©FORECAST E10.7 FOR IMPROVED LEO SATELLITE OPERATIONS

W. Kent Tobiska[a]

ABSTRACT

LEO satellite operators often require accurate and precise knowledge of their spacecraft location and attitude for the recent past, the present, and the near future. Unwanted orbital and orientation changes occur due to drag and perturbations related to atmospheric density changes. These changes are induced by solar extreme ultraviolet irradiance variations, i.e., one of the effects of space weather. A method for improving low-Earth orbiting satellite operations 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 E10.7 proxy. E10.7 is a replacement for 10.7-cm radio flux, F10.7, in atmospheric density models that are linked with orbit determination algorithms. Recent validation work shows the improvement of using daily E10.7 versus F10.7 for satellite orbit determination. The operational development application, and use of the E10.7 proxy are described. A research grade version of SOLAR2000 for historical irradiances and recent publications related to SOLAR2000 and E10.7 are found on the web site http://SpaceWx.com.

BACKGROUND

Space Weather Risks to Operational LEO Satellites

The Low-Earth Orbit (LEO) region of near-Earth space between 100 and 1000 km is populated with civilian and military satellites. These spacecraft are critical links in our commercial, research, and defense infrastructure and have grown through remarkable technological advances in the past five decades. In part, as a consequence of the technological advances that have been incorporated into newer generation spacecraft, satellite operators have recognized a variety of risks from the space environment. Risks to space assets 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 dynamically variable nature of the Sun-Earth interaction on short time scales is called space weather. It can provoke unknown perturbations to satellite orbits and attitudes, can cause interference with radio wave and GPS signal propagation through the Earth's ionosphere, and can adversely affect spacecraft electronics through charged particle effects. Several of the major LEO satellite operator requirements in relation to space weather events are listed in Table 1. An assessment of the existing capability to satisfy those requirements for a categoric time frame is also provided.

Over the past decade, scientific knowledge about the Sun's effects upon the Earth has progressed to the point where space weather products deriving from space physics models are operational. These products are increasingly able to mitigate risks from the space environment. More importantly, data sources that are required to drive these products are now sufficiently regular and robust so as to enable a short-term forecast capability with quantifiable uncertainty. Several types of space environment models, e.g., 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 end of the chain of linked operational applications.

TABLE 1. SEVERAL MAJOR LEO SATELLITE OPERATOR REQUIREMENTS

	LEO satellite operator requirements	Product type	Capability
1)	quantify risk assessment and probabilities, post-analysis	historical	**available**
2)	system requirement specification, calibration, validation	historical	**available**
3)	monitoring to provide alerts, warnings, and tailored displays	nowcast/forecast	**available**
4)	GPS near real time scintillation and irregularity mitigation	nowcast/forecast	future application
5)	high time resolution (minutes to hours) solar irradiances	nowcast/forecast	**available**
6)	near-term (hours to days) forecasts for solar irradiances	nowcast/forecast	**available**
7)	RF link paths and probabilities	nowcast/forecast	**available mid-2002**
8)	high precision location knowledge	nowcast/forecast	**available mid-2002**
9)	high precision pointing capability	nowcast/forecast	future application
10)	debris avoidance capability	nowcast/forecast	future application

[a] Chief Scientist, Space Environment Technologies/SpaceWx, Pacific Palisades, CA, 90272;
ktobiska@spacenvironment.net; http://SpaceWx.com

Atmospheric Density Variations and Satellite Drag

Variations in solar extreme ultraviolet (EUV) irradiances, on time scales of minutes to years, impact the upper atmosphere (thermosphere and ionosphere) densities. These variations affect satellite operational and mission planning activities through changes in the neutral constituent and electron densities. For example, when solar activity is high, the extreme ultraviolet irradiances heat and expand the Earth's upper atmosphere. This increases atmospheric drag and the subsequent orbital decay rate of spacecraft and debris.

EUV heating is the major source of uncertainty behind satellite drag models. Because of the scarcity of EUV measurements, the 10.7-cm solar radio flux, F10.7, has traditionally been used as a proxy for solar EUV heating. Although it was known at the beginning of the satellite era that F10.7 did not contribute to atmospheric heating, ionization, or dissociation processes, it became a useful surrogate for solar EUV emissions from empirical relationships. It is currently used as the solar variation driver in most atmospheric density analytical and empirical models linked with orbit propagators.

The existing state-of-the-art capabilities contain 15% uncertainties (J. Owens and F. Marcos, private communications, 2000). This represents the practical limit of F10.7 proxy capability where significant improvements in atmospheric density calculations are unlikely. The limitations of F10.7 are not surprising since it has no physical connection to the upper atmosphere, only marginally represents solar EUV irradiances, and will not capture temporal changes of less than a day.

METHODOLOGY

The SOLAR2000 Model

SOLAR2000 is 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- 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 (ISO) solar irradiance draft standard WD 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]. SOLAR2000 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, i.e., to preserve a knowledge-bridge from historical measurements to eventual first principles' representation of solar irradiances and to provide research and operational solar irradiances. 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 SOLAR2000 operational grade model is developed for use in operations and forecast applications. It utilizes real-time solar irradiance proxy inputs of F10.7 for coronal emissions and Mg II core-to-wing ratio for chromospheric emissions between 2000-2003 and will use GOES-N EUV broadband data beginning in 2004. It produces historical, nowcast, forecast, and high time resolution solar irradiances tailored for specific user requirements. For example, a 3-day forecast daily irradiance product is shown in Figure 1. The E10.7 current epoch forecast is compared with the solar cycle 23 minimum to maximum values in the top panel and with the recent history of the past 54 days (approximately two solar rotations) in the bottom panel.

E10.7 Proxy

Satellite operators often desire greater precision and accuracy in spacecraft attitude and orbit determination. To aid the operational environment, space physics modelers in the 1990s began active development of parameters to better represent the space environment. As the process has accelerated of transitioning models-for-research to models-for-operations, a complementary objective of model improvement came from government agency space weather programmatic goals. At the same time, a paradigm shift occurred for modelers when they realized that it is much easier to develop a new irradiance proxy than to change millions of lines of legacy code. In this context, work by G. Schmidtke[7] was resurrected in 2000.

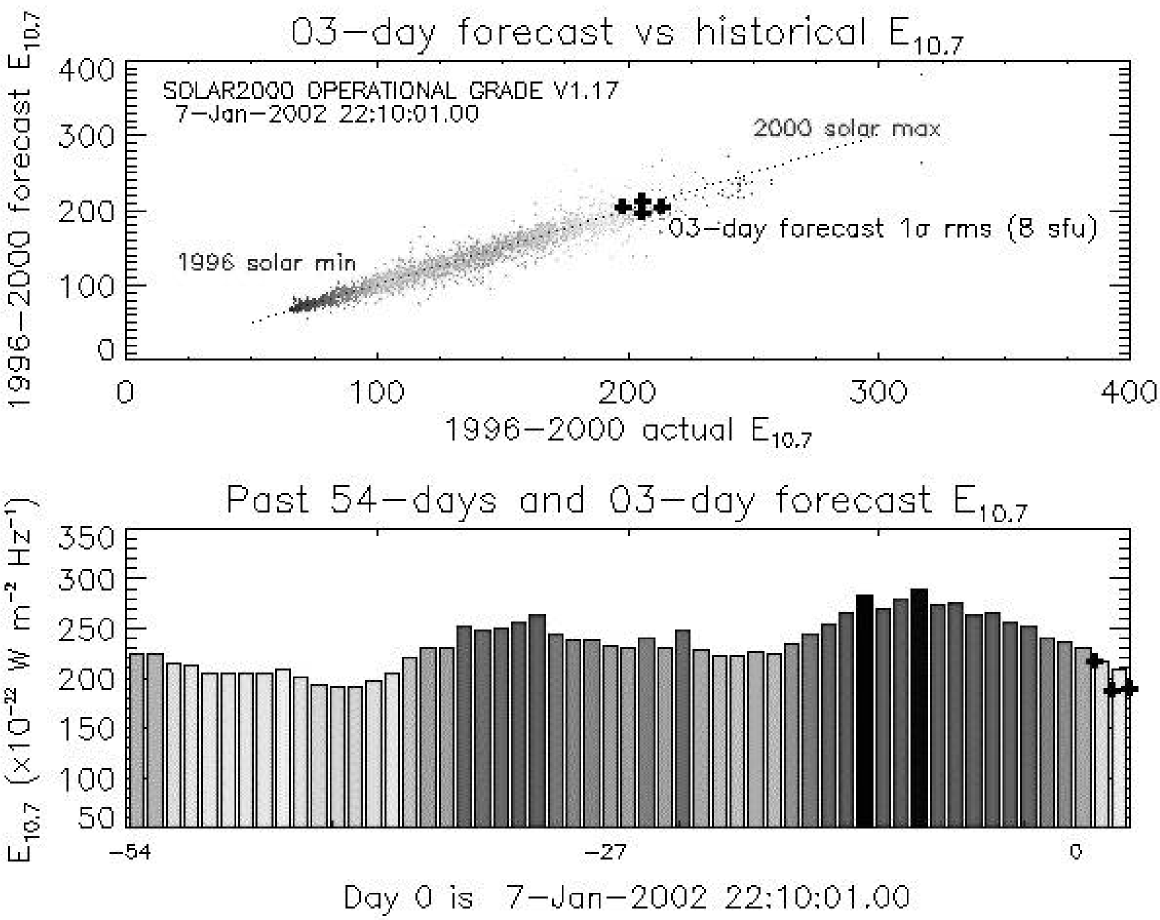

Figure 1: Current epoch 3-day forecast E10.7 compared to actual E10.7 for solar cycle 23 minimum (1996) through maximum (2000) (top panel). E10.7 for the next 72-hour period from the current epoch compared to the previous 54-days of E10.7 (bottom panel).

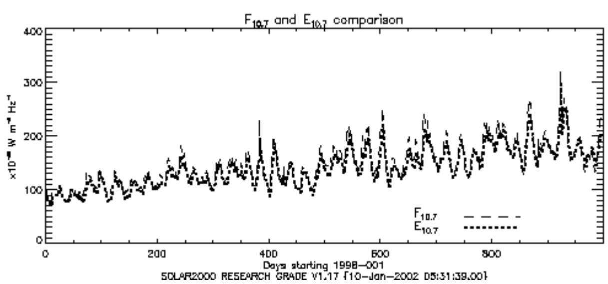

Figure 2: SOLAR2000 historical E10.7 compared to F10.7 for 1000 days starting on January 1, 1998.

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, i.e., the solar EUV energy, *I(λ,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 as the historical F10.7 proxy and renamed E10.7 to indicate that it is the total EUV energy arriving at 1 AU and is reported in F10.7 units. Figure 2 shows SOLAR2000 historical E10.7 compared to F10.7 for 1000 days starting on January 1, 1998.

Improvement of Densities using E10.7

In a series of E10.7 validations that was performed by Tobiska[3], an improvement in thermospheric density modeling for satellite operators was demonstrated using the daily E10.7 compared to F10.7. In that study, the daily altitude decay for the Solar Mesosphere Explorer (SME) satellite was modeled using both daily proxies and compared with the actual mean equatorial altitude data. The F10.7 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, E10.7 was able to capture nearly all 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 E10.7.

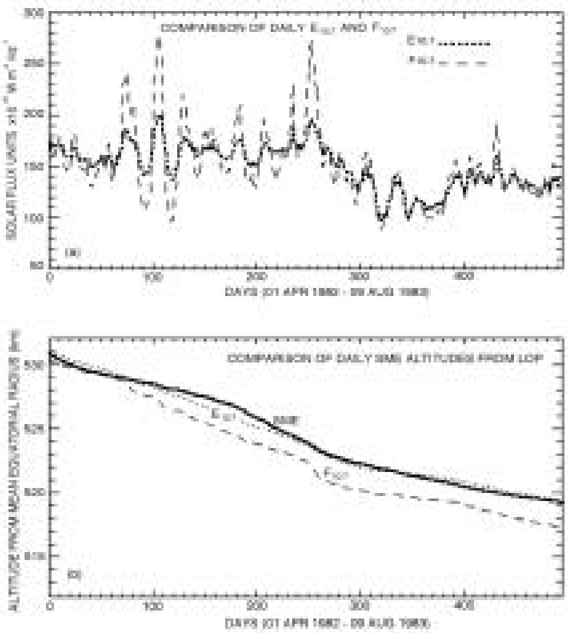

Figure 3. The top panel (a) shows the comparison between $E_{10.7}$ and $F_{10.7}$ for the period of April 1, 1982 through August 9, 1983. $F_{10.7}$ varies much more than $E_{10.7}$ and produces an overestimate of the EUV heating of the atmosphere. The bottom panel (b) demonstrates that excess $F_{10.7}$ causes the J71 model and the orbit propagator to overestimate the drag on SME. This results in unrecoverable orbit altitude error compared to the SME ephemeris data. On the other hand, $E_{10.7}$ used in the J71 atmosphere and orbit propagator captures nearly all the solar variability.

OPERATIONAL E10.7

Historical Solar Irradiances

The SOLAR2000 operational grade model produces E10.7 for historical, nowcast, forecast, and high time resolution conditions. Historical E10.7 is used for satellite operations in quantifying risks and probabilities as well as for post-analysis studies of particular events. It is also used in system specification for calibration, validation, and requirements-definition.

Nowcast and Forecast Solar Irradiances

In the context of space-weather operations, nowcast is defined as the current 24-hour period while forecast is defined as the epoch starting 24 hours from the current epoch. Nowcast E10.7 is used for monitoring solar activity, providing alerts and warnings. It can also be used as a solar driver for modeling ionospheric total electron content (TEC) that is combined with data to provide GPS near real time scintillation/irregularity mitigation. E10.7 that is reported in high time resolution (minutes to hours) aids the high precision location knowledge and pointing specification. An E10.7-based parameter in high time resolution can be used in ray-trace models to provide operational RF link paths and probabilities. Forecast E10.7 can similarly be used for operational near-term (hours to days) RF link paths and probabilities, high precision location knowledge (including debris avoidance), and high precision pointing capability. Nowcast and forecast E10.7 are produced in SOLAR2000 in the same way historical irradiances are produced, i.e., time-step proxies for chromospheric and coronal emissions generate a full solar spectrum and the 1.862 – 104.9 nm energy flux is integrated, then converted, to F10.7 units. Nowcast and forecast proxies are generated as the first step in this process. Figure 4 shows these proxies for seven nowcast and forecast time periods (24-hour, 72-hour, 14-day, 28-day, 6-month, 11-year, and 55-year) plus the previous 7 days in a log-log plot. Very short time scale, high time resolution events such as large solar flares are neither nowcast nor forecast.

In SOLAR2000, all proxies are nowcast and forecast using the fundamental assumption of solar irradiance persistence over time scales of interest. 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 differ between each time scale, are described here, and are summarized in Table 2. The current algorithms start with the Viereck *et al*.[8] method for nowcast of a current Mg II value, e.g.,

$$EUV_{\mathrm{Mg\ II\ proxy}} = 0.6\ \mathrm{Mg\ II}_{\mathrm{daily}} + 0.4\ \mathrm{Mg\ II}_{\mathrm{29\text{-}day\ avg.}}$$

The 72-hour forecast is generated with an autoregressive technique using the previous 14 days of data to determine the trend of the next 3 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 function that is 7-days wide in order to smooth the day-to-day variability. The 6-month forecast uses the previous 6-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

TABLE 2. EXISTING ALGORITHMS FOR SOLAR INDICES' FORECAST

Time period	Product type	Algorithm
0 – 24 hours	nowcast	Viereck et al., 2001[8]
24 – 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)
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

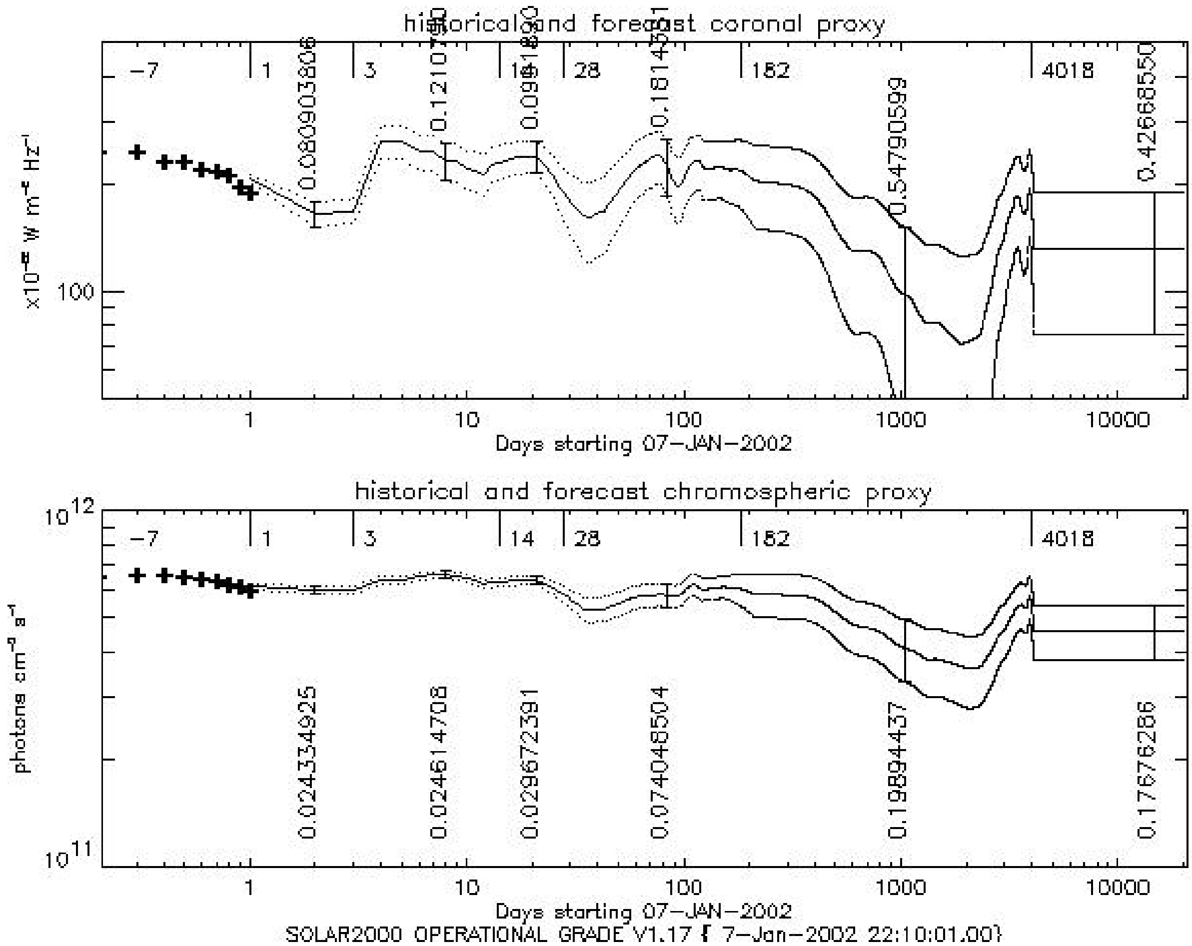

Figure 4: SOLAR2000 forecast proxies for coronal (top panel) and chromospheric (bottom panel) emissions over several distinct time periods. The fractional 1σ rms uncertainty, valid to 2 decimal places, is shown for each period.

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 previous 5 solar cycles.

The appropriate rms 1σ 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, i.e., 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 smooth 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 E10.7 versus the actual derived E10.7 and this is shown in the top panel scatter plot of Figure 1. In that figure, the current epoch nowcast E10.7 is compared to historical E10.7 for the rise of solar cycle 23 from January 1, 1996 through December 31, 2000. The current epoch 3-day forecast is projected onto that scatter plot. Similar comparisons exist for each time period and show different scatter.

High Time Resolution (minute to hours)

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 minutely time scales. The current cadence of information retrieval is set to one hour update intervals for the Penticton F10.7, the coronal proxy, and the NOAA 16 SBUV Mg II, the chromospheric proxy, since the data are available at asynchronous and sometimes irregular epochs. In other words, a new solar spectrum and a new E10.7 is nowcast and forecast every hour.

For the operational grade model, the 20 UT F10.7 values are used after official NOAA/SEC release ("Issued" data in Table 3). These data are neither adjusted to 1 AU or for flare effects. For the research grade model, the WDC adjusted data is used, i.e., the F10.7 is adjusted to 1 AU with flare effects removed. In 2001 and into 2002, the Mg II core-to-wing ratio data from the NOAA 16 SBUV instrument is released by NOAA/SEC once per day. Hence, the proxy information is currently over-sampled.

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-minute cadence such that flare information at high time resolution will be captured similar to the GOES 1-8 Å data that is now available. SOLAR2000 will generate a detailed EUV spectrum using the GOES-N data beginning in 2004 while the F10.7 and Mg II proxies will continue to be collected as redundant proxy data sets.

Operational Use of E10.7 in Atmospheric Models

E10.7 has been designed for use in thermospheric models that generate multiple dimensions of density data such as MSIS, MET, or Jacchia and Harris-Priester type models. In general, any model that uses F10.7 as an input for solar activity can use E10.7. An example format is the 3-day forecast bulletin of Table 3. Each line (record) in this bulletin is a time step of three hours starting 24 hours ago and continuing 72 hours into the future. Each record shows the time step in two formats, i.e., year, month, day, hour, minute and absolute Julian day. Next, the daily integrated solar spectrum (S_C), the daily F10.7 (F10), its 81-day averaged value (F81), the daily Lyman-alpha irradiance (LYA), its 81-day value (L81), the daily E10.7 (E10), its 81-day value (E81), and the daily geomagnetic index Ap (A_p) are shown. S_C represents variability only in the range of 1-122 nm. In addition, for high time resolution operational use, the 3-hourly E10.7 (3hE), the 3-hourly E81 (3hB), the 3-hourly geomagnetic index ap (3ha), the 3-hourly 1-σ E10.7 (1sE), the 3-hourly 1-σ ap (1sa), and the source (SRC) of the data are shown. Data source types are Historical, Issued, and Predicted. The 3-hour values are currently interpolated and actual 3-hour 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-hourly) values come from NOAA SEC predictions and these will improve as new algorithms are developed. Figure 5 compares the interpolated 3-hour E10.7 and 81-day average values with the daily E10.7 values over a typical 4-day period of time (-24 to +72 hours from current epoch).

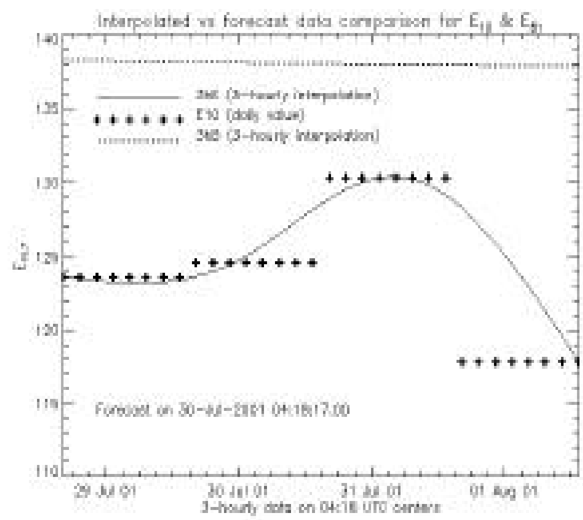

Figure 5: Interpolated versus forecast E10.7 for –24 to +72 hours from the current epoch.

E10.7 is operationally available to LEO satellite operators in the format of Table 3 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 de-orbit/re-entry capability, pointing precision and location knowledge requirements, and specification of the lower thermosphere (90-150 km) for the proposed sub-orbital 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 our commercial, research, and defense infrastructure. 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 may have a restricted distribution to unique forecast or operations centers. SOLAR2000 specifically produces the E10.7 proxy that provides a capability for greater precision and accuracy in spacecraft attitude and orbit determination in an operational environment.

Historical E10.7 is provided for satellite operations to quantify risks and probabilities as well as to assist post-analysis event studies. It is also used for calibration, validation, and requirements-definition. Nowcast E10.7 (within the current 24-hour interval), and forecast E10.7 (starting 24 hours in the future), are produced by SOLAR2000 in the same way historical irradiances are produced, i.e., using forecast proxies instead of historical proxies. Examples of these forecast proxies for seven time periods, in addition to the previous 7 days, are shown. As a validation metric, an operational scatter plot of 3-day forecast E10.7 compared with actual E10.7 for the five-year rise in solar activity from 1996 through 2000 is presented. An operational bulletin is presented in which the E10.7, other solar indices, and the geomagnetic parameters used in atmospheric density models are shown for 3-day forecasts with 3-hour 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-minute EUV will become available for satellite operational use via the E10.7 proxy. Any operational code, such as thermospheric density or ionospheric models, that uses F10.7 as a solar variability input, can use the E10.7 proxy. This includes code based on MSIS, MET, or Jacchia and Harris-Priester type models. Substituting E10.7 for the traditional F10.7 in these models results in a significant improvement for specifying the space environment.

ACKNOWLEDGMENTS

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, by the NASA LWS contract NASW-01006, by the NATO EST.CLG 975301 collaborative travel grant, and by the NOAA/SEC-SET CRADA. All relevant documentation for SOLAR2000, along with the research grade SOLAR2000 IDL GUI application, can be downloaded from http://SpaceWx.com .

REFERENCES

[1] Tobiska, W.K, T. Woods, F. Eparvier, R. Viereck, L. Floyd, D. Bouwer, G. Rottman, and O.R. White, "The SOLAR2000 empirical solar irradiance model and forecast tool," *J. Atm. Solar Terr. Phys.*, Vol. 62, No. 14, 2000, pp. 1233-1250.

[2] Tobiska, W.K., "Status of the SOLAR2000 solar irradiance model," *Phys. Chem. Earth*, Vol. 25, No. 5-6, 2000, pp. 383-386.

[3] Tobiska, W.K., "Validating the Solar EUV Proxy, E10.7", *J. Geophys.Res.*, **106,** A12, 2001, pp. 29969-29978.

[4] Tobiska, W.K. and A.A. Nusinov, Status of the draft ISO solar irradiance standard, *Phys. Chem. Earth*, Vol. 25, No. 5-6, 2000, pp. 387-388.

[5] Tobiska, W.K., "Variability in the TSI from Irradiances Shortward of Lyman-alpha," *Adv. Space Research*, 2002, in press.

[6] National Space Weather Program, Implementation Plan, 2nd Edition, FCM-P31-2000, Washington, DC, July 2000.

[7] Schmidtke, G, "EUV indices for solar-terrestrial relations," *Geophys. Res. Lett.*, Vol. 3, 1976, pp. 573-576.

[8] Viereck. R., L. Puga, D. McMullin, D. Judge, M. Weber, and W.K. Tobiska, "The Mg II Index: A Proxy for Solar EUV," *Geophys. Res. Lett.*, Vol. 28, 2001, pp. 1343-1346.

TABLE 3. FORECAST BULLETIN FOR SOLAR AND GEOMAGNETIC INDICES

```
:Product: Modified Flux Data                         mfd.txt (Rev. E)
:Issued:   7-Jan-2002 22:10:01.00 UTC
# Prepared by SpaceWx
# Point-of-contact: W. Kent Tobiska (http://SpaceWx.com)
#
# Metadata:
# Units: Year, Month, Day (YR, MO, DA) are calendar year, integer month, day of month
#        Hour, Minute (HH, MM) are integer hour and minute in UT
#        Julian Day (JD) is the corresponding absolute Julian date
#        S_C = is integrated solar spectrum x10-04 + 1366.05 Watts per meter squared
#        F10, F81 = is solar 10.7 cm radio flux x10-22 Watts per meter squared per Hertz
#        Lya, L81 = is Lyman-alpha x10+09 photons per centimeter squared per second
#        E10, E81, 3hE, 3hB = is daily, 81-day, 3-hour, 3-hour-averaged E10.7
#                    x10-22 Watts per meter squared per Hertz
#        Ap, 3ha = is daily mean and 3-hourly planetary geomagnetic index in 2 nT
#        1sE, 1sa = is 1 sigma uncertainty of 3hE, 3ha in units of those indices
#        SRC = is the source of the data (Historical, Issued, Predicted)
# Notes: the integrated solar spectrum (1-122 nm) in SOLAR2000 v1.yz is not the same as
#   TSI variation. The full TSI variation is captured in v3.yz and higher.
#   H Lyman-alpha irradiance is both a line emission and a chromospheric FUV index.
#   E10.7 is the unadjusted, integrated 1-105 nm EUV reported in F10.7 units.
#
# Source: SOLAR2000 OPERATIONAL GRADE V1.17
# Location: SpaceWx {sparc unix IDL 5.4}
# Missing data: -1
#                          Modified Daily Flux file
#   CALENDAR        JULIAN
# YR  MO DA HHMM      Day      S_C F10 F81 LYA L81 E10 E81 A_p 3hE 3hB 3ha 1sE 1sa SRC
#-------------------------------------------------------------------------------------
 2002 01 06 2100 2452281.37500 548 189 225 599 624 208 239   4 208 239   4   5   4   I
 2002 01 07 0000 2452281.50000 548 189 225 599 624 208 239   4 207 239   4   5   4   I
 2002 01 07 0300 2452281.62500 548 189 225 599 624 208 239   4 206 239   4   5   4   I
 2002 01 07 0600 2452281.75000 548 189 225 599 624 208 239   4 205 239   4   5   4   I
 2002 01 07 0900 2452281.87500 548 189 225 599 624 208 239   4 204 239   5   5   4   I
 2002 01 07 1200 2452282.00000 548 189 225 599 624 208 239   4 204 239   5   5   4   I
 2002 01 07 1500 2452282.12500 548 189 225 599 624 208 239   4 203 239   6   5   4   I
 2002 01 07 1800 2452282.25000 548 189 225 599 624 208 239   4 203 239  -1   5   4   I
 2002 01 07 2100 2452282.37500 547 189 225 599 623 205 238   9 204 239  -1   5   4   P
 2002 01 08 0000 2452282.50000 547 189 225 599 623 205 238   9 204 238   7   5   4   P
 2002 01 08 0300 2452282.62500 547 189 225 599 623 205 238   9 205 238   7   5   4   P
 2002 01 08 0600 2452282.75000 547 189 225 599 623 205 238   9 206 238   7   5   4   P
 2002 01 08 0900 2452282.87500 547 189 225 599 623 205 238   9 208 238  15   5   4   P
 2002 01 08 1200 2452283.00000 547 189 225 599 623 205 238   9 209 238  15   5   4   P
 2002 01 08 1500 2452283.12500 547 189 225 599 623 205 238   9 211 238  15   5   4   P
 2002 01 08 1800 2452283.25000 547 189 225 599 623 205 238   9 213 238   7   5   4   P
 2002 01 08 2100 2452283.37500 553 206 224 609 623 219 238   9 215 238   4  11   4   P
 2002 01 09 0000 2452283.50000 553 206 224 609 623 219 238   9 217 238   7  11   4   P
 2002 01 09 0300 2452283.62500 553 206 224 609 623 219 238   9 218 238   7  11   4   P
 2002 01 09 0600 2452283.75000 553 206 224 609 623 219 238   9 219 238   7  11   4   P
 2002 01 09 0900 2452283.87500 553 206 224 609 623 219 238   9 219 238  15  11   4   P
 2002 01 09 1200 2452284.00000 553 206 224 609 623 219 238   9 219 238  15  11   4   P
 2002 01 09 1500 2452284.12500 553 206 224 609 623 219 238   9 218 238  15  11   4   P
 2002 01 09 1800 2452284.25000 553 206 224 609 623 219 238   9 216 238   7  11   4   P
 2002 01 09 2100 2452284.37500 542 164 223 599 622 190 237   9 214 237   4  11   4   P
 2002 01 10 0000 2452284.50000 542 164 223 599 622 190 237   9 212 237   7  11   4   P
 2002 01 10 0300 2452284.62500 542 164 223 599 622 190 237   9 209 237   7  11   4   P
 2002 01 10 0600 2452284.75000 542 164 223 599 622 190 237   9 205 237   7  11   4   P
 2002 01 10 0900 2452284.87500 542 164 223 599 622 190 237   9 201 237  15  11   4   P
 2002 01 10 1200 2452285.00000 542 164 223 599 622 190 237   9 198 237  15  11   4   P
 2002 01 10 1500 2452285.12500 542 164 223 599 622 190 237   9 194 237  15  11   4   P
 2002 01 10 1800 2452285.25000 542 164 223 599 622 190 237   9 190 237   7  11   4   P
```