# Readme for Science-Quality GOES 13-15 Lyman alpha (EUVS Channel E) Irradiance Data

Janet Machol[1,2], Allyssa Riley, Rodney Viereck[1,3], and Andrew Jones[4]

[1]Cooperative Institute for Research in Environmental Sciences, U. of Colorado Boulder
[2]NOAA National Centers for Environmental Information
[3]NOAA Space Weather Prediction Center
[4]Laboratory for Atmospheric and Space Physics, U. of Colorado Boulder

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Table 1: Document Versions

| Date | Change Description |
|---|---|
| 15 Dec 2023 | Revised Fig. 2. |
| 20 Sep 2023 | Separated Channel E/Lyman alpha information to separate Readme. |
| | Added Version 5 information. |
| | Reformatted documents in latex. |
| 30 Sep 2016 | Added references. |
| 30 Sep 2015 | Fixed equation in Figure 13 caption. |
| 12 Aug 2015 | Corrected Equation 2. |
| 4 Mar 2015 | 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. Channel A measured wavelengths near 15 nm, Channel B measured the 30.4-nm He II solar line, and Channel E measured the solar Lyman alpha line at 121.6 nm. GOES-14 is unique in that it measured duplicate A and B bands (with A' and B' channels) instead of C and D bands. The raw data was in counts with a 10.24 second sample rate and a requirement of $<15\%$ uncertainty.

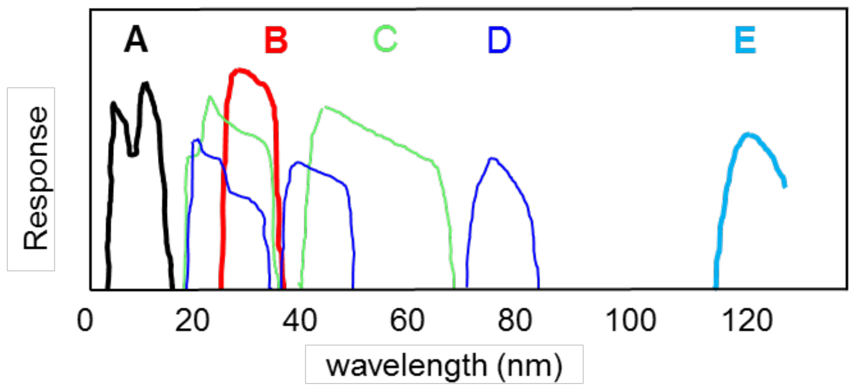



Figure 1: The wavelength responses of Channels A-E for GOES EUVS.

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 and B bands until 2014 (Version 2), and the E band through March 2020.

Figure 2 shows measurement time periods for the three GOES satellites. The latest data versions for Lyman alpha irradiances are Version 5 for GOES-14 and -15, and Version 4 for GOES-13 (through early 2016). He II (30.4 nm) data is available into 2014 as Version 2 data. In 2024, a new version of the data will be provided publicly for the full time range that will include He II data for all three satellites as well as GOES-13 Lyman alpha. GOES-15 measurements occurred from 2010 until March 2020, GOES-14 measurements occurred primarily from 2018 through 2020, and GOES-13 data measurements occurred sporadically from 2006 through 2018.

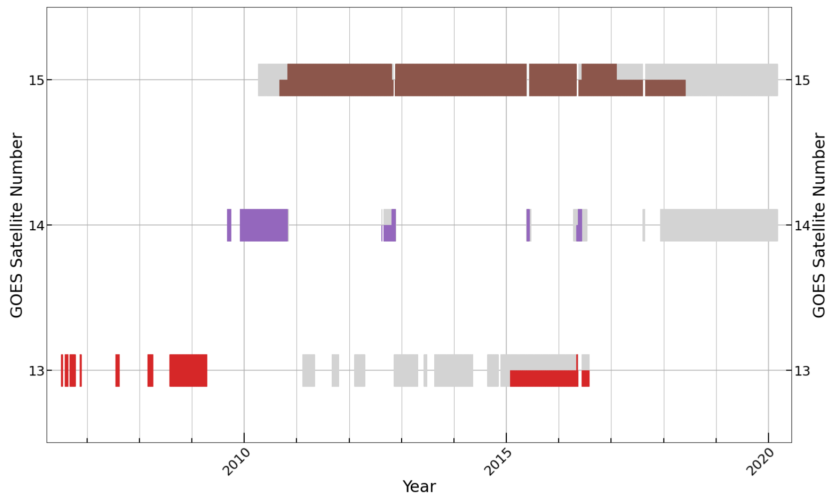



Figure 2: EUVS measurements for GOES-13 through -15. Coloring indicates primary (full-thickness lines) and secondary (half-thickness lines) satellites.

This Readme gives details of the EUVS Channel E science-quality data for GOES 13-15. Users of the GOES data are responsible for inspecting the data and understanding the known caveats prior to use. A separate Readme about the EUVS Channels A and B science-quality data, is provided at `https://www.ngdc.noaa.gov/stp/satellite/goes/doc/GOES_13-15_EUVS_ChansAB_Science-Quality_Data_Readme.pdf`. 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 pamela.wyatt@noaa.gov for questions about data access.

# 2 Data 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 to the present date 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.

Count data was 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 and were measured pre-flight by ATC with the EUV beam at Brookhaven National Laboratory. 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, $C$, were rederived from a convolution of the measured detector spectral responses with a quiet sun spectrum. (The original conversion factors 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.

An additional scale factor is applied to the irradiance from Equation 1 that simultaneously scales the bandpass of the EUVS-E broadband channel to a 1-nm band around the Lyman $\alpha$ line and accounts for the significant degradation that occurs at these wavelengths. This is done in a single step by fitting the daily averaged data to match that of Lyman $\alpha$ 1-nm irradiances measured by SORCE SOLSTICE (McClintock et al., 2005). This process provides corrected 1-minute Lyman $\alpha$ irradiances with a residual from this scaling of a few percent or less.

## 2.2 GOES-14 and -15 Science-Quality Data (Version 5)

For GOES-14 and -15, the latest science-quality data is Version 5 and has been reprocessed for the full mission periods from March 2009 through March 2020. Version 5 data does not yet exist for GOES-13. Figure 3 shows GOES-14 and -15 Version 5 daily Lyman $\alpha$ irradiances. An example of an annual plot is shown in Figure 4.

The Version 5 data is available as netcdf files with formats that match those of the later GOES-R series data. Available products include 10-s irradiances, 1-minute and daily averaged irradiances, and plots. There are daily and mission aggregations for the 1-minute averaged data. Links to the Version 5 science-quality data, plots, responsivity data, and associated documentation is available from the GOES 1-15 tab at `https://www.ngdc.noaa.gov/stp/satellite/goes-r.html`.

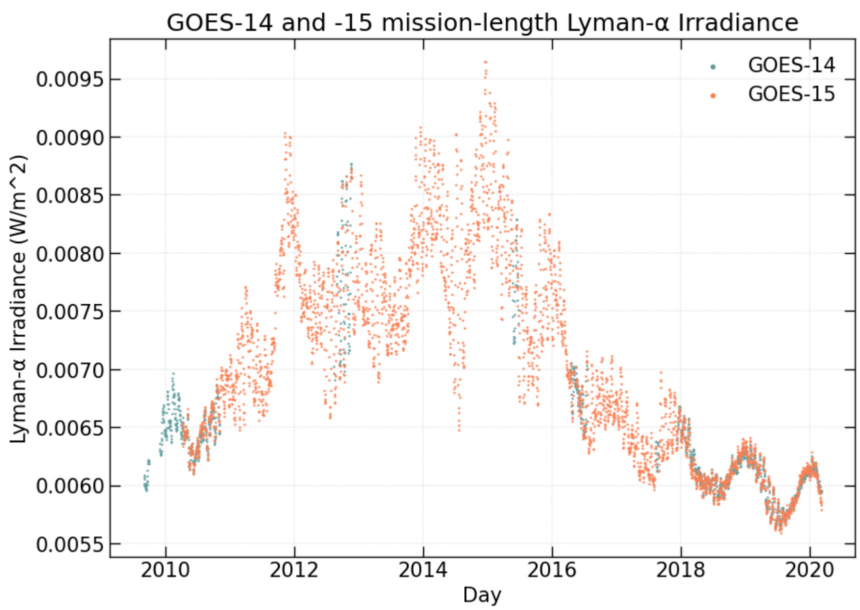



Figure 3: Mission-length comparison between Version 5 GOES-14, and -15 Lyman $\alpha$ irradiances.

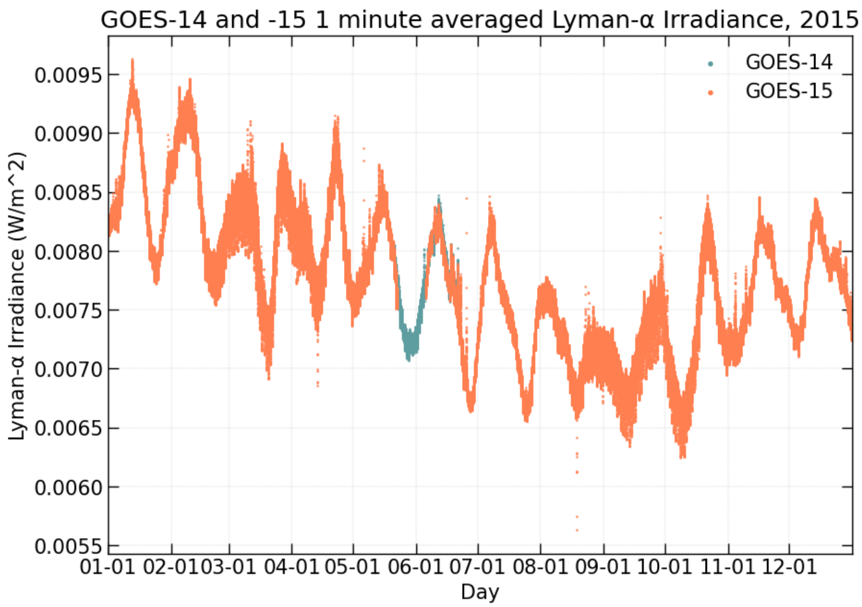



Figure 4: 1-min and daily averaged Lyman $\alpha$ irradiances for 2015 for GOES-14 and -15.

### 2.3 GOES-13 Science-Quality Data (Version 4)

Version 4 science-quality data exists for all three satellites that carried the first EUVS and covers 2006 through 2016. Figure 5 shows the Lyman $\alpha$ irradiances for the Version 4 data for GOES -13 through -15.

Version 4 data is probably mostly useful for GOES-13, for which Version 5 data does not exist; there are plans to create Version 5 data for GOES-13 EUVS-B. The GOES-13 instrument was run sporadically during its mission. Data products include ASCII files with 1-minute and daily cadence data and netcdf files with 1-minute cadence data. There are annual and mission length data files and annual plots. An example of an annual plot is shown in 6. The Version 4 products for GOES-13 through -15 are available at `https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/euvs/`.

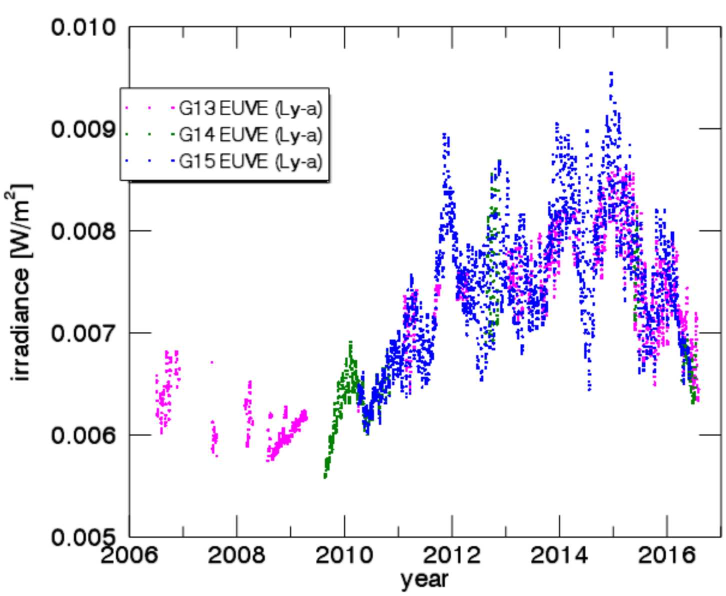



Figure 5: Version 4 Lyman $\alpha$ irradiances for GOES-13, -14 and -15.

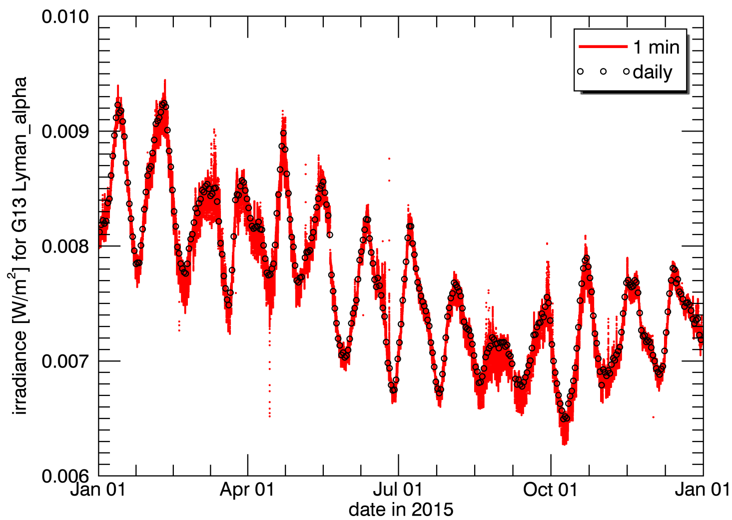



Figure 6: GOES-13 Channel E 1-min and daily averaged irradiances for 2015.

# 3 Version 5 Data Products

## 3.1 Data Overview

For Version 5, the NCEI archive provides raw (10.24 s) counts irradiances and flags. Thre are also files with 1-minute and daily averaged irradiances and flags. Table 2 lists the main types of available data files. There are yearly and mission length aggregations. Count and irradiance values are given for the satellite location, i.e., not adjusted to 1 AU. The files provide two irradiance values: one for the full band and not degradation corrected, and one for the 1-nm band from 121-122 nm which is degradation corrected. The netcdf data format for the averaged data is almost identical to that used for the GOES-R satellite series as described in the GOES-R Level 2 EUVS Data Users Guide ( `https://data.ngdc.noaa.gov/platforms/solar-space-observing-satellites/goes/goes16/l2/docs/GOES-R_EUVS_L2_Data_Users_Guide.pdf`).

All files contain a factor to adjust the irradiances to 1 AU. Ephemeris data for the GOES satellites is available separately. The files have space for variables for EUVS Channel B (30.4 nm) measurements, but these are currently all fill values.

Table 2: Version 5 science-quality files for Channel E.

| File Type | Cadence | Description |
|---|---|---|
| ir10s | 10 sec | counts, irradiances, and flags |
| avg1m | 1 min | irradiances and flags |
| avg1d | daily | irradiances, and flags |
| responsivity* | — | detector response functions |
| ephemeris** | 1 min | satellite location |

* `https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/euvs/responsivity/`.
** `https://www.ncei.noaa.gov/data/goes-space-environment-monitor/access/sat_locations/`.

# 4 Version 4 Data Products

## 4.1 Data Overview

For Version 4, the NCEI archive provides 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 3 lists the main types of available data files. There are yearly and mission length aggregations. Count and irradiance values are at the satellite location, i.e., not adjusted to 1 AU. The files provide two irradiance values: one for the full band and not degradation corrected, and one for the 1-nm band from 121-122 nm which is degradation corrected.

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 irradiance files contain a column with 1 AU correction factors. Ephemeris data for the GOES satellites is also available.

Table 3: Version 4 science-quality files for Channel E.

| File Type | Cadence | Description | Subdirectory* |
|---|---|---|---|
| *1 min* | 1 min | counts, irradiances, and flags | GOES_V4 |
| *1 min* | 1 min | counts, irradiances, and flags (netcdf) | GOES_V4_netcdf |
| _daily | daily | counts, irradiances, and flags | GOES_V4 |
| _Cnts | 10.24 s | raw counts | raw_10s |
| _Flags | 10.24 s | flags | raw_10s |
| *plots* | 1 min, daily | annual irradiance plots | plots_V4 |
| *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/`.

## 4.2 10-s Raw Data

The EUVS detectors accumulate counts for 10.24 s. The 10-s cadence raw data uses the SWPC data quality flags as defined in Table 4. The time stamps occur 2.048 s after the end of the accumulation as explained in Appendix A.6.

Table 4: 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) |

## 4.3 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 SWPC flags are revised int the processing so that there are flags before 2010 and better coverage for the later dates. The averaged irradiances are created from the averaged counts with Eq. 1. The timestamps for the Version 4 data have been corrected based on the timing explained in A.6.

The flags for the 1 minute data are shown in Table 5. 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 5: Flags for 1-min data

| Flag | Definition |
|---:|---|
| 0 | good 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).

### 4.4 Daily Averages

The daily averages are based on averages of the 1 min data and geocoronal absorption periods. The geocoronal periods, defined to be times within $\pm 4$ h of local midnight have dips near midnight due to geocoronal hydrogen absorption. The dips range from about 0.3 to 6% and are largest around the equinoxes. Excluding the dips results in about a 1% change in the daily averages and by default results in also excluding eclipses. There are only two flags options for the daily averages as shown in Table 6. Timestamps are the middle of the integrated period.

Table 6: Flags for daily averages

| Flag | Definition |
|---:|---|
| 0 | good data |
| -999 | bad or missing data |

## 5 Acknowledgements

We thank Kim Baugh, Pamela Wyatt and Josh Riley for data management assistance. The LASP WHI spectrum was obtained from `https://lasp.colorado.edu/lisird/data/whi_ref_spectra`.

## 6 References

Evans, J.S., Strickland, D.J., Woo, W.K., and D. R. McMullin, S. P. Plunkett, R. A. Viereck, S. M. Hill, T. N. Woods, F. G. Eparvier (2010), Sol Phys 262: 71. https://doi.org/10.1007/s11207-009-9491-x

McClintock, William E., M. Snow and T. N. Woods, (2005), Solar Phys. 230. https://doi.org/10.1007/s11207-005-1585-5

Viereck, R., F. Hanser, J. Wise, S. Guha, A. Jones, D. McMullin, S. Plunket, D. Strickland, S. Evans (2007), "Solar extreme ultraviolet irradiance observations from GOES: design characteristics and initial performance", Proc. SPIE 6689, Solar Physics and Space Weather Instrumentation II, 66890K. https://doi.org/10.1117/12.734886

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

Woods, T. N., P. C. Chamberlin, J. W. Harder, R. Hock, M. Snow, F. G. Eparvier, J. Fontenla, W. E. McClintock, and E. C. Richard (2009), Solar Irradiance Reference Spectra (SIRS) for the 2008 Whole Heliosphere Interval (WHI), Geophys. Res. Lett., 36. https://doi.org/10.1029/2008GL036373

# 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 7 and 8. 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 7: Channel E calibration factors.

| Satellite | Background* [counts] | Gain* [A/counts] | Visible Light Contamination [A] | Bandpass [nm] |
|---|---|---|---|---|
| 13 | 25096 | 1.90E-15 | 1.32E-12 | 113.5-132.8 |
| 14 | 25188 | 1.94E-15 | 2.49E-12 | 113.7-135.9 |
| 15 | 40947 | 1.90E-15 | 2.23E-12 | 116.3-132.4 |

* Assumes a telescope temperature of 12C.

Table 8: Channel E flux conversion factors ($C$) and measurement band to solar line scale factors ($f$) at solar minimum.

| Satellite | $C$ [A/(W/m$^2$)] | $f_{Lyman\_\alpha}$ 121.0 - 121.9 nm |
|---|---|---|
| 13 | 2.612E-09 | 0.884 |
| 14 | 2.630E-09 | 0.855 |
| 15 | 2.612E-09 | 0.884 |

## A.2 Response Curve

The EUVS-E responsivity, the LASP WHI quiet sun solar spectrum, and the convolved detector response for GOES-15 is shown in Figure 7. The responses for the different satellites are similar but not identical.

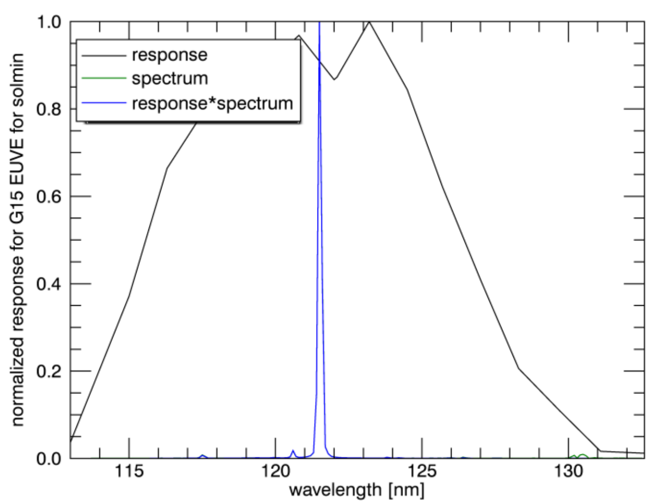



Figure 7: The EUVS-E responsivity, the LASP WHI quiet sun solar spectrum, and the convolved detector response for GOES-15.

## A.3 Degradation and Background Calibration (Version 5)

The channel E data is scaled to the daily SORCE SOLSTICE Lyman $\alpha$ values with a piece-wise linear function for GOES-14 (Figure 8) and a piece-wise exponential-plus-linear function for GOES-15 (Figure 9) that simultaneously corrects for degradation and the absolute value. The residual from this scaling is a few percent or less, and so this provides corrected 1 minute Lyman $\alpha$ data which is based on daily Lyman $\alpha$ from SOLSTICE.

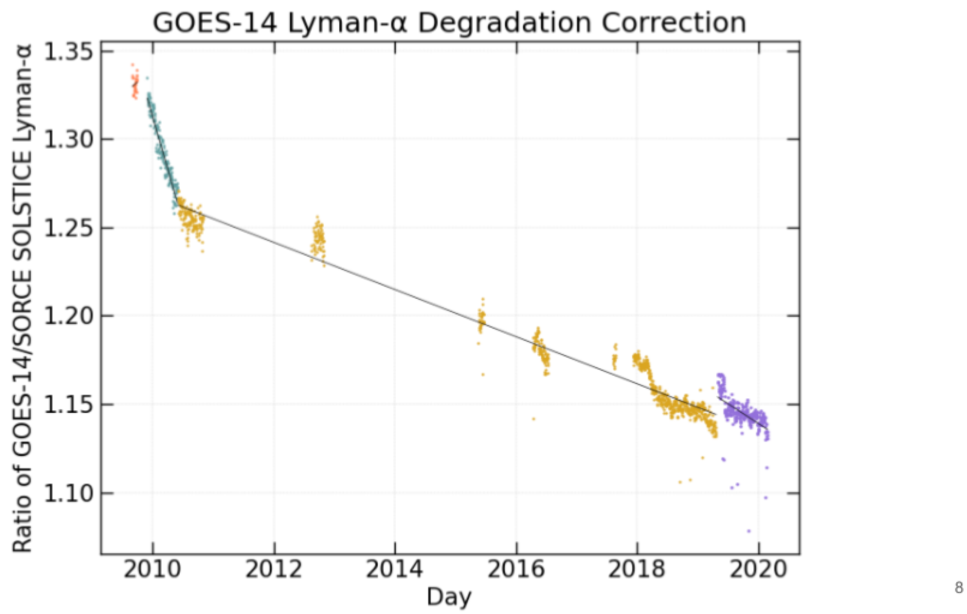



Figure 8: Piecewise degradation correction function for GOES-14.

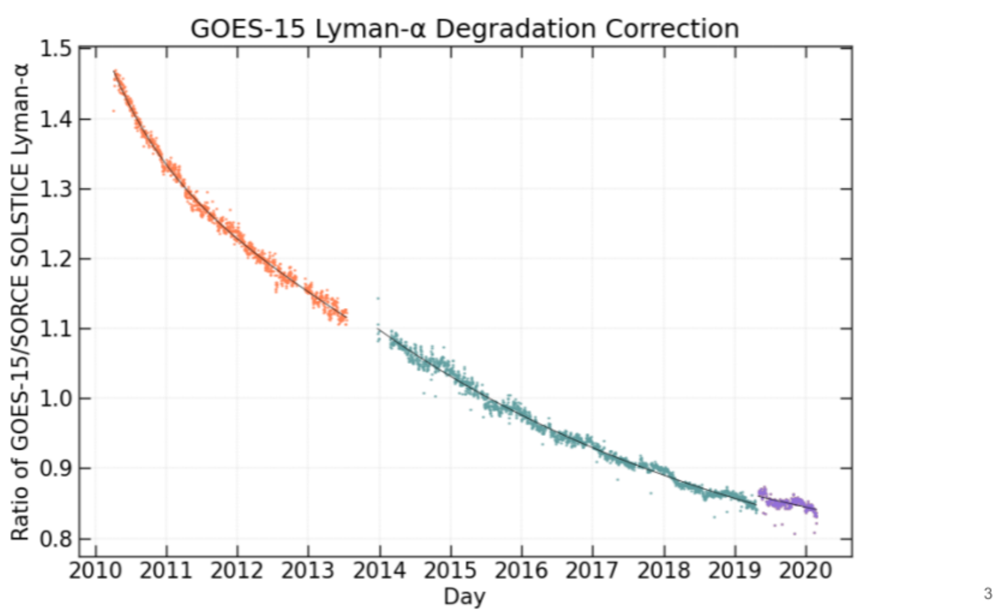



Figure 9: Piecewise degradation correction function for GOES-15.

The degradation equation is

$$y(\Delta t) = A \cdot exp(B \cdot \Delta t) + C \cdot \Delta t + D \tag{2}$$

where $\Delta t = t - t_0$ is the number of days since start-of-fit day, $t0$. The dates for $t0$ are 2009-09-01 for GOES-14 and 2010-03-25 for GOES-15. The coefficients for the degradation functions are in 9.

Table 9: Coefficients for Version 5 degradation (Equation 2)

| Satellite | Dates | A | B | C | D |
|---|---|---|---|---|---|
| 14 | $<$ 2009-11-01 | 0 | 0 | 7.97e-5 | 1.33 |
| 14 | 2009-11-01 $\leq$ t $<$ 2010-06-01 | 0 | 0 | -3.26e-4 | 1.35 |
| 14 | $>$ 2010-06-01 | 0 | 0 | -3.66e-5 | 1.27 |
| 15 | $<$ 2013-12-01 | 0.16 | -3.23e-3 | -1.72e-4 | 1.32 |
| 15 | $\geq$ 2013-12-01 | 0.72 | -5.29e-4 | -1.34e-5 | 7.67 |

The background functions for GOES-14 and -15 were found by calculating the irradiance when the satellite points away from the Sun, time periods known as “off-points”. We smoothed the data and fit a function (not shown) to the smoothed points to determine the background correction.

## A.4 Degradation and Background Calibration (Version 4)

### A.4.1 Degradation Parameters

For Version 4, the Lyman alpha degradation function was defined as

$$y(t) = A_0 \cdot exp[A_1 \cdot (t - t_0)] + A2 \cdot (t - t_0) + A_3 \tag{3}$$

for time, $t$, in units of Julian Day. The 1-minute and daily Lyman $\alpha$ data from Channel E is corrected for degradation and scaled to SOLSTICE by dividing by this function. The fit for GOES-14 starts on 1 Dec 2009 and excludes the data in 2012. Coefficients for Equation 3 are given in Table 10. The amount of degradation for Channel E as a function of year is given in Table 11.

Table 10: Coefficients for the Version 4 degradation fit (Equation 3)

| Satellite | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $t_0$ [Julian Day] |
|---|---|---|---|---|---|
| 13* | -10.506987 | -6.5582174e-5 | -0.00068685569 | 11.635565 | 2453857 |
| 14 | 0.20419478 | -0.0070176921 | -2.7219186e-5 | 1.0905254 | 2454984 |
| 15 | 0.20327572 | -0.0016817982 | -0.00011181107 | 1.1090724 | 2455257 |

* We do not recommend using the GOES-13 Channel E data until the corrections are improved.

Table 11: Degradation rates as a function of years since launch

| Satellite | after: 1 year | 2 years | 5 years | 10 years |
|---|---|---|---|---|
| 13 | 1% | 1% | 6% | 23% |
| 14 | 15% | 17% | 20% | 23% |
| 15 | 10% | 17% | 30% | 46% |

### A.4.2 Background Equation

For Version 4 for Channel E, the background counts are determined as a function of the Imager Mounting Platform (IMP) temperature which is usually in the range of 4-6 °C.

$$Background(T) = (A + B \cdot T + C \cdot T^2) \cdot D \tag{4}$$

The coefficients (Table 12) for this function were found by comparing the background to the temperature when the satellite points away from the sun, time periods known as 'offpoints'. For this calibration, the IMP temperature measurement was chosen instead of the SXI temperature measurement, because it has better resolution, although it is physically further away from the instrument.

The temperature-dependent background resolved about half of the discrepancies with respect to SORCE SOLSTICE for GOES 15. For GOES 14, there are temperature variations up to 20 C in 2012 and a linear function was inadequate. Since the offpoint background measurements only cover a small temperature range, the background counts quadratic function from the Data Handbook was scaled to the measured background at 4.3 °C, although this still did not adequately correct the data in 2012.

Table 12: Coefficients for background count function (Equation 4)

| Satellite | A | B | C | D |
|---|---|---|---|---|
| 13 | 25326.335 | -41.787008 | 0 | 1 |
| 14 | 40348.1 | 37.4596 | 1.62123 | 0.621658 |
| 15 | 40638.198 | 77.106458 | 0 | 1 |

## A.5 Scaling to Other Bandpasses

The equations to convert between the different bandpasses as in Table 8 are given below. This method does not consider spectral changes due to solar activity.

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 $\gamma$ is a photon, and d$\lambda$ is the wavelength step size in units of nm.

The conversion factor is the energy per photon:

$$E/\gamma = \frac{hc}{\lambda[nm] \cdot \gamma} \cdot \frac{10^{-9}m}{nm} \tag{5}$$

$$= \frac{(6.626x10^{-27}erg \cdot s)(3 \cdot 10^{8}\ m/s)}{\lambda[nm] \cdot \gamma} \cdot \frac{10^{9}nm}{m} \cdot \frac{1W}{10^{7}erg/s} \cdot \frac{10^{4}cm^{2}}{m^{2}} \tag{6}$$

$$= \frac{1.988x10^{-12}(cm^{2}\ s\ nm)(Wm^{-2})}{\lambda[\mathrm{nm}] \cdot \gamma} \tag{7}$$

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

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

$$J_{total\_quiet}[Wm^{-2}] = \sum_i J_i[Wm^{-2}d\lambda^{-1}] \tag{8}$$

The current for the quiet time is given by

$$I_{total\_quiet}[A]] = \sum_i R_i[A\ m^{2}\ W^{-1}] \cdot J_i[Wm^{-2}d\lambda^{-1}] \tag{9}$$

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

$$J_{total\_meas} = \frac{J_{total\_quiet}}{I_{total\_quiet}} \cdot I_{meas} \tag{10}$$

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

$$f_{subset} = \sum_i \frac{J_i[Wm^{-2}d\lambda^{-1}]}{J_{total\_quiet}[Wm^{-2}]} \tag{11}$$

## A.6 Timing

The EUVS channels accumulate counts for 10.24 s. As shown in Figure 10, 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. Timing is corrected in Versions 4 and 5.

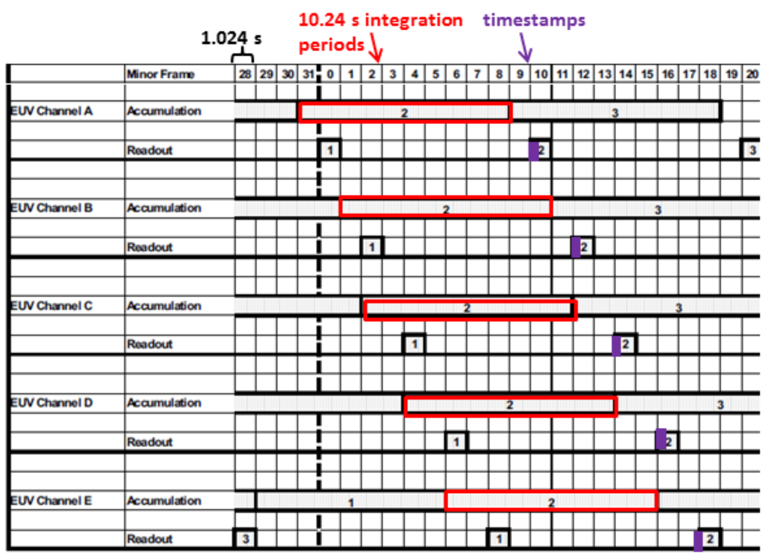



Figure 10: Sketch of EUVS instrument timing. Telemetry minor frames are 1.024 s. Integration is 10.24 s and timestamps occur 1.024 or 2.048 s after the end of the integration, depending on channel.

## A.7 Future Corrections

More details such as impacts of solar activity, angle, particle backgrounds and limb effects could be considered. In the future, 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.It is not clear which other terms in Eq. 1 should be calculated more carefully. Gain does not vary much with temperature and so the correction does not lie there. The visible light is missing a 3.4% 1 AU correction, but since the visible light is only about 1% of the total signal, this is also a very small effect. 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] than has been applied so far.

# 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 A.5. For these comparisons, the GOES data was adjusted to 1 AU. 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.

## B.1 Version 5 Comparisons

Figure 11 shows comparisons of daily GOES irradiance measurements between GOES-14 and -15 with GOES-16. Figure 12 shows the corresponding ratios of the GOES-14 and -15 irradiances to those from GOES-16. The standard deviation of the GOES-14/-15 satellites is 0.6%. Although there was good overlap with SORCE SOLSTICE until 2020 (when SOLSTICE was deactivated), there was little overlap between the three GOES satellites. Where available starting 2017, GOES-16 data should be used instead of data from the earlier satellites, due to the narrower instrument bandpasses.

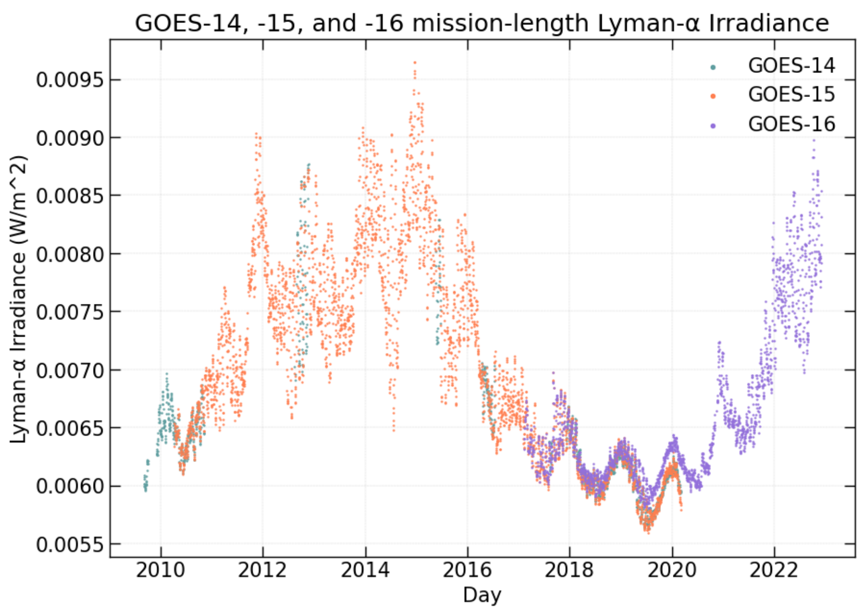



Figure 11: Mission-length comparison of Lyman $\alpha$ daily-average irradiances between Version 5 GOES-14, and -15 with GOES-16 measurements.

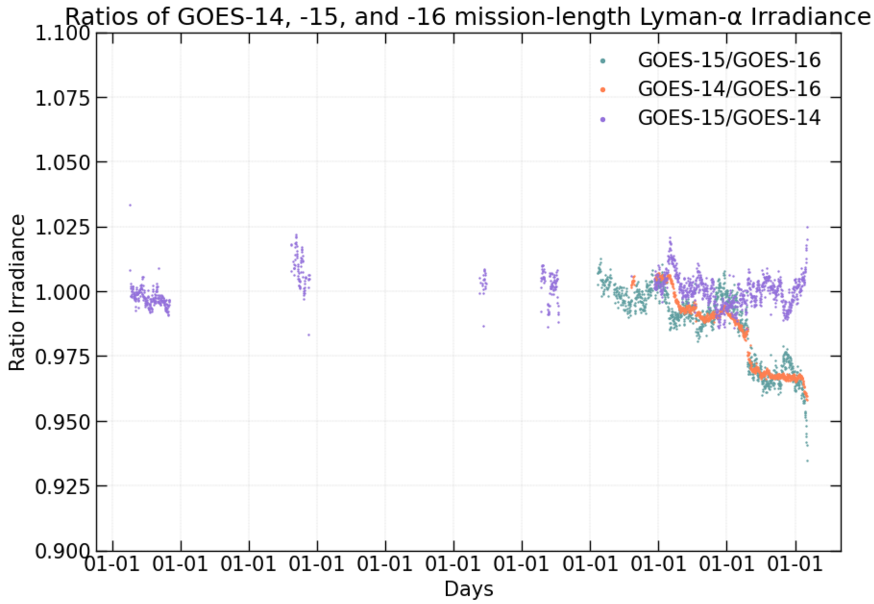
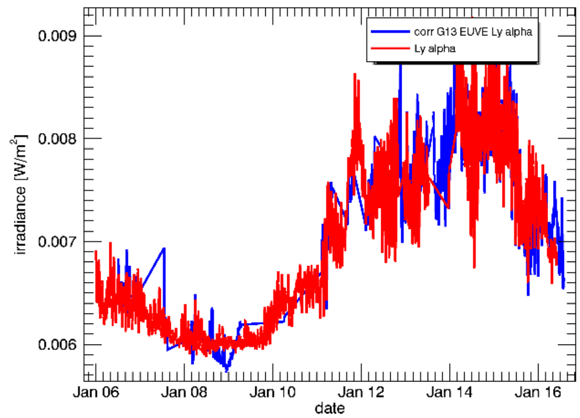


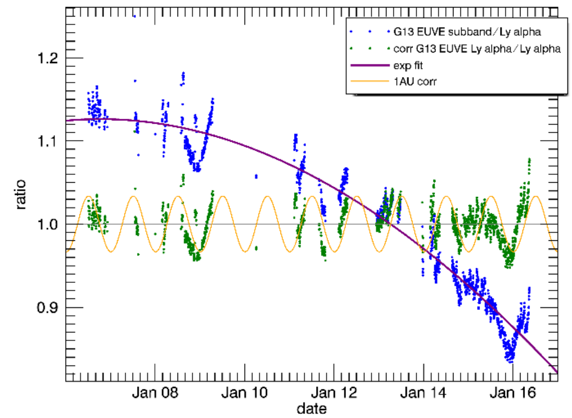

Figure 12: Mission-length comparison of the ratio of Lyman $\alpha$ irradiances between Version 5 GOES-14 and -15 with GOES-16 measurements. The date range is from 2009 into 2020.

## B.2 Version 4 Comparisons

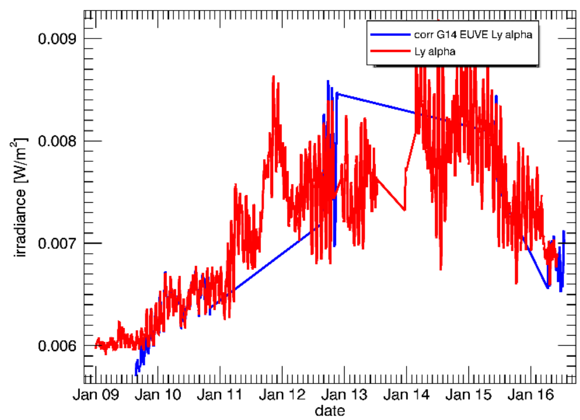
Figure 13 shows comparisons of daily GOES irradiance measurements with Version 15 SORCE SOLSTICE. GOES-15 has a very good fit, but the limited and possibly oscillating ratios for GOES-13 and -14 make for less than ideal fits. For GOES-14, the Channel E measurements prior to 1 Dec 2009 has a much slow decay and the reason for this is not known, and so the degradation fit is started on that date.



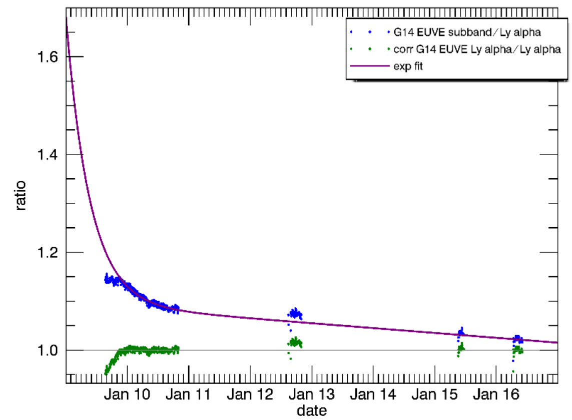

(a) GOES-13 irradiances.



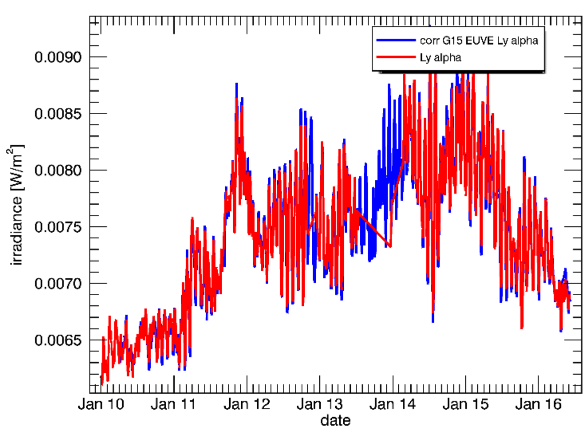

(b) GOES-13 degradation fit.



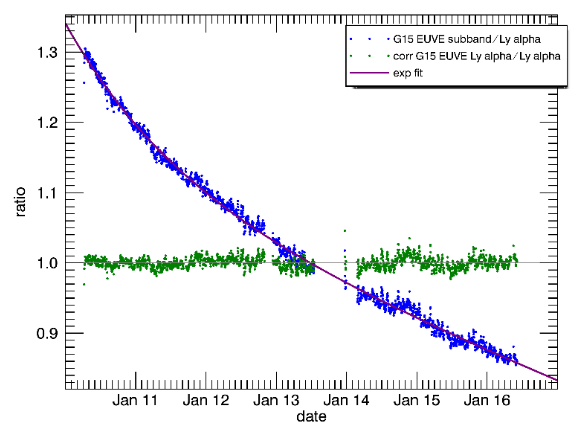

(c) GOES-14 irradiances.




(d) GOES-14 degradation fit.




(e) GOES-15 irradiances.




(f) GOES-15 degradation fit.

Figure 13: Plots (left) show irradiances for V4 GOES with degradation correction and V15 SORCE SOLSTICE. Plots (right) show the exponential fit to the irradiance ratio (GOES divided by SORCE SOLSTICE) that is used to recalibrate and remove degradation from the GOES data.

## 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 13 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 13: Hardware components for GOES 13-15 EUVS.

| Component | Manufacturer | Details |
|---:|---:|---:|
| EUVS | ATC | |
| detectors | IRD | AXUV photodiode |
| gratings | MIT | A,B: 5000 lines/mm<br>C,D: 2500 lines/mm<br>E: 1667 lines/mm |
| thin filters on detectors | Lebow | A: 50/200/70 nm of Ti/Mo/C<br>B: 150/5 nm of Al/Al2O3<br>C: 150/2 nm of Al/Al2O3<br>D: 150/2 nm of Al/Al2O3 |
| Lyman-$\alpha$ 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.