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VARIABILITY IN THE SOLAR CONSTANT FROM IRRADIANCES SHORTWARD OF LYMAN-ALPHA

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ABSTRACT

The variation in the solar constant, S(t), is reproduced by the SOLAR2000 Research Grade v1.05 empirical solar irradiance model and is described for 5 solar cycles between cycles 18 and 23 (February 14, 1947 through May 31, 2000). This solar constant variation is dependent upon the derivation data sets and the formulation of SOLAR2000 which are described in more detail. The S(t) temporal variability in SOLAR2000 is shown for the solar spectrum between 1–122 nm. The variability is consistent with previous discussions in the literature and a new result is shown where the 1–122 nm wavelength range accounts for about 5-14% of the standard deviation reported in the ASTM E-490 standard. The minimum-maximum range of S(t) variation due to 1–122 nm variability is between 1367.2768 Wm² on 1986-152 and 1367.2877 Wm² on 1957-340. The mean S(t) in these data is 1367.2796 Wm².

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SOLAR2000 MODEL BACKGROUND

The SOLAR2000 Research Grade v1.05 empirical solar irradiance model (SOLAR2000, released July 17, 2000) is derived from measured solar irradiances. It produces the full solar spectrum between X-ray and radio wavelengths (1-1,000,000 nm) at 1 AU (see Figure 1) and is temporally and spectrally resolved. The default output of the model has a spectral resolution of 1 nm although EUV irradiances in 809 lines (SC#21REFW format) or 39 lines and wavelength groups (EUV91/EUV97 format) are also provided. SOLAR2000 generates the historical daily solar variability through time starting on February 14, 1947 and continues to a few days before the current epoch (Tobiska, et al., 2000; Tobiska, 2000).

The overarching scientific goal behind developing SOLAR2000 is to understand how the Sun varies spectrally and through time from X-ray to radio wavelengths. This will contribute to answering key scientific questions and will aid national programmatic goals related to solar irradiance specification.

SOLAR2000 irradiances are designed to be a fundamental energy input into planetary atmosphere models. SOLAR2000 can be used as a comparative model with measurement sets and with numerical/first principles solar models. SOLAR2000, especially through the E10.7 solar EUV proxy (Tobiska, et al., 2001), is a particularly useful tool to model and/or predict the solar radiation component of the space environment for space weather applications.

SOLAR2000 accurately characterizes the temporal solar irradiance variability across the soft X-ray and extreme ultraviolet spectrum through Lyman-• (121.6 nm). Planned upgrades to SOLAR2000 versions 2.yz, 3.yz, and 4.yz will include variability in the UV, VIS/IR, and a theoretical spectrum, respectively.

The model uses the ASTM E-490 solar standard as a placeholder for wavelengths longward of Lyman-•. The ASTM E-490 standard uses the definition of the solar constant as "the total solar irradiance at normal incidence on a surface in free space at the Earth's mean distance from the Sun (1 AU)." This standard pro vides a table of irradi-

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ance values that, integrated over the entire spectrum as the total solar irradiance (TSI), define the solar constant, S, and zero air mass solar spectral irradiance. Their value of the solar constant is 1366.1 Wm² excluding EUV, soft X-rays, and X-rays. This value is the mean of daily averages from six different satellites over the 1978-1998 time period, all measured with absolute cavity radiometers (Fröhlich and Lean, 1998). The reported standard deviation of this mean value is 425 ppm, with a 0.37% minimum-to-maximum range (1363-1368 Wm²). The standard can be obtained directly from ASTM.

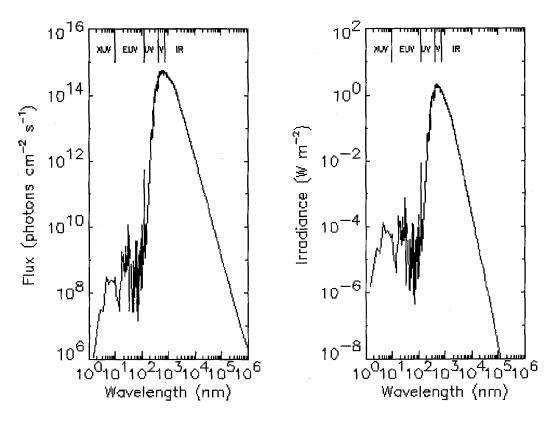


Fig. 1. The SOLAR2000 Research Grade v1.05 spectrum at 1 nm resolution in both photon flux and SI units of Wm² on July 25, 1999.

ISO is also developing a solar irradiance standard that is a process-based standard rather than a tabular listing of irradiance values. The ISO draft international standard specifies the representations of solar irradiances and is applicable to measurements, reference spectra, empirical models, and first-principles models. Its purpose is to provide a standard specification of all solar irradiances for use by space systems and materials users. There are four general compliance items of that draft standard. First, solar irradiances are reported in SI units of Watts per square meter corrected to 1 AU. Second, the method of determining irradiances is documented, including data collection, processing, calibration, validation, accuracy, precision, methodology, algorithm, and archiving information. For empirical models such as SOLAR2000, a description of the rationale for use of the selected proxies, the proxies and independent data sets used in the derivation, and the model's mathematical formulation is also required. Third, the compliant data set or model is published in an internationally-available peer review journal. Fourth, the compliant data set or model is archived in a method consistent with current technology that ensures international accessibility. A draft of the ISO solar irradiance standard is available for review at the http://www.SpaceWx.com/

web site. SOLAR2000 is fully compliant with the provisions of that draft standard in addition to incorporating the ASTM.E-490 solar standard spectrum longward of Lyman-••

DERIVATION OF XUV/EUV/LYMAN-ALPHA SPECTRUM IN SOLAR2000

The scientific basis and algorithm of SOLAR2000 is described by Tobiska, et al. (2000) and the validation of the E10.7 solar EUV proxy is described by Tobiska, et al., (2001). The derivation of SOLAR2000 is described here in more detail as it relates to the formulation of the solar constant, S(t), defined above. This report describes the temporal variability of S(t) as a function of the variability of the solar spectrum between 1 and 122 nm which is generated through SOLAR2000 version 1.05. The data sets used in the derivation of SOLAR2000 Research Grade v1.05 are listed in Table 1.

Table 1. Data sets used to derive the SOLAR2000 Research Grade v1.05 model

λ range (nm)	#λ	date	reference	method
5.0-105.0	37	Apr 23, 1974	Hinteregger (1985)	AFGL rocket
1.862-200.0	1664	Jul 18, 1976	Hinteregger (1985)	Composite reference spectrum
5.0-105.0, 121.6	38	Feb 19, 1979	Hinteregger (1985)	AFGL rocket
5.0-105.0, 121.6	38	Aug 14, 1979	Hinteregger (1985)	AFGL rocket
5.0-105.0, 121.6	38	Nov 10, 1979	Hinteregger (1985)	AFGL rocket
16.8-121.6	15	1977 - 1980	Hinteregger (1985)	AE-E
0.1-6 broadband	_	1977 - 1980	Kreplin & Horan (1992);	SOLRAD
			Tobiska & Eparvier	
1			(1998)	
EUV broadband	_	Aug 10, 1982	Ogawa et al. (1986)	USC rocket
EUV broadband	_	Aug 16, 1983	Ogawa et al. (1986)	USC rocket
EUV broadband	_	Oct 24, 1988	Ogawa et al. (1990)	USC rocket
30.4-108.5	21	Nov 10, 1988	Woods & Rottman (1990)	LASP rocket
0.5-199.5	200	Oct 27, 1992	Woods et al. (1998)	LASP rocket
0.5-199.5	200	Oct 4, 1993	Woods et al. (1998)	LASP rocket
0.5-199.5	200	Nov 3, 1994	Woods et al. (1998)	LASP rocket
25.0-34.0,0.10-77.0	2	Nov 13, 1996	Judge (private communi-	SOHO CELIAS/SEM
			cation, 1997)	
31.34-62.49	70	May 15, 1997	Brekke et al. (2000)	SOHO CDS
0.2 - 4.0	4	_	Acton (private communi-	YOHKOH (SXT)
			cation, 1999)	
121.6	1	Feb 14, 1947 to	Tobiska et al. (1997)	Composite data set
·		Sep 30, 1999	Woods et al. (2000)	
115-400	_	_	Woods et al. (1996)	UARS SOLSTICE, SUSIM
115-1,000,000		_	ASTM E490	Composite ref. spectrum
45-109.9	27		Avrett (private communi-	Continua, center low Sun
			cation, 1991)	

As part of the SOLAR2000 derivation, an integer value mask, or key, is used to identify the temperature-defined solar source region of each wavelength on the SC#21REFW ~1 Å format (Hinteregger, et al., 1981). In an expanded version of the SC#21REFW format, SOLAR2000 uses a mask where -1 is the initialization value, 0 indicates photospheric, 1 indicates chromospheric, 2 indicates coronal, and 3 indicates blended lines. These mask values are used in a multiple linear regression algorithm to help determine the appropriate proxy for use in the derivation. A spectral format is initially established using the SC#21REFW structure. As the multiple linear regression proceeds using the 81-day average and the detrended daily proxy value, on one hand, and the irradiance data on the other, an algorithmic decision is made as to which proxy provides the better correlation. The decision at each wavelength is made to maximize the value of the correlation coefficient, r, as shown in Tobiska, et al., (2001) by selecting the best proxy. Figure 2 shows the new key assigned to each 1 nm wavelength bin in the region between 1.862 – 104.9 nm. Using the data sets (Table 1) and the algorithm for multiple linear regression (Tobiska, et al.,

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2000), SOLAR2000 produces comprehensive, modeled irradiances throughout the soft X-ray and EUV region of the spectrum.

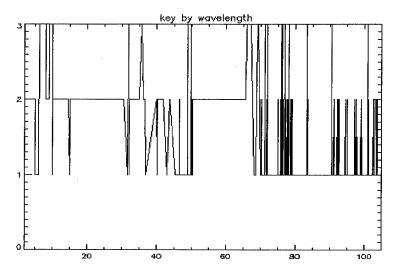


Fig. 2. SOLAR2000 Research Grade v1.05 temperature-defined solar source region keys. These result from the highest correlation coefficient from the multiple linear regression between proxies and data.

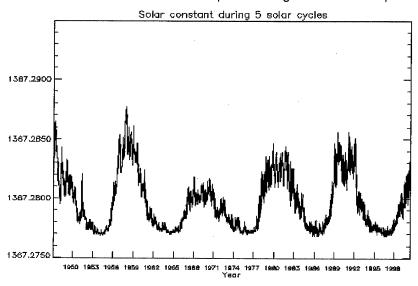


Fig. 3. S(t) for 5 solar cycles from February 14, 1947 through May 31, 2000.

Table 2. Changes in the solar constant due to 1-122 nm variability

Solar cycle	SC18	SC19	SC20	SC21	SC22
Solar maximum	1947-114	1957-340	1968-001	1979-314	1989-166
Solar max S	1367.2865	1367.2877	1367.2818	1367.2847	1367,2857
Solar minimum	1954-024	1964-185	1976-056	1986-152	1996-293
Solar min S	1367.2769	1367.2770	1367.2770	1367.2768	1367.2768
Max/min ratio	1.0000070	1.0000078	1.0000035	1.0000057	1.0000065

Tobiska, et al., (2001) describe deficiencies in that algorithm and the upgrade process of SOLAR2000. There are several planned upgrades to SOLAR2000 over the first half of the decade starting in 2000. These upgrades will include additional spectral range variability, enhanced accuracy of the data with the inclusion of new data sets and improved algorithms, and the development of nowcast and forecast irradiances.

S(t) IN SOLAR2000

The formulation of S(t) is dependent upon the formulation of irradiances in SOLAR2000. SOLAR2000 converts the integrated solar energy flux in units of ergs cm²s¹ $\Delta\lambda^2$ to SI units of Wm² in order to obtain S(t). Figure 3 shows this converted S(t) for five solar cycles from February 14, 1947 through May 31, 2000. The values are consistent with the Fröhlich and Lean (1998) discussion.

The minimum-maximum range of S(t) variation due to variability in the 1–122 nm wavelength range is between 1367.2768 Wm² on both 1986-152, 1996-293 and 1367.2877 Wm² on 1957-340. The mean S(t) in these data is 1367.2796 Wm² which is within the minimum-maximum range of ASTM E-490. The ratio to the mean is 0.99999792 and 1.0000059, respectively, for the lowest point in cycle 21 and highest point in cycle 19. Compared to the mean, these values are 21 to 59 ppm which implies that the 1–122 nm wavelength range accounts for about 5–14% of the standard deviation reported in the ASTM E-490 standard. Each individual solar cycle maximum-to-minimum variability ratio is shown in Table 2.

CONCLUSION

The variation in the solar constant, S(t), as reproduced by the SOLAR2000 Research Grade v1.05 empirical solar irradiance model, is described for five solar cycles between cycles 18 and 23 (February 14, 1947 through May 31, 2000). This variation is dependent upon the derivation data sets and the formulation of irradiances in SOLAR2000 as described in the discussion and references. The S(t) temporal variability in the 1–122 nm wavelength range is reproduced by the model and is shown for 1947–2000.

SOLAR2000 converts the integrated solar energy flux in units of ergs cm²s⁻¹ $\Delta\lambda$ ⁻¹ to SI units of Wm² in order to obtain S(t). The variability is consistent with previous discussions in the literature and a new result is shown where the 1–122 nm wavelength range accounts for about 5–14% of the standard deviation reported in the ASTM E-490 standard. The minimum-maximum range of S(t) variation due to 1–122 nm variability is between 1367.2768 Wm² on 1986-152 and 1367.2877 Wm² on 1957-340. The mean S(t) in these model data is 1367.2796 Wm².

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