and maximum. The responses for the different satellites are similar but not identical.



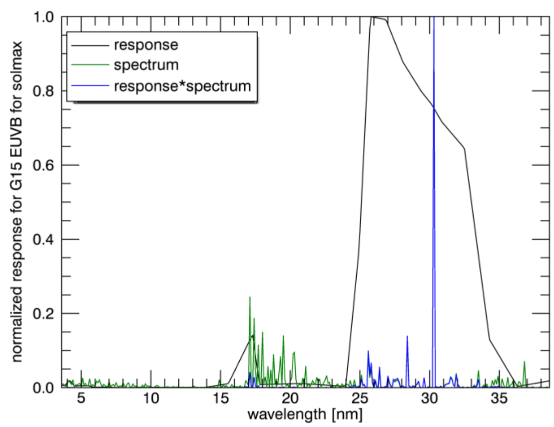
(a) Channel A, solar minimum.



(b) Channel B, solar minimum.



(c) Channel A, solar maximum.



(d) Channel B, solar maximum.

Figure 6: Comparison of the EVE MEGS-A 'GOES-A' band with the 5-15 nm subset of the EUVS-A Channel for GOES-13 through -15.

A.3 Calibration Method

The original calibrations were done by ATC with the EUV beam at Brookhaven National Laboratory; (they are in the Cal and Data Handbook which is not publicly available). The background values, B, do not vary much in time after the initial few months. We rederived these background values by looking at measurements from time periods when the instrument was pointing away from the sun. We also rederived the conversion values, C, since the ones in the Handbook are of poor quality; they were created with a flat spectrum and are given in the wrong units — [A/(W/m^2-nm)] instead of [A/(W/m^2)]. Previously, SWPC applied additional empirical correction factors in the conversion from counts to fluxes; these are no longer used.

More details such as impacts of solar activity, angle, particle backgrounds and limb effects could be considered. In the future, more correct comparisons should be done for regimes based on solar activity, at least a quiet regime and a flare regime. Assuming solar maximum instead of solar minimum conditions can result in a 10% increase in the irradiance. However, when the bandpasses are scaled to match other instruments, sometimes the variability in f almost exactly cancels the variability in C, and so the net ratio between the instrument measurements does not change significantly.

For GOES 13, which is misaligned to the sun, temperature and angular effects are known to be impacting the filter angle and require a more complicated correction [Viereck et al., 2007; Evans et al., 2010].

A.4 Timing

The EUVS channels accumulate counts for 10.24 s. As shown in Figure 7, for Channels A and B, the time stamps occur 1.024 s after the end of the accumulation, while for Channels C-E, the time stamps occur 2.048 s after the end of the accumulation. The integration periods for different channels are not concurrent.

For version 2 data (Channels A and B), the 1-min average timestamps are incorrectly offset by about 11 s. This error is because the 10-s timestamp offsets were incorrectly assumed to be at the start of the accumulations instead of 1-2 s beyond the ends.

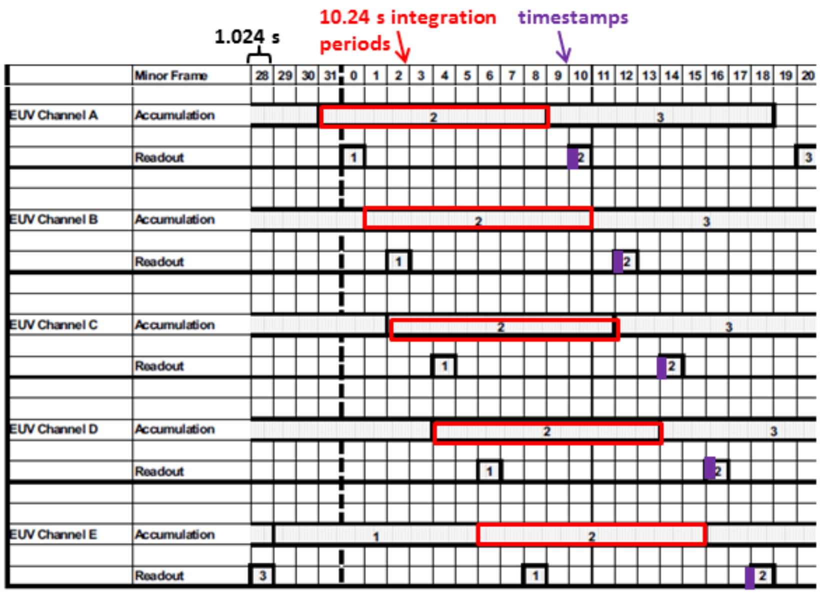


Figure 7: Sketch of EUVS instrument timing. Telemetry minor frames are 1.024 s. Integration is 10.24 s and timestamps occur 1.024 or 2.048 s after the end of the integration, depending on channel.

A.5 Channel A Temperature Correction

The GOES NOP EUV-A Channel data has noise spikes that are correlated with the Imager Mounting Platform (IMP) heater. The heater keeps the IMP at a stable temperature and has fixed set points that are not controllable from the ground. During the coldest parts of the GOES season (summer), the heaters cycle about every 10 – 50 minutes. During the warmest parts of the GOES season (winter) the heaters are sometimes not required at all and may stay off for weeks at a time.

A temperature gradient across two dissimilar metal components of the IMP may be producing very small currents that get into the EUV-A detector signal current. Thus, as the IMP is warmed by the heater, a reverse current combined with the detector current makes the EUV-A net signal go down. When the heater goes off, the plates cool, and the current goes the other way, thus increasing the signal from the detector. Only the EUV optical housing that is mounted closest to the IMP seems to experience this heater noise, and within that housing, only the A channel is noticeably affected. In some of the EUVS sensors, the heater noise can also be seen in the B channel (mounted in the same housing) but this noise is vastly reduced and is therefore not removed from the signal.

The heater noise is partially removed from the GOES EUV-A data by using the SXI PCM2 temperature sensor as a proxy for the heater with a routine developed by Rodney Viereck. The SXI PCM2 temperatures are sampled about every 30 s. To process these data, the noise spikes and outliers are removed from the count data and then a 7 point or 3.5 minute box-car smoothing is applied. The first derivative of the temperature is then calculated. This first derivative looks similar to the heater noise in the EUV-A signal and is scaled to fit the EUV-A signal. A small time shift of the SXI PCM2 data is required to maximize the fit of the SXI PCM2 data to the EUV-A data but this shift and the scaling remain constant throughout the mission. An example of the Channel A data with the heater noise and the heater noise correction is shown in Figure 8.

The smoothing and the time-shifting of the SXI PCM2 data make it impossible to calculate the correction in real-time; however, the delay introduced by this process is less than 5 minutes. For GOES-15, the impact of the heater noise has not changed since launch. Heater noise corrections were done for GOES 13 and 15 only, because on GOES-14, there is SXI heater data only for 2009. On GOES 14, the A channel is expected to be much more impacted than the A' channel by temperature effects.

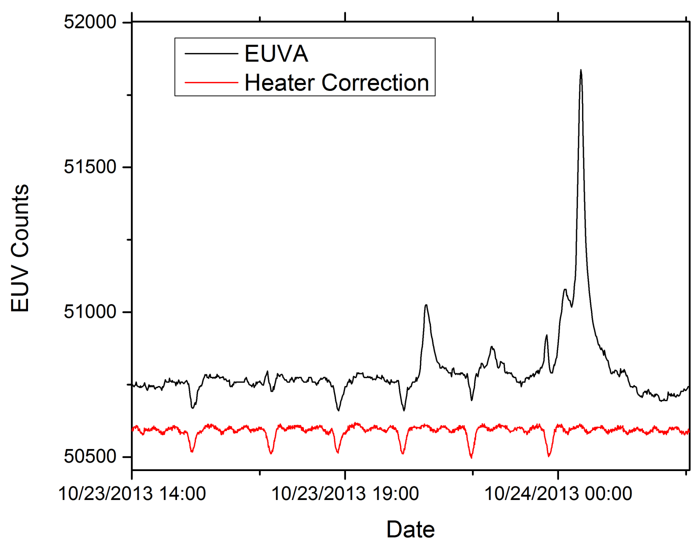
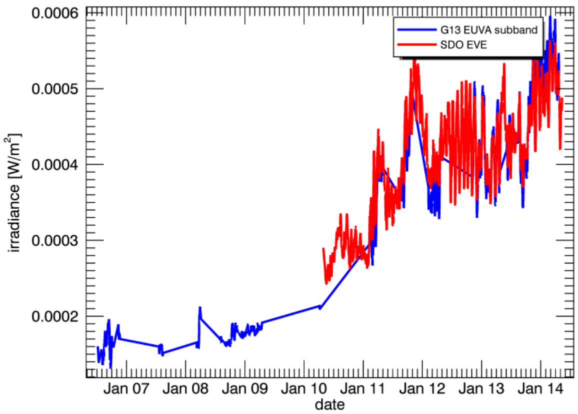


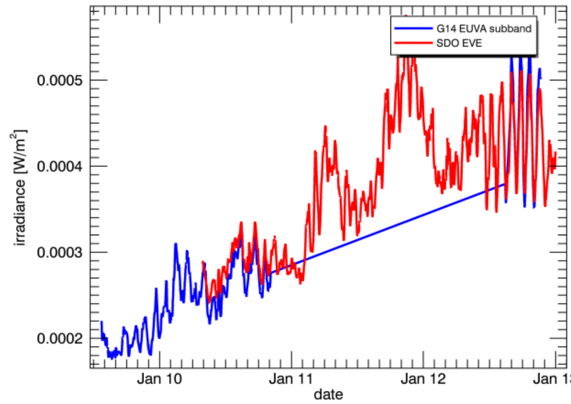
Figure 8: Channel A raw counts (black) showing heater noise and corrected counts (red) for a correction based on SXI heater current.

Appendix B Validation with Other Satellites

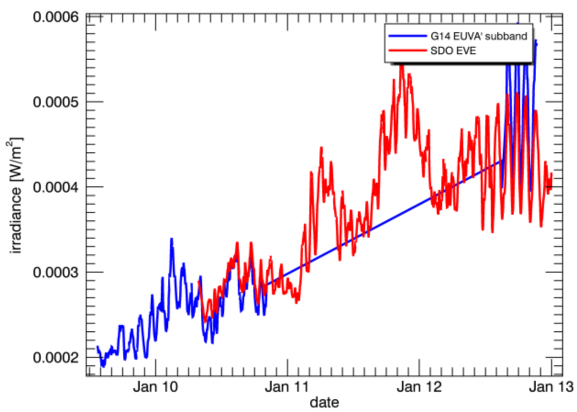
To validate the GOES EUVS irradiances, we compared them with irradiances from other satellite EUV instruments. We estimated the fraction of the GOES channel irradiance that would fall in the other instrument bandpass as described in Appendix B.2. For these comparisons, the GOES data was adjusted to 1 AU. Major sources of discrepancies between data sets are calibration errors, incomplete correction for differing bandpasses, and the use in the GOES calibrations of solar minimum reference factors instead of factors that vary with solar activity. A source of error for the SOHO SEM irradiances is that this 26-34 nm band includes 17-nm scatter which sometimes results in a double-humped peak for each solar rotation since it is has an angular factor (Andrew Jones, personal communication).



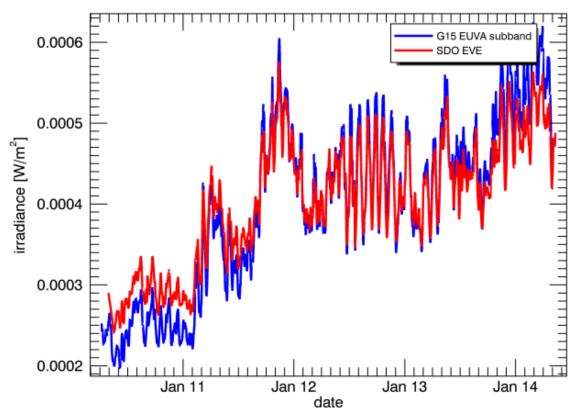
(a) GOES-13.



(b) GOES-14



(c) GOES-14 (EUVS-A').

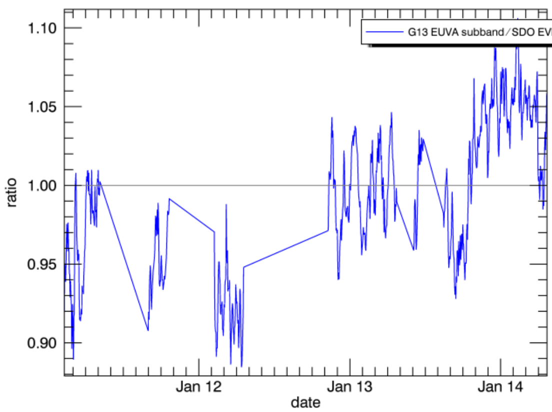


(d) GOES-15.

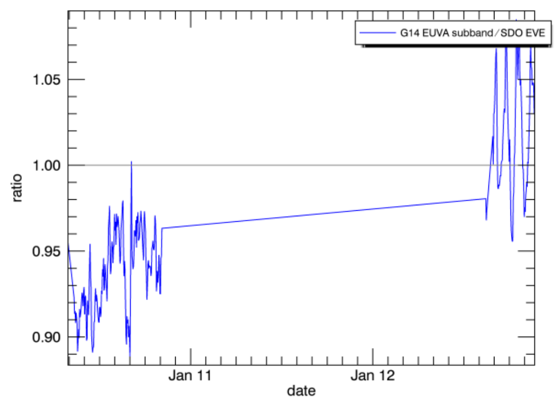
Figure 9: Comparison of scaled EUVS-A and -A' irradiances to the EVE 'GOES-A' band irradiances for a 5-15 nm bandpass.

B.1 Comparisons with SDO EVE and SOHO SEM

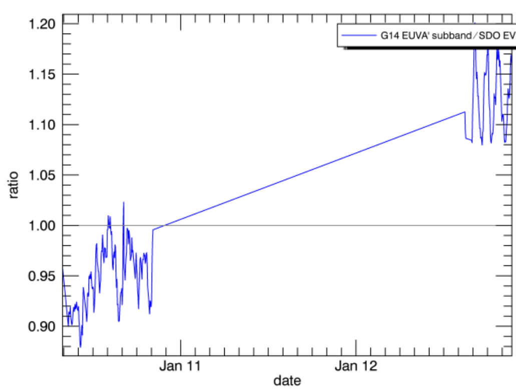
This section shows time series irradiance comparisons with the following calibrated data sets: SDO EVE, version 4; and SOHO SEM, version 3. Figure 9 shows EUVS-A and -A' irradiances scaled to 5-15 nm bandpasses compared with EVE 'GOES-A' band (derived from MEGS A for the 5 to 15 nm band). Figure 11 shows EUVS-B and -B' scaled irradiances compared with EVE MEGS-A 'GOES-B' band (for a 25-34 nm band) and Figure 12 shows them compared with the SOHO SEM (for a 26-34 nm band). Figures 10 and 10 show the associated band ratios.



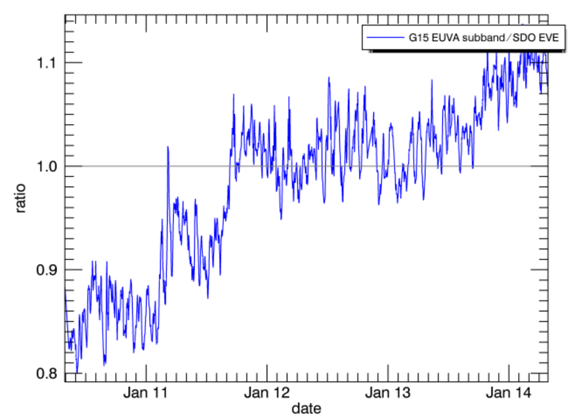
(a) GOES-13.



(b) GOES-14

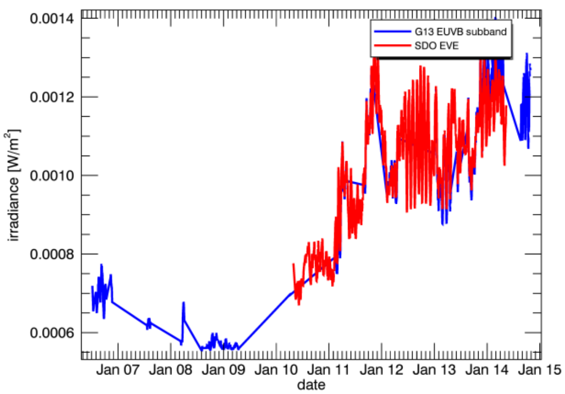


(c) GOES-14 (EUVS-A').

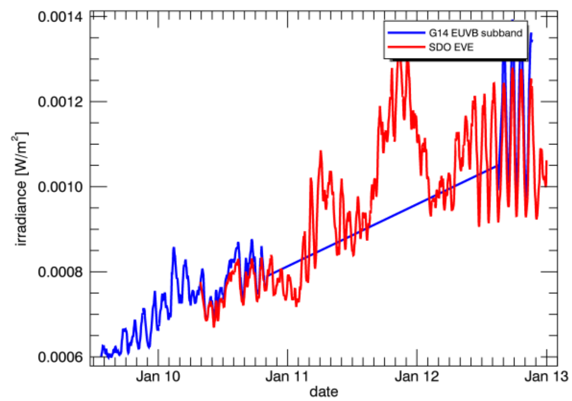


(d) GOES-15.

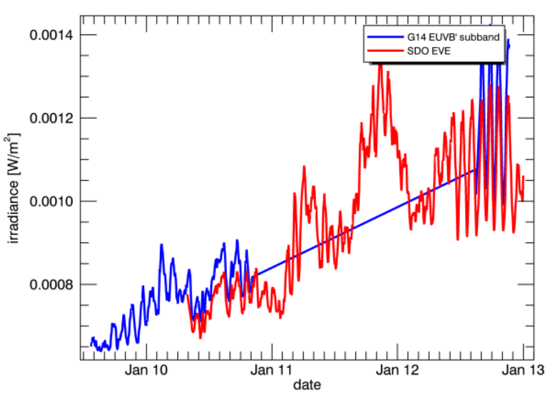
Figure 10: Ratios of EUVS-A and -A' irradiances with EVE irradiances from Figure 9.



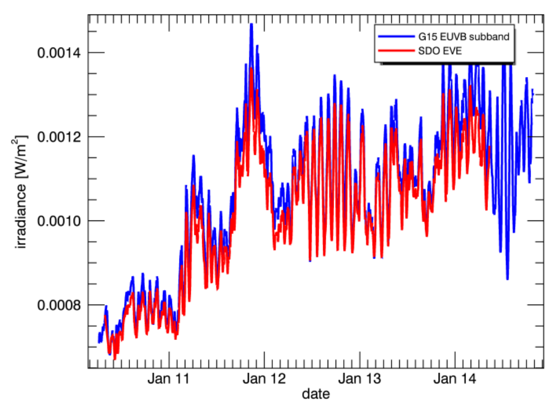
(a) GOES-13.



(b) GOES-14.

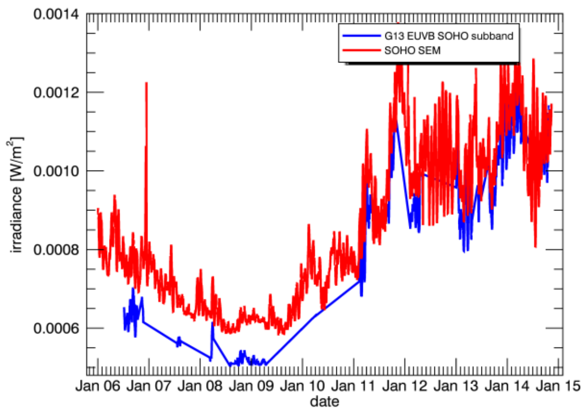


(c) GOES-14 (EUVS-B').

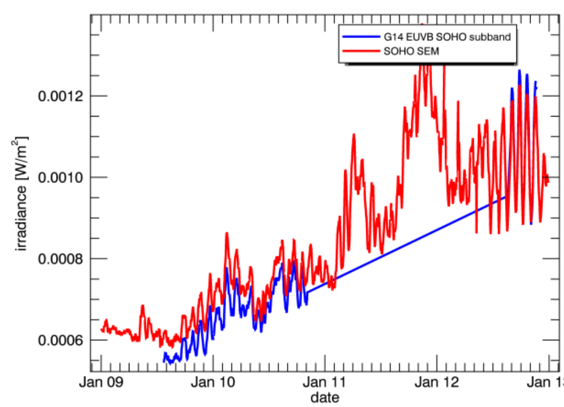


(d) GOES-15.

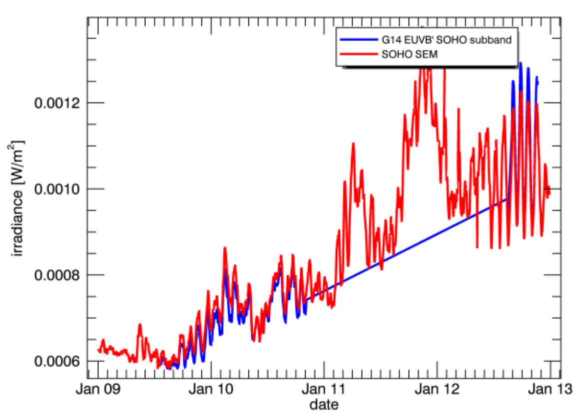
Figure 11: Comparison of scaled EUVS-B and -B' irradiances to the EVE 'GOES-B' band irradiances (25-34 nm).



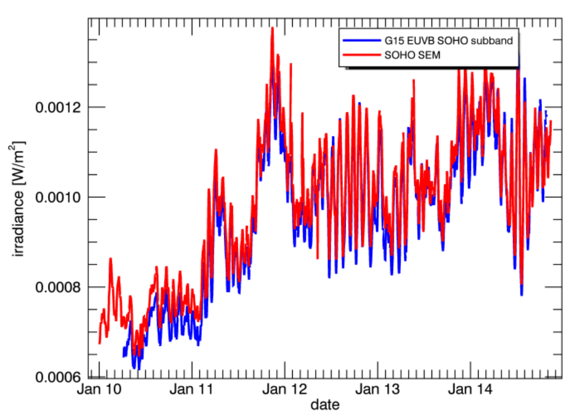
(a) GOES-13.



(b) GOES-14.

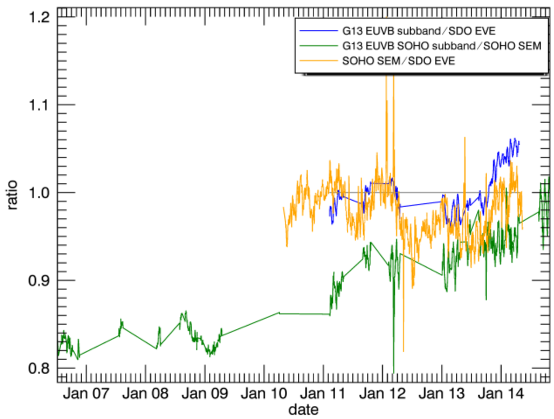


(c) GOES-14 (EUVS-B').

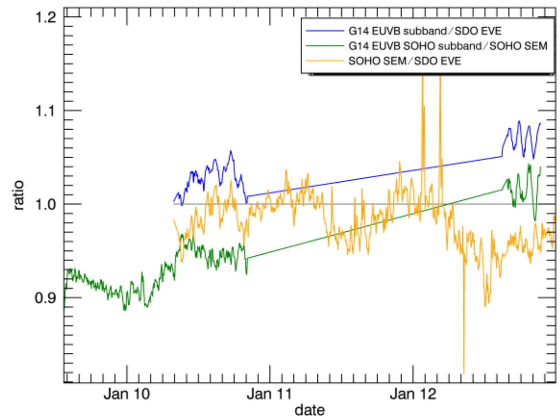


(d) GOES-15.

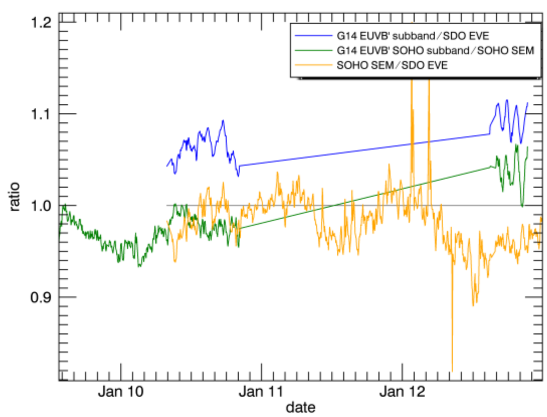
Figure 12: Comparison of scaled EUVS-B and -B' irradiances to the SOHO SEM band (26-34 nm).



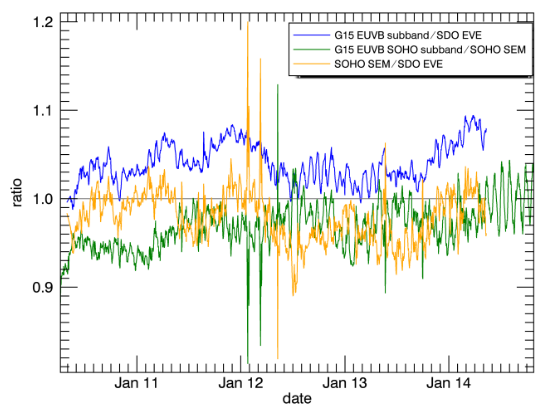
(a) GOES-13.



(b) GOES-14.



(c) GOES-14 (EUVS-B').



(d) GOES-15.

Figure 13: Ratios between GOES EUVS-B, SDO EVE, and SOHO SEM irradiances shown in Figures 11 and 12

B.2 Scaling to Other Bandpasses

After applying a 1 AU correction to irradiances, the irradiance data was compared with daily values from other instruments to test the calibrations as shown in Section B.1. The equations to convert from between the different bandpasses are given in this section.

The units conversion between irradiance (J_i) in photon units, $J_i[\gamma \ cm^{-2} s^{-1} \ d\lambda^{-1}]$ to $J_i[Wm^{-2} \ d\lambda^{-1}]$ is useful. Here γ is a photon, and dλ is the wavelength step size in units of nm.

The conversion factor is the energy per photon:

$$E/\gamma = \frac{hc}{\lambda[nm] \cdot \gamma} \cdot \frac{10^{-9}m}{nm} \tag{2}$$

$$= \frac{(6.626x10^{-27}erg \cdot s)(3 \cdot 10^{8} \ m/s)}{\lambda[nm] \cdot \gamma} \cdot \frac{10^{9}nm}{m} \cdot \frac{1W}{10^{7}erg/s} \cdot \frac{10^{4}cm^{2}}{m^{2}} \tag{3}$$

$$= \frac{1.988x10^{-12}(cm^{2} \ s \ nm)(Wm^{-2})}{\lambda[\mathrm{nm}] \cdot \gamma} \tag{4}$$

where h is Planck's constant, c is the speed of sound, and λ is the wavelength.

For a quiet sun approximation, the total irradiance over a band is given by

$$J_{total\_quiet}[Wm^{-2}] = \sum_{i} J_i[Wm^{-2}d\lambda^{-1}] \tag{5}$$

The current for the quiet time is given by

$$I_{total\_quiet}[A]] = \sum_{i} R_i[A \ m^{2} \ W^{-1}] \cdot J_i[Wm^{-2}d\lambda^{-1}] \tag{6}$$

During a quiet time, if the measured current is I_{meas}, then the total flux in the band is

$$J_{total\_meas} = \frac{J_{total\_quiet}}{I_{total\_quiet}} \cdot I_{meas} \tag{7}$$

To compare with another instrument on a different type of satellite, the total flux can be scaled by the fraction of the flux that is in the bandpass of the other instrument. The fraction of irradiance in energy units in some band subset, where i is in the subset, is estimated as

$$f_{subset} = \sum_{i} \frac{J_i[Wm^{-2}d\lambda^{-1}]}{J_{total\_quiet}[Wm^{-2}]} \tag{8}$$

Appendix C GOES EUVS Hardware

The EUVS on GOES-13-15 were all very similar. The five channels of the EUV were measured via three spectrograph units (benches) with east-west dispersion. The units varied in the grating spacing. For GOES 13 and 15, the first unit measured Channels A and B and the second unit measures Channels C and D. For all three GOES satellites, Channel E was measured on the third spectrograph. The nominal bandpasses for the channels were: A: 5-15 nm, B: 25-34 nm, C: 17-67 nm, D: 17-84 nm, and E: 118-127 nm. Sample rates were once every 32.768 s. The overall instruments were made by ATC. Table 8 shows some details of the spectrograph elements.

For GOES 14, the C and D channels did redundant measurements at the usual A and B wavelengths and are referred to as Channels A' and B', The A' and B' detectors were arranged in opposite order as A and B so that they had opposite impacts of angular effects from sources near the solar limb. The intent for GOES-14 was that each pair of channels can be averaged to produce an irradiance with reduced error due to angular effects. Another difference for GOES 14, is that for this EUVS, Channels B, B' and E were nitrided to try to reduce degradation.

Table 8: Hardware components for GOES 13-15 EUVS.

Component	Manufacturer	Details
EUVS	ATC	
detectors	IRD	AXUV photodiode
gratings	MIT	A,B: 5000 lines/mm C,D: 2500 lines/mm E: 1667 lines/mm
thin filters on detectors	Lebow	A: 50/200/70 nm of Ti/Mo/C B: 150/5 nm of Al/Al2O3 C: 150/2 nm of Al/Al2O3 D: 150/2 nm of Al/Al2O3
Lyman-α filter	Acton Labs	free standing

Several design features and manufacturing techniques were incorporated to minimize the impact of contamination (Viereck et al., 2007). The first optical component is the transmission grating. The buildup of contaminants from outside the sensor will occur primarily on the grating bars which will have minimal impact on the transmission properties. The grating can accumulate molecular contaminants to a thickness of tens of nanometers before experiencing a noticeable change in transmission whereas an optical component such as a filter or window will exhibit a significant decrease in performance (depending on the material) for more than about 0.5 nm of contaminants. To minimize the contaminants on internal optical surfaces, the EUVS was manufactured in a clean environment. The few electronic components and wires required to control and read the silicon diodes are at the back of the optical housing and are kept extremely clean. The entire package was stored with a dry nitrogen purge or in a vacuum during most of its testing and prelaunch storage activities. Zeolite absorbers inside the optical housing are designed to capture any residual contaminants that remain inside the optical housing after launch.