Pergamon

Phys. Chem. Earth (C), Vol. 25, No. 5-6, pp. 383–386, 2000

1464-1917/00/$ - see front matter

PII: S1464-1917(00)00037-4

Status of the SOLAR2000 Solar Irradiance Model

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Received 31 October 1999; accepted 15 March 2000

Abstract. SOLAR2000 is a collaborative project for accurately characterizing solar irradiance variability across the full spectrum. The SOLAR2000 model is being developed as an image- and full-disk proxy empirical solar irradiance model covering the spectral range of 1-10,000 nm at 1 nm resolution starting in 1947. The overarching scientific goal of the project is to understand how the Sun varies spectrally and through time from the X-rays to infrared wavelengths by providing a self-consistent solar spectrum derived from space-based measurements. The model is used as a fundamental energy input for planetary atmosphere models and as a baseline for first principles solar models. It is a tool to specify the solar radiation component of the space environment and will be compliant with the International Standards Organization (ISO) solar irradiance standard. SOLAR2000 is being developed in five (spectral range) phases and five forecast time scales for research, contract, operations, and commercial grades of the model. © 2000 Elsevier Science Ltd. All rights reserved

1 Model overview

The solar irradiance model, SOLAR2000, is an empirical model that is derived from measured solar irradiances between the X-rays and the infrared (1-10,000 nm) at 1 AU (figure 1). The default output of the model has a spectral resolution of 1 nm and provides daily solar variability through time starting on February 14, 1947.

Information from SOLAR2000 will expand the scope of our knowledge about the quiet and variable Sun while providing a comparative database for future studies of the Sun's changes and its envelope of variability. As a fundamental energy input into planetary atmosphere models, it is applicable for climate and energy processes research. As a model derived from measurements, it can be compared with numerical/first principles solar models to help explain solar physical processes. As a tool to model or predict the solar radiation component of the space environment, it is a crucial part of space weather programs.

ISO is developing a solar irradiance standard and SOLAR2000 is compliant with the provisions of that standard in four ways. 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 for data collection, processing, archiving, validation, accuracy, precision, methodology, and algorithm information. A description of the proxies and independent datasets used in the derivation, the mathematical formulation of the model, and the rationale for use of the proxies selected is also provided. Third, the model will be published in an internationally-available peer review journal (Tobiska, *et al.,* 2000). Fourth, the model will be archived in a method consistent with current technology that ensures international accessibility. It will be also be publicly available on the web at http://www.spacenvironment.net.

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2 Applications

To complement its research use, SOLAR2000 can be joined with other models to provide space environment information. Such information can help identify ionospheric impacts upon cellular telephone service, GPS position error due to TEC scintillation effects, skip for shortwave radio propagation, and ionospheric effects on OMEGA and Loran VLF navigation systems. SOLAR2000 irradiances coupled with thermospheric models improve estimates for satellite orbit lifetime, reentry corridors, and maneuver designs. In the manned space program, docking and EVA activities benefit from improved thermospheric density knowledge and ionizing radiation forecasts. These technological improvements are enabled by greater accuracy for spectral solar irradiances and smaller uncertainty in their variability. A solar proxy, E10.7, has also been developed as a product of the SOLAR2000 model (Tobiska, *et al.,* 2000). It is the integrated solar EUV flux at the top of the Earth's atmosphere reported in 10.7 cm radio flux units. Table 1 outlines the range of SOLAR2000 research, operations, and commercial applications.

3 Development phases and forecast time scales

SOLAR2000 has a five-phase development process that encompasses model definition and design, soft X-ray (XUV) and extreme ultraviolet (EUV) modeling, far ultraviolet (FUV) modeling, UV irradiance modeling, and visible, infrared, total solar irradiance (TSI) modeling. The

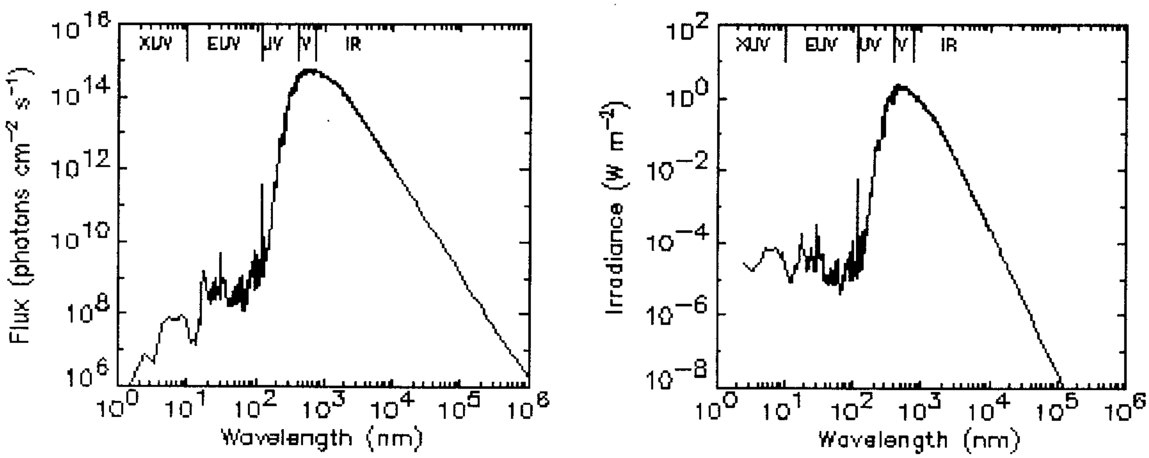

Figure 1. The SOLAR2000/RG V1.03 spectrum at 1 nm resolution in both photon flux and Wm^{-2}.

Table 1. SOLAR2000 applications*

human timescale	*past*	*present*	*future*
solar timescale			
multiple solar cycles	• sun-climate studies (r)		• sun-climate studies (r)
solar cycle	• global warming studies (r)		• global warming (r) • mission planning (c,g,m)
months	• solar-terrestrial studies (r) • post-analysis (c,g,m)		• scheduling (c,g,m) • reentry (c,g,m)
weeks	• solar-terrestrial studies (r) • post-analysis (c,g,m)		• scheduling (c,g,m) • reentry (c,g,m)
days	• post-analysis (c,g,m)		• station-keeping (c,g,m) • reentry (c,g,m)
hours	• post-analysis (c,g,m)	• RT ops (c,g,m) • reentry (c,g,m)	• station-keeping (c,g,m) • docking (c,g,m) • GPS (c,g,m)
minutes	• post-analysis (c,g,m)	• RT ops (c,g,m) • reentry (c,g,m) • GPS (c,g,m) • HF frequencies (c,g,m)	• station-keeping (c,g,m) • docking (c,g,m) • HF usable frequencies (c,g,m)

*applications: c (commercial), r (research), m (military), g (government agency).

first three phases are complete in SOLAR2000/RG V1.03. Beyond spectral development for historical irradiances, there are five time scales inherent in solar irradiance forecasting and specification. Each time scale relies on a different mathematical method for its representation and each time scale is associated with different technological requirements.

For example, a 1-72 hour forecast will use a neural-net algorithm and is relevant to satellite docking, station-keeping, and reentry operations for the next few orbits. This time scale is also important for forecasting ionospheric conditions related to GPS and HF mapping at specific geographic locations. A 3-14 day forecast will use solar image processing to provide irradiance information from persistent features on the near-Sun face. A 14-28 day forecast will rely on solar far-side interplanetary hydrogen Lyman-α backscatter measurements. Forecasts in this time frame will help scheduling and satellite operations and will enable ionosphere forecasts for GPS and HF applications on intermediate time scales. A 1-6 month forecast will use FFT non-stationary periodicities to estimate solar irradiances with the assumption that the time scale for active region evolution and decay extends over several months. A

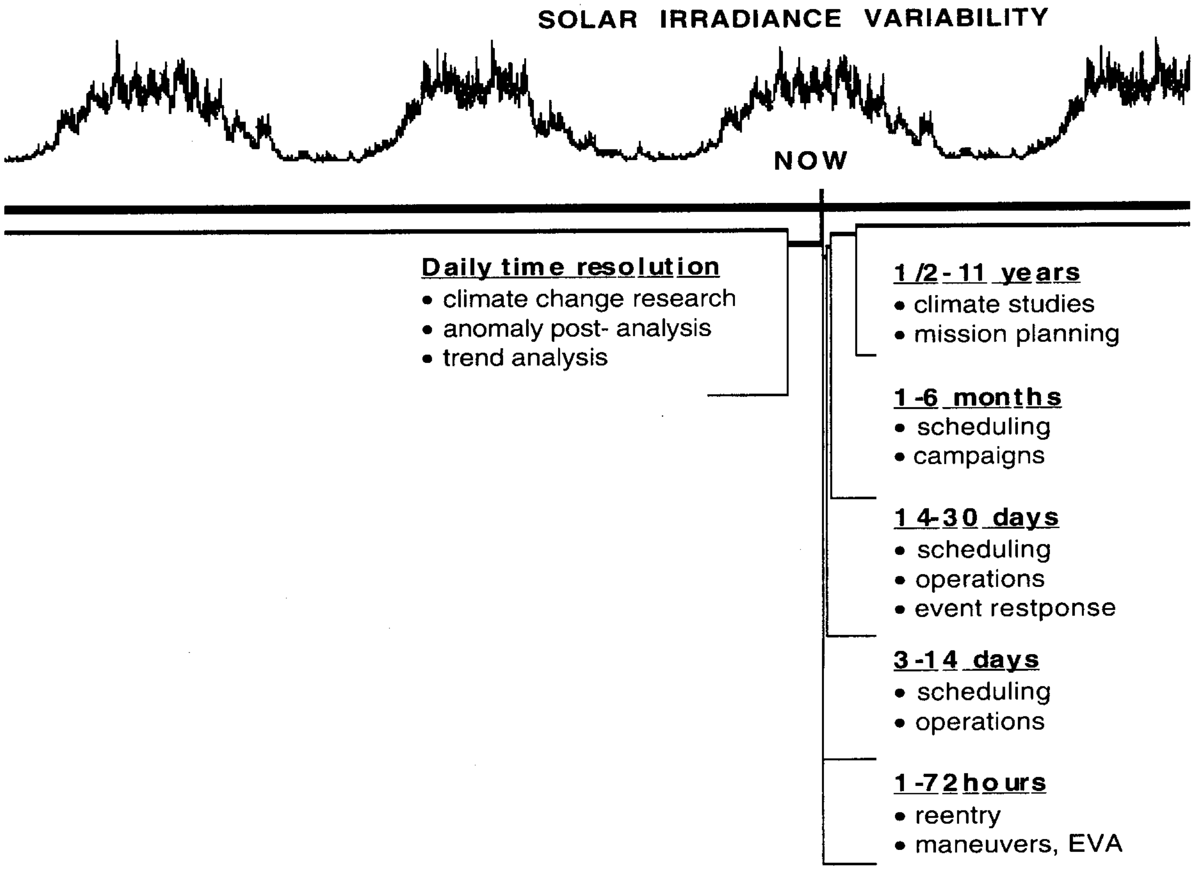

Figure 2. Five timescales of solar irradiance forecasting and historical daily irradiances.

1/2-11 year forecast will be built on existing statistical methods for estimating 10.7 cm flux. Irradiances produced for long-term forecasts are important for satellite mission planning and spacecraft design criteria as well as for ionospheric, GPS, and HF climatological estimates (figure 2).

4 Model Grades

There are four grades of SOLAR2000 that are useful for different applications. The core source code is similar for each grade of model. The research-grade (RG) model is designed for scientific and engineering research to provide daily historical solar irradiances. The model is accessible through FTP and internet browser. The contract-grade (CG) model is designed to link historical and climatological solar irradiances with other empirical or first principles models for collaborative research projects. The operations-grade (OP) model will uniquely support forecast and operations centers, such as the NOAA Space Environment Center, with data ingest, model runs, and daily solar spectral outputs. The commercial-grade (CM) model is designed as a secure module for local or remote (internet) access linked to specific commercial products.

5 Datasets used in the derivation

SOLAR2000 is derived from a multiple linear regression algorithm based upon reference spectra, rocket data, and satellite data (table 2). The derivation algorithm is described by Tobiska, *et al.* (2000). The data are combined with solar proxies representing different source regions in the solar atmosphere. The technique was originally developed by H.E. Hinteregger (1985) for the SERF1 model and expanded in the development of EUV91 and EUV97 (Tobiska, 1991; Tobiska and Eparvier, 1998). SOLAR2000 relies on the measurements listed in table 2. Future additions will be listed at http://www.spacenvironment.net.

Acknowledgements

Support for this work has been provided by the NASA TIMED contract NAS5-97179 (APL Contract 774017, UCB SPO BS0059849), by the NASA SOHO contract NAS5-98172, and by the NATO Collaborative Linkage Grant (NATO EST.CLG 975301). The documentation for SOLAR2000 can be downloaded from the Space Environment Initiative web site http://www.spacenvironment.net.

Table 2. Datasets used to derive SOLAR2000/RG V1.03

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); Tobiska & Eparvier (1998)	SOLRAD
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.* (1996b)	LASP rocket
0.5-199.5	200	Oct 4, 1993	Woods *et al.* (1996b)	LASP rocket
0.5-199.5	200	Nov 3, 1994	Woods *et al.* (1996b)	LASP rocket
25.0-34.0,0.10-77.0	2	Nov 13, 1996	Judge (private communication)	USC rocket
31.34-62.49	70	May 15, 1997	Brekke *et al.* (1999)	SOHO CDS
121.6	1	Feb 14, 1947 to Sep 30, 1999	Tobiska *et al.* (1997) Woods *et al.* (2000)	Composite data set
115-400	–	–	Woods *et al.* (1996a)	UARS SOLSTICE, SUSIM
115-1,000,000	–	–	ASTM E490	Composite reference spectrum
45-109.9	27	–	Avrett (private comm.)	Continua, center low Sun

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