INTERNATIONAL STANDARD

ISO 21348

First edition
2007-05-01

Space environment (natural and artificial) — Process for determining solar irradiances

Environnement spatial (naturel et artificiel) — Procédé de détermination des irradiances solaires

Reference number
ISO 21348:2007(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO 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.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21348 was prepared by Technical Committee ISO/TC 20, *Aicraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard provides guidelines for specifying the process of determining solar irradiances. Solar irradiances are reported through products such as measurement sets, reference spectra, empirical models, theoretical models and solar irradiance proxies or indices. These products are used in scientific and engineering applications to characterize within the natural space environment solar irradiances that are relevant to space systems and materials.

Examples of applications using input solar irradiance energy include the determination of atmospheric densities for spacecraft orbit determination, attitude control and re-entry calculations, as well as for debris mitigation and collision avoidance activity. Direct and indirect pressure from solar irradiance upon spacecraft surfaces also affects attitude control separately from atmospheric density effects.

Solar irradiances are used to provide inputs for

a) calculations of ionospheric parameters,

b) photon-induced radiation effects, and

c) radiative transfer modelling of planetary atmospheres.

Input solar irradiance energy is used to characterize material properties related to spacecraft thermal control, including surface temperatures, reflectivity, absorption and degradation. Solar energy applications requiring 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.

A solar irradiance product certifies compliance with this process-based standard by following compliance criteria that are described in this International Standard. The compliance criteria in Clause 7 are based upon solar irradiance product types that are described in Clause 5 and solar irradiance spectral categories described in Clause 6. The method for certifying compliance of a solar irradiance product with this International Standard is provided in Clause 8.

Space environment (natural and artificial) — Process for determining solar irradiances

1 Scope

This International Standard specifies the process for determining solar irradiances and is applicable to measurement sets, reference spectra, empirical models, theoretical models, and solar irradiance proxies or indices 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.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
astronomical unit
ua
AU
unit of length approximately equal to the mean distance between the Sun and the Earth with a currently accepted value of (149 597 870 691 $\pm$ 3) m

See References [1] and [2].

NOTE 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 (see Reference [3]).

1 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 2 π/k, where k is the Gaussian gravitational constant and is $(0{,}017\ 202\ 098\ 95\ AU^3\ d^{-2})^{1/2}$. The most current published authoritative source for the value of 1 ua is from Reference [2].

2.2
solar irradiance
radiation of the Sun integrated over the full disk and expressed in SI units of power through a unit of area, W m^{-2}

NOTE 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 is W m^{-2} nm^{-1}. Mixed spectral solar irradiance units (e.g. 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 as a 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 International Standard at the present time unless the radiances are integrated across the full disk to represent an irradiance.

For the calibration of ground-based instruments (pyrheliometers) measuring total solar irradiance (TSI), the World Radiometric Reference (WRR) was introduced in 1980 by the World Meteorological Organisation (WMO) as a primary standard to ensure world-wide homogeneity of solar radiation measurements. The WRR is created through an ensemble of absolute cavity radiometers called the World Standard Group (WSG), located and maintained at the World Radiation Centre by the Physikalisch-Meteorologisches Observatorium Davos in Switzerland. The uncertainty of the WRR is 0,3 %. The comparison of the WRR with the SI scale that is represented by cryogenic radiometers and based on radiance measurements agrees within the quoted uncertainties of the two scales (see References [4] and [5]). The transfer of the WRR to space has been done but, because the resulting uncertainty is large compared to the variations of the solar constant, a non-mandatory Space Absolute Radiation Reference (SARR) has been introduced (see Reference [6]).

2.3
solar constant
S
total solar irradiance at normal incidence to the top of the Earth's atmosphere through a unit surface and at 1 ua with a mean value of 1 366 W m^{-2}

See Reference [7].

NOTE The solar constant, a historical term, is not constant. It varies geometrically with the Earth's distance from the Sun and physically with the Sun's magnetic field activity on short to long timescales, as well as with the observer's heliocentric latitude. The value of 1366 W m^{-2} is the measurement community's current agreement expressed through a TSI space-based composite dataset that is normalized to an arbitrarily selected set of missions defining the SARR (see Reference [6]). A range of measured values extends from SORCE/TIM 2003-2004(+?) values (~1 362 W m^{-2}) to NIMBUS-7/HF 1978-1993 values (~1 372 W m^{-2}), but also includes SMM/ACRIM I 1980-1989 (~1 368 W m^{-2}), ERBS/ERBE 1984-2003 (~1 365 W m^{-2}), UARS/ACRIM II 1991-2001 (~1 364 W m^{-2}), EURECA/SOVA2 1992-1993 (~1 367 W m^{-2}), SOHO/VIRGO 1996-2004(+?) (~1 366 W m^{-2}) and ACRIMSAT/ACRIM III 2000-2004(+?) (~1 364 W m^{-2}) measurements. The SARR reduces all solar constant space measurements to a single ensemble dataset. The currently measured 1-sigma variation in the composite dataset is approximately 0,6 W m^{-2} and there is a long-term (yearly) smoothed solar cycle minimum to maximum relative variation about the mean value of approximately 1,4 W m^{-2} (see Reference [7]).

3 Symbols and abbreviated terms

λ designates the spectral wavelength of solar irradiance and is given in units of length, nm.

4 General concept and assumptions

4.1 Solar irradiance representation

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 substitutes (proxies) and activity indicators (indices) that are intended to represent solar irradiances, and

— solar images containing full-disk 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. A standardized process for determining solar irradiances enables suppliers and users of these products to exchange information with a common, understandable language.

4.2 Robustness of standard

The implementation of this International Standard 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 model and solar irradiance proxies or indices. It is likely that there will be an evolving solar standard user community. Given the continual change in these areas, this International Standard is designed as a robust document in scope and format, so as to support and encourage these changes.

4.3 Process-based standard

This International Standard does not specify one measurement set, one reference spectrum, one solar model or one solar irradiance proxy/index as a single standard. In order to encourage continual improvements in solar irradiance products, this International Standard is a process-based standard for determining solar irradiances. A solar irradiance product, after its development, may follow the process described in Clause 7 to certify compliance with this International Standard.

4.4 Process-ownership of standard development

The process owner for developing this International Standard is ISO/TC 20/SC 14/WG 4, or its successor(s). The participants in this process are the delegates and technical experts to ISO/TC 20/SC 14/WG 4. The expertise of the international solar science and material science communities was utilized in the development of this International Standard.

4.5 Parallel activity of certification to standard

Coincident with and subsequent to the publication of this International Standard, ISO/TC 20/SC 14/WG 4 participants expect solar irradiance product providers to supply measurement sets, reference spectra, models and solar irradiance proxies or indices that certify compliance with this International Standard (see Reference [8]). Solar irradiance products that are compliant will be designated as such for international space systems and materials users.

5 Solar irradiance product types

5.1 Rationale

Solar irradiance product types are established such that the suppliers and users have a common, easy-to-recognize method of identifying standard-compliant solar irradiance products.

5.2 Type designation

A solar irradiance product can be a measurement set, reference spectrum, empirical model, first-principles model or solar irradiance proxy/index. A solar irradiance product has the characteristics of only one type.

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.

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

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.

Type 4 is a first-principles or theoretical 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.

Type 5 is a surrogate solar irradiance product, also called a proxy or index. There is not yet consensus regarding common definitions of proxies and indices; often the terms are used interchangeably. An evolving usage of the term “solar irradiance proxy” is a measured or modelled data type that can be used as a substitute for solar spectral irradiances at different specified wavelengths or over a wavelength bandpass; it may be only empirically related. Alternatively, an evolving usage of the term “solar irradiance index” is a measured or modelled data type that is an indicator, or expresses an activity level, of solar irradiances and can represent a specified wavelength or integrated irradiances over a wavelength bandpass. Proxies and indices can represent other irradiance-related solar features, including irradiance deficit from sunspots or sunspot numbers. Examples also exist where both terms may apply to the same measurement when used in different circumstances. A solar measurement at one wavelength is an index of activity for the regime of solar temperatures that creates the solar emission, yet a generalization of the same measurement to a broader wavelength bandpass encompassing other solar temperature regimes would be considered a proxy. The intent of this International Standard is to encourage developers and users of proxies or indices to clearly specify their origins and applications. Proxies and indices have a quantifiable value related to physical solar processes and can be reported through a specified time interval.

6 Solar irradiance spectral categories

6.1 General

Definitions of solar irradiance spectral categories are based on recommendations or usages by provider and user communities. There can be differing or overlapping definitions used by separate communities, and these definitions are collected in this Clause. This International Standard does not recommend one definition over another in cases of ambiguity or overlap. It is also anticipated that these definitions will change or evolve as convention dictates. The information in subclauses 6.2 to 6.9 are summarized in tabular format in Table 1 (with the SI prefixes and symbols for multiples given in Table 2), and in graphical format in Figure 1.

The common wavelength unit used in this Clause is the SI-derived submultiple unit nanometre (nm), where 1 nm = 1×10^{-9} m, and where the metre (m) is the SI base unit for length. This Clause also refers to other SI-derived, community-recognized units where appropriate. These include microns or micrometres (1 µm = 1×10^{-6} m), millimetres (1 mm = 1×10^{-3} m), centimetres (1 cm = 1×10^{-2} m) and Hertz (s^{-1}).

6.2 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} (see 2.1, 2.2 and 7.2). The solar constant, as described in 2.3, is the mean value of the TSI.

6.3 Gamma-rays

Gamma-ray irradiances are defined as the wavelength range of (0,000 01 $\leqslant \lambda <$ 0,001) nm.

NOTE This definition is commonly used by data providers for this spectral category.

6.4 X-rays

6.4.1 **Hard X-ray** irradiances are defined as the wavelength range of (0,001 ⩽ λ < 0,1) nm.

NOTE This definition is commonly used by data providers for this spectral category.

6.4.2 **Soft X-ray** (XUV or SXR) irradiances are defined as the wavelength range of (0,1 ⩽ λ < 10) nm.

NOTE 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.

6.5 Ultraviolet

6.5.1 **Ultraviolet** (UV) irradiances are defined as the wavelength range of (100 ⩽ λ < 400) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation (see References [9] and [10]).

6.5.2 **Vacuum Ultraviolet** (VUV) irradiances are defined as the wavelength range of (10 ⩽ λ < 200) nm.

NOTE This definition is commonly used by data providers of this spectral category as well as by the materials sciences community.

6.5.3 **Extreme Ultraviolet** (EUV) irradiances are defined as the wavelength range of (10 ⩽ λ < 121) nm.

NOTE 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, for example, the ionization potential for O_2 at 102,7 nm, the edge of crystal window transmission for MgF_2 at 115 nm, and is shortward of the H I Lyman-α emission at 121,6 nm.

6.5.4 **Lyman-alpha** (Lyman-α) irradiances are defined as the wavelength range of (121 ⩽ λ < 122) nm.

NOTE The hydrogen Lyman-alpha line is the most prominent single emission in this part of the spectrum and originates from the solar transition region (line centre) and chromosphere (line wings). The emission corresponds to the $1s^2S$-$2p^{2p0}$ resonance transition of hydrogen at 121,566 8 nm and 121,567 4 nm. The line centre and wing emissions span the range of 121,4 nm to 121,8 nm and are important throughout the solar system, e.g. terrestrial D-region ionization, planetary and cometary hydrogen corona and interstellar hydrogen entering the heliosphere are affected by these irradiances.

6.5.5 **Far Ultraviolet** (FUV) irradiances are defined as the wavelength range of (122 ⩽ λ < 200) nm.

NOTE This definition is commonly used by data providers of this spectral category.

6.5.6 **Ultraviolet C** (UVC) irradiances are defined as the wavelength range of (100 ⩽ λ < 280) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation (see References [9] and [10]).

6.5.7 **Middle Ultraviolet** (MUV) irradiances are defined as the wavelength range of (200 ⩽ λ < 300) nm.

NOTE This definition is commonly used by the aeronomy community.

6.5.8 **Ultraviolet B** (UVB) irradiances are defined as the wavelength range of (280 ⩽ λ < 315) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation (see References [9] and [10]).

6.5.9 **Near Ultraviolet** (NUV) irradiances are defined as the wavelength range of (300 ⩽ λ < 400) nm.

NOTE This definition is commonly used by the aeronomy community.

6.5.10 Ultraviolet A (UVA) irradiances are defined as the wavelength range of $(315 \leqslant \lambda < 400)$ nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation (see References [9] and [10]).

6.6 Visible

6.6.1 Visible, optical or VIS irradiances are defined as the wavelength range of $(380 \leqslant \lambda < 760)$ nm (see Reference [11]).

NOTE 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 and 760 nm. However, some people have visual perception as far as 830 nm. The term "light" only applies to the visible part of the electromagnetic spectrum.

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

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

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

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

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

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

6.7 Infrared

6.7.1 Infrared (IR) irradiances are defined as the wavelength range of $(760 \leqslant \lambda < 1\,000\,000)$ nm.

NOTE 760 nm is 0,76 μm and 1 000 000 nm is 1 mm. Infrared is often divided into three spectral categories, i.e. near, middle and far infrared.

6.7.2 Near Infrared (IR-A) irradiances are defined as the wavelength range of $(760 \leqslant \lambda < 1\,400)$ nm.

NOTE 760 nm is 0,76 μm and 1 400 nm is 1,4 μm.

6.7.3 Middle Infrared (IR-B) irradiances are defined as the wavelength range of $(1\,400 \leqslant \lambda < 3\,000)$ nm.

NOTE 1 400 nm is 1,4 μm and 3 000 nm is 3 μm.

6.7.4 Far infrared (IR-C) irradiances, also sometimes called submillimetric irradiances, are defined as the wavelength range of $(3\,000 \leqslant \lambda < 1\,000\,000)$ nm.

NOTE 3 000 nm is 3 μm and 1 000 000 nm is 1 mm.

6.8 Microwave

Microwave irradiances are defined as the wavelength range of $(1\,000\,000 \leqslant \lambda < 15\,000\,000)$ nm.

NOTE 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 include (see Reference [12]):

W $(100{,}0 \geqslant \nu > 56{,}0)$ GHz or $(3{,}00 \times 10^6 \leqslant \lambda < 5{,}35 \times 10^6)$ nm;

V $(56{,}0 \geqslant \nu > 46{,}0)$ GHz or $(5{,}35 \times 10^6 \leqslant \lambda < 6{,}52 \times 10^6)$ nm;

Q $(46{,}0 \geqslant \nu > 36{,}0)$ GHz or $(6{,}52 \times 10^6 \leqslant \lambda < 8{,}33 \times 10^6)$ nm;

K $(36{,}00 \geqslant \nu > 10{,}90)$ GHz or $(8{,}33 \times 10^6 \leqslant \lambda < 2{,}75 \times 10^7)$ nm;

X $(10{,}90 \geqslant \nu > 5{,}20)$ GHz or $(2{,}75 \times 10^7 \leqslant \lambda < 5{,}77 \times 10^7)$ nm;

C $(6{,}20 \geqslant \nu > 3{,}90)$ GHz or $(4{,}84 \times 10^7 \leqslant \lambda < 7{,}69 \times 10^7)$ nm;

S $(5{,}20 \geqslant \nu > 1{,}55)$ GHz or $(5{,}77 \times 10^7 \leqslant \lambda < 1{,}93 \times 10^8)$ nm;

L $(1{,}550 \geqslant \nu > 0{,}390)$ GHz or $(1{,}93 \times 10^8 \leqslant \lambda < 7{,}69 \times 10^8)$ nm;

P $(0{,}390 \geqslant \nu > 0{,}225)$ GHz or $(7{,}69 \times 10^8 \leqslant \lambda < 1{,}33 \times 10^9)$ nm.

6.9 Radio

Solar radio irradiances can be defined as the wavelength range of $(100\,000 \leqslant \lambda < 100\,000\,000\,000)$ nm, although most reports of solar measurements range from $(1\,000\,000 \leqslant \lambda < 10\,000\,000\,000)$ nm.

NOTE 100 000 nm is 0,1 mm or approximately 3 000 GHz, and 100 000 000 000 nm is 100 m or approximately 3 000 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 include (see Reference [12]):

Extremely High Frequency (EHF)	$(300 \geqslant \nu > 30)$ GHz or $(1{,}00 \times 10^6 \leqslant \lambda < 1{,}00 \times 10^7)$ nm;
Super High Frequency (SHF)	$(30 \geqslant \nu > 3)$ GHz or $(1{,}00 \times 10^7 \leqslant \lambda < 1{,}00 \times 10^8)$ nm;
Ultra High Frequency (UHF)	$(3\,000 \geqslant \nu > 300)$ MHz or $(1{,}00 \times 10^8 \leqslant \lambda < 1{,}00 \times 10^9)$ nm;
Very High Frequency (VHF)	$(300 \geqslant \nu > 30)$ MHz or $(1{,}00 \times 10^9 \leqslant \lambda < 1{,}00 \times 10^{10})$ nm;
High Frequency (HF)	$(30 \geqslant \nu > 3)$ MHz or $(1{,}00 \times 10^{10} \leqslant \lambda < 1{,}00 \times 10^{11})$ nm.

The calculation of Hertz in frequency units, ν, is $\nu = c/\lambda$, where the speed of light in a vacuum, c, is defined as (299 792 458) m s^{-1} and λ is the wavelength of interest in metres, e.g. the 10,7 cm solar radio flux can be converted to frequency in Hz as follows: (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.

7 Compliance criteria

7.1 Rationale

The compliance criteria for this International Standard consist of activities that are common to solar irradiance product types (see Clause 5) and solar irradiance spectral categories (see Clause 6). These criteria specify a compliance process for the determination of solar irradiances that includes the reporting, documenting, publishing and archiving of solar irradiance products.

7.2 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.

7.3 Documenting

7.3.1 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.

7.3.2 For **measurements**, including spacecraft observations, rocket experiment datasets 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.

7.3.3 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 datasets, 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.

7.3.4 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 or indices shall be described. The measurement datasets used in the derivation, the mathematical formulation of the model, the method of resolving discrepancies between multiple datasets, the derivation algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes, shall be documented.

7.3.5 For first-principles or **theoretical 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.

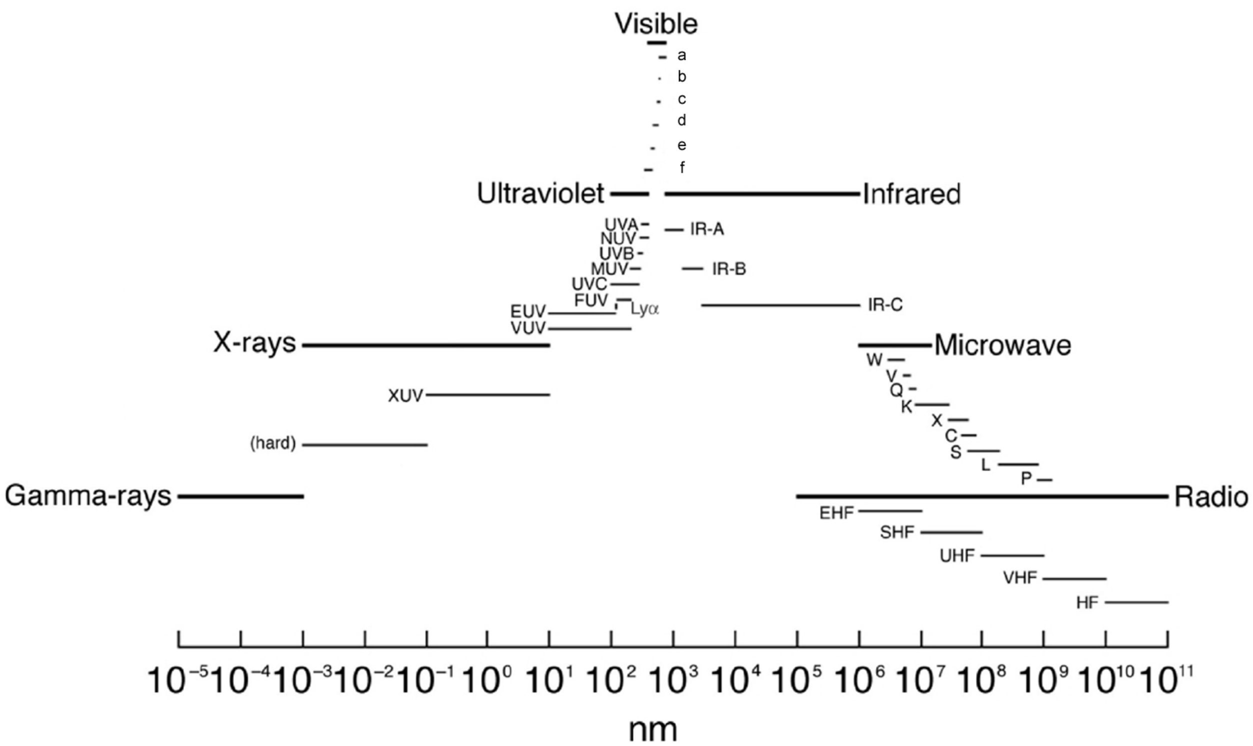
7.3.6 For **solar irradiance proxies** or **indices**, a description of the rationale for developing the proxy or index and its areas of application shall be described. Where appropriate, the datasets used in the derivation, the mathematical formulation of the proxy or index, the method of resolving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

Table 1 — Definitions of solar irradiance spectral categories

Spectral category	Spectral sub-category	Wavelength range nm	Wavelength range (SI prefixes from Table 2)	Notes
Total solar irradiance				full-disk, 1 ua solar irradiance integrated across all λ
Gamma-rays		$0{,}000\,01 \leqslant \lambda < 0{,}001$	$10\ \text{fm} \leqslant \lambda < 1\ \text{pm}$	
X-rays		$0{,}001 \leqslant \lambda < 0{,}1$	$1\ \text{pm} \leqslant \lambda < 0{,}10\ \text{nm}$	Hard X-rays
	XUV	$0{,}1 \leqslant \lambda < 10$	$0{,}10\ \text{nm} \leqslant \lambda < 10\ \text{nm}$	Soft X-rays
Ultraviolet	UV	$100 \leqslant \lambda < 400$	$100\ \text{nm} \leqslant \lambda < 400\ \text{nm}$	Ultraviolet
	VUV	$10 \leqslant \lambda < 200$	$10\ \text{nm} \leqslant \lambda < 200\ \text{nm}$	Vacuum Ultraviolet
	EUV	$10 \leqslant \lambda < 121$	$10\ \text{nm} \leqslant \lambda < 121\ \text{nm}$	Extreme Ultraviolet
	H Lyman-α	$121 \leqslant \lambda < 122$	$121\ \text{nm} \leqslant \lambda < 122\ \text{nm}$	Hydrogen Lyman-alpha
	FUV	$122 \leqslant \lambda < 200$	$122\ \text{nm} \leqslant \lambda < 200\ \text{nm}$	Far Ultraviolet
	UVC	$100 \leqslant \lambda < 280$	$100\ \text{nm} \leqslant \lambda < 280\ \text{nm}$	Ultraviolet C
	MUV	$200 \leqslant \lambda < 300$	$200\ \text{nm} \leqslant \lambda < 300\ \text{nm}$	Middle Ultraviolet
	UVB	$280 \leqslant \lambda < 315$	$280\ \text{nm} \leqslant \lambda < 315\ \text{nm}$	Ultraviolet B
	NUV	$300 \leqslant \lambda < 400$	$300\ \text{nm} \leqslant \lambda < 400\ \text{nm}$	Near Ultraviolet
	UVA	$315 \leqslant \lambda < 400$	$315\ \text{nm} \leqslant \lambda < 400\ \text{nm}$	Ultraviolet A
Visible	VIS	$380 \leqslant \lambda < 760$	$380\ \text{nm} \leqslant \lambda < 760\ \text{nm}$	optical
		$360 \leqslant \lambda < 450$	$360\ \text{nm} \leqslant \lambda < 450\ \text{nm}$	purple
		$450 \leqslant \lambda < 500$	$450\ \text{nm} \leqslant \lambda < 500\ \text{nm}$	blue
		$500 \leqslant \lambda < 570$	$500\ \text{nm} \leqslant \lambda < 570\ \text{nm}$	green
		$570 \leqslant \lambda < 591$	$570\ \text{nm} \leqslant \lambda < 591\ \text{nm}$	yellow
		$591 \leqslant \lambda < 610$	$591\ \text{nm} \leqslant \lambda < 610\ \text{nm}$	orange
		$610 \leqslant \lambda < 760$	$610\ \text{nm} \leqslant \lambda < 760\ \text{nm}$	red
Infrared	IR	$760 \leqslant \lambda < 1\,000\,000$	$760\ \text{nm} \leqslant \lambda < 1{,}00\ \text{mm}$	
	IR-A	$760 \leqslant \lambda < 1\,400$	$760\ \text{nm} \leqslant \lambda < 1{,}40\ \mu\text{m}$	Near Infrared
	IR-B	$1\,400 \leqslant \lambda < 3\,000$	$1{,}40\ \mu\text{m} \leqslant \lambda < 3{,}00\ \mu\text{m}$	Middle Infrared
	IR-C	$3\,000 \leqslant \lambda < 1\,000\,000$	$3{,}00\ \mu\text{m} \leqslant \lambda < 1{,}00\ \text{mm}$	Far infrared
Microwave		$1\,000\,000 \leqslant \lambda < 15\,000\,000$	$1{,}00\ \text{mm} \leqslant \lambda < 15{,}00\ \text{mm}$	
	W	$3{,}00 \times 10^6 \leqslant \lambda < 5{,}35 \times 10^6$	$3{,}00\ \text{mm} \leqslant \lambda < 5{,}35\ \text{mm}$	$(100{,}0 \geqslant \nu > 56{,}0)$ GHz
	V	$5{,}35 \times 10^6 \leqslant \lambda < 6{,}52 \times 10^6$	$5{,}35\ \text{mm} \leqslant \lambda < 6{,}52\ \text{mm}$	$(56{,}0 \geqslant \nu > 46{,}0)$ GHz
	Q	$6{,}52 \times 10^6 \leqslant \lambda < 8{,}33 \times 10^6$	$6{,}52\ \text{mm} \leqslant \lambda < 8{,}33\ \text{mm}$	$(46{,}0 \geqslant \nu > 36{,}0)$ GHz
	K	$8{,}33 \times 10^6 \leqslant \lambda < 2{,}75 \times 10^7$	$8{,}33\ \text{mm} \leqslant \lambda < 27{,}5\ \text{mm}$	$(36{,}00 \geqslant \nu > 10{,}90)$ GHz
	X	$2{,}75 \times 10^7 \leqslant \lambda < 5{,}77 \times 10^7$	$27{,}50\ \text{mm} \leqslant \lambda < 57{,}70\ \text{mm}$	$(10{,}90 \geqslant \nu > 5{,}20)$ GHz
	C	$4{,}84 \times 10^7 \leqslant \lambda < 7{,}69 \times 10^7$	$48{,}40\ \text{mm} \leqslant \lambda < 76{,}90\ \text{mm}$	$(6{,}20 \geqslant \nu > 3{,}90)$ GHz
	S	$5{,}77 \times 10^7 \leqslant \lambda < 1{,}93 \times 10^8$	$57{,}70\ \text{mm} \leqslant \lambda < 193{,}00\ \text{mm}$	$(5{,}20 \geqslant \nu > 1{,}55)$ GHz
	L	$1{,}93 \times 10^8 \leqslant \lambda < 7{,}69 \times 10^8$	$193{,}00\ \text{mm} \leqslant \lambda < 769{,}00\ \text{mm}$	$(1{,}550 \geqslant \nu > 0{,}390)$ GHz
	P	$7{,}69 \times 10^8 \leqslant \lambda < 1{,}33 \times 10^9$	$769{,}00\ \text{mm} \leqslant \lambda < 1{,}33\ \text{m}$	$(0{,}390 \geqslant \nu > 0{,}225)$ GHz
Radio		$100\,000 \leqslant \lambda < 100\,000\,000\,000$	$0{,}10\ \text{mm} \leqslant \lambda < 100\ \text{m}$	measurements: $(1\,000\,000 \leqslant \lambda < 10\,000\,000\,000)$ nm
	EHF	$1{,}00 \times 10^6 \leqslant \lambda < 1{,}00 \times 10^7$	$1{,}00\ \text{mm} \leqslant \lambda < 10{,}00\ \text{mm}$	Extremely High Frequency $(300 \geqslant \nu > 30)$ GHz
	SHF	$1{,}00 \times 10^7 \leqslant \lambda < 1{,}00 \times 10^8$	$10{,}00\ \text{mm} \leqslant \lambda < 100{,}00\ \text{mm}$	Super High Frequency $(30 \geqslant \nu > 3)$ GHz
	UHF	$1{,}00 \times 10^8 \leqslant \lambda < 1{,}00 \times 10^9$	$100{,}00\ \text{mm} \leqslant \lambda < 1{,}00\ \text{m}$	Ultra High Frequency $(3\,000 \geqslant \nu > 300)$ MHz
	VHF	$1{,}00 \times 10^9 \leqslant \lambda < 1{,}00 \times 10^{10}$	$1{,}00\ \text{m} \leqslant \lambda < 10{,}00\ \text{m}$	Very High Frequency $(300 \geqslant \nu > 30)$ MHz
	HF	$1{,}00 \times 10^{10} \leqslant \lambda < 1{,}00 \times 10^{11}$	$10{,}00\ \text{m} \leqslant \lambda < 100{,}00\ \text{m}$	High Frequency $(30 \geqslant \nu > 3)$ MHz

Table 2 — SI prefixes and symbols for multiples and submultiples

Submultiple	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	d	10	deca	da
10^{-2}	centi	c	10^{2}	hecto	h
10^{-3}	milli	m	10^{3}	kilo	k
10^{-6}	micro	μ	10^{6}	mega	M
10^{-9}	nano	n	10^{9}	giga	G
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a	10^{18}	exa	E
NOTE See Reference [13]					



NOTE Visible light annotation is:

a red

b orange

c yellow

d green

e blue

f purple

Figure 1 — Solar irradiance spectral categories from gamma-rays through radio wavelengths

7.4 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/indices can be found, accessed or recreated by an international community.

7.5 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.

8 Certification

Certification of compliance with this International Standard shall be achieved by complying with the criteria listed in Clause 7. Self-declaration of compliance in an archival publication as part of 7.4 can be accomplished by using the following statement: “The process used for determining solar irradiances reported herein is compliant with International Standard ISO 21348, *Space environment (natural and artificial) — Process for determining solar irradiances*.” The type designation (Clause 5) and the solar irradiance spectral category (Clause 6) shall be identified as part of the self-declaration of compliance.

Bibliography

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

[2] The Jet Propulsion Laboratory (JPL), Planetary and Lunar Ephemerides, DE405/LE405. http://ssd.jpl.nasa.gov/iau-comm4/de405iom/

[3] National Institute of Standards and Technology (NIST), Special Publication 330, 2001, *The International System of Units (SI)*

[4] ROMERO, J., FOX, N.P. and FRÖHLICH, C. 1st comparison of the solar and an SI radiometric scale, *Metrologia,* **28**, pp. 125-128, 1990

[5] ROMERO, J., FOX, N.P. and FRÖHLICH, C. Improved comparison of the World Radiometric Reference and the SI radiometric scale, *Metrologia,* **32** (6), pp. 523-524, 1995

[6] CROMMELYNCK, D., FICHOT, A., LEE, R.B. III, and ROMERO, J. First realisation of the Space Absolute Radiometric Reference (SARR) during the ATLAS 2 flight period, *Adv. Space Res.,* **16** (8), pp. 17-23, 1995

[7] ASTM E 490–00a, 2000, *Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables*

[8] TOBISKA, W.K. and NUSINOV, A.A. Status of the draft ISO Solar Irradiance Standard, *Phys. Chem. Earth* (C), **25** (5-6), pp. 387-388, 2000

[9] World Health Organization (WHO), *Global Solar UV Index: A Practical Guide* 2002

[10] ISO/CIE 17166:1999, *Erythema reference action spectrum and standard erythema dose*

[11] CIE 17.4, 1987, *International Lighting Vocabulary*, 4th ed. (joint IEC/CIE publication)

[12] *Reference Data for Radio Engineers* (ed. VALKENBURG, M.E.), Howard W. Sams & Co., Inc., ITT, 1982

[13] WILKINSON, G.A. IAU Style Manual, Comm. 5, IAU Transactions XXB, 1987

ICS 49.140

Price based on 12 pages