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The TIGER (thermospheric–ionospheric geospheric research) program: Introduction

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Abstract

In 1998, the long-term TIGER Program was established within the framework of the SCOSTEP International Solar Cycle Study Working (ISCS) Group 1, Panel 2. The primary objective of this initiative is to determine the variable solar extreme ultraviolet/ultraviolet (EUV/UV) and X-ray fluxes to improve the existing and future thermospheric–ionospheric (T/I) models and to derive EUV/UV indices or proxies for various applications in space research and space-related fields such as navigation and communication. In 2004, the 5th TIGER Symposium was held as a session of COSPAR. The science topics are summarized in the following sections.

Keywords: Solar EUV/UV and X-ray fluxes; Solar variability; EUV/UV radiation modelling; Modelling of the thermosphere/ionosphere

1. The TIGER program

To make continuous progress in understanding and modelling the T/I processes, it is necessary to envisage timescales ranging from minutes (flares) to years (solar cycles). This can be done in the space weather to global change context by making use of a broad range of worldwide existing resources with respect to manpower, experience, hardware, methods, flight opportunities, and funding resources. The TIGER program aims to facilitate the coordination of these existing and planned activities and to help define missing links for achieving the scientific goals. The latter ones are dealt with at regularly organized symposia (Schmidtke, 2000):

1st TIGER Symposium in Freiburg/Germany (1998).
2nd TIGER Symposium in St. Petersburg/Russia (1999).
3rd TIGER Symposium in Boulder/USA (2001).
4th TIGER Symposium on the Internet (2002).
5th TIGER/COSPAR Symposium in Paris/France (2004).
6th TIGER/COSPAR Symposium in Bejing/China (2006).

The topics and subtopics of the scientific program of the 5th TIGER Symposium were:

1. Measurement of solar EUV/UV radiation.
   1.1 Results from recent missions.
   1.2 XUV monitoring missions.
   1.3 Intercomparison of EUV/UV measurements.
   1.4 EUV/UV data base.
   1.5 Are there solar XUV precursors to space weather activities?

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2. EUV/UV space instrumentation and its calibration.
   - 2.1 Calibration standards.
   - 2.2 Common use of calibration equipment/procedures.
   - 2.3 Effects causing efficiency changes in EUV/UV instruments.
3. Modelling of solar EUV/UV radiation.
   - 3.1 Empirical modelling of the solar EUV/UV irradiance.
   - 3.2 Physical modelling of solar EUV/UV emissions.
   - 3.3 Intercomparison of results from EUV/UV models.
   - 3.4 Definition and needs of/for solar EUV/UV indices.
   - 3.5 Is the use of the MgII index an improvement over the $F_{10.7}$ index?
   - 3.6 ISO solar irradiance standard.
   - 3.7 Can a XUV Space Weather index be derived?
4. Modelling of the thermosphere/ionosphere.
   - 4.1 General circulation modelling.
   - 4.2 Semi-empirical modelling.
   - 4.3 Photochemical and airglow modelling.

2. Measurement of solar EUV/UV radiation

Quasi-continuous satellite-based measurements from the total solar disk play a key role in the determination of the highly variable EUV/UV fluxes relevant to upper atmospheric physics of the solar system planets. A recent review of solar EUV irradiance measurements is published by Woods et al. (2004). Though many missions have been conducted in the past (see Fig. 1 demonstrating the time/wavelength coverage), our knowledge still has to be improved strongly to achieve the accuracy of the results and the solar cycle coverage as needed for modern upper atmospheric and solar physics and their various applications in T/I and EUV/UV modelling, climatology, satellite orbit prediction, navigation and communication. Based on the recent improvements of the complex EUV/UV optical technology as well as the semi-empirical EUV/UV modelling, a threefold philosophy has been developed that is already applied and will further be applied in the frame of the TIGER program in order to optimize the limited resources available in international and national space programs: first, satellite missions with sophisticated instrumentation such as spectrometers to be added by missions with low-cost broadband instruments are providing the primary data sets; second, in order to derive these data with highest possible accuracy, re-calibration of the space instrumentation is one of the central activities; and third, semi-empirical EUV/UV modelling represents the data sets as derived from the measurements and tests the compliance of data from different missions. These three points are discussed in the corresponding topics of the symposium.

The application of these results in the various fields is of special interest for T/I modelling as the large number of talks in Topic 4 underlines the importance.

3. EUV/UV space instrumentation and its calibration

EUV/UV calibration procedures are well established in the laboratory at accuracy levels of a few percent. However, due to various surface effects on the optical components of satellite instrumentation in a vacuum, and by interaction with EUV/UV and particle radiation in space, the instruments' efficiencies change with time in unpredictable ways thus decreasing the reliability of the detected data. For this reason calibration of the instru-

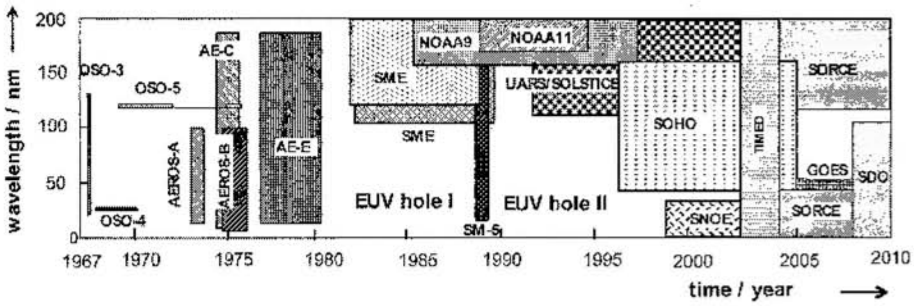

Fig. 1. Time/wavelength coverage of solar flux measurements from satellites: In the spectral region from 100 to 200 nm satellites flown are providing a good temporal coverage of the solar fluxes starting with the mission of the Atmospheric Explorer C. At shorter wavelengths there are substantial gaps (EUV holes I and II). OSO, Orbiting Solar Observatory (Timothy, 1977); AEROS, aeronomy satellite (Lämmerzahl and Bauer, 1974); AE, atmospheric explorer (Hinteregger et al., 1973); SME, solar mesospheric explorer (Mount and Rottman, 1983); NOAA, National Oceanic and Atmospheric Administration: satellites (see NOAA homepage); SM, San Marco satellite (Schmidtke et al., 1985); UARS/SOLSTICE, (Woods et al., 1996); SOHO, Solar and Heliospheric Observatory (Pauluhn et al., 2002); SNOE, students nitric oxide explorer (Solomon et al., 2001); TIMED, thermospheric–ionospheric–mesospheric energetics and dynamics (Woods et al., 2005); SORCE, solar radiation and climate experiment (Woods et al., 2000); GOES, geostationary satellite server (see GOES homepage); SDO, Solar Dynamics Observatory (see SDO homepage).

ments in the laboratory prior to launch is not sufficient for extended satellite missions. Instruments must be re-calibrated or at least be cross-calibrated repeatedly in-flight to determine the complex set of efficiency parameters with time and with temperature for each set of optical components, down to the individual pixel point of a channel plate. The calibration methods and procedures for selected components are dealt with in the course of the TIGER program.

4. Modelling of solar EUV/UV radiation

Good progress has been achieved in EUV solar flux modelling in terms of accuracy, as shown notionally in Fig. 2. Depending on wavelength, the goal is to improve the radiometric accuracy within one decade to about 5% in the 120-nm spectral region and better than 10% in the 20-nm spectral region with an almost monotonic interpolation in between. This is an ambitious goal for the TIGER program.

The most used models of the solar spectral irradiance are compiled in Fig. 3 with their applicable wavelength ranges indicated.

The improvement of already existing (Schmidtke, 1976) and the evaluation of new EUV/UV indices for different applications were described in the TIGER Symposium. Typical examples are given below (Tobiska and Bouwer, 2005):

EUV/UV – EUV/UV spectral irradiance (image calibration).
$E_{10.7}$ – EUV energy flux (satellite drag, TEC, n_e)
E_{TEC} – related to Total Electron Content and ionospheric plasma parameters.

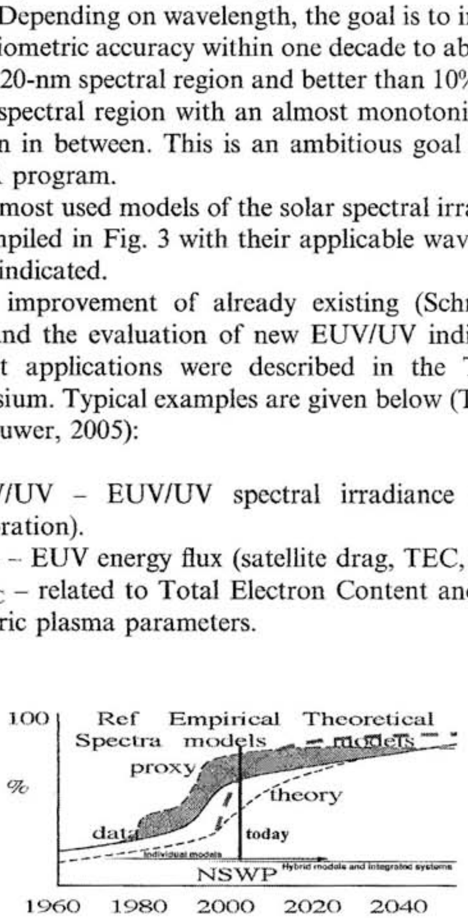

Fig. 2. The progress in EUV solar flux modelling is demonstrated by achieving higher radiometric accuracy with time. The notional improvement in measurements (data) is shown by the solid line, the improvement in physics-based modelling (theory) is shown by the short dash line and the dark gray dash line, and the improvements in empirical modelling (proxy) are shown in the long dash line. Eventually, one expects theory and data to compare very well. The gray region marks the area where proxy models fill a theory-data gap. The TIGER 2004 meeting is marked by the vertical black line (today) and the US National Space Weather Program era is marked by "NSWP." For the future it is an ambitious goal for the TIGER program to improve the accuracy to about 5% in the 120-nm spectral region and better than 10% in the 20-nm spectral region within one decade.

S – integrated solar spectrum (solar radiation pressure, s/c attitude)
R_{SN} – derived sunspot number (HF ray-trace algorithms)
T_{inf} – derived exospheric temperature (climate change studies)
Q_{EUV} – thermospheric heat rate (aeronomy validation)
P_{EUV} – EUV hemispheric power (aeronomy comparison w/J heat)
E_{1-40} – integrated EUV 1–40 nm energy (aeronomy validation)
X_{b10} and X_{hf} – X-ray background and flare indices (flare effects)
E_{SRB} – Schumann–Runge band energy (solar-dynamics coupling)
E_{SRC} – Schumann–Runge continuum energy (solar-dynamics coupling)

5. Modelling of the thermosphere/ionosphere

Daily solar irradiance measurements in the ultraviolet have now reached a state of reliability and availability that enables them to be used directly in general circulation model simulations of the thermosphere–ionosphere system in place of solar proxy model inputs. Fig. 4 shows an example of calculations performed using a new method for incorporating TIMED/SEE measurements (Woods et al., 2005) in the NCAR Thermosphere–Ionosphere–Electrodynamics General Circulation Model (TIE-GCM), (Richmond et al., 1992) including the effects of photoelectron ionization and subsequent dissociative and photochemical processes.

Advancement is also being made in photochemical and airglow modelling using recent information on solar ultraviolet spectral variability. Comparisons between ionospheric measurements, the International Reference Ionosphere empirical model, and photochemical model calculations, demonstrate good progress toward improved understanding of energy deposition and ionization processes in the lower ionosphere.

6. Outlook

The future activities that will benefit the TIGER program are additional measurements of the solar EUV irradiance and thermospheric airglow and advances in modelling the solar EUV irradiance and the thermosphere and ionosphere. The continued measurements of the solar EUV irradiance by TIMED SEE and SOHO instruments could overlap with the future measurements by the Russian Solar Patrol mission in 2004, the NOAA GOES missions in 2005, the ESA SOL-ACES instru-

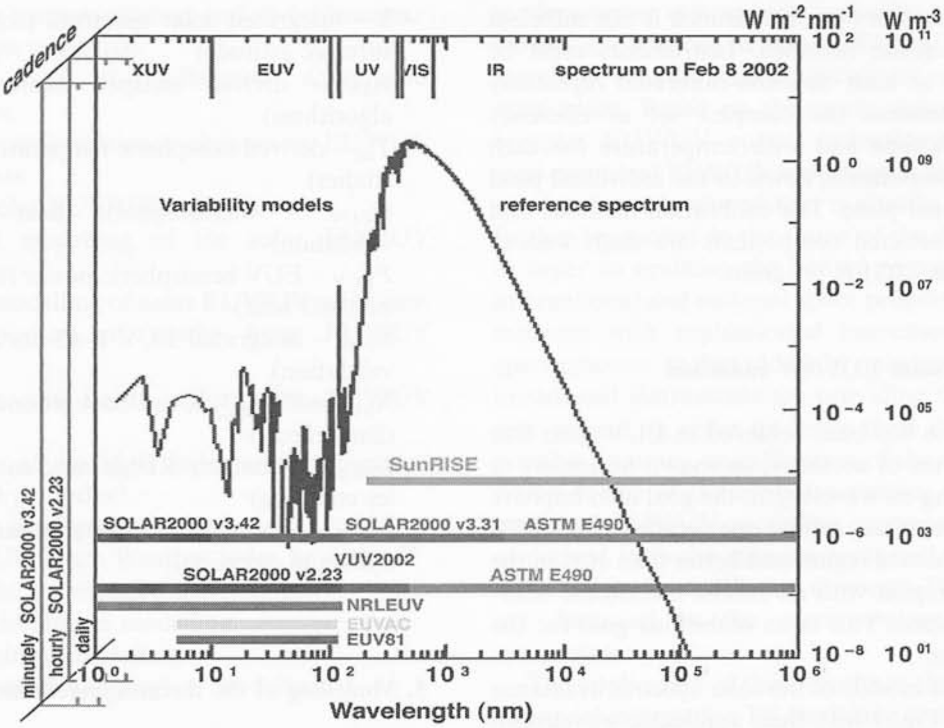

Fig. 3. Solar reference spectrum and solar spectral irradiance models with their applicable wavelength ranges indicated (Tobiska and Nusinov, 2005). The primary window is for models that provide daily solar irradiances and the z-axis windows denoting irradiance cadences (left y-axis drawn) are for models that provide hourly and minutely spectra, respectively. The ISO 21348 defined spectral windows are indicated at the top of the figure.

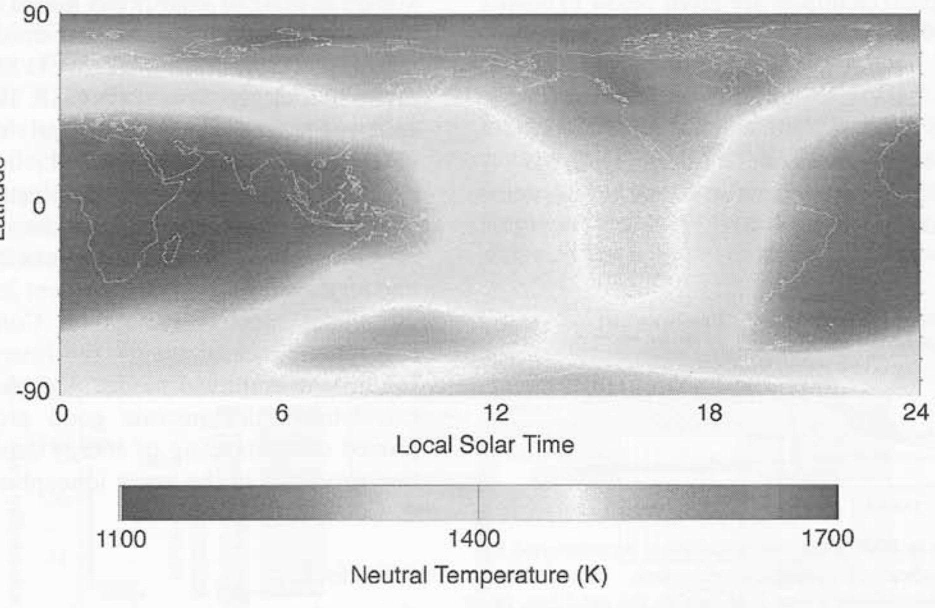

Fig. 4. An example simulation showing the global neutral temperature in the thermosphere using the NCAR Thermosphere–Ionosphere–Electrodynamics General Circulation Model (TIE-GCM) on 8 September 2002, UT 0, at the +4 pressure level (about 300 km). Measured solar irradiance from the TIMED/SEE instrument was used to perform the model simulation.

ment aboard the International Space Station in 2006, and the EVE instrument aboard the NASA Solar Dynamics Observatory (SDO) in 2008. Continued airglow measurements by the TIMED GUVI instrument could overlap with the future measurements from the Geospace missions planned for the NASA Living With a Star (LWS) program and from a variety of US military satellites. In addition to the existing models, a new integrated effort for advancing the T/I models has been initiated by 13 USA institutions that have formed the

Center for Integrated Space weather Modelling (CISM). The CISM plans, as well as other new model development plans, include a goal for making reliable forecasts that are needed for international space weather efforts.

The role of airglow in upper atmospheric physics will be investigated in more detail at the 6th TIGER symposium in Beijing in 2006.

References

Hinteregger, H.E., Bedo, D.E., Manson, J.E. The EUV spectrophotometer on atmospheric explorer. Radio Sci. 8, 349–356, 1973.

Lämmerzahl, P., Bauer, S.J. The AEROS mission. J. Geophys. 40 (5), 571–576, 1974.

Mount, G.H., Rottman, G.J. The solar absolute spectral irradiance 1150–3173 Angstrom: May 17, 1982. J. Geophy. Res. 88, 5403–5410, 1983.

Pauluhn, A., Huber, M.C.E., von Steiger, R. (Eds.). The Radiometric Calibration of SOHO, ISSI Scientific Report SR-002, International Space Science Institute, ESA Publications Division, 2200 AG Noordwijk, The Netherlands, 2002.

Richmond, A.D., Ridley, E.C., Roble, R.G. A thermosphere/ionosphere general circulation model with coupled electrodynamics. Geophys. Res. Lett. 19, 601–604, 1992.

Schmidtke, G. EUV indices for solar–terrestrial relations. Geophys. Res. Lett. 8 (10), 573–576, 1976.

Schmidtke, G., Seidl, P., Wita, C. Airglow-solar spectrometer instrument (20–700 nm) aboard the San Marco D/L satellite. Appl. Opt. 24, 3206–3213, 1985.

Schmidtke, G. TIGER: a program for the thermospheric–ionospheric research. Phys. Chem. Earth (C) 25 (5–6), 363–369, 2000.

Solomon, S.C., Bailey, S.M., Woods, T.N. Effect of solar soft X-rays on the lower ionosphere. Geophys. Res. Lett. 28, 2149–2152, 2001.

Timothy, J.G.. In: White, O. (Ed.), The Solar Output and Its Variations. Colorado Assoc. Univ. Press, Boulder, CO, pp. 237–245, 1977.

Tobiska, W.K., Bouwer, S.D. New developments in SOLAR2000 for space research and operations, Adv. Space Res., in review, 2005 (this issue).

Tobiska, W.K., Nusinov, A.A. Status of ISO draft international standard for determining solar irradiances (DIS 21348). Adv. Space Res., 2005, in review.

Woods, T.N., Prinz, D.K., London, J., Rottman, G.J., Crane, P.C., Cebula, R.P., Hilsenrath, E., Brueckner, G.E., Andrews, M.D., White, O.R., VanHoosier, M.E., Floyd, L.E., Herring, L.C., Knapp, B.G., Pankratz, C.K., Reiser, P.A. Validation of the UARS solar ultraviolet irradiances: comparison with the ATLAS1 and 2 measurements. J. Geophys. Res. 101, 9541–9569, 1996.

Woods, T., Rottman, G., Harder, J., Lawrence, G., McClintock, B., Kopp, G., Pankratz, C. Overview of the EOS SORCE mission, in: Earth Observing Systems V, in: William L., Barnes (Ed.), SPIE Proceedings, vol. 4135. International Society for optical Engineering, Bellingham, WA, pp. 192–203, 2000.

Woods, T., Acton, L.W., Bailey, S., Eparvier, F., Garcia, H., Judge, D., Lean, J., McMullin, D., Schmidtke, G., Solomon, S.C., Tobiska, W.K., Warren, H.P. Solar extreme ultraviolet and X-ray irradiance variations, in: Solar Variability and Its Effect on Climate. In: Pap, J., Fröhlich, C., Hudson, H., Kuhn, J., McCormack, J., North, G., Sprig, W., Wu, S.T. (Eds.), Geophys. Monograph Series, vol. 141. American Geophysical Union, Washington, DC, pp. 127–140, 2004.

Woods, T.N., Eparvier, F.G., Bailey, S.M., Chamberlain, P.C., Lean, J., Rottman, G.J., Solomon, S.C., Tobiska, W.K., Woodraska, D. The solar EUV experiment (SEE): mission overview and first results. J. Geophys. Res. 110, A01312, doi:10.1029/2004JA010765, 2005.