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COMPARATIVE SOLAR EUV FLUX FOR THE SAN MARCO ASSI

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ABSTRACT

The Airglow and Solar Spectrometer Instrument (ASSI) on the San Marco D/L satellite has measured solar extreme ultraviolet irradiances. The data are currently being released for analysis. As a preliminary step in evaluating this important dataset, modeled solar irradiances from 4 to 105 nm are presented for comparison to the San Marco data. The comparable flux for March–December 1988 is obtained from a revised and extended empirical solar extreme ultraviolet model derived from OSO 1, OSO 3, OSO 4, OSO 6, AEROS A, and AE-E satellite and six rocket flight datasets. Model wavelength intervals having the highest photon flux include the 15–35 and 85–105-nm ranges. Solar rotational features are prominent on several occasions in the model time series. A useful example is the modeled integrated flux between 30–31 nm which includes the Si XI (30.3-nm) and He II (30.4-nm) irradiance. The modeled flux in this 1-nm range shows both an absolute 22% increase from beginning to end of mission and a solar rotational variability with a typical peak-to-valley ratio of 14%. The absolute modeled irradiance in this wavelength interval is 9×10^9 photons cm^{-2} s^{-1} ±35%.

INTRODUCTION

The San Marco D/L satellite, launched on 25 March 1988 into an equatorial orbit ranging from 190 to 610 km in altitude, carried the Airglow Solar Spectrometer Instrument (ASSI) in its scientific payload. The observations of the solar EUV by this instrument for over 8 months was the first time in 8 years that such measurements had been continuously made. Previous satellite observations of solar EUV were carried out by the OSO, AEROS, and AE series satellites for intervals between 1962–1980. There have been no continuous solar EUV measurements since the end of the AE–E satellite observations on 30 December 1980. Donnelly /1/ has called this paucity of data the "EUV hole"; there are no new satellite observations scheduled in the near future.

The ASSI measured both solar and airglow irradiance from 20–700 nm and therefore had to meet conflicting requirements in spectral ranges, resolutions, pointing accuracy, and fields of view. Schmidtke *et al.* /2/ describe the ASSI in detail. For the solar EUV observations <130 nm, ASSI had a spectral resolution of approximately 1 nm, independent solar-pointing control which allowed the instrument to collect solar irradiance during the semiannual 23° change in the sun's inclination relative to the orbit plane and satellite spin axis (parallel to the Earth's spin axis), and a bias voltage mechanism combined with a variable entrance slit to extend the intensity-sensitivity range over several orders of magnitude. The solar EUV spectral range was 20–110 nm.

During the San Marco D/L mission, two solar EUV rockets made measurements in both broadband integrated flux and 1-nm spectral resolution as discussed by Ogawa *et al.* /3/ and Woods and Rottman /4/. Their measurements provide important constraints on the absolute magnitude of the solar EUV. Ogawa *et al.* /3/ describe the 5.0–57.5-nm total integrated flux measured on 24 October 1988 by the University of Southern California (USC) rocket with a silicon photodiode detector which had an uncertainty of ±14%. Woods and Rottman /4/ describe the 30–100-nm irradiance observed with 1-nm resolution by the Laboratory for Atmospheric and Space Physics (LASP) rocket on 10 November 1988 with a spectrograph having a wavelength-dependent uncertainty of ±5–35% and an overall average uncertainty of ±13%. The preflight EUV calibration of ASSI has received preliminary validation by the LASP rocket data.

Since there were no long-term solar EUV measurements made in conjunction with the San Marco dataset, the instrument degradation calibration is made by analyzing the in-flight calibration mode and by intercomparing the overlapping channels from the short wavelengths through the visible. In the latter wavelength region (above 300 nm) the sun itself is used as a standard light source during the mission. Modeled time series EUV irradiances will be compared to the observed irradiance time series in order to validate the instrument degradation curve. Tobiska /5/ describes the solar EUV irradiance model which was revised and extended from the SERF2 solar EUV flux model. The model, which produces EUV irradiances at 1 AU by discrete line and wavelength interval, uses ground- and space-based measurements of solar chromospheric and coronal emissions to produce modeled chromospheric and coronal EUV flux, respectively. Prior to the model and data comparison, an estimated range of flux values and some anticipated features in the observed EUV dataset are presented here.

MODEL EUV DISCUSSION

The solar EUV flux model used in this study /5/ was developed as a revised and extended model from SERF2 described by Tobiska and Barth /6/. The empirical model is derived from six satellite datasets, including OSO 1 (28.4 and 30.4 nm), OSO 3 (25.6, 28.4, and 30.4 nm), OSO 4 (30.4 nm), OSO 6 (30.4 and 58.4 nm), AEROS A (28.4, 30.4, and 58.4 nm), and AE-E (14.0–105.0 nm), and six rockets, including three ionization cell or silicon photodiode instruments, two spectrographs, and one spectrometer. The rocket measurements described by Ogawa *et al.* /3/ and Woods and Rottman /4/ are incorporated into this model development. Improvements from the SERF2 model relevant to the San Marco mission include a more accurate reproduction of solar rotational variation at all wavelengths and less uncertainty in the absolute magnitude of several important solar EUV lines. These changes contributed to a simpler model formulation based upon a multiple linear regression algorithm. The model can be expressed as an EUV irradiance, I, at a wavelength, λ, on a given date, t

$$I(\lambda,t) = a_0(\lambda) + a_1(\lambda)F_1(t) + \cdots + a_n(\lambda)F_n(t) \qquad (1)$$

with $n = 4$ independent terms and where $F_n(t)$ is one of four proxy datasets used to model either chromospheric or coronal irradiances. The four proxy datasets are H Lyman α, He I 10,830 Å equivalent width scaled to Lyman α, $F_{10.7}$ daily values, and $F_{10.7}$ 81-day running mean values. The a_n coefficients derived in the model development are detailed by Tobiska /5/.

The model was run from 1 March (88060 in year-day format) through 25 December 1988 (88360), with the results shown in Figure 1. The irradiances are binned in 5-nm intervals between 2 and 105 nm and are slightly smoothed for display purposes. Several features are apparent from Figure 1. The 15–35-nm and the 85–105-nm intervals contribute the largest photon fluxes at the top of the Earth's atmosphere for all levels of solar activity. March through December 1988 was during the rising phase of solar cycle 22 and the absolute values of the irradiances generally increase in the model. Finally, the effects of solar rotation, which give a 27-day periodicity with phase shifts to the modeled flux, are noticeable.

An example of model flux was selected to provide estimates for the San Marco D period. The ASSI B/IV spectrometer channel 17 had a center wavelength, $\lambda(\beta_0)$, of 30.4 nm at the exit angle, β_0, with resolution of approximately 1 nm. Corresponding to this, the modeled flux time series of the Si XI (30.3 nm) and He II (30.4 nm) were summed for the March–December 1988 timeframe. These combined wavelengths were selected for two major reasons. First, from a solar perspective, the 30.4-nm line is representative of solar EUV variability on the timescale of the San Marco mission and there have been numerous measurements of this wavelength as described above. These two lines provide nearly all the irradiance in the 30–31-nm spectral range. Second, from an aeronomical perspective, the 30.4-nm wavelength provides a substantial fraction of the terrestrial thermospheric heating and photoelectron production in the ionospheric F-region during all levels of solar activity. The photoabsorption and photoionization cross sections of the major neutral thermospheric constituents have representative values at this wavelength.

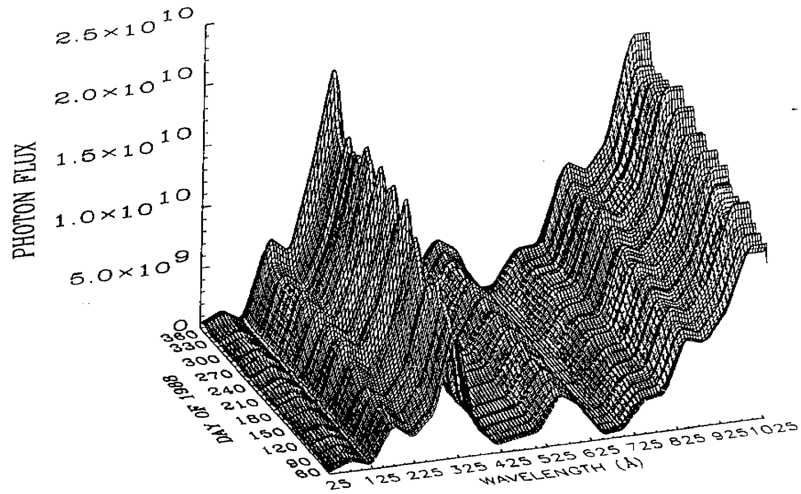

Fig. 1. Solar EUV model flux from 1 March through 25 December 1988 between 1.8 and 105.0 nm in 5-nm bins. Values have been smoothed with a 3-bin running mean algorithm to reduce noise in the display. The rise of cycle 22 combined with phase-shifted solar rotational variations are evident in the figure. The largest fluxes, in units of photons cm^{-2} s^{-1}, are in the 15–35 and 85–105 nm intervals.

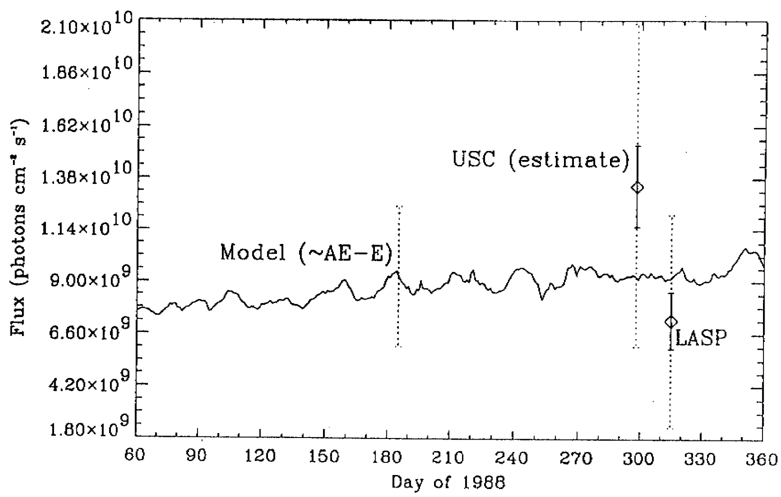

Fig. 2. The time series of two lines, Si XI (303.31 Å) and He II (303.78 Å), summed during the period of 1 March (88060) through 25 December 1988 (88360). See text for discussion of model values compared to two rocket data points, the associated uncertainties, and the characteristics of the modeled time series.

Figure 2 shows the modeled time series which was heavily weighted by the absolute values from the AE-E dataset. The uncertainty in the AE-E data which were used for these wavelengths was ±35% and is shown in the dotted line error bars on day 185. Superimposed on Figure 2 are the rocket-observed Si XI plus He II irradiances from the USC (88298) and LASP (88315) flights. The USC observation, which had an uncertainty of ±14%, denoted by the solid error bars, was performed by a silicon photodiode detector which integrated the entire 5.0–57.5-nm range. To obtain line emission values, a first order approximation was made of the combined Si XI and He II lines for the USC flight ($F_{10.7}$ = 168) by using the Air Force Geophysics Laboratory (AFGL) 14 August 1979 rocket flight spectrum described by Van Tassel *et al.* /7/. The latter rocket flew during similar levels of solar activity ($F_{10.7}$ = 154). The AFGL spectrum was first scaled in the 5.0–57.5-nm range to the USC-observed level; the scaled Si XI and He II lines were extracted and then summed to provide the data point on Figure 2 marked "USC (estimate)." The error bars (dotted lines) were then expanded to ±55% to account for uncertainty in the extraction scheme. The LASP observation of the 1-nm interval containing these two lines (when $F_{10.7}$ = 148) had an uncertainty of ±18% (solid error bar). Woods /private communication, 1990/ noted that this considered the question of scattered light but did not account for error resulting from applying a Gaussian fit to the line(s) to obtain the published value. The Woods and Rottman /4/ published dataset did not include a listing for the Si XI line at 30.3 nm. When modeling the He II line, Tobiska /5/ increased the LASP measurement uncertainty to ±68% (denoted by the dotted error bar) to encompass 2σ values. During the San Marco period, the uncertainties in the model daily values (Figure 2) overlap the data point uncertainties.

The He II (30.4-nm) line proved to be one of the most difficult lines to model in the entire EUV spectrum. There were 11 distinct datasets, which were often not consistent with one another. Most other lines and intervals had better agreement among the fewer datasets. However, in the San Marco time period, if the AE–E uncertainty is used for the model, then it is consistent with the smaller error bars of both the LASP and USC-estimated measurements.

If the model values are assumed to be a reasonable estimate of the Si XI plus He II irradiance during the San Marco period, then the following features can be noted. There is an increase in the average absolute value of the flux from 1 March through 25 December 1988. If a linear representation is made of the model values in the form $y(t) = a + bx(t)$, where $x(t)$ are day numbers, $x(0)$ is 1 March, and $y(t)$ is the model value on a date, then $a = 7.7 \times 10^9$ and $b = 7.2 \times 10^6$. This allows one to empirically estimate the ratio of flux on 30 November to 1 April as

$$\frac{I(30.4\,\text{nm},88335)}{I(30.4\,\text{nm},88092)} = 1.22 \tag{2}$$

i.e., there is a 22% average flux increase over the mission duration. Additionally, solar rotational maxima are clearly seen on the dates 88105, 88132, 88160, 88185, and 88244. A typical peak-to-valley ratio in a 27-day solar rotational feature is between the maximum on 88244 and the preceding minimum on 88233 (ratio = 1.14). In both the He II AE–E data and model values, the typical peak-to-valley ratio during the rise of cycle 21 was 1.11 to 1.15.

In Figure 3, the model spectrum for the date of the LASP rocket flight (88315) is shown from 1.8–105.0 nm at a resolution of the SC21REFW spectrum described by Hinteregger *et al.* /8/. This spectrum has approximately 1–2 Å resolution. The He I, H Lyman, and C I continua are prominent, as are discrete emission lines throughout the spectrum. The total integrated flux for the 30.0–31.0-nm range is 1.0×10^{10} photons cm^{-2} s^{-1} ±35%, while the 5.0–57.5-nm range integrated flux is 4.8×10^{10} photons cm^{-2} s^{-1}. The uncertainty in the latter integrated value is unquantified. However, Tobiska /5/ shows that this value is well within the expected range for moderate solar activity.

CONCLUSIONS

A newly revised and extended solar EUV flux model has been run to estimate the characteristics of the solar EUV which are observed by the San Marco D ASSI. Observations were made between March and December 1988 and the model time series covers 1 March through 25 December 1988. The application of this study will be to assist the validation of the ASSI background count calibration method.

Model results anticipate that the ASSI observations should show a general increase in all levels of solar flux from the beginning to the end of the mission with solar rotational features superimposed upon the time series. The most prominent peaks in solar rotational activity in the model occur on 5 dates of 88105, 88132, 88160, 88185, and 88244. Particularly high photon counts should be seen in the 15–35-nm and 85–105-nm intervals. In the interval between 30–31 nm, which includes the Si XI (30.3-nm) and He II (30.4-nm) lines, the absolute model value is 9×10^9 photons cm^{-2} s^{-1} ±35% for the entire period with a value near 1.0×10^{10} on the date of the 10 November 1988 LASP rocket flight. For this period during the rise of cycle 22, typical peak-to-valley ratios in

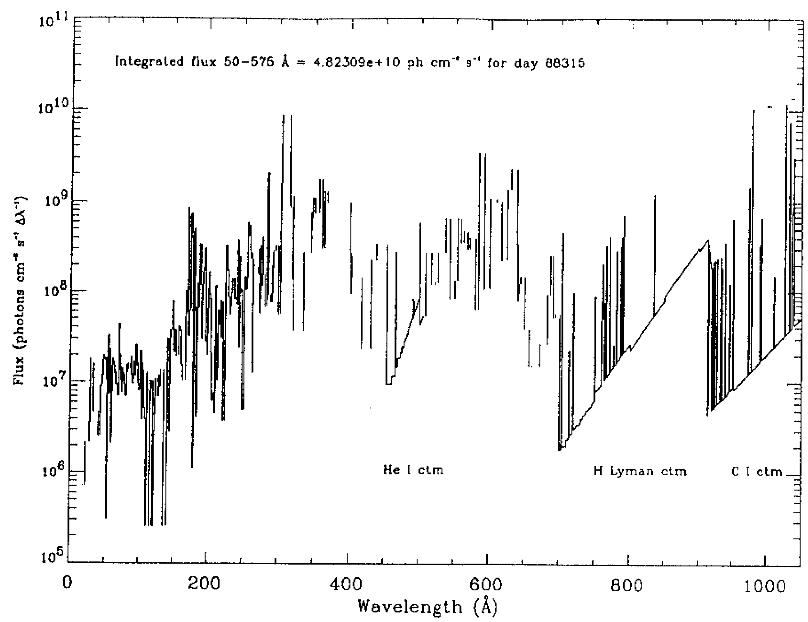

Fig. 3. Model spectrum at the same resolution as the SC21REFW reference spectrum described by Hinteregger *et al.* /8/ between 1.8 and 105.0 nm. The spectrum is created by first scaling the SC21REFW values in each 5 nm interval by the appropriate ratio to achieve the model values. The discrete lines calculated by the model are then superimposed upon the scaled spectrum.

solar rotational features are reasonably between 1.11 and 1.15. Finally, the probable absolute average flux increase in this 1-nm interval from beginning to end of mission is approximately 22%.

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