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Forecast $E_{10.7}$ for Improved Low-Earth-Orbit Satellite Operations

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Low-Earth-orbit satellite operators often require accurate and precise knowledge of their spacecraft location and attitude for the recent past, the present, and the near future. The same is true of space surveillance operators tracking space debris with low perigee orbits. Unwanted orbital and attitude orientation changes occur as a result of drag and perturbations that are related to atmospheric density changes. These changes are primarily induced by solar extreme ultraviolet irradiance variations and geomagnetic storms, that is, one of the effects of space weather. A method for improving low-Earth-orbiting satellite operations and space surveillance tracking has been developed using the SOLAR2000 empirical solar irradiance model. SOLAR2000 is an operational grade solar irradiance specification model that provides high time resolution, nowcast, and forecast solar irradiances including the $E_{10.7}$ proxy. $E_{10.7}$ is a replacement for 10.7-cm solar radio flux $F_{10.7}$ in atmospheric density models that are linked with orbit determination algorithms. Recent previous validation work shows the improvement of using daily $E_{10.7}$ vs $F_{10.7}$ for satellite orbit determination. The operational application and use of the $E_{10.7}$ proxy are described in this work.

Nomenclature

$E(t)$	=	integrated energy flux, 1–105 nm in the same units as $I(\lambda, t)$ and specified as a function of time
$E_{10.7}$	=	integrated solar extreme UV energy flux at the top of atmosphere and normalized to solar flux units
$F_{10.7}$	=	10.7-cm solar radio flux, solar flux units (sfu); 1 sfu = 1×10^{-22} W m^{-2} Hz^{-1}
$I(\lambda, t)$	=	energy flux, ergs cm^{-2} s^{-1} $\Delta\lambda^{-1}$ full-disk solar radiance specified as a function of wavelength and time
$Qeuv$	=	thermosphere heating rate, ergs cm^{-2} s^{-1}
$S(t)$	=	integrated solar spectral flux, specified as a function of time and sometimes called the solar constant
t	=	time designator
λ	=	wavelength interval, nm
σ	=	one standard deviation designator

Introduction

THE low-Earth-orbit (LEO) region of near-Earth space between 100- and 1000-km altitude is populated with civilian and military satellites. These spacecraft are critical links in commercial, research, and defense infrastructures, and their population has grown as a result of the remarkable technological advances in the past five decades. Partly as a consequence of size, mass, and performance improvements that have been incorporated into newer generation spacecraft, satellite operators increasingly recognize risks to their space and ground systems from the space environment. Risks to space assets predominantly come from the sun's photon and charged particle interaction with the near-Earth space environment and with space systems operating in that environment. The short-term dynamic and variable nature of the sun's influence on Earth is called space weather and is the major environmental cause of model error in satellite orbit perturbations. Space weather can perturb satellite attitudes and trajectories, can cause interference with high-frequency (HF) radio links, can degrade global positioning system (GPS) location accuracy as the signal propagates through the Earth's ionosphere, and can adversely affect spacecraft electronics performance through charged particle effects. Several of the LEO satellite operator's major risks in relation to space weather events, their requirements to mitigate those risks, the time regimes related to the requirements, and availability of methods for meeting the requirements are listed in Table 1.

Over the past decade, scientific knowledge about the sun's effects upon the Earth has progressed to the point where space weather operational systems have been developed from space physics models. These systems are increasingly able to mitigate risks from the space environment. More important, the input data sources that are required to drive the models underlying these systems are now sufficiently operational so as to enable a short-term forecast capability with quantifiable uncertainty. Several types of space environment models, for example, solar irradiance, ionosphere, and upper-atmosphere density models, are now coupled with orbit propagators for operational use. SOLAR2000 is an example of such a model at the front of the chain of linked operational applications. (Documentation for the SOLAR2000 research grade model and a downloadable software application that runs the model is available from http://SpaceWx.com.)

Variations in solar extreme ultraviolet (EUV) irradiances, on timescales of minutes to years, impact the upper-atmosphere regime that is often part of space and ground systems' operations. These irradiance variations affect satellite operations and mission planning activities, for example, by changing the neutral constituent and electron densities. When solar activity is high, the EUV irradiances heat and expand the Earth's upper atmosphere with a time lag of a few hours as well as increase the total electron content (TEC) and change the peak ionization layer locations within a few minutes. The effect of the former process is to increase atmospheric drag and to increase orbital decay rates of spacecraft and debris. The effect of the latter process is to disturb HF radio communications and contribute to increased range uncertainty in GPS single frequency signals.

EUV heating is the major source of uncertainty within satellite drag models. Because of the scarcity of EUV measurements, the 10.7-cm solar radio flux $F_{10.7}$ has traditionally been used as a proxy for solar EUV heating. Although it was known at the beginning of the satellite era that $F_{10.7}$ does not contribute to atmospheric heating, ionization, or dissociation processes, it became a useful surrogate for solar EUV emissions in empirical relationships. It is often used as the solar variation driver in atmospheric density analytical and empirical models linked with orbit propagators.

The existing models using $F_{10.7}$, for example, Jacchia-type or mass spectrometer incoherent scatter (MSIS) models, have reached a 15% statistical uncertainty barrier in their neutral density

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Table 1 LEO satellite operator requirements, time regimes, and capabilities

Requirement	Time regime	Capability status[a]
Quantify environmental risks and conduct postanalysis studies	Historical	Available now
Specify system requirements and conduct calibration or validation studies	Historical	Available now
Monitor space weather background state and events with watches warnings, and alerts	Nowcast/forecast	Available now
GPS location error mitigated by near real-time scintillation and irregularity information	Nowcast/forecast	Available ~2005
Specify high time resolution (minutes to days) solar irradiance variability for thermospheric neutral densities and ionospheric electron densities	Nowcast/forecast	Available now
Specify near-term (days to months) solar irradiance variability for thermospheric neutral densities and ionospheric electron densities	Nowcast/forecast	Available now
Specify HF radio paths and probabilities of links	Nowcast/forecast	Available ~2003
Specify high-precision orbit location knowledge	Nowcast/forecast	Available ~2003
Specify high-precision attitude and pointing capability	Nowcast/forecast	Available ~2003
Specify debris location knowledge and avoidance capability	Nowcast/forecast	Available ~2004

[a]Based on reported capabilities at NOAA/SEC Space Weather Week, Boulder, CO, April 2002.

specification compared to derived densities from satellite drag (F. Marcos, private communication, Monterey, CA, Aug. 2002). This barrier represents a practical limit of $F_{10.7}$ proxy capability for specifying solar irradiances. The limitations of $F_{10.7}$ are not surprising because it has no physical connection to the upper atmosphere; it only marginally represents solar EUV irradiances because it is dominated by solar coronal emission processes and will not capture temporal changes of less than a day. The solar irradiance information barrier, using only $F_{10.7}$, can now be removed using the $E_{10.7}$ proxy. A description of the methodology used to create the proxy as well as its operational applications is described.

Methodology

The $E_{10.7}$ proxy is generated by the empirical SOLAR2000 irradiance model. The SOLAR2000 model is developed as a collaborative project for accurately characterizing solar irradiance variability across the spectrum.[1,2] The overarching scientific goal of the SOLAR2000 project is to understand how the sun varies spectrally and through time from the x rays to the infrared wavelengths. A primary project task is to develop a full-disk proxy-based and image-based empirical solar irradiance model that is valid in the spectral range of 1–10,000 nm for historical modeling and for forecasting throughout the solar system.

SOLAR2000 irradiance products are useful as fundamental energy inputs into planetary atmosphere models, for comparison with numerical/first principles solar models, and for modeling or predicting the solar radiation component of the space environment.[3] SOLAR2000 is compliant with the International Standards Organization solar irradiance draft standard CD 21348.[4] Temporal and spectral information from the model expands the scope of our knowledge about the quiet and variable sun, providing a comparative database for future studies of the sun's changes and its envelope of variability.[5] The SOLAR2000 model also represents an archive of information from multiple instruments, captured across many spacecraft and rockets, spectral bands, and periods of time. This archival aspect is a unique contribution of SOLAR2000 and fulfills two primary model purposes, that is, to preserve a knowledge bridge from historical measurements to eventual first principles' representation of solar irradiances and to provide solar irradiances for research and operations. SOLAR2000 has been identified as an important element in meeting U.S. national operational space system requirements for space weather information and forecasting of the near-Earth space environment.[6]

The operational grade version of the SOLAR2000 model is developed for use in operations and forecast applications. It utilizes real-time solar irradiance proxy inputs of the $F_{10.7}$ for coronal emissions and the Mg II core-to-wing ratio for chromospheric emissions in the time frame between 2000–2003. Beginning in 2004, the model will use GOES-N EUV broadband data to generate the EUV portion

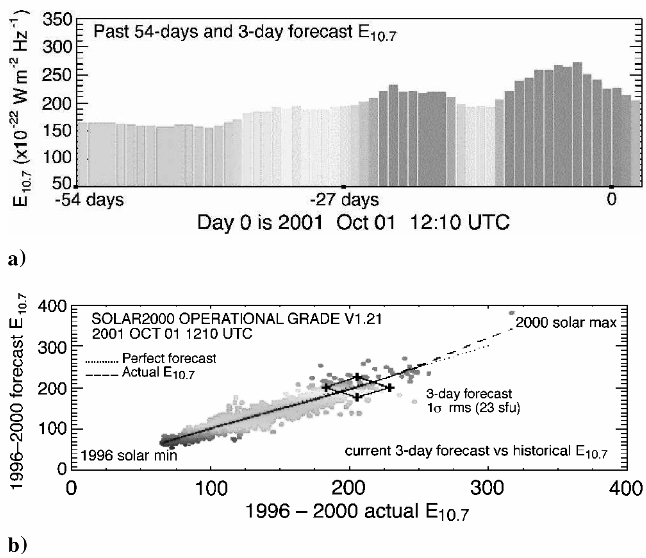


Fig. 1 Panel a) shows the three-day forecast solar irradiance proxy $E_{10.7}$ with two previous solar rotations (54 days), and panel b) compares current epoch with historical solar cycle 23 values.

of the spectrum. The model produces historical, nowcast, forecast, and high time resolution solar irradiances tailored for specific user requirements. For example, a three-day forecast daily irradiance product is shown in Fig. 1. The $E_{10.7}$ past 54 days (approximately two solar rotations) recent history and the next three-day forecast is shown in the top panel, whereas the current epoch forecast is compared with the historical forecast capability during solar cycle 23 in the bottom panel.

Because satellite operators and space surveillance orbital analysts are requiring greater precision and accuracy in spacecraft attitude and orbit determination, space physics modelers in the 1990s began active development of parameters to better represent the space environment. This activity has accelerated the process of transitioning models for research to models for operations and is guided, in part, by a goal of model improvement articulated in government agency space weather programmatic documents.[6] At the same time a paradigm shift occurred when it was realized that it is much easier to develop a new irradiance proxy using improved solar irradiance variability information than to ask anonymous users to change millions of lines of legacy code so as to utilize new solar models. In this context work by G. Schmidtke[7] was resurrected in 2000.

Tobiska et al.[1] and Tobiska[3] examined the thermospheric daily heating rate $Q(t)$ in search of a new proxy and found that $Q(t)$ compared favorably with a much simpler approximation, that is, the solar EUV energy $I(\lambda, t)$ (ergs cm^{-2} s$^{-1}\Delta\lambda^{-1}$), integrated between 1.862–104.9 nm at the top of the Earth's atmosphere $E(t)$. Tobiska et al.[1] found only minor differences at the 1–2% level when these two quantities were compared after $E(t)$ was translated into units of $Q(t)$ by linear regression. Subsequently, the term $E(t)$ was converted to the same units, solar flux units, as the historical $F_{10.7}$ proxy and renamed $E_{10.7}$ to indicate that it is the total EUV energy arriving at 1 astronomical unit (AU) reported in sfu. Tobiska[3] provides the detailed derivation of $E_{10.7}$, and Fig. 2 shows SOLAR2000 historical $E_{10.7}$ compared to $F_{10.7}$ for 1000 days starting 1 January 1998.

As part of a series of $E_{10.7}$ validations that were performed by Tobiska,[3] an improvement in thermospheric density modeling useful for satellite operators was demonstrated using the daily $E_{10.7}$ compared to $F_{10.7}$. In that study the Jet Propulsion Laboratory-developed long-term orbit predictor was used with a singly averaged propagation method and numerical integration of the averaged equations of motion where perturbations are included in spherical harmonics of up to a 21 × 21 field along with lunar–solar gravity, drag, and solar radiation pressure. For the orbit runs described in previous work, spherical harmonics of degree and order 3, two-body ephemerides for sun–moon gravity, no solar radiation pressure, and osculating altitude drag was used. The drag module consists of solar flux and atmospheric density subroutines that incorporate an experimental, modified Jacchia 1971 atmospheric density model in which the primary change was in the nighttime minimum exospheric temperature formulation of Eq. (1):

$$T_C = 1.15(379 + 3.24SF) \tag{1}$$

where SF is the solar flux, either $E_{10.7}$ or $F_{10.7}$, and the multiplicative factor of 1.15 is the average day and night temperatures from Tobiska.[8,9] Normally, a Jacchia-type model T_C includes both 81-day and daily solar flux; however, the advantage of using the experimental formulation is that one can judge the relative similarities and differences of one proxy vs another if both are smoothed or not smoothed in an identical manner. Previous work of Tobiska et al.[1] and Tobiska[3] describes the detailed results of those comparative studies. Tobiska et al.[1] described the monthly mean flux comparison where both proxies gave nearly identical results, and Tobiska[3] described the daily comparison with differing results.

A general summary of Tobiska[3] is that the daily altitude decay for the Solar Mesosphere Explorer (SME) satellite was modeled using both daily proxies and compared with the actual mean equatorial

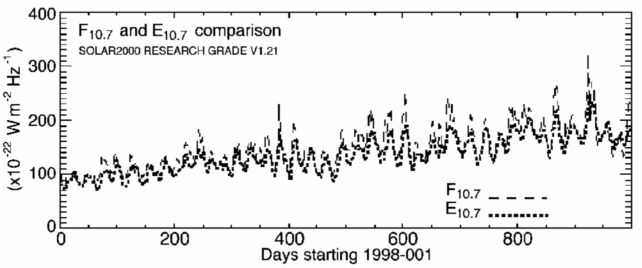


Fig. 2 SOLAR2000 historical $E_{10.7}$ compared to F10.7 for 1000 days starting on 1 January 1998.

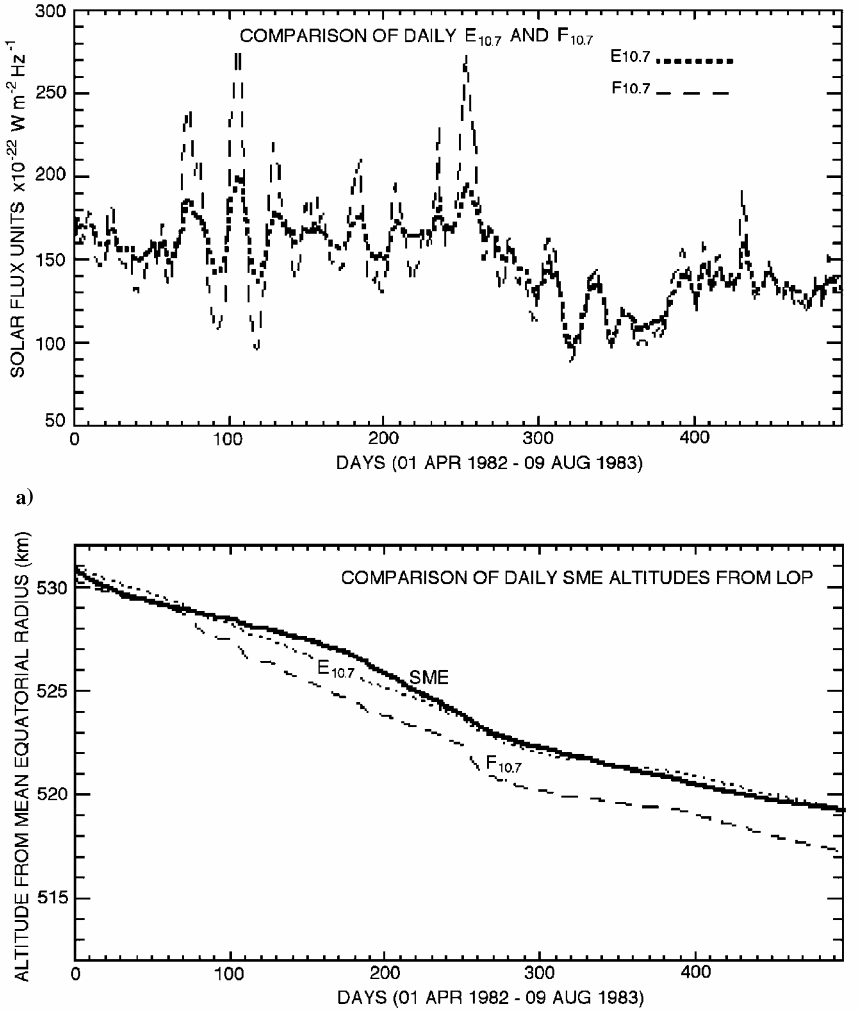


Fig. 3 Panel a) compares $E_{10.7}$ and $F_{10.7}$ between 1 April 1982 and 9 August 1983. Panel b) demonstrates overestimated drag on SME caused by excess $F_{10.7}$ in the Jacchia-type model.

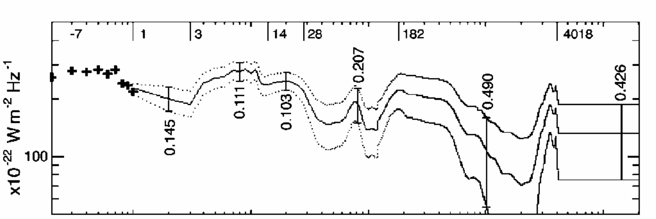
altitude data. The $F_{10.7}$ overestimated the daily EUV energy input into the atmosphere by up to 60% and underestimated it by as much as 50% during active solar conditions. Conversely, $E_{10.7}$ was able to capture nearly all of the solar variability that affected atmospheric densities over a 16-month period of time. Figure 3 shows this improvement in SME's orbit specification using $E_{10.7}$ for the period of 1 April 1982 through 9 August 1983. $F_{10.7}$ varies much more than $E_{10.7}$ and produces an overestimate of the EUV heating of the atmosphere. The second panel demonstrates that excess $F_{10.7}$ causes the Jacchia-type model and the orbit propagator to overestimate the drag on SME. This results in unrecoverable orbit altitude error compared to the SME ephemeris data.

Operational $E_{10.7}$

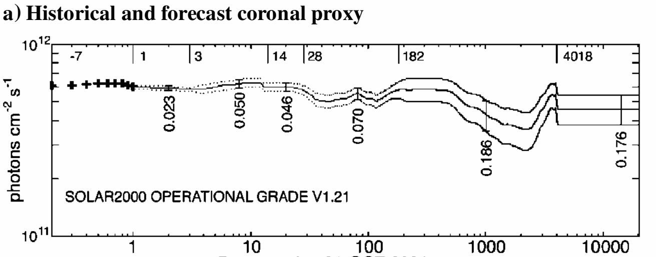
The SOLAR2000 operational grade model produces $E_{10.7}$ for historical, nowcast, forecast, and high time resolution conditions. Historical $E_{10.7}$ is used for satellite operations in quantifying environmental risks, conducting postanalysis studies, and for specifying system requirements and conducting calibration or validation studies.

In the context of space weather operations, nowcast is the period from 24 hours ago to the current epoch, whereas forecast starts at the current epoch. Nowcast $E_{10.7}$ is used for monitoring the solar irradiance background state and event activity, where watches, warnings, alerts, and summaries are provided by the National Oceanic and Atmospheric Administration (NOAA) Space Environment Center (SEC).

In models such as the Global Assimilative Ionospheric Model, it can also be used as a solar driver for modeling ionospheric TEC that, combined with TEC occultation data, provides GPS near real-time scintillation/irregularity knowledge. $E_{10.7}$, now produced on three-hourly time centers, provides high time resolution (minutes to days) information to aid with high-precision location knowledge and pointing specification. Another $E_{10.7}$-related parameter, the derived sunspot number *Rsn* is provided in high time resolution and is used in ray-trace models to provide a background state for operational HF radio link paths. Forecast $E_{10.7}$ can similarly be used for operational near-term (days to months) HF radio links, high-precision location knowledge (including space debris location estimation and avoidance), and high-precision pointing capability. Nowcast and forecast $E_{10.7}$ are produced in SOLAR2000 in the same way historical irradiances are produced. This is done by first forecasting time-step proxies for chromospheric and coronal emissions to generate a full solar spectrum. Subsequently, the 1.862–104.9-nm energy flux is integrated and converted to sfu. The nowcast and forecast proxies generated as the first step in this process are shown in Fig. 4. In this figure seven nowcast and forecast time periods (24 hours, 72 hours, 14 days, 28 days, 6 months, 11 years, and 55 years), plus the previous seven days, are shown in a log-log plot. Very short timescale, high time resolution events such as large solar flares are currently neither nowcast nor forecast. The fractional 1-σ rms uncertainty, valid to two decimal places, is shown for each period.



a) Historical and forecast coronal proxy



b) Historical and forecast chromospheric proxy

Fig. 4 Panel a) shows the previous seven days, current epoch, and forecast SOLAR2000 coronal proxy, and panel b) shows the chromospheric proxy.

Table 2 Existing algorithms for solar irradiances forecasts

Time period	Time regime	Algorithm[a]
−24–0 hours	Nowcast	Viereck et al.[10]
0–72 hours	Forecast	Autoregression using past 14 days
3–14 days	Forecast	Substitution of past 14 days with no smooth
14–28 days	Forecast	Substitution of past 28 days with 7-day smooth (convolution)
1–6 months	Forecast	Substitution of past 6 months with 30-day smooth (convolution)
$\frac{1}{2}$–11 years	Forecast	Substitution of past 11 years with 365-day smooth (convolution)
1–5 solar cycles	Forecast	Mean of five solar cycles

[a]First-generation forecasting algorithms based on SOLAR2000.

In SOLAR2000, all proxies are nowcast and forecast in first generation algorithms based on the fundamental assumption of solar irradiance persistence over timescales of interest. For second-generation algorithm development there is ongoing work to improve all parts of the prediction scheme, and those preliminary concepts are outlined in Tobiska et al.[1] The existing algorithms described here differ between each timescale and are summarized in Table 2. The current algorithms start with the Viereck et al.[10] method for nowcast of a current Mg II value in Eq. (2), for example,

$$\mathrm{EUV}_{\mathrm{Mg\ II\ proxy}} = 0.6\ \mathrm{Mg\ II}_{\mathrm{daily}} + 0.4\ \mathrm{Mg\ II}_{29\text{-day avg}} \tag{2}$$

The 72-hour forecast is generated with an autoregressive technique using the previous 14 days of data to determine the trend of the next three days. The 14-day forecast uses the data starting 14 days ago through the current epoch. The 28-day forecast uses the previous 28-day data convolved with a triangular convolutional function that is seven-days wide in order to smooth the day-to-day variability. The six-month forecast uses the previous six-month data convolved with a triangular function that is 30 days wide in order to smooth the day-to-day variability. The 11-year forecast uses the previous 11-year data convolved with a triangular function that is 365-day wide to smooth the day-to-day variability. The 55-year forecast is the mean of the preceding five solar cycles.

The appropriate rms 1-σ uncertainty is calculated for each time period using both model uncertainty and data variation about the mean of a specific time period. The forecasts are generated backwards, that is, the array containing the entire 55-year data set, starting at the current epoch, is produced first and then each preceding time period overwrites its values up through the current daily nowcast. Discontinuities between time periods are minimized using a smoothing technique through the data points for an appropriate number of days either side of the discontinuity. Despite the simplicity of the existing algorithms, there is good agreement with the nowcast $E_{10.7}$ vs the actual derived $E_{10.7}$, and this is shown in the bottom-panel scatter plot of Fig. 1. In that figure the current epoch nowcast $E_{10.7}$ is compared to historical $E_{10.7}$ for the rise of solar cycle 23 from 1 January 1996 through 31 December 2000. The current epoch three-day forecast is projected onto that scatter plot. Similar comparisons exist for each time period and show different scatter.

Although high time resolution events such as large solar flares are not forecast, the capability is built into SOLAR2000 operations grade model to capture real-time large flaring events as they unfold on a few-minutes resolution timescales. The current cadence of information retrieval is set to one-hour update intervals for the Penticton $F_{10.7}$, the coronal proxy, and the NOAA satellite series SBUV

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:Product: Modified Flux Data              MFD.TXT (Rev. G)
:Issued:   1-Oct-2001 12:10:00.00 UTC
# Prepared by Space Environment Technologies/SpaceWx
# Point-of-contact: W. Kent Tobiska (http://SpaceWx.com)
#
# Metadata:
# Units: Year, Month, Day (YYYY, MM, DD) are UT calendar year,
#          integer month, day of month, hour, minute (hh, mm)
#        S_C is integrated solar spectrum
#          in x10-04 + 1366.05 Watts per meter squared
#        F10, F81 are daily and 81-day solar 10.7 cm radio flux
#          in x10-22 Watts per meter squared per Hertz
#        Lya, L81 are daily and 81-day Lyman-alpha
#          in x10+09 photons per centimeter squared per second
#        E10, E81, E3h, B3h are daily, 81-day, 3-hr, 3-hr-avg E10.7
#          in x10-22 Watts per meter squared per Hertz
#        Ap, a3h are daily mean, 3-hr planetary geomag 2 nT index
#        E1s, a1s are 1 sigma uncertainty of E3h, a3h in proxy units
#        SRC is the data source (Historical, Issued, Predicted)
# Notes: S_C in SOLAR2000 v1.yz is not the TSI variation.
#        E10.7 is unadjusted, integrated 1-105 nm EUV in F10.7 units
#
# Source: SOLAR2000 OPERATIONAL GRADE V1.21
# Location: SpaceWx (PowerMac MacOS IDL 5.5)
# Missing data: -1
#                             Modified Flux Data file
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#---------------------------------------------------------------------
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 200109301500 561 216 238 601 593 226 228  48 226 228  48  11  31   I
 200109301800 561 216 238 601 593 226 228  48 226 228  67  11  31   I
 200109302100 561 216 238 601 593 226 228  48 227 228  48  11  31   I
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Fig. 5 Forecast bulletin for Solar and geomagnetic indices: example format of forecast bulletin.

Mg II, the chromospheric proxy, because the data are available at asynchronous and sometimes irregular epochs. In other words, a new solar spectrum and a new $E_{10.7}$ is nowcast and forecast every hour.

For the operational grade model the 20 UT $F_{10.7}$ "observed" values are used after official NOAA/SEC release ("Issued" data in Fig. 5). These data are adjusted neither to 1 AU nor for flare effects. For the research grade model the World Data Center adjusted data are used, that is, the $F_{10.7}$ is adjusted to 1 AU with flare effects removed. In 2001 and 2002 the Mg II core-to-wing ratio data from the NOAA 16 SBUV instrument were released by NOAA/SEC once per day. Hence, the proxy information is currently oversampled.

This information cadence will change starting in 2002 with the launch of the NOAA 17 SBUV. That spacecraft will become the prime operational satellite, and NOAA 16 (as the secondary satellite) SBUV data will become available at a higher cadence. Even more dramatic improvements to the cadence will occur in 2004 with EUV data to be provided by five broadband detectors on the GOES-N spacecraft. The GOES-N EUV data will have a 5-min cadence such that flare information at high time resolution will be captured similar to the GOES 1-8 Å data that are now available. SOLAR2000 will generate a detailed EUV spectrum using the GOES-N data beginning in 2004, and the $F_{10.7}$ and Mg II proxies will continue to be collected as redundant proxy data sets.

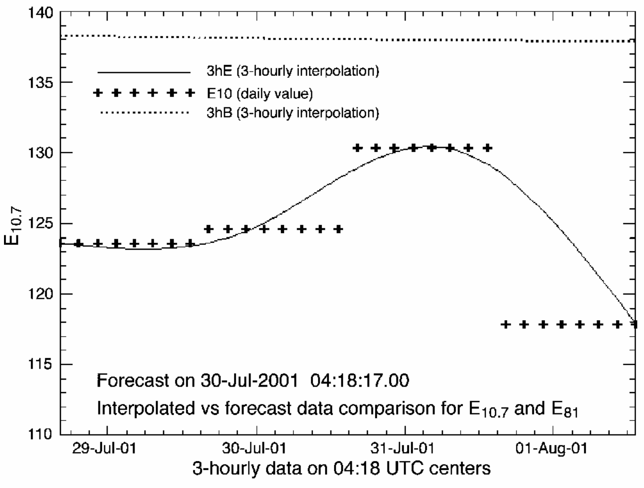

Fig. 6 Interpolated vs forecast $E_{10.7}$ for −24 to +72 hours from the current epoch.

$E_{10.7}$ has been designed for use in thermospheric models that generate multiple dimensions of density data such as MSIS, Marshall Engineering Thermosphere (MET), or Jacchia and Harris–Priester-type models. In general, any model that uses $F_{10.7}$ as an input for solar activity can use $E_{10.7}$. An example format is the three-day forecast bulletin of Fig. 5. Each line (record) in this bulletin is a time step of three hours starting 24 h ago and continuing 72 h into the future. Each record shows the time step in year, month, day, hour, and minute. Next, the daily integrated solar spectrum (S_C), the daily $F_{10.7}$ (F10), its 81-day averaged value (F81), the daily Lyman-alpha irradiance (LYA), its 81-day average (L81), the daily $E_{10.7}$ (E10), its 81-day average (E81), and the daily geomagnetic index Ap (A_p) are shown. S_C represents variability only in the range of 1–122 nm for SOLAR2000 versions 1.yz. For high time resolution operational use, the 3-h $E_{10.7}$ (E3h), the 3-h E81 (B3h), the 3-h geomagnetic index ap (a3h), the 3-h 1-σ $E_{10.7}$ (E1s), the 3-h 1-σ ap (a1s), and the source (SRC) of the data are shown. Data source types are historical (H), issued (I), and predicted (P). The 3-h values are interpolated in the first-generation algorithms where actual 3-h values will replace the interpolated values with the inclusion of the GOES-N high time resolution broadband EUV data. The Ap (daily) and ap (3-h) values come from NOAA SEC predictions, and these will improve as new algorithms are developed. Figure 6 compares the interpolated 3-h $E_{10.7}$ and 81-day average values with the daily $E_{10.7}$ values over a typical four-day period of time (−24 to +72 hours from current epoch).

$E_{10.7}$ is operationally available to LEO satellite operators in the format of Fig. 5 for the purpose of mitigating space weather effects such as atmospheric drag upon spacecraft orbit and attitude parameters. This operational capability supports improvements such as increased spacecraft launch rates and use of low-Earth space, debris and collision avoidance strategies, spacecraft deorbit/reentry capability, pointing precision and location knowledge requirements, and specification of the lower thermosphere (90–150 km) for the proposed suborbital space plane flights.

Conclusions

The LEO region of near-Earth space between 100 and 1000 km is becoming more populated with civilian and military satellites that link commercial, research, and defense infrastructures, as well as an increased population of space debris. We describe an operational tool that models and predicts the solar radiation component of the space environment. The SOLAR2000 operational grade model is developed for support of operations and forecast facilities and utilizes real-time solar proxy inputs. It produces dedicated data streams for user-specified irradiance products that might have a restricted distribution to unique forecast or operations centers. SOLAR2000 specifically produces the $E_{10.7}$ proxy that provides a capability for greater precision and accuracy in spacecraft attitude and orbit determination in an operational environment.

Historical $E_{10.7}$ is provided for satellite operations to quantify risks and probabilities as well as to assist postanalysis event studies. It is also used for calibration, validation, and requirements definition. Nowcast $E_{10.7}$ (within the current 24-h interval) and forecast $E_{10.7}$ (starting 24 h in the future) are produced by SOLAR2000 in the same way historical irradiances are produced, that is, using forecast proxies instead of historical proxies. Examples of these forecast proxies for seven time periods, in addition to the previous seven days, are shown. As a validation metric, an operational scatter plot of three-day forecast $E_{10.7}$ compared with actual $E_{10.7}$ for the five-year rise in solar activity from 1996 through 2000 is presented. An operational bulletin is presented in which the $E_{10.7}$, other solar indices, and the geomagnetic parameters used in atmospheric density models are shown for three-day forecasts with 3-h time steps. The current algorithms that are used to produce the forecast proxies are described.

High time resolution data are produced, although the existing proxy cadence provides little new information content for periods less than a day. However, with the operations of the GOES-N spacecraft in 2004 a cadence of 5-min EUV will become available for satellite operational use via the $E_{10.7}$ proxy. Any operational code, such as thermospheric density or ionospheric models, that uses $F_{10.7}$ as a solar variability input can use the $E_{10.7}$ proxy. This includes code based on MSIS, MET, Jacchia, or Harris–Priester-type models. Substituting $E_{10.7}$ for the traditional $F_{10.7}$ in these models results in a significant improvement for specifying the space environment.

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