Status of ISO Draft International Standard for Determining Solar Irradiances (DIS 21348)

W. Kent Tobiska[1] and Anatoliy A. Nusinov[2]

[1]*Space Environment Technologies, 1676 Palisades Dr., Pacific Palisades, CA 90272, USA*
[2]*Institute of Applied Geophysics, Russian State Committee on Hydrometeorology and Environment Control, 9 Rostokinskaya St., Moscow, 129128, Russia*

Abstract

The International Standards Organization Technical Committee 20, *Aircraft and space vehicles*, Subcommittee 14, *Space systems and operations*, Working Group 4, *Space Environment – Natural and Artificial* has developed a Draft International Standard "Space environment (natural and artificial) – Process for determining solar irradiances" (DIS 21348). The draft standard specifies the process for determining all representations of solar irradiances including measurements, reference spectra, empirical models, theoretical models, and solar irradiance proxies. The purpose of the standard is to provide common methods and formats for characterizing all solar irradiances for use by space systems and materials users. The space physics scientific community and other engineering disciplines will also be potential users of this standard. This paper describes DIS 21348, including: a) the process of developing international standards related to the space environment as well as the basis, common definitions, motivation, and scope for this solar irradiance draft international standard; b) the definitions of solar irradiance product types; c) the definitions of spectral irradiance categories; d) the compliance criteria; and e) the certification process.

1. Background to DIS 21348

1.1 The process of developing an International Standard

The International Standards Organization (ISO) is a worldwide federation of national standards bodies that have become ISO member bodies. International organizations, both governmental and non-governmental, act in liaison with ISO to develop standards of mutual benefit. ISO also collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization. International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, "Rules for the structure and drafting of International Standards" (2001).

What is an International Standard? In the broadest sense, an International Standard can be described as a reference framework, or a common technological language, between suppliers and their customers which facilitates trade and the transfer of technology. Compliance with an International Standard means compliance with a set of requirements that will facilitate the exchange of data or products among diverse communities.

The work of preparing International Standards is normally carried out through ISO technical committees and their working groups convened under the direction of member bodies. The main task of technical committees is the preparation of draft International Standards. These begin with New Work Item (NWI) concept approvals, proceed through the development of Working Drafts (WD) which provide technical content to the documents, and continue with the circulation of Committee Drafts (CD) that incorporate comments from member body technical experts. Following comment inclusion, technical committee member bodies approve documents as Draft International Standards (DIS) and send them to the publication process. The publication process, led by ISO headquarters in Geneva, includes editorial reviews and corrections that lead to Final Draft International Standards (FDIS). A DIS requires 75% approval by the member bodies to reach the FDIS stage. Following acceptance of corrected document proofs by ISO headquarters and a positive FDIS vote, a document is published as an International Standard (IS). The entire process, from concept to IS publication, takes an average of 5 years.

ISO Technical Committee (TC) 20 organizes all standardization issues related to Aircraft and Space Vehicles. There are six active subcommittees (SC) in TC20, four of which work with specific products such as aircraft electrical equipment (SC1), air cargo and ground equipment (SC9), aircraft fluid systems and components (SC10), and airframe bearings (SC15). Two subcommittees work with space issues and are considered sectoral committees. They have a larger area of responsibility distributed among several working groups (WG). Of the two subcommittees, Space Data and Information Transfer Systems (SC13) and Space Systems and Operations (SC14) which are soon to merge as a new TC, the latter (SC14) has authorized the standard-related process of determining solar irradiance work that is described in this paper. Within SC14, there are six broad working groups; Working Group (WG) 4 is convened by Russia and organizes the space environment (natural and artificial) standardization work.

The process of drafting an international standard starts with the selection of a Project Lead (PL) to organize the work. The PL is an expert in the field, is expected to have adequate resources for carrying out the project, is required to act in a purely international capacity, and should be prepared to act as a consultant regarding technical matters. The PL organizes the drafting of the International Standard starting with the submission of a NWI. He or she collects technical material and organizes the writing of the WD, is the point-of-contact to the SC Secretary for document administration, and organizes the solicitation and incorporation of expert comments to the draft document when it reaches CD stage. The PL is also responsible, via the SC Secretary, for reviewing editorial changes to the document in the DIS and FDIS stages immediately prior to publication.

In the course of developing a standard, there may not be consensus to proceed to the publication of a standard. Alternative documentation routes exist for providing technically-accepted guidelines that are not International Standards but that are useful for user communities. These types of documents include Technical Specifications (TS) or Technical Reports (TR).

1.2 The basis for a solar irradiance International Standard

1.2.1 Definitions related to solar irradiance

Solar irradiance is the Sun's radiation integrated over the full disk and expressed in SI units of power through a unit of area, W m^{-2}. The commonly used term "full disk" includes all of the Sun's irradiance coming from the solar photosphere and temperature regimes at higher altitudes, including the chromosphere, transition region, and corona. Some users refer to these composite irradiances as "whole Sun." Solar irradiance is more precisely synonymous with "total solar irradiance" while spectral solar irradiance is the derivative of irradiance with respect to wavelength and can be expressed in SI units of W m^{-3}; an acceptable SI submultiple unit description can be W m^{-2} nm^{-1}. Mixed spectral solar irradiance units, for example quanta cm^{-2} s^{-1} nm^{-1}, photons cm^{-2} s^{-1} $Å^{-1}$, and ergs cm^{-2} s^{-1} nm^{-1}, can be useful as an addition to, but not replacement for, SI unit reporting. Solar radiances, or the emergent energy from a spatial area that is less than the full disk of the Sun, are not explicitly covered by this draft standard unless the radiances are integrated across the full disk to represent an irradiance.

The *total solar irradiance* (TSI) is the Sun's irradiances integrated across all wavelengths at normal incidence to the top of the Earth's atmosphere through a unit surface and at 1 astronomical unit with a currently accepted mean value of (1366.1 ±0.58) W m^{-2} (E 490 – 00a, 2000). This value is historically known as the solar constant although, in fact, it is not constant. The TSI varies with geometry of the Earth's distance from the Sun as well as with the magnetic field activity in the Sun on short to long timescales. The 1-sigma uncertainty is 0.58 W m^{-2} and there is a long-term (yearly) smoothed solar cycle minimum to maximum relative variation about the mean value of approximately 0.1% (E 490 – 00a, 2000). Solar irradiance can also vary slightly based upon the finite-size of the effective solar disk and limb darkening. The solar flux at a heliospheric distance of R, given in Astronomical Units (AU), is not simply TSI × R^{-2} but can be a smaller value because of these two effects. Once the radius of the Sun is determined, e.g., the photosphere radius, the finite-size effect can be computed. The limb-darkening effect depends upon the solar atmosphere model that is used. If a simple gray-atmosphere model is selected then both effects can be calculated analytically for any orientation of the surface receiving the solar photons. For instance, at 0.1 AU, the correction factor amounts to approximately 0.99951 whereas at 0.2 AU it is approximately 0.99988. In practice, the solar irradiance at 1 AU coincides with that from a point-like sun. In contrast, at 3 solar radii from the "photosphere surface," the irradiance reduction amounts to 0.9858 using the above example.

An *Astronomical Unit* (ua) also uses the accepted nomenclature of AU and is a unit of length approximately equal to the mean distance between the Sun and Earth with a currently accepted value of (149 597 870 691 ±3) m (SI, 1998; DE405). Distances between objects within the solar system are frequently expressed in terms of ua. The ua or AU is a non-SI unit accepted for use with the International System and whose value in SI units is obtained experimentally. Its value is such that, when used to describe the motion of bodies in the solar system, the heliocentric gravitation constant is $(0.017\ 202\ 098\ 95)^2$ ua^3 d^{-2} where one day, d, is 86 400 s (DE405). One AU is slightly less than the average distance between the Earth and the Sun since an AU is based on the radius of a Keplerian circular orbit of a point-mass having an orbital period in days of 2π/k where k is the Gaussian gravitational constant and is $(0.01720209895\ AU^3\ d^{-2})^{1/2}$. The most current published authoritative source for the value of 1 ua is from the Jet Propulsion Laboratory (JPL) Planetary and Lunar Ephemerides, DE405/LE405 (DE405).

1.2.2 Motivation for standardizing solar irradiances

Space systems and materials users understood by the late 1990's that a common method of specifying solar irradiances was needed. These users have a variety of applications requiring input solar irradiance energy such as for the determination of atmospheric densities for spacecraft orbit determination and attitude control as well as for debris mitigation, the calculation of ionospheric parameters, and the radiative transfer modeling through planetary atmospheres. Knowledge of solar irradiance energy is also important for determining direct and indirect pressure upon spacecraft surfaces that affects attitude control separately from atmospheric density effects. Input solar irradiance energy is used to characterize material properties related to spacecraft thermal control including surface temperatures, reflectivity, absorption, and degradation. It was also realized that solar energy applications which require a standard process for determining solar irradiance energy include solar cell power simulation, material degradation, and the development of lamps and filters for terrestrial solar simulators.

This recognition occurred at a time when measurements and modeling of solar irradiances began to mature. A wide variety of solar irradiance measurements had been or were being made using space- and ground-based instrumentation that depended upon wavelength or bandpass selection. The measurements had differing degrees of accuracy and precision as well as spectral and temporal resolution; as a result, it became increasingly difficult to reconcile measurements and models. In addition, spatial (radiance) measurements were being made by the solar physics community as they detailed the physical processes occurring in the Sun's thermal and non-thermal features and users wanted to compare radiance measurements with irradiance values.

Because of the breadth of effects by solar irradiances upon engineering activities, and coincident with the maturation of measurements, empirical/theoretical modeling, and integrated irradiance proxy development by the scientific communities, it was recognized that a major effort was needed to standardize solar irradiance specification and use. In this context, ISO DIS 21348, was envisioned. While the overall process owner for developing this draft standard has been ISO TC20/SC14/WG4, the draft standard has greatly benefitted from the active participation by the technical experts to ISO TC20/SC14/WG4 as well as the international solar science and material science communities.

The DIS 21348 joint Project Leads are Drs. W. Kent Tobiska (USA) and Anatoliy A. Nusinov (Russia). DIS 21348 was approved as a NWI by TC20/SC14 on June 10, 2000 (Tobiska and Nusinov, 2000) and moved to the document-writing WD stage. The document was accepted as a CD with comments due on August 6, 2002. After receipt and resolution of 110 comments from 8 countries (Brazil, China, Germany, Italy, Japan, Russia, United Kingdom, and United States), the document was approved for registration as a DIS on April 19, 2004.

1.3 Scope of DIS 21348

ISO DIS 21348 specifies the process for determining solar irradiances and is applicable to measurement sets, reference spectra, empirical models, theoretical models, and solar irradiance proxies that provide solar irradiance products representing parts or all of the solar electromagnetic spectrum. Its purpose is to create a standard method for specifying all solar irradiances for use by space systems and materials users.

Solar irradiance products that are frequently reported to space systems users are derived from measurements and/or models. Examples of solar irradiance products include, but are not limited to, spectral and time series intensities, surrogates or proxies intended to represent solar irradiances, and solar images containing spectral information. Because knowledge of solar irradiance spectral and temporal characteristics is fundamental to the understanding of a wide variety of physical and technical processes, and because solar irradiances have been reported and are used in a variety of formats, it is recognized that the standardization of the process for determining solar irradiances is important. Standardized processes for determining solar irradiances enables suppliers and users of these products to exchange information with a common, understandable language.

The implementation of DIS 21348 assumes that there will continue to be technical improvements in the accuracy and precision of measurements because ground-based and space-based instrumentation use new detectors, filters, and computer hardware/software algorithms and because there is improved understanding of the Sun's physical processes. There is also the expectation of continual improvements in the reporting and calculation of reference spectra, empirical models, first-principles models, and solar irradiance proxies. It is likely that there will be an evolving solar standard user community. Given the continual change in these areas, DIS 21348 is designed as a robust document in scope and format so as to support and encourage these changes.

Robustness is achieved with the format in which the draft standard is written. For example, DIS 21348 does not specify one measurement set, one reference spectrum, one solar model, or one solar irradiance proxy as a single standard. Instead, in order to encourage continual improvements in solar irradiance products, DIS 21348 is written as a process-based standard for determining solar irradiances. In other words, in the course of developing a solar irradiance product, a reporting process is followed in order to certify compliance with the standard.

Because the draft standard is process-based, and no specific product is selected as the standard, it was recognized by all participants that the scientific and engineering communities required some type of detailed solar irradiance specification for their separate activities. As a result, a parallel effort is in progress by the scientific community to provide published measurement sets, reference spectra, models, and solar irradiance proxies that certify compliance with this standard. Papers that are published in conjunction with the 2004 COSPAR TIGER Symposium contain solar irradiance material for solar science, space systems, and materials users.

2. Solar product types

Solar irradiance product types have been established so that the suppliers and users have a common, easy-to-recognize method of identifying standard-compliant solar irradiance products. A solar irradiance product can be a measurement set, reference spectrum, empirical model, first-principles model, or solar irradiance proxy and has the characteristics of only one type.

2.1 Type 1

Type 1 is a measurement set product. Solar irradiances are measured by space- or ground-based instrumentation (including balloons and rockets) at specified wavelengths, with an identifiable wavelength bandpass, having a quantifiable value based upon a calibrated reference source, integrated over an identified spatial area, and reported through a specified time interval.

2.2 Type 2

Type 2 is a reference spectrum product. Reference spectra can be derived from single and/or multiple measurement sets and can be combined with models. Reference spectra represent generalized characteristics of solar irradiances for identified solar activity conditions or unique dates.

2.3 Type 3

Type 3 is an empirical model product. An empirical solar irradiance model is derived from space- or ground-based measurement sets (including balloons and rockets). It uses proxies to represent solar irradiances at specified wavelengths and produces irradiances with an identifiable wavelength bandpass, having a quantifiable value related to the measurements, integrated over an identified spatial area, and reported through a specified time interval. A hybrid model can combine empirical methods, data assimilation, or physics-based algorithms and is included in this type.

2.4 Type 4

Type 4 is a theoretical or first-principles model product. A first-principles solar irradiance model is derived from the fundamental physics describing energy, momentum, and/or mass conservation, transfer, and state changes. It produces solar irradiances at specified wavelengths, with an identifiable wavelength bandpass, having a quantifiable value related to the physical processes, integrated over an identified spatial area, and reported through a specified time interval.

2.5 Type 5

Type 5 is a surrogate solar irradiance product, also called a proxy. A solar irradiance proxy can represent solar spectral irradiances at specified wavelengths related to an identifiable wavelength bandpass. Alternatively, it can represent integrated irradiances or other irradiance-related solar features including irradiance deficit from sunspots or sunspot numbers. It has a quantifiable value related to solar processes and can be reported through a specified time interval.

3. Spectral irradiance categories

Solar irradiance spectral category definitions are based on recommendations or usages by provider/user communities. There can be differing or overlapping definitions used by separate communities and these definitions have been collected in DIS 21348. The draft standard does not recommend one definition over another in cases of ambiguity or overlap and it is also anticipated that these definitions will change or evolve as convention dictates. Table 1 provides a compact listing of the spectral irradiance categories and Figure 1 provides a graphical view of the categories. An example of spectral irradiances is shown in Figure 2. In this case, the composite spectral irradiances from the SOLAR2000 v2.23 model (Tobiska, *et al.,* 2000) are shown in W m^{-3} and W m^{-2} nm^{-1} for February 8, 2002 from soft X-rays (XUV) to far infrared (FIR) wavelengths at 1 nm resolution.

3.1 Total Solar Irradiance

The Total Solar Irradiance (TSI) is the full-disk (whole Sun) solar irradiance at 1 ua integrated across all wavelengths and is reported in units of W m^{-2}. The solar constant is the mean value of the TSI.

3.2 Gamma-rays

Gamma-ray irradiances are defined as the wavelength range of ($0.00001 \leq \lambda < 0.001$) nm and this definition is commonly used by data providers for this spectral category.

3.3 X-rays

Hard X-ray irradiances are defined as the wavelength range of ($0.001 \leq \lambda < 0.1$) nm and this definition is commonly used by data providers for this spectral category.

Soft X-ray irradiances, also called the XUV or SXR, are defined as the wavelength range of ($0.1 \leq \lambda < 10$) nm. and this definition is commonly used by data providers of this spectral category. As a less common practice, some aeronomers consider soft X-rays to extend to 30 nm.

3.4 Ultraviolet

Ultraviolet or UV irradiances are defined as the wavelength range of ($100 \leq \lambda < 400$) nm and this definition is given by the Global Solar UV Index (UVI) designation (WHO, 2002; ISO 17166).

Vacuum Ultraviolet or VUV irradiances are defined as the wavelength range of ($10 \leq \lambda < 200$) nm and this definition is commonly used by data providers of this spectral category as well as by the materials sciences community.

Extreme Ultraviolet or EUV irradiances are defined as the wavelength range of ($10 \leq \lambda < 120$) nm and this definition is commonly used by data providers of this spectral category. Sometimes aeronomers use a less common definition of 30 nm as the shorter wavelength cut-off. The longer wavelength cut-off includes the ionization potential for O_2 at 102.7 nm, the edge of crystal window transmission for MgF_2 at 115 nm, and is below H I Lyman-α emission at 121.6 nm.

Far Ultraviolet or FUV irradiances are defined as the wavelength range of ($120 \leq \lambda < 200$) nm and this definition is commonly used by data providers of this spectral category.

Ultraviolet C or UVC irradiances are defined as the wavelength range of ($100 \leq \lambda < 280$) nm and this definition is given by the Global Solar UV Index (UVI) designation (WHO, 2002; ISO 17166).

Middle Ultraviolet or MUV irradiances are defined as the wavelength range of ($200 \leq \lambda < 300$) nm and this definition is commonly used by the aeronomy community.

Ultraviolet B or UVB irradiances are defined as the wavelength range of ($280 \leq \lambda < 315$) nm and this definition is given by the Global Solar UV Index (UVI) designation (WHO, 2002; ISO 17166).

Near Ultraviolet or NUV irradiances are defined as the wavelength range of ($300 \leq \lambda < 400$) nm and this definition is commonly used by the aeronomy community.

Ultraviolet A or UVA irradiances are defined as the wavelength range of ($315 \leq \lambda < 400$) nm and this definition is given by the Global Solar UV Index (UVI) designation (WHO, 2002; ISO 17166).

3.5 Visible

Visible, optical, or VIS irradiances are defined as the wavelength range of ($380 \leq \lambda < 760$) nm (CIE, 1987). Solar visible irradiances are defined with respect to the part of the electromagnetic spectrum that stimulates the human retinal cones, i.e., photopic vision. Human sensitivity to light varies between individuals and most human visual perception is between 380 nm to 760 nm. However, some people have visual perception out to 830 nm. The term "light" only applies to the visible part of the electromagnetic spectrum.

Purple irradiances are defined as the wavelength range of ($360 \leq \lambda < 450$) nm.

Blue irradiances are defined as the wavelength range of ($450 \leq \lambda < 500$) nm.

Green irradiances are defined as the wavelength range of ($500 \leq \lambda < 570$) nm.

Yellow irradiances are defined as the wavelength range of ($570 \leq \lambda < 591$) nm.

Orange irradiances are defined as the wavelength range of ($591 \leq \lambda < 610$) nm.

Red irradiances are defined as the wavelength range of ($610 \leq \lambda < 760$) nm.

3.6 Infrared

Infrared or IR irradiances are defined as the wavelength range of ($760 \leq \lambda < 1\,000\,000$) nm (760 nm is 0.76 μm and 1 000 000 nm is 1 mm). Infrared is often divided into 3 spectral categories, i.e., the near, middle and far-infrared.

Near infrared or IR-A irradiances are defined as the wavelength range of ($760 \leq \lambda < 1\,400$) nm (760 nm is 0.76 μm and 1 400 nm is 1.4 μm).

Middle infrared or IR-B irradiances are defined as the wavelength range of ($1\,400 \leq \lambda < 3\,000$) nm (1 400 nm is 1.4 μm and 3 000 nm is 3 μm).

Far infrared or IR-C irradiances, also sometimes called submillimetric irradiances, are defined as the wavelength range of ($3\,000 \leq \lambda < 1\,000\,000$) nm (3 000 nm is 3 μm and 1 000 000 nm is 1 mm).

3.7 Microwave

Microwave irradiances are defined as the wavelength range of ($1\,000\,000 \leq \lambda < 15\,000\,000$) nm (1 000 000 nm is 1 mm and 15 000 000 nm is 1.5 cm). Solar microwave irradiances can create interference or noise for radio communications and navigation frequencies. Frequency bands of interference that also overlap into the radio wavelengths (Reference Data for Radio Engineers, 1982) include:

W: ($100.0 \geq \nu > 56.0$) GHz or ($3.00\times10^6 \leq \lambda < 5.35\times10^6$) nm;

V: ($56.0 \geq \nu > 46.0$) GHz or ($5.35\times10^6 \leq \lambda < 6.52\times10^6$) nm;

Q: ($46.0 \geq \nu > 36.0$) GHz or ($6.52\times10^6 \leq \lambda < 8.33\times10^6$) nm;

K: ($36.00 \geq \nu > 10.90$) GHz or ($8.33\times10^6 \leq \lambda < 2.75\times10^7$) nm;

X: ($10.90 \geq \nu > 5.20$) GHz or ($2.75\times10^7 \leq \lambda < 5.77\times10^7$) nm;

C: ($6.20 \geq \nu > 3.90$) GHz or ($4.84\times10^7 \leq \lambda < 7.69\times10^7$) nm;

S: ($5.20 \geq \nu > 1.55$) GHz or ($5.77\times10^7 \leq \lambda < 1.93\times10^8$) nm;

L: ($1.550 \geq \nu > 0.390$) GHz or ($1.93\times10^8 \leq \lambda < 7.69\times10^8$) nm; and

P: ($0.390 \geq \nu > 0.225$) GHz or ($7.69\times10^8 \leq \lambda < 1.33\times10^9$) nm.

3.8 Radio

Solar *radio* irradiances can be defined as the wavelength range of ($100\,000 \leq \lambda < 100\,000\,000\,000$) nm although most reports of solar measurements range from ($1\,000\,000 \leq \lambda < 10\,000\,000\,000$) nm (100 000 nm is 0.1 mm or approximately 3000 GHz and 100 000 000 000 nm is 100 m or approximately 3000 kHz; 1 000 000 nm is 1 mm or approximately 300 GHz and 10 000 000 000 nm is 10 m or approximately 30 Mhz). Solar radio irradiances can create interference or noise for radio communications and navigation frequencies. Frequency bands of interference (Reference Data for Radio Engineers, 1982) include:

Extremely High Frequency (EHF): ($300 \geq \nu > 30$) GHz or ($1.00\times10^6 \leq \lambda < 1.00\times10^7$) nm;

Super-High Frequency (SHF): ($30 \geq \nu > 3$) GHz or ($1.00\times10^7 \leq \lambda < 1.00\times10^8$) nm;

Ultra-High Frequency (UHF): ($3000 \geq \nu > 300$) MHz or ($1.00\times10^8 \leq \lambda < 1.00\times10^9$) nm;

Very-High Frequency (VHF): ($300 \geq \nu > 30$) MHz or ($1.00\times10^9 \leq \lambda < 1.00\times10^{10}$) nm; and

High Frequency (HF): ($30 \geq \nu > 3$) MHz or ($1.00\times10^{10} \leq \lambda < 1.00\times10^{11}$) nm.

The calculation of Hertz in frequency units, ν, is $\nu = c/\lambda$, where c, the speed of light in a vacuum, is defined as (299 792 458) m s^{-1} and λ is the wavelength of interest in meters. For example, the 10.7 cm solar radio flux can be converted to frequency in Hz: (299 792 458 m s^{-1})/(0.107 m) = 2 801.799 MHz. Note that 1 kHz = 1×10^3 Hz, 1 MHz = 1×10^6 Hz, and 1 GHz = 1×10^9 Hz.

4. Compliance criteria

The compliance criteria for DIS 21348 consist of activities that are common to solar irradiance product types and solar irradiance spectral categories. These criteria specify a compliance process for the determination of solar irradiances that includes the reporting, documenting, publishing, and archiving of solar irradiance products.

4.1 Reporting

Solar irradiances shall be reported in SI units, W m^{-2} and solar spectral irradiances shall be reported in SI units, W m^{-3}. The conversion to other appropriate conventional units such as W m^{-2} nm^{-1} can be additionally applied. The reported irradiances shall be described as to whether or not they are corrected to 1 ua. It is recommended, though not required, that reported irradiances are corrected to 1 ua. If applicable, the wavelength bins (spectral sampling) and spectral resolution (bandpass) shall be reported for solar irradiance products.

4.2 Documenting

The method of determining solar irradiances shall be documented and, as appropriate, shall include data collection, retrieval, processing, calibration, validation, verification, accuracy, and precision methodology and/or algorithms, as well as archiving information.

Measurements. For measurements, including spacecraft observations, rocket experiment data sets, and ground-based observations (including balloons), a description of the responsible agent or institution and the instrumentation used to collect and retrieve the irradiances shall be provided. The data processing algorithms, the instrument calibration techniques and heritage, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

Reference spectra. For reference spectra, including the mean of spectra over several solar cycles or spectra for a variety of solar activity conditions, the rationale for specifying a spectrum as a reference shall be described. The measurement set(s) used to derive the reference spectrum, the method of resolving discrepancies between multiple data sets, the data processing algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

Empirical models. For empirical models, including those based on one or many space- or ground-based measurement sets, or for hybrid models, a description of the rationale for developing the model, its areas of application, and the rationale for selecting proxies shall be described. The measurement data sets used in the derivation, the mathematical formulation of the model, the method of resolving discrepancies between multiple data sets, the derivation algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

Theoretical models. For theoretical or first-principles models of solar processes, a description of the physical principles that are used as the basis of the model, the rationale for developing the model, and its areas of application shall be described. The numerical algorithms that produce solar irradiances, the mathematical formulation of the model, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

Solar irradiance proxies. For solar irradiance proxies, a description of the rationale for developing the proxy and its areas of application shall be described. Where appropriate, the data sets used in the derivation, the mathematical formulation of the proxy, the method of resolving discrepancies between multiple data sets, the derivation algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

4.3 Publishing

The documented solar irradiance product shall be published in an internationally-accessible journal which uses scientific or discipline-area peer review in the publication process. For any irradiance product, the published article may point to a permanent electronic archival location where the archived measurements, spectra, models, or proxies can be found, accessed, or recreated by an international community.

4.4 Archiving

The documented and published solar irradiance product shall be archived in a method consistent with any contemporary technology that ensures long-term international accessibility.

5. Certification process

Certification of compliance with DIS 21348 shall be achieved by complying with the criteria listed above. Self-declaration of compliance in an archival publication can be accomplished by using the statement “The process used for determining solar irradiances reported herein is compliant with ISO International Standard 21348: Space Environment (Natural and Artificial) – Process for determining solar irradiances.” The type designation and the solar irradiance spectral category shall be identified along with the self-declaration of compliance.

Acknowledgment

Support for this work has been provided by the NATO EST.CLG 975301 collaborative travel grant, by the NASA TIMED contract NAG5-11408 (UCB), by the NASA Living With a Star contracts NASW-02030 (GSFC) and 4200000428 (MSFC), and by the NOAA/SEC-SET CRADA. The DIS 21348 is available for review through the ISO Solar Standard link at http://SpaceWx.com.

References

Commision Internationale de l’Eclairage. International Lighting Vocabulary, 4th ed., Publication No. 17.4 (joint IEC/CIE publication), 1987.

DE405/LE405, The JPL Planetary and Lunar Ephemerides, http://ssd.jpl.nasa.gov/iau-comm4/de405iom/.

E 490 – 00a, Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables, © ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, 2000.

Joint ISO/CIE Standard: ISO 17166:1999/CIE S007-1998, Erythema Reference Action Spectrum and Standard Erythema Dose.

Reference Data for Radio Engineers, Howard W. Sams & Co., Inc., ITT, 1982.

The International System of Units (SI), Bureau International des Poids et Mesures (BIPM), 1998.

Tobiska, W. K. and A. A. Nusinov, Status of the draft ISO solar irradiance standard, *Phys. Chem. Earth (C),* **25,** No. 5-6, 387-388, 2000.

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.,* **62,** 14, 1233-1250, 2000.

World Health Organization (WHO) *Global Solar UV Index: A Practical Guide* 2002.

World Health Organization (WHO), *Global Solar UV Index: A Practical Guide,* Geneva, 2002.

E-mail address of W.K. Tobiska ktobiska@spacenvironment.net

Manuscript received ; revised ; accepted

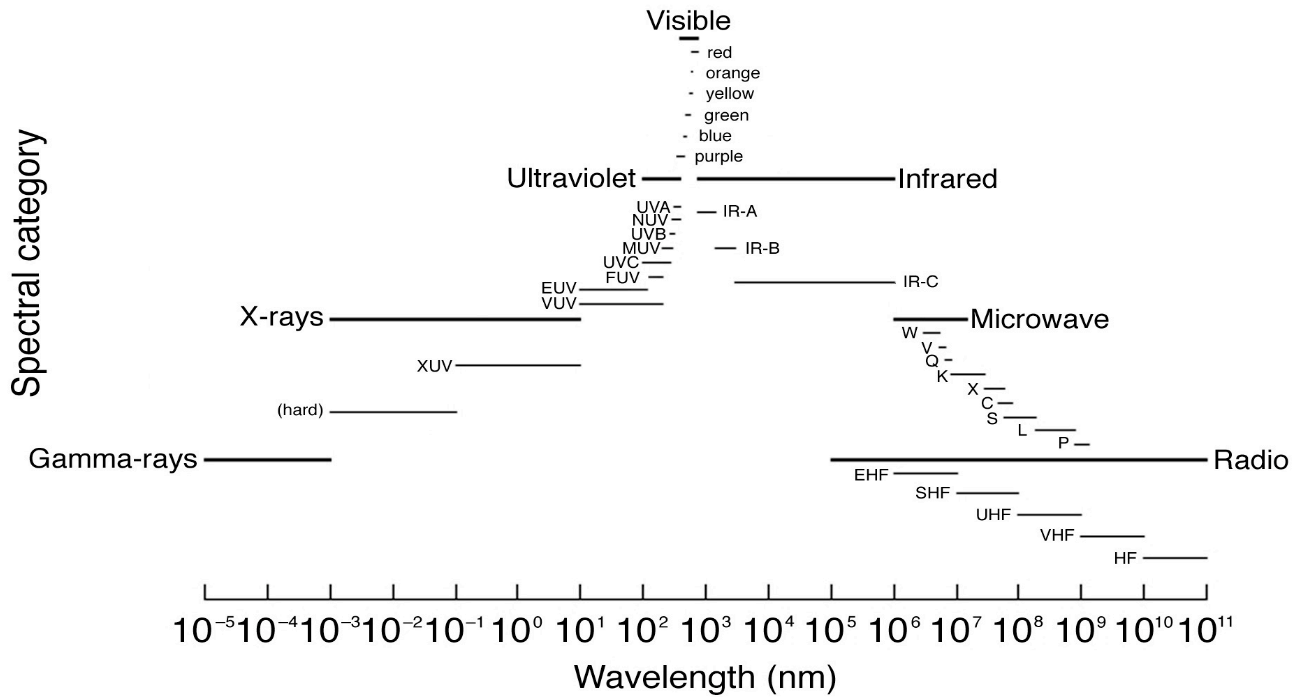

Fig. 1. Solar irradiance spectral categories from gamma-rays through radio wavelengths.

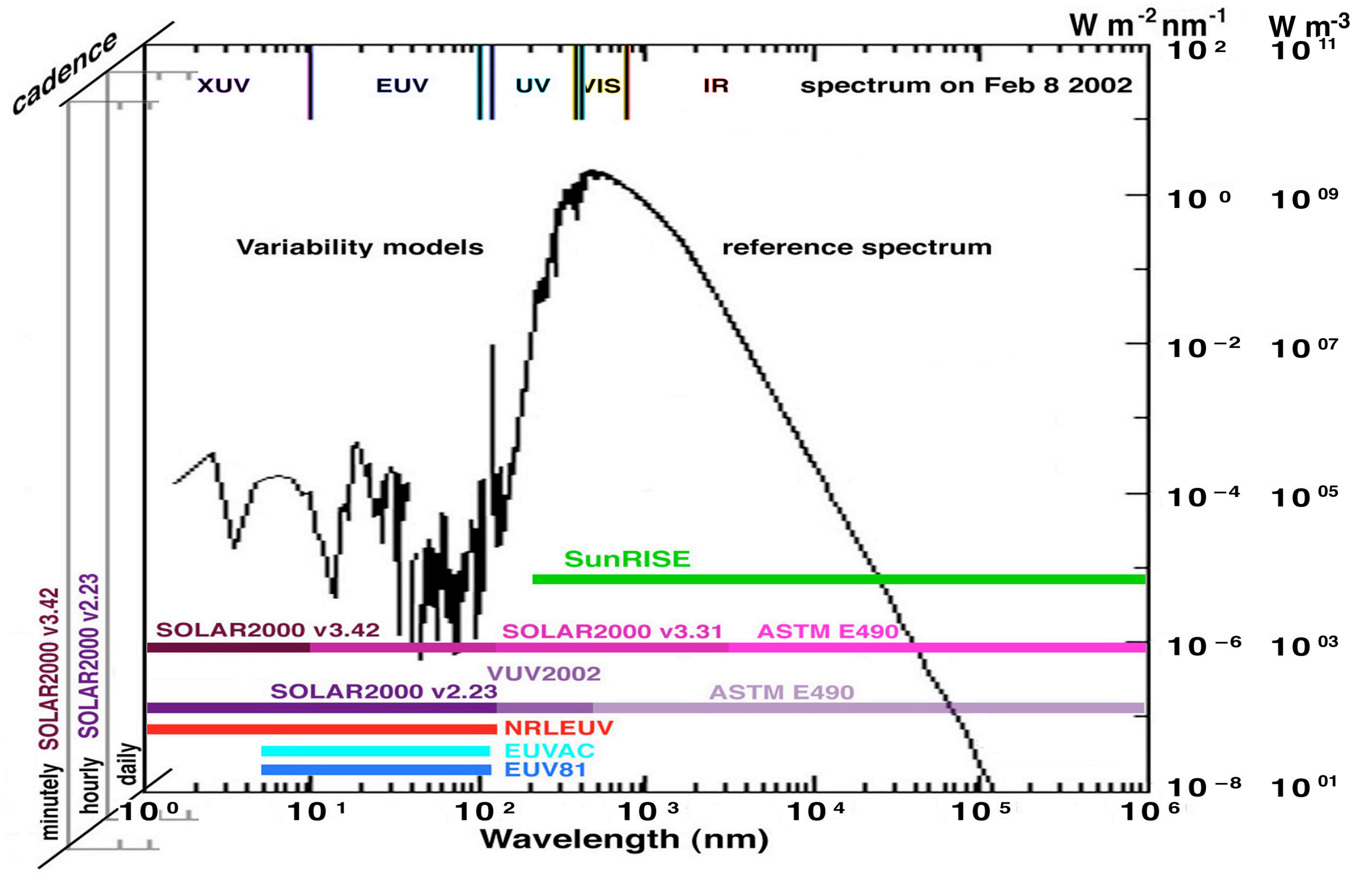

Fig. 2. Composite solar spectral irradiances in W m^{-3} and W m^{-2} nm^{-1} from the SOLAR2000 v2.23 model on February 8, 2002 from the soft X-rays to the far infrared wavelengths at 1 nm resolution. Spectral categories are identified along the top axis, horizontal bars below the spectrum indicate the range of spectral coverage by several solar spectral models and a reference spectrum, and the z-axis indicates the cadence of available spectra from the models. The SOLAR2000 Research Grade model is publicly available via FTP download from the SOLAR2000 link at http://SpaceWx.com.

Table 1. Definitions of solar irradiance spectral categories

Spectral category	Spectral sub-category	Wavelength range (nm)	Notes
Total Solar Irradiance			full-disk, 1 ua solar irradiance integrated across all wavelengths
Gamma-rays		0.00001 ≤ λ < 0.001	
X-rays		0.001 ≤ λ < 0.1	Hard X-rays
	XUV	0.1 ≤ λ < 10	Soft X-rays
Ultraviolet	UV	100 ≤ λ < 400	Ultraviolet
	VUV	10 ≤ λ < 200	Vacuum Ultraviolet
	EUV	10 ≤ λ < 120	Extreme Ultraviolet
	FUV	120 ≤ λ < 200	Far Ultraviolet
	UVC	100 ≤ λ < 280	Ultraviolet C
	MUV	200 ≤ λ < 300	Middle Ultraviolet
	UVB	280 ≤ λ < 315	Ultraviolet B
	NUV	300 ≤ λ < 400	Near Ultraviolet
	UVA	315 ≤ λ < 400	Ultraviolet A
Visible	VIS	380 ≤ λ < 760	optical
		360 ≤ λ < 450	purple
		450 ≤ λ < 500	blue
		500 ≤ λ < 570	green
		570 ≤ λ < 591	yellow
		591 ≤ λ < 610	orange
		610 ≤ λ < 760	red
Infrared	IR	760 ≤ λ < 1 000 000	
	IR-A	760 ≤ λ < 1 400	Near Infrared
	IR-B	1 400 ≤ λ < 3 000	Middle Infrared
	IR-C	3 000 ≤ λ < 1 000 000	Far infrared
Microwave		1 000 000 ≤ λ < 15 000 000	
	W	3.00×106 ≤ λ < 5.35×106	(100.0 ≥ ν > 56.0) GHz
	V	5.35×106 ≤ λ < 6.52×106	(56.0 ≥ ν > 46.0) GHz
	Q	6.52×106 ≤ λ < 8.33×106	(46.0 ≥ ν > 36.0) GHz
	K	8.33×106 ≤ λ < 2.75×107	(36.00 ≥ ν > 10.90) GHz
	X	2.75×107 ≤ λ < 5.77×107	(10.90 ≥ ν > 5.20) GHz
	C	4.84×107 ≤ λ < 7.69×107	(6.20 ≥ ν > 3.90) GHz
	S	5.77×107 ≤ λ < 1.93×108	(5.20 ≥ ν > 1.55) GHz
	L	1.93×108 ≤ λ < 7.69×108	(1.550 ≥ ν > 0.390) GHz
	P	7.69×108 ≤ λ < 1.33×109	(0.390 ≥ ν > 0.225) GHz
Radio		100 000 ≤ λ < 100 000 000 000	measurements: (1 000 000 ≤ λ < 10 000 000 000) nm
	EHF	1.00×106 ≤ λ < 1.00×107	Extremely High Frequency (300 ≥ ν > 30) GHz
	SHF	1.00×107 ≤ λ < 1.00×108	Super-High Frequency (30 ≥ ν > 3) GHz
	UHF	1.00×108 ≤ λ < 1.00×109	Ultra-High Frequency (3000 ≥ ν > 300) MHz
	VHF	1.00×109 ≤ λ < 1.00×1010	Very-High Frequency (300 ≥ ν > 30) MHz
	HF	1.00×1010 ≤ λ < 1.00×1011	High Frequency (30 ≥ ν > 3) MHz