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Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface[1]

This standard is issued under the fixed designation G173; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

A wide variety of solar spectral energy distributions occur in the natural environment and are simulated by artificial sources during product, material, or component testing. To compare the relative optical performance of spectrally sensitive products a reference standard solar spectral distribution is required. These tables replace ASTM standard G159, which has been withdrawn. The solar spectral energy distribution presented in this standard are not intended as a benchmark for ultraviolet radiation in weathering exposure testing of materials. The spectra are based on version 2.9.2 of the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) atmospheric transmission code (**1**,**2**).[2] SMARTS uses empirical parameterizations of version 4.0 of the Air Force Geophysical Laboratory (AFGL) Moderate Resolution Transmission model, MODTRAN (**3**,**4**) for some gaseous absorption processes, and recent spectroscopic data for others. An extraterrestrial spectrum differing only slightly from the extraterrestrial spectrum in Tables E490 is used to calculate the resultant spectra (**5**). The hemispherical tilted spectrum is similar to the hemispherical spectrum in use since 1987, but differs from it because: (*1*) the wavelength range for the current spectrum has been extended deeper into the ultraviolet; (*2*) uniform wavelength intervals are now used; (*3*) more representative atmospheric conditions are represented,; and (*4*) SMARTS Version 2.9.2 has been used as the generating model. For the same reasons, and particularly the adoption of a remarkably less turbid atmosphere than before, significant differences exist in the reference direct normal spectrum compared to previous versions of this standard. The input parameters used in conjunction with SMARTS for the selected atmospheric conditions are tabulated. The SMARTS model and documentation are available as an adjunct (ADJG173CD[3]) to this standard.

1. Scope

1.1 These tables contain terrestrial solar spectral irradiance distributions for use in terrestrial applications that require a standard reference spectral irradiance for hemispherical solar irradiance (consisting of both direct and diffuse components) incident on a sun-facing, 37° tilted surface or the direct normal spectral irradiance. The data contained in these tables reflect reference spectra with uniform wavelength interval (0.5 nanometer (nm) below 400 nm, 1 nm between 400 and 1700 nm, an intermediate wavelength at 1702 nm, and 5 nm intervals from 1705 to 4000 nm). The data tables represent reasonable cloudless atmospheric conditions favorable for photovoltaic (PV) energy production, as well as weathering and durability exposure applications.

1.2 The 37° slope of the sun-facing tilted surface was chosen to represent the average latitude of the 48 contiguous United States. A wide variety of orientations is possible for exposed surfaces. The availability of the SMARTS model (as an adjunct, ADJG173CD[3]) to this standard) used to generate the standard spectra allows users to evaluate differences relative to the surface specified here.

1.3 The air mass and atmospheric extinction parameters are chosen to provide (*1*) historical continuity with respect to previous standard spectra, (*2*) reasonable cloudless atmospheric conditions favorable for photovoltaic (PV) energy production or weathering and durability exposure, based upon modern broadband solar radiation data, atmospheric profiles, and improved knowledge of aerosol optical depth profiles. In nature, an extremely large range of atmospheric conditions can

[1] These tables are under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.09 on Radiometry.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[3] Available from ASTM International Headquarters. Order Adjunct No. ADJG173CD. Original adjunct produced in 2005.

be encountered even under cloudless skies. Considerable departure from the reference spectra may be observed depending on time of day, geographical location, and changing atmospheric conditions. The availability of the SMARTS model (as an adjunct (ADJG173CD[3])to this standard) used to generate the standard spectra allows users to evaluate spectral differences relative to the spectra specified here.

2. Referenced Documents

2.1 *ASTM Standards:*[4]

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables

E772 Terminology of Solar Energy Conversion

2.2 *ASTM Adjunct:*[3]

ADJG173CD Simple Model for Atmospheric Transmission of Sunshine

3. Terminology

3.1 *Definitions*—Definitions of most terms used in this specification may be found in Terminology E772.

3.2 *Definitions:*The following definition differs from that in Terminology E772, representing information current as of this revision.

3.2.1 *solar constant*—the total solar irradiance at normal incidence on a surface in free space at the earth's mean distance from the sun. (1 astronomical unit, or AU = 1.496 × 10^{11} m).

3.2.1.1 *Discussion*—The solar constant is now known within about ±1.5 $W{\cdot}m^{-2}$. Its current accepted values are 1366.1 $W{\cdot}m^{-2}$ (Tables E490) or 1367.0 $W{\cdot}m^{-2}$ (World Meteorological Organization, WMO), and are subject to change. Due to the eccentricity of the earth's orbit, the actual extraterrestrial solar irradiance varies by ±3.4 % about the solar constant as the earth-sun distance varies through the year. Throughout this standard the solar constant is defined as 1367.0 $W{\cdot}m^{-2}$.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *aerosol optical depth (AOD)*—the wavelength-dependent total extinction (scattering and absorption) by aerosols in the atmosphere. This optical depth (also called "optical thickness") is defined here at 500 nm.

3.3.1.1 *Discussion*—See Appendix X1.

3.3.2 *air mass zero (AM0)*—describes solar radiation quantities outside the Earth's atmosphere at the mean Earth-Sun distance (1 Astronomical Unit). See Tables E490.

3.3.3 *integrated irradiance* $E_{\lambda 1\text{-}\lambda 2}$—spectral irradiance integrated over a specific wavelength interval from λ_1 to λ_2, measured in $W{\cdot}m^{-2}$; mathematically:

$$E_{\lambda 1-\lambda 2} = \int_{\lambda 1}^{\lambda 2} E_\lambda \, d\lambda \quad (1)$$

3.3.4 *solar irradiance, hemispherical* E_H—on a given plane, the solar radiant flux received from within the 2π steradian field of view of a tilted plane from the portion of the sky dome and the foreground included in the plane's field of view, including both diffuse and direct solar radiation.

3.3.4.1 *Discussion*—For the special condition of a horizontal plane the hemispherical solar irradiance is properly termed global solar irradiance, E_G. Incorrectly, global tilted, or total global irradiance is often used to indicate hemispherical irradiance for a tilted plane. In case of a sun-tracking receiver, this hemispherical irradiance is commonly called global normal irradiance. The adjective global should refer only to hemispherical solar radiation on a horizontal, not a tilted, surface.

3.3.5 *solar irradiance, spectral* E_λ—solar irradiance E per unit wavelength interval at a given wavelength λ (unit: Watts per square meter per nanometer, $W{\cdot}m^{-2}{\cdot}nm^{-1}$):

$$E_\lambda = \frac{dE}{d\lambda} \quad (2)$$

3.3.6 *spectral interval*—the distance in wavelength units between adjacent spectral irradiance data points.

3.3.7 *spectral passband*—the effective wavelength interval within which spectral irradiance is allowed to pass, as through a filter or monochromator. The convolution integral of the spectral passband (normalized to unity at maximum) and the incident spectral irradiance produces the effective transmitted irradiance.

3.3.7.1 *Discussion*—Spectral passband may also be referred to as the spectral bandwidth of a filter or device. Passbands are usually specified as the interval between wavelengths at which one half of the maximum transmission of the filter or device occurs, or as full-width at half-maximum, FWHM.

3.3.8 *spectral resolution*—the minimum wavelength difference between two wavelengths that can be identified unambiguously.

3.3.8.1 *Discussion*—In the context of this standard, the spectral resolution is simply the interval, Δλ, between spectral data points, or the *spectral interval*.

3.3.9 *total ozone*—the depth of a column of pure ozone equivalent to the total of the ozone in a vertical column from the ground to the top of the atmosphere (unit: atmosphere-cm or atm-cm).

3.3.10 *total precipitable water*—the depth of a column of water (with a section of 1 cm^2) equivalent to the condensed water vapor in a vertical column from the ground to the top of the atmosphere (unit: cm or g/cm^2).

3.3.11 *wavenumber*—a unit of frequency, ν, in units of reciprocal centimeters (symbol cm^{-1}) commonly used in place of wavelength, λ (units of length, typically nanometers). To convert wavenumber to nanometers, λ nm = $1 \cdot 10^7 / \nu$ cm^{-1}. See X1.2.

4. Significance and Use

4.1 Absorptance, reflectance, and transmittance of solar energy are important factors in material degradation studies, solar thermal system performance, solar photovoltaic system performance, biological studies, and solar simulation activities. These optical properties are normally functions of wavelength, which require the spectral distribution of the solar flux be

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

known before the solar-weighted property can be calculated. To compare the relative performance of competitive products, or to compare the performance of products before and after being subjected to weathering or other exposure conditions, a reference standard solar spectral distribution is desirable.

4.2 These tables provide appropriate standard spectral irradiance distributions for determining the relative optical performance of materials, solar thermal, solar photovoltaic, and other systems. The tables may be used to evaluate components and materials for the purpose of solar simulation where either the direct or the hemispherical (that is, direct beam plus diffuse sky) spectral solar irradiance is desired. However, these tables are not intended to be used as a benchmark for ultraviolet radiation used in indoor exposure testing of materials using manufactured light sources.

4.3 The total integrated irradiances for the direct and hemispherical tilted spectra are 900.1 $W \cdot m^{-2}$ and 1000.4 $W \cdot m^{-2}$, respectively. Note that, in PV applications, no amplitude adjustments are required to match standard reporting condition irradiances of 1000 $W \cdot m^{-2}$ for hemispherical irradiance.

4.4 Previously defined global hemispherical reference spectrum (G159) for a sun-facing 37°-tilted surface served well to meet the needs of the flat plate photovoltaic research, development, and industrial community. Investigation of prevailing conditions and measured spectra shows that this global hemispherical reference spectrum can be attained in practice under a variety of conditions, and that these conditions can be interpreted as representative for many combinations of atmospheric parameters. Earlier global hemispherical reference spectrum may be closely, but not exactly, reproduced with improved spectral wavelength range, uniform spectral interval, and spectral resolution equivalent to the spectral interval, using inputs in X1.4.

4.5 Reference spectra generated by the SMARTS Version 2.9.2 model for the indicated conditions are shown in Fig. 1. The exact input file structure required to generate the reference spectra is shown in Table 1.

4.6 The availability of the adjunct (ADJG173CD[3]) standard computer software for SMARTS allows one to (*1*) reproduce the reference spectra, using the above input parameters; (*2*) compute test spectra to attempt to match measured data at a specified FWHM, and evaluate atmospheric conditions; and (*3*) compute test spectra representing specific conditions for analysis vis-à-vis any one or all of the reference spectra.

4.7 Differences from the previous standard spectra (G159) can be summarized as follows:

4.7.1 Extended spectral interval in the ultraviolet (down to 280 nm, rather than 305 nm),

4.7.2 Better resolution (2002 wavelengths, as compared to 120),

4.7.3 Constant intervals (0.5 nm below 400 nm, 1 nm between 400 and 1700 nm, and 5 nm above),

4.7.4 Better definition of atmospheric scattering and gaseous absorption, with more species considered,

4.7.5 Better defined extraterrestrial spectrum,

4.7.6 More realistic spectral ground reflectance, and

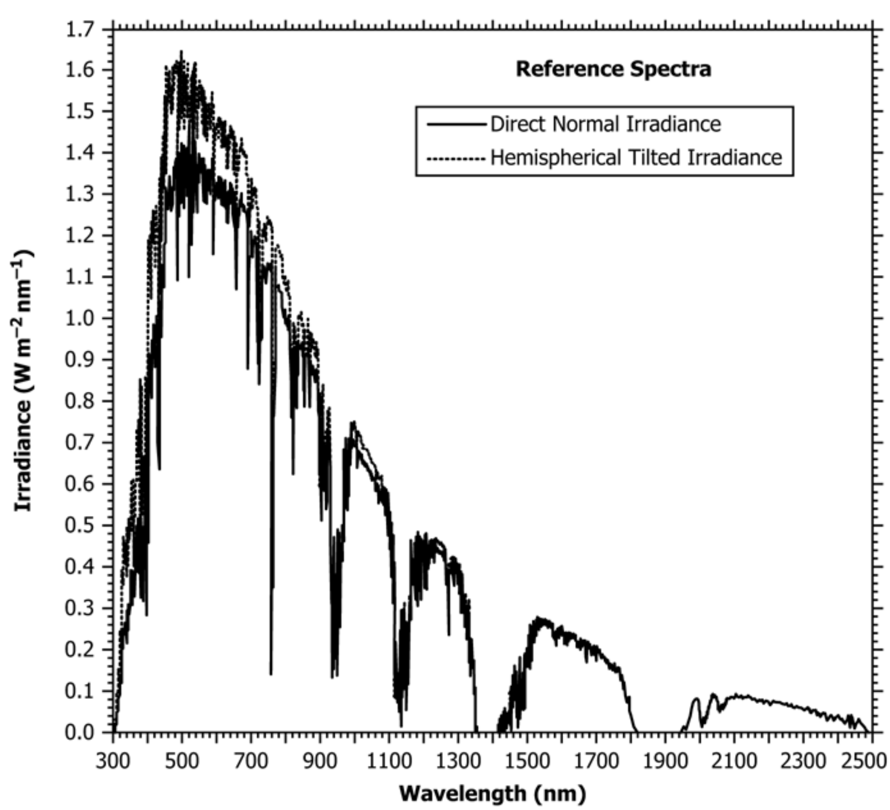


FIG. 1 Plot of Direct Normal Spectral Irradiance (Solid Line) and Hemispherical Spectral Irradiance on 37° Tilted Sun-Facing Surface (Dotted Line) Computed Using Smarts Version 2.9.2 Model With Input File in Table 1

TABLE 1 SMARTS Version 2.9.2 Input File to Generate the Reference Spectra

Card ID	Value	Parameter/Description/Variable Name
1	'ASTM_G 173_Std_Spectra'	Header
2	1	Pressure input mode (1 = pressure and altitude): ISPR
2a	1013.25 0.	Station Pressure (mb) and altitude (km): SPR, ALT
3	1	Standard Atmosphere Profile Selection (1 = use default atmosphere): IATM1
3a	'USSA'	Default Standard Atmosphere Profile: ATM
4	1	Water Vapor Input (1 = default from Atmospheric Profile): IH2O
5	1	Ozone Calculation (1 = default from Atmospheric Profile): IO3
6	1	Pollution level mode (1 = standard conditions/no pollution): IGAS (see X1.3)
7	370	Carbon Dioxide volume mixing ratio (ppm): qCO2 (see X1.3)
7a	1	Extraterrestrial Spectrum (1 = SMARTS/Gueymard): ISPCTR
8	'S&F_RURAL'	Aerosol Profile to Use: AEROS
9	0	Specification for aerosol optical depth/turbidity input (0 = AOD at 500 nm): ITURB
9a	0.084	Aerosol Optical Depth at 500 nm: TAU5
10	38	Far field Spectral Albedo file to use (38= Light Sandy Soil): IALBDX
10b	1	Specify tilt calculation (1 = yes): ITILT
10c	38 37 180	Albedo and Tilt variables-Albedo file to use for near field, Tilt, and Azimuth: IALBDG, TILT, WAZIM
11	280 4000 1.0 1367.0	Wavelength Range-start, stop, mean radius vector correction, integrated solar spectrum irradiance: WLMN, WLMX, SUNCOR, SOLARC
12	2	Separate spectral output file print mode (2 = yes): IPRT
12a	280 4000 .5	Output file wavelength-Print limits, start, stop, minimum step size: WPMN, WPMX, INTVL
12b	2	Number of output variables to print: IOTOT
12c	8 9	Code relating output variables to print (8 = Hemispherical tilt, 9 = direct normal + circumsolar): OUT(8), OUT(9)
13	1	Circumsolar calculation mode (1 = yes): ICIRC
13a	0 2.9 0	Receiver geometry-Slope, View, Limit half angles: SLOPE, APERT, LIMIT
14	0	Smooth function mode (0 = none): ISCAN
15	0	Illuminance calculation mode (0 = none): ILLUM
16	0	UV calculation mode (0 = none): IUV
17	2	Solar Geometry mode (2 = Air Mass): IMASS
17a	1.5	Air mass value: AMASS

4.7.7 Lower aerosol optical depth, yielding significantly larger direct normal irradiance.

5. Technical Bases for the Tables

5.1 These tables are modeled data generated using an air mass zero (AM0) spectrum based in part on the extraterrestrial spectrum of Kurucz (**5**), the 1976 U.S. Standard Atmosphere (**6**), the Shettle and Fenn Rural Aerosol Profile (**7**), the SMARTS radiative transfer code, version 2.9.2, and associated input data files.

5.2 In order to provide spectral data with a uniform spectral step size and improved spectral resolution, the AM0 spectrum used in conjunction with SMARTS to generate the terrestrial spectrum is slightly different from the ASTM extraterrestrial spectrum, Standard E490. Because Standard E490 and SMARTS both use the Kurucz data, the SMARTS and Tables E490 spectra are in good agreement though they do not have the same spectral interval step sizes, spectral interval centers, or spectral resolution.

5.3 The 1976 U.S. Standard Atmosphere (USSA) is used to provide documented atmospheric properties and concentrations of absorbers. However, some newly documented (and relatively minor) absorbers are taken into consideration in the present standard spectra. See X1.3.

5.4 The SMARTS model code and documentation is available from the NREL (National Renewable Energy Lab) website (www.nrel.gov).

5.5 These terrestrial solar spectral data are based on the work of Gueymard (**1**,**2**) and Gueymard et al. (**8**). Previously defined reference spectra were based on the work of Bird, Hulstrom, and Lewis (**9**). The current spectra reflect current (as of 2002) improved knowledge of gaseous absorption, atmospheric aerosol optical properties, transmission properties, and radiative transfer modeling.

5.6 The terrestrial solar spectra in the tables have been computed with a spectral resolution equivalent to that of the wavelength interval. Parameterizations in the SMARTS2 model are based on high resolution (2 cm^{-1}) MODTRAN (**2**,**3**,**10**,**11**) results subsequently "degraded" or smoothed to the SMARTS2 model wavelength interval.

5.6.1 *Discussion*—This approach emulates the procedure of measuring spectral data with a monochromator by using the wavelength interval equivalent to the spectral passband of the instrument.

5.7 To represent favorable conditions for PV energy production and exposure conditions for weathering and durability testing, sites in the National Solar Radiation Data Base (**12**) with annual daily average direct normal solar radiation exceeding 6 $kWh \cdot m^{-2}$ (or 21.6 $MJ \cdot m^{-2}$) per day were analyzed. The mean aerosol optical depth at 500 nm for these sites was determined to be 0.085. A very slightly smaller AOD of 0.084 results in a hemispherical tilted spectrum integrating to 1000.4 W/m^2, nearly exactly the irradiance used in photovoltaic standard reporting conditions. See X1.2.

5.8 Previous reference spectra were generated using a wavelength-independent albedo of 0.2. The present standards utilize measured wavelength-dependent reflectance data, representing light sandy soil of the southwest U.S. See Fig. X1.1.

5.9 The direct normal spectrum includes the circumsolar spectral irradiance that would be measured with a collimated spectroradiometer or pyrheliometer with a 5.8° field of view (aperture half-angle of 2.9°) representing common commercially available radiometers.

5.10 The profile for the United States Standard Atmosphere of 1976 results in a carbon dioxide volume mixing ratio of 330 ppm. It's current (2001) measured value is about 370 ppm. The latter is the value used in the computation of the reference spectra, as noted in Table 1.

5.11 The selected air mass value of 1.5 for a plane parallel atmosphere above a flat earth corresponds to a zenith angle of 48.19°. The SMARTS2 computation of air mass accounts for atmospheric curvature and the vertical density profile of molecules, which results in a solar zenith angle of 48.236°, or an equivalent plane parallel atmosphere air mass of 1.50136. The angle of incidence computed by SMARTS2 for the direct beam irradiance incident on a 37°-tilted plane facing the sun is thus 11.236°.

6. Solar Spectral Irradiance

6.1 Table 2 presents the reference spectral irradiance data for direct normal spectral irradiance within a 5.8° field of view centered on the sun; and hemispherical spectral solar irradiance on a plane tilted at 37° toward the sun, for the conditions specified in Table 1.

6.2 The spectral table contains:

6.2.1 Direct normal spectral irradiance in the wavelength range 280 to 4000 nm.

6.2.2 Hemispherical solar spectral irradiance incident on an sun-facing plane tilted to 37° from the horizontal in the wavelength range 280 to 4000 nm.

6.2.3 Data in the tables relate to the absolute air mass of 1.5. The direct irradiance contains a circumsolar component for a field of view of 5.8° centered on the sun.

6.2.4 The columns in each table contain:

6.2.4.1 Columns 1, 4, 7: wavelength in nanometers (nm).

6.2.4.2 Columns 2, 5, 8: mean hemispherical spectral irradiance incident on surface tilted 37° toward the sun. E_{λ} in Watts per square meter per nanometer, $W{\cdot}m^{-2}{\cdot}nm^{-1}$.

6.2.4.3 Columns 3, 6, 9: mean direct spectral irradiance within 5.8° field of view incident on surface normal to the sun rays. E_{λ} in Watts per square meter per nanometer, $W{\cdot}m^{-2}{\cdot}nm^{-1}$.

6.3 Fig. 1 is a plot of the direct normal and hemispherical spectral irradiance from the data in Table 2.

TABLE 2 Standard Air Mass 1.5 Direct Normal and Hemispherical Spectral Solar Irradiance for 37° Sun-Facing Tilted Surface

Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$
280.0	4.73E-23	2.54E-26	316.0	0.1235	0.0671	352.0	0.5179	0.3267
280.5	1.23E-21	1.09E-24	316.5	0.1504	0.0811	352.5	0.4896	0.3095
281.0	5.69E-21	6.13E-24	317.0	0.1716	0.0930	353.0	0.5204	0.3298
281.5	1.57E-19	2.75E-22	317.5	0.1825	0.0997	353.5	0.5723	0.3635
282.0	1.19E-18	2.83E-21	318.0	0.1759	0.0958	354.0	0.6050	0.3852
282.5	4.54E-18	1.33E-20	318.5	0.1859	0.1001	354.5	0.6116	0.3904
283.0	1.85E-17	6.76E-20	319.0	0.2047	0.1097	355.0	0.6114	0.3914
283.5	3.54E-17	1.46E-19	319.5	0.1959	0.1069	355.5	0.5903	0.3788
284.0	7.27E-16	4.98E-18	320.0	0.2053	0.1128	356.0	0.5539	0.3563
284.5	2.49E-15	2.16E-17	320.5	0.2453	0.1331	356.5	0.5194	0.3350
285.0	8.01E-15	9.00E-17	321.0	0.2502	0.1341	357.0	0.4567	0.2953
285.5	4.26E-14	6.44E-16	321.5	0.2384	0.1282	357.5	0.4622	0.2995
286.0	1.37E-13	2.35E-15	322.0	0.2220	0.1220	358.0	0.4301	0.2794
286.5	8.38E-13	1.85E-14	322.5	0.2171	0.1197	358.5	0.3993	0.2600
287.0	2.74E-12	7.25E-14	323.0	0.2123	0.1162	359.0	0.4695	0.3065
287.5	1.09E-11	3.66E-13	323.5	0.2486	0.1339	359.5	0.5655	0.3701
288.0	6.23E-11	2.81E-12	324.0	0.2754	0.1485	360.0	0.5982	0.3924
288.5	1.72E-10	9.07E-12	324.5	0.2832	0.1547	360.5	0.5653	0.3717
289.0	5.63E-10	3.50E-11	325.0	0.2789	0.1550	361.0	0.5202	0.3428
289.5	2.07E-09	1.54E-10	325.5	0.3244	0.1794	361.5	0.5096	0.3365
290.0	6.02E-09	5.15E-10	326.0	0.3812	0.2087	362.0	0.5342	0.3535
290.5	1.38E-08	1.33E-09	326.5	0.4072	0.2216	362.5	0.5851	0.3880
291.0	3.51E-08	3.90E-09	327.0	0.3981	0.2183	363.0	0.6019	0.4001
291.5	1.09E-07	1.44E-08	327.5	0.3847	0.2129	363.5	0.5854	0.3899
292.0	2.68E-07	4.08E-08	328.0	0.3512	0.1977	364.0	0.6063	0.4047
292.5	4.27E-07	7.04E-08	328.5	0.3716	0.2068	364.5	0.6006	0.4018
293.0	8.65E-07	1.58E-07	329.0	0.4224	0.2330	365.0	0.6236	0.4181
293.5	2.27E-06	4.71E-07	329.5	0.4688	0.2586	365.5	0.6863	0.4611
294.0	4.17E-06	9.46E-07	330.0	0.4714	0.2619	366.0	0.7353	0.4951
294.5	6.59E-06	1.60E-06	330.5	0.4280	0.2410	366.5	0.7366	0.4969
295.0	1.23E-05	3.22E-06	331.0	0.4026	0.2284	367.0	0.7229	0.4887
295.5	2.78E-05	8.02E-06	331.5	0.4181	0.2364	367.5	0.7091	0.4804
296.0	4.79E-05	1.47E-05	332.0	0.4362	0.2451	368.0	0.6676	0.4532
296.5	7.13E-05	2.33E-05	332.5	0.4392	0.2466	368.5	0.6631	0.4511
297.0	9.68E-05	3.32E-05	333.0	0.4294	0.2426	369.0	0.6932	0.4724
297.5	1.86E-04	6.79E-05	333.5	0.4072	0.2327	369.5	0.7447	0.5086
298.0	2.90E-04	1.11E-04	334.0	0.4150	0.2382	370.0	0.7551	0.5167
298.5	3.58E-04	1.43E-04	334.5	0.4451	0.2543	370.5	0.6826	0.4680
299.0	4.92E-04	2.03E-04	335.0	0.4639	0.2648	371.0	0.6934	0.4763
299.5	8.61E-04	3.74E-04	335.5	0.4531	0.2589	371.5	0.7205	0.4959
300.0	0.0010	0.0005	336.0	0.4152	0.2381	372.0	0.6744	0.4651
300.5	0.0012	0.0006	336.5	0.3821	0.2210	372.5	0.6425	0.4439
301.0	0.0019	0.0009	337.0	0.3738	0.2177	373.0	0.6189	0.4283
301.5	0.0027	0.0013	337.5	0.4005	0.2343	373.5	0.5579	0.3868
302.0	0.0029	0.0015	338.0	0.4341	0.2532	374.0	0.5564	0.3865
302.5	0.0043	0.0022	338.5	0.4553	0.2655	374.5	0.5523	0.3844
303.0	0.0071	0.0037	339.0	0.4636	0.2710	375.0	0.5893	0.4109
303.5	0.0090	0.0048	339.5	0.4745	0.2785	375.5	0.6516	0.4551
304.0	0.0095	0.0051	340.0	0.5018	0.2966	376.0	0.6748	0.4722
304.5	0.0120	0.0065	340.5	0.5007	0.2967	376.5	0.6639	0.4654
305.0	0.0165	0.0089	341.0	0.4714	0.2793	377.0	0.7123	0.5001
305.5	0.0187	0.0102	341.5	0.4694	0.2785	377.5	0.7946	0.5589
306.0	0.0186	0.0102	342.0	0.4893	0.2912	378.0	0.8560	0.6031
306.5	0.0211	0.0116	342.5	0.5077	0.3030	378.5	0.8342	0.5889
307.0	0.0278	0.0152	343.0	0.5149	0.3086	379.0	0.7439	0.5262
307.5	0.0356	0.0195	343.5	0.4861	0.2925	379.5	0.6668	0.4726
308.0	0.0378	0.0208	344.0	0.4184	0.2535	380.0	0.7008	0.4975
308.5	0.0414	0.0228	344.5	0.4031	0.2444	380.5	0.7508	0.5340
309.0	0.0405	0.0223	345.0	0.4590	0.2785	381.0	0.7638	0.5442
309.5	0.0433	0.0237	345.5	0.4893	0.2976	381.5	0.6884	0.4914
310.0	0.0509	0.0278	346.0	0.4778	0.2913	382.0	0.5868	0.4196
310.5	0.0655	0.0359	346.5	0.4866	0.2975	382.5	0.5076	0.3636
311.0	0.0829	0.0454	347.0	0.4940	0.3032	383.0	0.4550	0.3265
311.5	0.0841	0.0462	347.5	0.4767	0.2935	383.5	0.4405	0.3166
312.0	0.0934	0.0509	348.0	0.4751	0.2931	384.0	0.5097	0.3669
312.5	0.0990	0.0538	348.5	0.4834	0.2988	384.5	0.6136	0.4424
313.0	0.1073	0.0583	349.0	0.4656	0.2886	385.0	0.6736	0.4864
313.5	0.1076	0.0590	349.5	0.4781	0.2972	385.5	0.6436	0.4655
314.0	0.1197	0.0653	350.0	0.5280	0.3291	386.0	0.6210	0.4498
314.5	0.1306	0.0705	350.5	0.5674	0.3547	386.5	0.6457	0.4685
315.0	0.1363	0.0737	351.0	0.5517	0.3460	387.0	0.6515	0.4734
315.5	0.1184	0.0648	351.5	0.5302	0.3339	387.5	0.6420	0.4673

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}	Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}	Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}
388.0	0.6358	0.4635	448.0	1.5081	1.2422	520.0	1.5236	1.3349
388.5	0.6314	0.4610	449.0	1.5045	1.2409	521.0	1.5346	1.3452
389.0	0.6854	0.5012	450.0	1.5595	1.2881	522.0	1.5690	1.3760
389.5	0.7597	0.5564	451.0	1.6173	1.3376	523.0	1.4789	1.2976
390.0	0.7970	0.5846	452.0	1.5482	1.2822	524.0	1.5905	1.3962
390.5	0.8037	0.5904	453.0	1.4297	1.1854	525.0	1.5781	1.3859
391.0	0.8514	0.6263	454.0	1.5335	1.2730	526.0	1.5341	1.3479
391.5	0.8634	0.6362	455.0	1.5224	1.2655	527.0	1.3417	1.1795
392.0	0.7949	0.5866	456.0	1.5724	1.3088	528.0	1.5357	1.3508
392.5	0.6626	0.4896	457.0	1.5854	1.3213	529.0	1.6071	1.4142
393.0	0.4798	0.3550	458.0	1.5514	1.2946	530.0	1.5446	1.3598
393.5	0.3815	0.2827	459.0	1.5391	1.2859	531.0	1.6292	1.4348
394.0	0.4957	0.3678	460.0	1.5291	1.2791	532.0	1.5998	1.4094
394.5	0.6839	0.5081	461.0	1.5827	1.3255	533.0	1.4286	1.2590
395.0	0.8077	0.6010	462.0	1.5975	1.3392	534.0	1.5302	1.3491
395.5	0.8604	0.6410	463.0	1.6031	1.3452	535.0	1.5535	1.3701
396.0	0.7566	0.5644	464.0	1.5544	1.3055	536.0	1.6199	1.4292
396.5	0.5502	0.4110	465.0	1.5350	1.2905	537.0	1.4989	1.3229
397.0	0.4262	0.3188	466.0	1.5673	1.3190	538.0	1.5738	1.3896
397.5	0.6295	0.4715	467.0	1.4973	1.2616	539.0	1.5352	1.3558
398.0	0.8525	0.6394	468.0	1.5619	1.3178	540.0	1.4825	1.3096
398.5	1.0069	0.7562	469.0	1.5682	1.3247	541.0	1.4251	1.2595
399.0	1.0693	0.8041	470.0	1.5077	1.2749	542.0	1.5511	1.3714
399.5	1.1021	0.8298	471.0	1.5331	1.2975	543.0	1.5256	1.3493
400.0	1.1141	0.8399	472.0	1.6126	1.3661	544.0	1.5792	1.3971
401.0	1.1603	0.8769	473.0	1.5499	1.3144	545.0	1.5435	1.3657
402.0	1.2061	0.9139	474.0	1.5671	1.3304	546.0	1.5291	1.3536
403.0	1.1613	0.8821	475.0	1.6185	1.3755	547.0	1.5490	1.3717
404.0	1.1801	0.8985	476.0	1.5631	1.3299	548.0	1.5049	1.3331
405.0	1.1511	0.8785	477.0	1.5724	1.3392	549.0	1.5520	1.3752
406.0	1.1227	0.8588	478.0	1.6230	1.3839	550.0	1.5399	1.3648
407.0	1.1026	0.8455	479.0	1.5916	1.3586	551.0	1.5382	1.3639
408.0	1.1514	0.8849	480.0	1.6181	1.3825	552.0	1.5697	1.3923
409.0	1.2299	0.9472	481.0	1.6177	1.3836	553.0	1.5250	1.3533
410.0	1.0485	0.8091	482.0	1.6236	1.3899	554.0	1.5549	1.3802
411.0	1.1738	0.9077	483.0	1.6038	1.3742	555.0	1.5634	1.3883
412.0	1.2478	0.9669	484.0	1.5734	1.3492	556.0	1.5366	1.3651
413.0	1.1971	0.9295	485.0	1.5683	1.3457	557.0	1.4988	1.3321
414.0	1.1842	0.9213	486.0	1.2716	1.0918	558.0	1.5310	1.3613
415.0	1.2258	0.9557	487.0	1.4241	1.2235	559.0	1.4483	1.2885
416.0	1.2624	0.9863	488.0	1.5413	1.3252	560.0	1.4740	1.3118
417.0	1.2312	0.9639	489.0	1.4519	1.2492	561.0	1.5595	1.3885
418.0	1.1777	0.9239	490.0	1.6224	1.3968	562.0	1.4847	1.3225
419.0	1.2258	0.9635	491.0	1.5595	1.3435	563.0	1.5408	1.3731
420.0	1.1232	0.8847	492.0	1.4869	1.2818	564.0	1.5106	1.3466
421.0	1.2757	1.0067	493.0	1.5903	1.3719	565.0	1.5201	1.3555
422.0	1.2583	0.9950	494.0	1.5525	1.3402	566.0	1.4374	1.2823
423.0	1.2184	0.9653	495.0	1.6485	1.4238	567.0	1.5320	1.3673
424.0	1.2117	0.9618	496.0	1.5676	1.3548	568.0	1.5180	1.3554
425.0	1.2488	0.9931	497.0	1.5944	1.3788	569.0	1.4807	1.3228
426.0	1.2135	0.9667	498.0	1.5509	1.3421	570.0	1.4816	1.3240
427.0	1.1724	0.9355	499.0	1.5507	1.3429	571.0	1.4331	1.2810
428.0	1.1839	0.9463	500.0	1.5451	1.3391	572.0	1.5134	1.3534
429.0	1.0963	0.8777	501.0	1.4978	1.2990	573.0	1.5198	1.3595
430.0	0.8746	0.7013	502.0	1.4966	1.2991	574.0	1.5119	1.3527
431.0	0.7939	0.6378	503.0	1.5653	1.3597	575.0	1.4777	1.3225
432.0	1.3207	1.0628	504.0	1.4587	1.2682	576.0	1.4654	1.3118
433.0	1.2288	0.9905	505.0	1.5635	1.3598	577.0	1.5023	1.3452
434.0	1.1352	0.9165	506.0	1.6264	1.4153	578.0	1.4560	1.3040
435.0	1.2452	1.0070	507.0	1.5560	1.3548	579.0	1.4770	1.3230
436.0	1.3659	1.1061	508.0	1.5165	1.3210	580.0	1.5020	1.3455
437.0	1.3943	1.1306	509.0	1.5893	1.3850	581.0	1.5089	1.3518
438.0	1.2238	0.9937	510.0	1.5481	1.3497	582.0	1.5320	1.3729
439.0	1.1775	0.9575	511.0	1.5769	1.3753	583.0	1.5479	1.3872
440.0	1.3499	1.0993	512.0	1.6186	1.4125	584.0	1.5448	1.3845
441.0	1.3313	1.0859	513.0	1.5206	1.3277	585.0	1.5324	1.3737
442.0	1.4250	1.1640	514.0	1.4885	1.3003	586.0	1.4953	1.3409
443.0	1.4453	1.1823	515.0	1.5314	1.3385	587.0	1.5281	1.3708
444.0	1.4084	1.1537	516.0	1.5455	1.3514	588.0	1.4934	1.3403
445.0	1.4619	1.1992	517.0	1.2594	1.1017	589.0	1.2894	1.1582
446.0	1.3108	1.0766	518.0	1.4403	1.2605	590.0	1.3709	1.2316
447.0	1.4903	1.2257	519.0	1.3957	1.2222	591.0	1.4662	1.3171

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}	Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}	Wavelength, nm	Hemispherical Tilt Irrad, W.m^{-2}.nm^{-1}	Direct + Circumsolar, W.m^{-2}.nm^{-1}
592.0	1.4354	1.2900	664.0	1.3967	1.2647	736.0	1.2059	1.0994
593.0	1.4561	1.3086	665.0	1.4214	1.2871	737.0	1.2039	1.0978
594.0	1.4491	1.3029	666.0	1.4203	1.2860	738.0	1.2269	1.1184
595.0	1.4308	1.2870	667.0	1.4102	1.2767	739.0	1.1905	1.0855
596.0	1.4745	1.3260	668.0	1.4150	1.2810	740.0	1.2195	1.1119
597.0	1.4788	1.3303	669.0	1.4394	1.3032	741.0	1.2148	1.1078
598.0	1.4607	1.3142	670.0	1.4196	1.2853	742.0	1.2153	1.1084
599.0	1.4606	1.3145	671.0	1.4169	1.2829	743.0	1.2405	1.1316
600.0	1.4753	1.3278	672.0	1.3972	1.2651	744.0	1.2503	1.1408
601.0	1.4579	1.3123	673.0	1.4094	1.2760	745.0	1.2497	1.1404
602.0	1.4360	1.2928	674.0	1.4074	1.2742	746.0	1.2470	1.1381
603.0	1.4664	1.3205	675.0	1.3958	1.2639	747.0	1.2477	1.1389
604.0	1.4921	1.3439	676.0	1.4120	1.2786	748.0	1.2401	1.1323
605.0	1.4895	1.3418	677.0	1.3991	1.2669	749.0	1.2357	1.1286
606.0	1.4822	1.3353	678.0	1.4066	1.2737	750.0	1.2341	1.1273
607.0	1.4911	1.3434	679.0	1.3947	1.2629	751.0	1.2286	1.1224
608.0	1.4862	1.3392	680.0	1.3969	1.2650	752.0	1.2330	1.1265
609.0	1.4749	1.3292	681.0	1.3915	1.2601	753.0	1.2266	1.1210
610.0	1.4686	1.3237	682.0	1.3981	1.2662	754.0	1.2420	1.1353
611.0	1.4611	1.3170	683.0	1.3830	1.2526	755.0	1.2383	1.1321
612.0	1.4831	1.3370	684.0	1.3739	1.2445	756.0	1.2232	1.1185
613.0	1.4621	1.3182	685.0	1.3748	1.2454	757.0	1.2221	1.1176
614.0	1.4176	1.2783	686.0	1.3438	1.2174	758.0	1.2295	1.1246
615.0	1.4697	1.3254	687.0	0.9682	0.8829	759.0	1.1945	1.0932
616.0	1.4310	1.2906	688.0	1.1206	1.0195	760.0	0.2660	0.2472
617.0	1.4128	1.2744	689.0	1.1278	1.0260	761.0	0.1540	0.1433
618.0	1.4664	1.3228	690.0	1.1821	1.0746	762.0	0.6877	0.6349
619.0	1.4733	1.3292	691.0	1.2333	1.1201	763.0	0.3795	0.3522
620.0	1.4739	1.3299	692.0	1.2689	1.1516	764.0	0.5388	0.4989
621.0	1.4802	1.3359	693.0	1.2609	1.1446	765.0	0.6860	0.6338
622.0	1.4269	1.2882	694.0	1.2464	1.1318	766.0	0.8146	0.7508
623.0	1.4165	1.2793	695.0	1.2714	1.1538	767.0	0.9742	0.8957
624.0	1.4118	1.2751	696.0	1.2684	1.1513	768.0	1.1138	1.0222
625.0	1.4026	1.2667	697.0	1.3403	1.2151	769.0	1.1278	1.0347
626.0	1.4012	1.2655	698.0	1.3192	1.1961	770.0	1.1608	1.0646
627.0	1.4417	1.3022	699.0	1.2918	1.1721	771.0	1.1686	1.0716
628.0	1.3631	1.2328	700.0	1.2823	1.1636	772.0	1.1778	1.0802
629.0	1.4114	1.2758	701.0	1.2659	1.1489	773.0	1.1771	1.0797
630.0	1.3924	1.2589	702.0	1.2674	1.1500	774.0	1.1771	1.0800
631.0	1.4161	1.2799	703.0	1.2747	1.1567	775.0	1.1771	1.0801
632.0	1.3638	1.2327	704.0	1.3078	1.1864	776.0	1.1798	1.0827
633.0	1.4508	1.3110	705.0	1.3214	1.1989	777.0	1.1727	1.0764
634.0	1.4284	1.2907	706.0	1.3144	1.1925	778.0	1.1713	1.0754
635.0	1.4458	1.3065	707.0	1.3090	1.1875	779.0	1.1765	1.0803
636.0	1.4128	1.2768	708.0	1.3048	1.1839	780.0	1.1636	1.0687
637.0	1.4610	1.3204	709.0	1.3095	1.1880	781.0	1.1607	1.0662
638.0	1.4707	1.3292	710.0	1.3175	1.1954	782.0	1.1662	1.0714
639.0	1.4646	1.3238	711.0	1.3155	1.1934	783.0	1.1614	1.0672
640.0	1.4340	1.2962	712.0	1.3071	1.1856	784.0	1.1536	1.0602
641.0	1.4348	1.2970	713.0	1.2918	1.1719	785.0	1.1586	1.0649
642.0	1.4376	1.2995	714.0	1.3029	1.1823	786.0	1.1592	1.0656
643.0	1.4525	1.3130	715.0	1.2587	1.1428	787.0	1.1450	1.0530
644.0	1.4462	1.3074	716.0	1.2716	1.1548	788.0	1.1305	1.0399
645.0	1.4567	1.3170	717.0	1.1071	1.0081	789.0	1.1257	1.0359
646.0	1.4150	1.2797	718.0	1.0296	0.9387	790.0	1.0910	1.0045
647.0	1.4086	1.2744	719.0	0.9232	0.8427	791.0	1.1058	1.0179
648.0	1.3952	1.2625	720.0	0.9855	0.8994	792.0	1.0953	1.0084
649.0	1.3519	1.2234	721.0	1.0861	0.9897	793.0	1.0875	1.0015
650.0	1.3594	1.2299	722.0	1.2407	1.1281	794.0	1.0972	1.0101
651.0	1.4447	1.3071	723.0	1.1444	1.0423	795.0	1.0932	1.0066
652.0	1.3871	1.2558	724.0	1.0555	0.9631	796.0	1.0742	0.9899
653.0	1.4311	1.2950	725.0	1.0380	0.9474	797.0	1.0913	1.0057
654.0	1.4153	1.2807	726.0	1.0813	0.9864	798.0	1.1121	1.0245
655.0	1.3499	1.2220	727.0	1.0850	0.9899	799.0	1.0905	1.0048
656.0	1.1851	1.0727	728.0	1.0400	0.9497	800.0	1.0725	0.9886
657.0	1.2393	1.1218	729.0	1.0466	0.9550	801.0	1.0843	0.9998
658.0	1.3855	1.2540	730.0	1.1285	1.0294	802.0	1.0856	1.0011
659.0	1.3905	1.2586	731.0	1.0703	0.9770	803.0	1.0657	0.9829
660.0	1.3992	1.2668	732.0	1.1534	1.0520	804.0	1.0782	0.9945
661.0	1.3933	1.2618	733.0	1.1962	1.0901	805.0	1.0545	0.9727
662.0	1.3819	1.2518	734.0	1.2357	1.1261	806.0	1.0974	1.0122
663.0	1.3844	1.2539	735.0	1.2178	1.1101	807.0	1.0859	1.0018

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$
808.0	1.0821	0.9984	880.0	0.9396	0.8743	952.0	0.2689	0.2542
809.0	1.0548	0.9735	881.0	0.9086	0.8456	953.0	0.3436	0.3244
810.0	1.0559	0.9749	882.0	0.9325	0.8679	954.0	0.4241	0.3999
811.0	1.0533	0.9727	883.0	0.9293	0.8649	955.0	0.3412	0.3220
812.0	1.0268	0.9488	884.0	0.9331	0.8686	956.0	0.3282	0.3100
813.0	1.0086	0.9324	885.0	0.9442	0.8791	957.0	0.2707	0.2559
814.0	0.9036	0.8368	886.0	0.9075	0.8452	958.0	0.4610	0.4345
815.0	0.8952	0.8293	887.0	0.9106	0.8480	959.0	0.3739	0.3529
816.0	0.8322	0.7717	888.0	0.9223	0.8590	960.0	0.4207	0.3969
817.0	0.8518	0.7898	889.0	0.9346	0.8704	961.0	0.4612	0.4348
818.0	0.8226	0.7630	890.0	0.9239	0.8608	962.0	0.4417	0.4166
819.0	0.9052	0.8384	891.0	0.9258	0.8626	963.0	0.5050	0.4759
820.0	0.8619	0.7990	892.0	0.9088	0.8469	964.0	0.4586	0.4324
821.0	0.9976	0.9229	893.0	0.8733	0.8141	965.0	0.5037	0.4747
822.0	0.9516	0.8808	894.0	0.8513	0.7941	966.0	0.5028	0.4738
823.0	0.6727	0.6258	895.0	0.8136	0.7596	967.0	0.5024	0.4735
824.0	0.9351	0.8662	896.0	0.7625	0.7127	968.0	0.6521	0.6130
825.0	0.9694	0.8975	897.0	0.6657	0.6231	969.0	0.6862	0.6448
826.0	0.9338	0.8653	898.0	0.7178	0.6714	970.0	0.6346	0.5969
827.0	0.9847	0.9118	899.0	0.5487	0.5146	971.0	0.7140	0.6706
828.0	0.8498	0.7887	900.0	0.7426	0.6943	972.0	0.6877	0.6463
829.0	0.9293	0.8614	901.0	0.5993	0.5616	973.0	0.6065	0.5708
830.0	0.9160	0.8493	902.0	0.6679	0.6250	974.0	0.5753	0.5417
831.0	0.9239	0.8567	903.0	0.6889	0.6448	975.0	0.5899	0.5554
832.0	0.8943	0.8296	904.0	0.8446	0.7886	976.0	0.5719	0.5387
833.0	0.9565	0.8862	905.0	0.8171	0.7634	977.0	0.6386	0.6008
834.0	0.9341	0.8661	906.0	0.7756	0.7250	978.0	0.6151	0.5790
835.0	1.0032	0.9292	907.0	0.6385	0.5983	979.0	0.6382	0.6005
836.0	0.9723	0.9014	908.0	0.6522	0.6109	980.0	0.6047	0.5694
837.0	1.0092	0.9349	909.0	0.7043	0.6591	981.0	0.7134	0.6706
838.0	0.9990	0.9259	910.0	0.6247	0.5855	982.0	0.6922	0.6510
839.0	1.0013	0.9278	911.0	0.6681	0.6258	983.0	0.6687	0.6292
840.0	1.0157	0.9412	912.0	0.6889	0.6451	984.0	0.7373	0.6929
841.0	1.0101	0.9363	913.0	0.6283	0.5891	985.0	0.6882	0.6473
842.0	0.9970	0.9241	914.0	0.6265	0.5874	986.0	0.7508	0.7055
843.0	1.0053	0.9317	915.0	0.6784	0.6355	987.0	0.7393	0.6949
844.0	0.9863	0.9143	916.0	0.5765	0.5410	988.0	0.7346	0.6906
845.0	1.0165	0.9423	917.0	0.7302	0.6835	989.0	0.7491	0.7039
846.0	1.0187	0.9445	918.0	0.5927	0.5561	990.0	0.7323	0.6884
847.0	0.9917	0.9195	919.0	0.7388	0.6916	991.0	0.7536	0.7083
848.0	0.9922	0.9201	920.0	0.7441	0.6966	992.0	0.7510	0.7060
849.0	0.9860	0.9145	921.0	0.7805	0.7300	993.0	0.7373	0.6933
850.0	0.8937	0.8290	922.0	0.7003	0.6558	994.0	0.7541	0.7089
851.0	0.9749	0.9045	923.0	0.7450	0.6970	995.0	0.7518	0.7067
852.0	0.9693	0.8994	924.0	0.7215	0.6757	996.0	0.7488	0.7041
853.0	0.9649	0.8954	925.0	0.7111	0.6662	997.0	0.7397	0.6956
854.0	0.8511	0.7900	926.0	0.7033	0.6588	998.0	0.7389	0.6948
855.0	0.9130	0.8475	927.0	0.7874	0.7368	999.0	0.7386	0.6946
856.0	0.9732	0.9034	928.0	0.5897	0.5536	1000.0	0.7353	0.6916
857.0	0.9917	0.9206	929.0	0.5513	0.5179	1001.0	0.7444	0.7001
858.0	0.9920	0.9209	930.0	0.4321	0.4068	1002.0	0.7281	0.6850
859.0	0.9917	0.9208	931.0	0.4092	0.3854	1003.0	0.7344	0.6909
860.0	0.9882	0.9176	932.0	0.3009	0.2839	1004.0	0.7234	0.6806
861.0	0.9868	0.9165	933.0	0.2484	0.2346	1005.0	0.6817	0.6414
862.0	0.9945	0.9237	934.0	0.1438	0.1360	1006.0	0.7125	0.6705
863.0	1.0005	0.9293	935.0	0.2508	0.2369	1007.0	0.7275	0.6846
864.0	0.9792	0.9096	936.0	0.1614	0.1527	1008.0	0.7269	0.6841
865.0	0.9632	0.8949	937.0	0.1634	0.1545	1009.0	0.7197	0.6774
866.0	0.8490	0.7888	938.0	0.2006	0.1896	1010.0	0.7191	0.6770
867.0	0.9155	0.8507	939.0	0.3989	0.3759	1011.0	0.7228	0.6803
868.0	0.9592	0.8914	940.0	0.4718	0.4441	1012.0	0.7188	0.6767
869.0	0.9496	0.8825	941.0	0.3720	0.3507	1013.0	0.7176	0.6756
870.0	0.9676	0.8993	942.0	0.4053	0.3819	1014.0	0.7207	0.6785
871.0	0.9539	0.8867	943.0	0.2783	0.2629	1015.0	0.7082	0.6668
872.0	0.9669	0.8989	944.0	0.2858	0.2699	1016.0	0.7113	0.6698
873.0	0.9572	0.8900	945.0	0.3682	0.3473	1017.0	0.7034	0.6624
874.0	0.9404	0.8745	946.0	0.1946	0.1841	1018.0	0.7142	0.6726
875.0	0.9269	0.8620	947.0	0.3711	0.3501	1019.0	0.6888	0.6488
876.0	0.9528	0.8863	948.0	0.2742	0.2591	1020.0	0.6990	0.6584
877.0	0.9562	0.8895	949.0	0.4940	0.4651	1021.0	0.7018	0.6611
878.0	0.9524	0.8861	950.0	0.1473	0.1394	1022.0	0.6897	0.6498
879.0	0.9366	0.8714	951.0	0.4838	0.4556	1023.0	0.6951	0.6549

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1
1024.0	0.6906	0.6508	1096.0	0.5032	0.4773	1168.0	0.4195	0.4002
1025.0	0.6975	0.6573	1097.0	0.5785	0.5481	1169.0	0.4231	0.4035
1026.0	0.6964	0.6563	1098.0	0.5029	0.4771	1170.0	0.4587	0.4373
1027.0	0.6931	0.6532	1099.0	0.5077	0.4816	1171.0	0.4483	0.4275
1028.0	0.6939	0.6540	1100.0	0.4858	0.4611	1172.0	0.4548	0.4337
1029.0	0.6863	0.6469	1101.0	0.4970	0.4717	1173.0	0.4564	0.4352
1030.0	0.6906	0.6509	1102.0	0.4688	0.4451	1174.0	0.3369	0.3219
1031.0	0.6874	0.6480	1103.0	0.4664	0.4429	1175.0	0.4524	0.4314
1032.0	0.6879	0.6485	1104.0	0.4677	0.4441	1176.0	0.4768	0.4545
1033.0	0.6761	0.6375	1105.0	0.5064	0.4807	1177.0	0.4724	0.4504
1034.0	0.6802	0.6414	1106.0	0.3979	0.3784	1178.0	0.3600	0.3439
1035.0	0.6823	0.6435	1107.0	0.4830	0.4587	1179.0	0.4837	0.4611
1036.0	0.6820	0.6432	1108.0	0.4157	0.3952	1180.0	0.4407	0.4205
1037.0	0.6750	0.6366	1109.0	0.4128	0.3925	1181.0	0.4551	0.4342
1038.0	0.6717	0.6336	1110.0	0.4790	0.4550	1182.0	0.3232	0.3090
1039.0	0.6764	0.6380	1111.0	0.3315	0.3157	1183.0	0.4387	0.4185
1040.0	0.6717	0.6337	1112.0	0.4136	0.3933	1184.0	0.4199	0.4008
1041.0	0.6718	0.6338	1113.0	0.2685	0.2560	1185.0	0.4074	0.3891
1042.0	0.6720	0.6341	1114.0	0.2999	0.2858	1186.0	0.4772	0.4552
1043.0	0.6653	0.6277	1115.0	0.2499	0.2383	1187.0	0.4558	0.4349
1044.0	0.6683	0.6307	1116.0	0.2014	0.1922	1188.0	0.3350	0.3204
1045.0	0.6645	0.6271	1117.0	0.0796	0.0762	1189.0	0.4157	0.3969
1046.0	0.6471	0.6108	1118.0	0.2175	0.2076	1190.0	0.4624	0.4412
1047.0	0.6569	0.6201	1119.0	0.1132	0.1082	1191.0	0.4466	0.4264
1048.0	0.6627	0.6256	1120.0	0.1419	0.1356	1192.0	0.4734	0.4517
1049.0	0.6590	0.6221	1121.0	0.1859	0.1775	1193.0	0.4543	0.4337
1050.0	0.6546	0.6180	1122.0	0.0817	0.0782	1194.0	0.4689	0.4475
1051.0	0.6552	0.6186	1123.0	0.1282	0.1226	1195.0	0.4470	0.4267
1052.0	0.6512	0.6149	1124.0	0.1087	0.1040	1196.0	0.4313	0.4119
1053.0	0.6492	0.6130	1125.0	0.1443	0.1379	1197.0	0.4772	0.4553
1054.0	0.6465	0.6105	1126.0	0.0516	0.0494	1198.0	0.4339	0.4143
1055.0	0.6485	0.6124	1127.0	0.1573	0.1503	1199.0	0.3649	0.3487
1056.0	0.6464	0.6106	1128.0	0.0992	0.0949	1200.0	0.4483	0.4279
1057.0	0.6448	0.6091	1129.0	0.1059	0.1013	1201.0	0.4371	0.4174
1058.0	0.6382	0.6029	1130.0	0.0706	0.0676	1202.0	0.4372	0.4174
1059.0	0.6188	0.5845	1131.0	0.2956	0.2820	1203.0	0.4341	0.4144
1060.0	0.6359	0.6007	1132.0	0.2341	0.2236	1204.0	0.3625	0.3465
1061.0	0.6212	0.5869	1133.0	0.1533	0.1466	1205.0	0.4369	0.4171
1062.0	0.6327	0.5978	1134.0	0.0417	0.0400	1206.0	0.4809	0.4587
1063.0	0.6224	0.5882	1135.0	0.0155	0.0148	1207.0	0.4299	0.4104
1064.0	0.6320	0.5972	1136.0	0.1288	0.1232	1208.0	0.4335	0.4138
1065.0	0.6291	0.5946	1137.0	0.2879	0.2747	1209.0	0.4143	0.3955
1066.0	0.6171	0.5833	1138.0	0.2033	0.1943	1210.0	0.4534	0.4327
1067.0	0.6203	0.5864	1139.0	0.2985	0.2848	1211.0	0.4223	0.4032
1068.0	0.6194	0.5856	1140.0	0.2560	0.2445	1212.0	0.4249	0.4057
1069.0	0.5863	0.5543	1141.0	0.1934	0.1849	1213.0	0.4696	0.4480
1070.0	0.6047	0.5718	1142.0	0.2248	0.2148	1214.0	0.4341	0.4144
1071.0	0.6166	0.5830	1143.0	0.3118	0.2976	1215.0	0.4278	0.4085
1072.0	0.6154	0.5819	1144.0	0.1133	0.1084	1216.0	0.4664	0.4451
1073.0	0.6036	0.5709	1145.0	0.1460	0.1398	1217.0	0.4553	0.4346
1074.0	0.6216	0.5878	1146.0	0.1576	0.1509	1218.0	0.4593	0.4384
1075.0	0.5925	0.5605	1147.0	0.0592	0.0567	1219.0	0.4466	0.4264
1076.0	0.6147	0.5814	1148.0	0.2711	0.2590	1220.0	0.4581	0.4372
1077.0	0.6043	0.5718	1149.0	0.2185	0.2089	1221.0	0.4653	0.4441
1078.0	0.6032	0.5708	1150.0	0.1216	0.1165	1222.0	0.4514	0.4310
1079.0	0.6047	0.5721	1151.0	0.2034	0.1945	1223.0	0.4441	0.4240
1080.0	0.5972	0.5652	1152.0	0.2476	0.2367	1224.0	0.4481	0.4279
1081.0	0.5808	0.5497	1153.0	0.2381	0.2276	1225.0	0.4624	0.4414
1082.0	0.5894	0.5577	1154.0	0.1425	0.1364	1226.0	0.4682	0.4470
1083.0	0.5981	0.5660	1155.0	0.3132	0.2990	1227.0	0.4330	0.4136
1084.0	0.5785	0.5478	1156.0	0.2809	0.2684	1228.0	0.4666	0.4454
1085.0	0.5933	0.5616	1157.0	0.3146	0.3004	1229.0	0.4672	0.4461
1086.0	0.5541	0.5250	1158.0	0.3117	0.2977	1230.0	0.4600	0.4393
1087.0	0.5670	0.5369	1159.0	0.3369	0.3216	1231.0	0.4720	0.4507
1088.0	0.5932	0.5616	1160.0	0.2865	0.2737	1232.0	0.4663	0.4453
1089.0	0.5792	0.5486	1161.0	0.3475	0.3317	1233.0	0.4540	0.4336
1090.0	0.5557	0.5266	1162.0	0.3500	0.3341	1234.0	0.4702	0.4489
1091.0	0.5884	0.5572	1163.0	0.4686	0.4464	1235.0	0.4650	0.4441
1092.0	0.5812	0.5505	1164.0	0.4019	0.3833	1236.0	0.4691	0.4480
1093.0	0.5106	0.4842	1165.0	0.3886	0.3708	1237.0	0.4634	0.4426
1094.0	0.5397	0.5112	1166.0	0.3749	0.3578	1238.0	0.4680	0.4469
1095.0	0.5207	0.4936	1167.0	0.4100	0.3911	1239.0	0.4627	0.4419

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1
1240.0	0.4608	0.4401	1312.0	0.3334	0.3199	1384.0	0.0000	0.0000
1241.0	0.4620	0.4413	1313.0	0.3135	0.3009	1385.0	0.0000	0.0000
1242.0	0.4625	0.4418	1314.0	0.2883	0.2769	1386.0	0.0000	0.0000
1243.0	0.4575	0.4371	1315.0	0.2858	0.2745	1387.0	0.0002	0.0002
1244.0	0.4553	0.4350	1316.0	0.3242	0.3111	1388.0	0.0000	0.0000
1245.0	0.4566	0.4362	1317.0	0.3122	0.2997	1389.0	0.0006	0.0006
1246.0	0.4595	0.4390	1318.0	0.3333	0.3198	1390.0	0.0005	0.0005
1247.0	0.4575	0.4372	1319.0	0.2686	0.2580	1391.0	0.0003	0.0003
1248.0	0.4586	0.4383	1320.0	0.2587	0.2486	1392.0	0.0000	0.0000
1249.0	0.4597	0.4393	1321.0	0.2987	0.2868	1393.0	0.0001	0.0001
1250.0	0.4571	0.4368	1322.0	0.3022	0.2902	1394.0	0.0001	0.0001
1251.0	0.4526	0.4326	1323.0	0.2328	0.2239	1395.0	0.0000	0.0000
1252.0	0.4510	0.4311	1324.0	0.2625	0.2523	1396.0	0.0000	0.0000
1253.0	0.4477	0.4280	1325.0	0.3222	0.3094	1397.0	0.0000	0.0000
1254.0	0.4436	0.4242	1326.0	0.2805	0.2696	1398.0	0.0013	0.0012
1255.0	0.4507	0.4309	1327.0	0.2663	0.2559	1399.0	0.0008	0.0008
1256.0	0.4402	0.4210	1328.0	0.2345	0.2256	1400.0	0.0000	0.0000
1257.0	0.4353	0.4163	1329.0	0.1776	0.1710	1401.0	0.0000	0.0000
1258.0	0.4450	0.4255	1330.0	0.2292	0.2205	1402.0	0.0018	0.0018
1259.0	0.4273	0.4087	1331.0	0.1448	0.1395	1403.0	0.0024	0.0023
1260.0	0.4311	0.4124	1332.0	0.1458	0.1405	1404.0	0.0007	0.0007
1261.0	0.4115	0.3937	1333.0	0.2030	0.1955	1405.0	0.0000	0.0000
1262.0	0.3957	0.3787	1334.0	0.1693	0.1630	1406.0	0.0020	0.0020
1263.0	0.4002	0.3830	1335.0	0.2312	0.2224	1407.0	0.0002	0.0002
1264.0	0.3715	0.3557	1336.0	0.1835	0.1767	1408.0	0.0016	0.0016
1265.0	0.3957	0.3787	1337.0	0.1645	0.1585	1409.0	0.0006	0.0006
1266.0	0.3853	0.3688	1338.0	0.1780	0.1715	1410.0	0.0005	0.0005
1267.0	0.3882	0.3716	1339.0	0.1768	0.1703	1411.0	0.0021	0.0021
1268.0	0.3705	0.3548	1340.0	0.1683	0.1622	1412.0	0.0026	0.0026
1269.0	0.2465	0.2366	1341.0	0.1704	0.1642	1413.0	0.0234	0.0227
1270.0	0.3874	0.3709	1342.0	0.1780	0.1715	1414.0	0.0004	0.0004
1271.0	0.4083	0.3906	1343.0	0.1271	0.1226	1415.0	0.0002	0.0002
1272.0	0.4088	0.3911	1344.0	0.0756	0.0730	1416.0	0.0356	0.0346
1273.0	0.4063	0.3887	1345.0	0.1090	0.1052	1417.0	0.0118	0.0114
1274.0	0.4061	0.3886	1346.0	0.0582	0.0562	1418.0	0.0136	0.0132
1275.0	0.4123	0.3946	1347.0	0.0601	0.0581	1419.0	0.0021	0.0021
1276.0	0.4169	0.3990	1348.0	0.0047	0.0046	1420.0	0.0083	0.0080
1277.0	0.4200	0.4019	1349.0	0.0162	0.0156	1421.0	0.0092	0.0089
1278.0	0.4276	0.4092	1350.0	0.0160	0.0155	1422.0	0.0463	0.0450
1279.0	0.4246	0.4063	1351.0	0.0046	0.0045	1423.0	0.0092	0.0090
1280.0	0.4220	0.4039	1352.0	0.0015	0.0015	1424.0	0.0170	0.0165
1281.0	0.4134	0.3955	1353.0	0.0001	0.0001	1425.0	0.0259	0.0251
1282.0	0.3731	0.3570	1354.0	0.0003	0.0003	1426.0	0.0278	0.0270
1283.0	0.4073	0.3898	1355.0	0.0000	0.0000	1427.0	0.0495	0.0482
1284.0	0.4208	0.4027	1356.0	0.0000	0.0000	1428.0	0.0046	0.0044
1285.0	0.4240	0.4058	1357.0	0.0001	0.0001	1429.0	0.0380	0.0370
1286.0	0.4271	0.4088	1358.0	0.0000	0.0000	1430.0	0.0616	0.0599
1287.0	0.4221	0.4041	1359.0	0.0000	0.0000	1431.0	0.0502	0.0488
1288.0	0.4199	0.4019	1360.0	0.0000	0.0000	1432.0	0.0025	0.0025
1289.0	0.4094	0.3919	1361.0	0.0000	0.0000	1433.0	0.0358	0.0349
1290.0	0.4129	0.3952	1362.0	0.0000	0.0000	1434.0	0.0210	0.0204
1291.0	0.4179	0.4000	1363.0	0.0000	0.0000	1435.0	0.0214	0.0208
1292.0	0.3962	0.3795	1364.0	0.0000	0.0000	1436.0	0.0384	0.0373
1293.0	0.4126	0.3951	1365.0	0.0000	0.0000	1437.0	0.0299	0.0291
1294.0	0.4042	0.3871	1366.0	0.0000	0.0000	1438.0	0.0133	0.0129
1295.0	0.4051	0.3880	1367.0	0.0000	0.0000	1439.0	0.0510	0.0497
1296.0	0.3896	0.3732	1368.0	0.0000	0.0000	1440.0	0.0396	0.0385
1297.0	0.3713	0.3558	1369.0	0.0000	0.0000	1441.0	0.0318	0.0310
1298.0	0.3918	0.3754	1370.0	0.0000	0.0000	1442.0	0.0363	0.0354
1299.0	0.4085	0.3913	1371.0	0.0000	0.0000	1443.0	0.0451	0.0439
1300.0	0.3531	0.3386	1372.0	0.0000	0.0000	1444.0	0.0618	0.0601
1301.0	0.3623	0.3473	1373.0	0.0000	0.0000	1445.0	0.0498	0.0484
1302.0	0.3918	0.3754	1374.0	0.0002	0.0002	1446.0	0.0231	0.0225
1303.0	0.3462	0.3320	1375.0	0.0003	0.0003	1447.0	0.0362	0.0353
1304.0	0.3006	0.2885	1376.0	0.0003	0.0002	1448.0	0.1157	0.1125
1305.0	0.3838	0.3678	1377.0	0.0001	0.0001	1449.0	0.1021	0.0994
1306.0	0.3845	0.3685	1378.0	0.0011	0.0011	1450.0	0.0274	0.0267
1307.0	0.3059	0.2936	1379.0	0.0001	0.0001	1451.0	0.0113	0.0110
1308.0	0.3470	0.3328	1380.0	0.0001	0.0001	1452.0	0.0624	0.0607
1309.0	0.3841	0.3682	1381.0	0.0000	0.0000	1453.0	0.0820	0.0798
1310.0	0.3011	0.2891	1382.0	0.0000	0.0000	1454.0	0.1376	0.1338
1311.0	0.3337	0.3201	1383.0	0.0000	0.0000	1455.0	0.0662	0.0644

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1
1456.0	0.0885	0.0862	1528.0	0.2793	0.2712	1600.0	0.2381	0.2313
1457.0	0.1170	0.1139	1529.0	0.2724	0.2646	1601.0	0.2232	0.2169
1458.0	0.1364	0.1327	1530.0	0.2552	0.2479	1602.0	0.2241	0.2178
1459.0	0.1631	0.1586	1531.0	0.2697	0.2620	1603.0	0.2240	0.2177
1460.0	0.0854	0.0832	1532.0	0.2784	0.2704	1604.0	0.2284	0.2220
1461.0	0.0903	0.0879	1533.0	0.2771	0.2692	1605.0	0.2368	0.2301
1462.0	0.1306	0.1271	1534.0	0.2689	0.2612	1606.0	0.2414	0.2345
1463.0	0.0432	0.0421	1535.0	0.2669	0.2592	1607.0	0.2330	0.2264
1464.0	0.1518	0.1477	1536.0	0.2746	0.2668	1608.0	0.2299	0.2234
1465.0	0.0934	0.0909	1537.0	0.2734	0.2656	1609.0	0.2273	0.2209
1466.0	0.0652	0.0635	1538.0	0.2720	0.2643	1610.0	0.2176	0.2115
1467.0	0.0361	0.0351	1539.0	0.2730	0.2652	1611.0	0.2268	0.2204
1468.0	0.0769	0.0749	1540.0	0.2649	0.2574	1612.0	0.2308	0.2242
1469.0	0.0948	0.0923	1541.0	0.2690	0.2614	1613.0	0.2372	0.2305
1470.0	0.0497	0.0484	1542.0	0.2693	0.2617	1614.0	0.2384	0.2316
1471.0	0.0178	0.0174	1543.0	0.2721	0.2644	1615.0	0.2410	0.2342
1472.0	0.0468	0.0456	1544.0	0.2721	0.2644	1616.0	0.2305	0.2240
1473.0	0.0702	0.0684	1545.0	0.2771	0.2692	1617.0	0.2347	0.2280
1474.0	0.0973	0.0948	1546.0	0.2748	0.2671	1618.0	0.2435	0.2366
1475.0	0.1846	0.1795	1547.0	0.2731	0.2654	1619.0	0.2410	0.2342
1476.0	0.0688	0.0670	1548.0	0.2668	0.2592	1620.0	0.2345	0.2278
1477.0	0.0697	0.0679	1549.0	0.2734	0.2657	1621.0	0.2343	0.2277
1478.0	0.0635	0.0618	1550.0	0.2699	0.2623	1622.0	0.2375	0.2308
1479.0	0.1200	0.1168	1551.0	0.2706	0.2629	1623.0	0.2425	0.2356
1480.0	0.0606	0.0591	1552.0	0.2718	0.2642	1624.0	0.2427	0.2358
1481.0	0.1153	0.1122	1553.0	0.2713	0.2637	1625.0	0.2378	0.2311
1482.0	0.0585	0.0570	1554.0	0.2647	0.2573	1626.0	0.2397	0.2329
1483.0	0.1486	0.1445	1555.0	0.2676	0.2601	1627.0	0.2408	0.2340
1484.0	0.1375	0.1338	1556.0	0.2631	0.2557	1628.0	0.2413	0.2345
1485.0	0.1250	0.1217	1557.0	0.2706	0.2630	1629.0	0.2414	0.2346
1486.0	0.1234	0.1201	1558.0	0.2685	0.2609	1630.0	0.2365	0.2298
1487.0	0.0606	0.0590	1559.0	0.2681	0.2605	1631.0	0.2381	0.2314
1488.0	0.0942	0.0917	1560.0	0.2657	0.2582	1632.0	0.2382	0.2315
1489.0	0.1897	0.1844	1561.0	0.2700	0.2624	1633.0	0.2327	0.2261
1490.0	0.1748	0.1699	1562.0	0.2676	0.2600	1634.0	0.2328	0.2263
1491.0	0.1978	0.1922	1563.0	0.2667	0.2592	1635.0	0.2337	0.2271
1492.0	0.1644	0.1599	1564.0	0.2626	0.2553	1636.0	0.2354	0.2288
1493.0	0.1816	0.1765	1565.0	0.2673	0.2598	1637.0	0.2270	0.2206
1494.0	0.2037	0.1979	1566.0	0.2625	0.2551	1638.0	0.2201	0.2139
1495.0	0.1825	0.1775	1567.0	0.2631	0.2557	1639.0	0.2203	0.2141
1496.0	0.1685	0.1639	1568.0	0.2572	0.2500	1640.0	0.2151	0.2091
1497.0	0.2285	0.2220	1569.0	0.2545	0.2474	1641.0	0.2196	0.2135
1498.0	0.1897	0.1844	1570.0	0.2418	0.2350	1642.0	0.2208	0.2147
1499.0	0.2176	0.2114	1571.0	0.2351	0.2285	1643.0	0.2154	0.2094
1500.0	0.2506	0.2434	1572.0	0.2378	0.2311	1644.0	0.2236	0.2173
1501.0	0.2655	0.2578	1573.0	0.2341	0.2275	1645.0	0.2182	0.2122
1502.0	0.2336	0.2269	1574.0	0.2415	0.2346	1646.0	0.2175	0.2115
1503.0	0.1849	0.1797	1575.0	0.2397	0.2329	1647.0	0.2277	0.2214
1504.0	0.1603	0.1559	1576.0	0.2468	0.2398	1648.0	0.2166	0.2106
1505.0	0.1840	0.1789	1577.0	0.2160	0.2099	1649.0	0.2187	0.2126
1506.0	0.2577	0.2503	1578.0	0.2352	0.2285	1650.0	0.2253	0.2190
1507.0	0.2551	0.2478	1579.0	0.2367	0.2301	1651.0	0.2086	0.2028
1508.0	0.2430	0.2361	1580.0	0.2446	0.2377	1652.0	0.2237	0.2175
1509.0	0.1869	0.1817	1581.0	0.2487	0.2417	1653.0	0.2228	0.2166
1510.0	0.2705	0.2627	1582.0	0.2420	0.2351	1654.0	0.2158	0.2099
1511.0	0.2647	0.2571	1583.0	0.2476	0.2405	1655.0	0.2223	0.2162
1512.0	0.2607	0.2532	1584.0	0.2490	0.2419	1656.0	0.2210	0.2149
1513.0	0.2424	0.2354	1585.0	0.2587	0.2514	1657.0	0.2222	0.2161
1514.0	0.2257	0.2193	1586.0	0.2557	0.2484	1658.0	0.2249	0.2187
1515.0	0.2657	0.2580	1587.0	0.2530	0.2458	1659.0	0.2212	0.2151
1516.0	0.2568	0.2494	1588.0	0.2511	0.2439	1660.0	0.2233	0.2172
1517.0	0.2493	0.2421	1589.0	0.2323	0.2257	1661.0	0.2238	0.2177
1518.0	0.2521	0.2449	1590.0	0.2418	0.2349	1662.0	0.2191	0.2131
1519.0	0.2444	0.2374	1591.0	0.2420	0.2350	1663.0	0.2224	0.2163
1520.0	0.2645	0.2569	1592.0	0.2523	0.2450	1664.0	0.2210	0.2150
1521.0	0.2751	0.2671	1593.0	0.2583	0.2509	1665.0	0.2118	0.2061
1522.0	0.2638	0.2562	1594.0	0.2562	0.2489	1666.0	0.1788	0.1741
1523.0	0.2800	0.2719	1595.0	0.2582	0.2508	1667.0	0.2107	0.2050
1524.0	0.2754	0.2674	1596.0	0.2445	0.2375	1668.0	0.2146	0.2088
1525.0	0.2588	0.2514	1597.0	0.2469	0.2399	1669.0	0.2152	0.2094
1526.0	0.2675	0.2598	1598.0	0.2542	0.2469	1670.0	0.2217	0.2157
1527.0	0.2622	0.2547	1599.0	0.2420	0.2351	1671.0	0.2188	0.2129

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$	Wavelength, nm	Hemispherical Tilt Irrad, $W.m^{-2}.nm^{-1}$	Direct + Circumsolar, $W.m^{-2}.nm^{-1}$
1672.0	0.2115	0.2058	1915.0	0.0000	0.0000	2275.0	0.0640	0.0633
1673.0	0.2163	0.2105	1920.0	0.0005	0.0004	2280.0	0.0663	0.0656
1674.0	0.2158	0.2100	1925.0	0.0009	0.0009	2285.0	0.0631	0.0624
1675.0	0.2136	0.2079	1930.0	0.0006	0.0005	2290.0	0.0632	0.0625
1676.0	0.2115	0.2058	1935.0	0.0036	0.0035	2295.0	0.0613	0.0606
1677.0	0.2123	0.2067	1940.0	0.0033	0.0032	2300.0	0.0588	0.0582
1678.0	0.2092	0.2037	1945.0	0.0109	0.0107	2305.0	0.0592	0.0585
1679.0	0.2130	0.2074	1950.0	0.0167	0.0165	2310.0	0.0639	0.0632
1680.0	0.2056	0.2002	1955.0	0.0100	0.0099	2315.0	0.0581	0.0575
1681.0	0.1945	0.1894	1960.0	0.0219	0.0216	2320.0	0.0520	0.0515
1682.0	0.2037	0.1983	1965.0	0.0286	0.0281	2325.0	0.0562	0.0556
1683.0	0.2091	0.2036	1970.0	0.0488	0.0481	2330.0	0.0568	0.0562
1684.0	0.1980	0.1928	1975.0	0.0679	0.0667	2335.0	0.0580	0.0574
1685.0	0.2132	0.2076	1980.0	0.0755	0.0742	2340.0	0.0458	0.0454
1686.0	0.2103	0.2048	1985.0	0.0831	0.0816	2345.0	0.0514	0.0509
1687.0	0.2048	0.1995	1990.0	0.0856	0.0841	2350.0	0.0415	0.0411
1688.0	0.2101	0.2047	1995.0	0.0812	0.0798	2355.0	0.0475	0.0470
1689.0	0.2072	0.2018	2000.0	0.0382	0.0375	2360.0	0.0502	0.0497
1690.0	0.2052	0.1999	2005.0	0.0150	0.0147	2365.0	0.0494	0.0489
1691.0	0.1930	0.1881	2010.0	0.0397	0.0391	2370.0	0.0308	0.0305
1692.0	0.2071	0.2017	2015.0	0.0266	0.0262	2375.0	0.0441	0.0437
1693.0	0.2113	0.2059	2020.0	0.0450	0.0442	2380.0	0.0426	0.0421
1694.0	0.2048	0.1995	2025.0	0.0740	0.0728	2385.0	0.0308	0.0305
1695.0	0.2097	0.2043	2030.0	0.0849	0.0835	2390.0	0.0371	0.0367
1696.0	0.2092	0.2038	2035.0	0.0964	0.0948	2395.0	0.0406	0.0402
1697.0	0.1811	0.1765	2040.0	0.0898	0.0883	2400.0	0.0442	0.0437
1698.0	0.2074	0.2021	2045.0	0.0911	0.0896	2405.0	0.0336	0.0333
1699.0	0.2055	0.2002	2050.0	0.0679	0.0669	2410.0	0.0338	0.0335
1700.0	0.1998	0.1946	2055.0	0.0549	0.0541	2415.0	0.0273	0.0271
1702.0	0.2040	0.1987	2060.0	0.0692	0.0682	2420.0	0.0266	0.0264
1705.0	0.1978	0.1928	2065.0	0.0619	0.0610	2425.0	0.0331	0.0328
1710.0	0.1879	0.1832	2070.0	0.0657	0.0647	2430.0	0.0451	0.0447
1715.0	0.1897	0.1849	2075.0	0.0774	0.0763	2435.0	0.0149	0.0148
1720.0	0.1870	0.1823	2080.0	0.0868	0.0855	2440.0	0.0432	0.0429
1725.0	0.1781	0.1737	2085.0	0.0851	0.0838	2445.0	0.0208	0.0207
1730.0	0.1741	0.1698	2090.0	0.0891	0.0878	2450.0	0.0136	0.0135
1735.0	0.1615	0.1576	2095.0	0.0897	0.0884	2455.0	0.0249	0.0247
1740.0	0.1682	0.1641	2100.0	0.0861	0.0849	2460.0	0.0334	0.0332
1745.0	0.1548	0.1511	2105.0	0.0932	0.0918	2465.0	0.0241	0.0240
1750.0	0.1657	0.1616	2110.0	0.0897	0.0883	2470.0	0.0167	0.0166
1755.0	0.1530	0.1493	2115.0	0.0917	0.0903	2475.0	0.0165	0.0164
1760.0	0.1600	0.1561	2120.0	0.0876	0.0863	2480.0	0.0080	0.0080
1765.0	0.1328	0.1297	2125.0	0.0886	0.0873	2485.0	0.0056	0.0056
1770.0	0.1417	0.1383	2130.0	0.0898	0.0884	2490.0	0.0035	0.0035
1775.0	0.1148	0.1121	2135.0	0.0900	0.0887	2495.0	0.0029	0.0029
1780.0	0.1005	0.0981	2140.0	0.0908	0.0894	2500.0	0.0071	0.0070
1785.0	0.0770	0.0752	2145.0	0.0895	0.0881	2505.0	0.0015	0.0015
1790.0	0.0889	0.0868	2150.0	0.0846	0.0834	2510.0	0.0022	0.0022
1795.0	0.0469	0.0459	2155.0	0.0848	0.0836	2515.0	0.0005	0.0005
1800.0	0.0318	0.0311	2160.0	0.0842	0.0829	2520.0	0.0004	0.0004
1805.0	0.0148	0.0145	2165.0	0.0763	0.0752	2525.0	0.0000	0.0000
1810.0	0.0097	0.0095	2170.0	0.0820	0.0808	2530.0	0.0000	0.0000
1815.0	0.0033	0.0032	2175.0	0.0804	0.0793	2535.0	0.0000	0.0000
1820.0	0.0010	0.0010	2180.0	0.0818	0.0806	2540.0	0.0000	0.0000
1825.0	0.0013	0.0012	2185.0	0.0746	0.0735	2545.0	0.0000	0.0000
1830.0	0.0000	0.0000	2190.0	0.0791	0.0779	2550.0	0.0000	0.0000
1835.0	0.0000	0.0000	2195.0	0.0790	0.0778	2555.0	0.0000	0.0000
1840.0	0.0000	0.0000	2200.0	0.0712	0.0702	2560.0	0.0000	0.0000
1845.0	0.0000	0.0000	2205.0	0.0740	0.0729	2565.0	0.0000	0.0000
1850.0	0.0000	0.0000	2210.0	0.0793	0.0782	2570.0	0.0000	0.0000
1855.0	0.0000	0.0000	2215.0	0.0763	0.0752	2575.0	0.0000	0.0000
1860.0	0.0000	0.0000	2220.0	0.0777	0.0766	2580.0	0.0000	0.0000
1865.0	0.0000	0.0000	2225.0	0.0755	0.0744	2585.0	0.0000	0.0000
1870.0	0.0000	0.0000	2230.0	0.0758	0.0747	2590.0	0.0000	0.0000
1875.0	0.0000	0.0000	2235.0	0.0743	0.0733	2595.0	0.0000	0.0000
1880.0	0.0001	0.0001	2240.0	0.0731	0.0721	2600.0	0.0000	0.0000
1885.0	0.0000	0.0000	2245.0	0.0708	0.0699	2605.0	0.0000	0.0000
1890.0	0.0002	0.0002	2250.0	0.0719	0.0710	2610.0	0.0000	0.0000
1895.0	0.0001	0.0001	2255.0	0.0677	0.0669	2615.0	0.0000	0.0000
1900.0	0.0000	0.0000	2260.0	0.0669	0.0661	2620.0	0.0000	0.0000
1905.0	0.0000	0.0000	2265.0	0.0681	0.0674	2625.0	0.0000	0.0000
1910.0	0.0000	0.0000	2270.0	0.0649	0.0641	2630.0	0.0000	0.0000

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1
2635.0	0.0000	0.0000	2995.0	0.0043	0.0043	3355.0	0.0036	0.0037
2640.0	0.0000	0.0000	3000.0	0.0078	0.0079	3360.0	0.0052	0.0053
2645.0	0.0000	0.0000	3005.0	0.0029	0.0029	3365.0	0.0072	0.0073
2650.0	0.0000	0.0000	3010.0	0.0068	0.0069	3370.0	0.0039	0.0040
2655.0	0.0000	0.0000	3015.0	0.0056	0.0056	3375.0	0.0085	0.0085
2660.0	0.0000	0.0000	3020.0	0.0006	0.0006	3380.0	0.0051	0.0052
2665.0	0.0000	0.0000	3025.0	0.0075	0.0076	3385.0	0.0075	0.0076
2670.0	0.0000	0.0000	3030.0	0.0061	0.0061	3390.0	0.0099	0.0100
2675.0	0.0000	0.0000	3035.0	0.0025	0.0025	3395.0	0.0095	0.0096
2680.0	0.0000	0.0000	3040.0	0.0020	0.0020	3400.0	0.0125	0.0126
2685.0	0.0000	0.0000	3045.0	0.0042	0.0043	3405.0	0.0045	0.0045
2690.0	0.0000	0.0000	3050.0	0.0010	0.0010	3410.0	0.0071	0.0072
2695.0	0.0000	0.0000	3055.0	0.0003	0.0003	3415.0	0.0073	0.0074
2700.0	0.0000	0.0000	3060.0	0.0063	0.0064	3420.0	0.0132	0.0133
2705.0	0.0000	0.0000	3065.0	0.0029	0.0029	3425.0	0.0100	0.0101
2710.0	0.0000	0.0000	3070.0	0.0017	0.0018	3430.0	0.0087	0.0088
2715.0	0.0000	0.0000	3075.0	0.0060	0.0061	3435.0	0.0116	0.0117
2720.0	0.0000	0.0000	3080.0	0.0036	0.0037	3440.0	0.0080	0.0081
2725.0	0.0000	0.0000	3085.0	0.0018	0.0018	3445.0	0.0113	0.0114
2730.0	0.0000	0.0000	3090.0	0.0024	0.0024	3450.0	0.0112	0.0113
2735.0	0.0000	0.0000	3095.0	0.0007	0.0007	3455.0	0.0083	0.0084
2740.0	0.0000	0.0000	3100.0	0.0044	0.0045	3460.0	0.0125	0.0127
2745.0	0.0000	0.0000	3105.0	0.0009	0.0009	3465.0	0.0098	0.0099
2750.0	0.0000	0.0000	3110.0	0.0008	0.0009	3470.0	0.0123	0.0124
2755.0	0.0000	0.0000	3115.0	0.0023	0.0023	3475.0	0.0109	0.0111
2760.0	0.0000	0.0000	3120.0	0.0098	0.0099	3480.0	0.0112	0.0113
2765.0	0.0000	0.0000	3125.0	0.0030	0.0031	3485.0	0.0121	0.0122
2770.0	0.0000	0.0000	3130.0	0.0058	0.0058	3490.0	0.0104	0.0105
2775.0	0.0000	0.0000	3135.0	0.0114	0.0116	3495.0	0.0123	0.0124
2780.0	0.0000	0.0000	3140.0	0.0033	0.0034	3500.0	0.0119	0.0120
2785.0	0.0000	0.0000	3145.0	0.0033	0.0033	3505.0	0.0118	0.0119
2790.0	0.0000	0.0000	3150.0	0.0067	0.0067	3510.0	0.0120	0.0121
2795.0	0.0000	0.0000	3155.0	0.0056	0.0057	3515.0	0.0115	0.0116
2800.0	0.0000	0.0000	3160.0	0.0092	0.0093	3520.0	0.0121	0.0122
2805.0	0.0000	0.0000	3165.0	0.0140	0.0142	3525.0	0.0114	0.0115
2810.0	0.0000	0.0000	3170.0	0.0125	0.0126	3530.0	0.0111	0.0112
2815.0	0.0000	0.0000	3175.0	0.0092	0.0093	3535.0	0.0095	0.0095
2820.0	0.0000	0.0000	3180.0	0.0106	0.0107	3540.0	0.0090	0.0091
2825.0	0.0000	0.0000	3185.0	0.0081	0.0082	3545.0	0.0095	0.0096
2830.0	0.0000	0.0000	3190.0	0.0042	0.0043	3550.0	0.0105	0.0106
2835.0	0.0000	0.0000	3195.0	0.0027	0.0027	3555.0	0.0091	0.0091
2840.0	0.0000	0.0000	3200.0	0.0004	0.0004	3560.0	0.0108	0.0109
2845.0	0.0000	0.0000	3205.0	0.0003	0.0003	3565.0	0.0109	0.0109
2850.0	0.0000	0.0000	3210.0	0.0001	0.0001	3570.0	0.0083	0.0084
2855.0	0.0000	0.0000	3215.0	0.0005	0.0005	3575.0	0.0086	0.0087
2860.0	0.0000	0.0000	3220.0	0.0016	0.0016	3580.0	0.0102	0.0103
2865.0	0.0002	0.0002	3225.0	0.0002	0.0002	3585.0	0.0092	0.0092
2870.0	0.0000	0.0000	3230.0	0.0003	0.0003	3590.0	0.0095	0.0095
2875.0	0.0004	0.0004	3235.0	0.0073	0.0074	3595.0	0.0097	0.0097
2880.0	0.0002	0.0003	3240.0	0.0037	0.0038	3600.0	0.0103	0.0103
2885.0	0.0005	0.0005	3245.0	0.0007	0.0007	3605.0	0.0104	0.0104
2890.0	0.0002	0.0002	3250.0	0.0026	0.0026	3610.0	0.0095	0.0095
2895.0	0.0027	0.0027	3255.0	0.0099	0.0100	3615.0	0.0095	0.0095
2900.0	0.0008	0.0008	3260.0	0.0012	0.0012	3620.0	0.0116	0.0117
2905.0	0.0001	0.0001	3265.0	0.0024	0.0025	3625.0	0.0102	0.0103
2910.0	0.0027	0.0028	3270.0	0.0012	0.0012	3630.0	0.0100	0.0100
2915.0	0.0013	0.0013	3275.0	0.0059	0.0060	3635.0	0.0103	0.0104
2920.0	0.0029	0.0029	3280.0	0.0029	0.0029	3640.0	0.0115	0.0115
2925.0	0.0011	0.0011	3285.0	0.0111	0.0112	3645.0	0.0106	0.0107
2930.0	0.0059	0.0060	3290.0	0.0088	0.0088	3650.0	0.0101	0.0102
2935.0	0.0065	0.0066	3295.0	0.0012	0.0012	3655.0	0.0110	0.0110
2940.0	0.0016	0.0016	3300.0	0.0018	0.0018	3660.0	0.0109	0.0110
2945.0	0.0014	0.0015	3305.0	0.0039	0.0040	3665.0	0.0103	0.0103
2950.0	0.0052	0.0053	3310.0	0.0039	0.0040	3670.0	0.0079	0.0079
2955.0	0.0023	0.0024	3315.0	0.0000	0.0000	3675.0	0.0048	0.0049
2960.0	0.0046	0.0047	3320.0	0.0001	0.0001	3680.0	0.0083	0.0084
2965.0	0.0074	0.0075	3325.0	0.0035	0.0035	3685.0	0.0094	0.0095
2970.0	0.0004	0.0004	3330.0	0.0047	0.0047	3690.0	0.0097	0.0097
2975.0	0.0009	0.0009	3335.0	0.0091	0.0091	3695.0	0.0101	0.0102
2980.0	0.0013	0.0014	3340.0	0.0035	0.0035	3700.0	0.0109	0.0109
2985.0	0.0070	0.0070	3345.0	0.0035	0.0036	3705.0	0.0108	0.0108
2990.0	0.0103	0.0104	3350.0	0.0080	0.0081	3710.0	0.0094	0.0094

TABLE 2 *Continued*

Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1	Wavelength, nm	Hemispherical Tilt Irrad, W.m-2.nm-1	Direct + Circumsolar, W.m-2.nm-1
3715.0	0.0092	0.0093	3815.0	0.0078	0.0078	3915.0	0.0070	0.0070
3720.0	0.0104	0.0104	3820.0	0.0097	0.0097	3920.0	0.0069	0.0070
3725.0	0.0107	0.0108	3825.0	0.0095	0.0095	3925.0	0.0069	0.0069
3730.0	0.0093	0.0093	3830.0	0.0096	0.0096	3930.0	0.0071	0.0071
3735.0	0.0086	0.0086	3835.0	0.0077	0.0077	3935.0	0.0074	0.0074
3740.0	0.0088	0.0089	3840.0	0.0090	0.0090	3940.0	0.0074	0.0074
3745.0	0.0103	0.0104	3845.0	0.0088	0.0088	3945.0	0.0075	0.0076
3750.0	0.0093	0.0093	3850.0	0.0088	0.0089	3950.0	0.0076	0.0076
3755.0	0.0090	0.0090	3855.0	0.0085	0.0085	3955.0	0.0077	0.0077
3760.0	0.0089	0.0089	3860.0	0.0080	0.0080	3960.0	0.0077	0.0078
3765.0	0.0086	0.0086	3865.0	0.0081	0.0081	3965.0	0.0078	0.0078
3770.0	0.0091	0.0092	3870.0	0.0074	0.0074	3970.0	0.0077	0.0077
3775.0	0.0091	0.0091	3875.0	0.0068	0.0068	3975.0	0.0075	0.0075
3780.0	0.0096	0.0096	3880.0	0.0065	0.0066	3980.0	0.0074	0.0074
3785.0	0.0088	0.0088	3885.0	0.0068	0.0068	3985.0	0.0074	0.0075
3790.0	0.0078	0.0078	3890.0	0.0069	0.0069	3990.0	0.0074	0.0074
3795.0	0.0089	0.0089	3895.0	0.0075	0.0075	3995.0	0.0072	0.0072
3800.0	0.0099	0.0099	3900.0	0.0079	0.0079	4000.0	0.0071	0.0071
3805.0	0.0093	0.0093	3905.0	0.0079	0.0080			
3810.0	0.0082	0.0083	3910.0	0.0071	0.0072			

7. Application of the Spectral Data to the Derivation of Effective Optical Properties

7.1 *Spectrally Modified Total Solar Irradiance:*

7.1.1 If $R(\lambda)$ is the wavelength-dependent property of a device, such as responsivity, transmittance, reflectance, absorptance and $E_\lambda(\lambda)$ represents the solar spectral irradiance, then E_S, the effective total solar irradiance weighted with the spectral property of the device, can be calculated as an integral of the product of $R(\lambda)$ and $E_\lambda(\lambda)$ as shown in Eq 3.

$$E_S = \int_0^\infty R(\lambda) E_\lambda(\lambda) d\lambda \tag{3}$$

7.2 *Solar Spectral Weighting:*

7.2.1 The mean value, R_S, of the property $R(\lambda)$, that is effective if the total solar spectrum is applied, can in general be calculated from the following equation:

$$R_S = \frac{\int_0^\infty R(\lambda) E_\lambda(\lambda) d\lambda}{\int_0^\infty E_\lambda(\lambda) d\lambda} \tag{4}$$

7.2.2 Since the spectral property and the spectral irradiance are usually known only as discrete values, the integrations of eqns 3 and 4 become summations, respectively:

$$E_S = \sum_{i=1}^{N} R(\lambda_i) E_\lambda(\lambda_i) \Delta\lambda_i \tag{5}$$

$$R_S = \frac{\sum_{i=1}^{N} R(\lambda_i) E_\lambda(\lambda_i) \Delta\lambda_i}{\sum_{i=1}^{N} E_\lambda(\lambda_i) \Delta\lambda_i} \tag{6}$$

where:

λ_i = wavelength of the ith data point out of the N for which the spectral data are known.

8. Validation

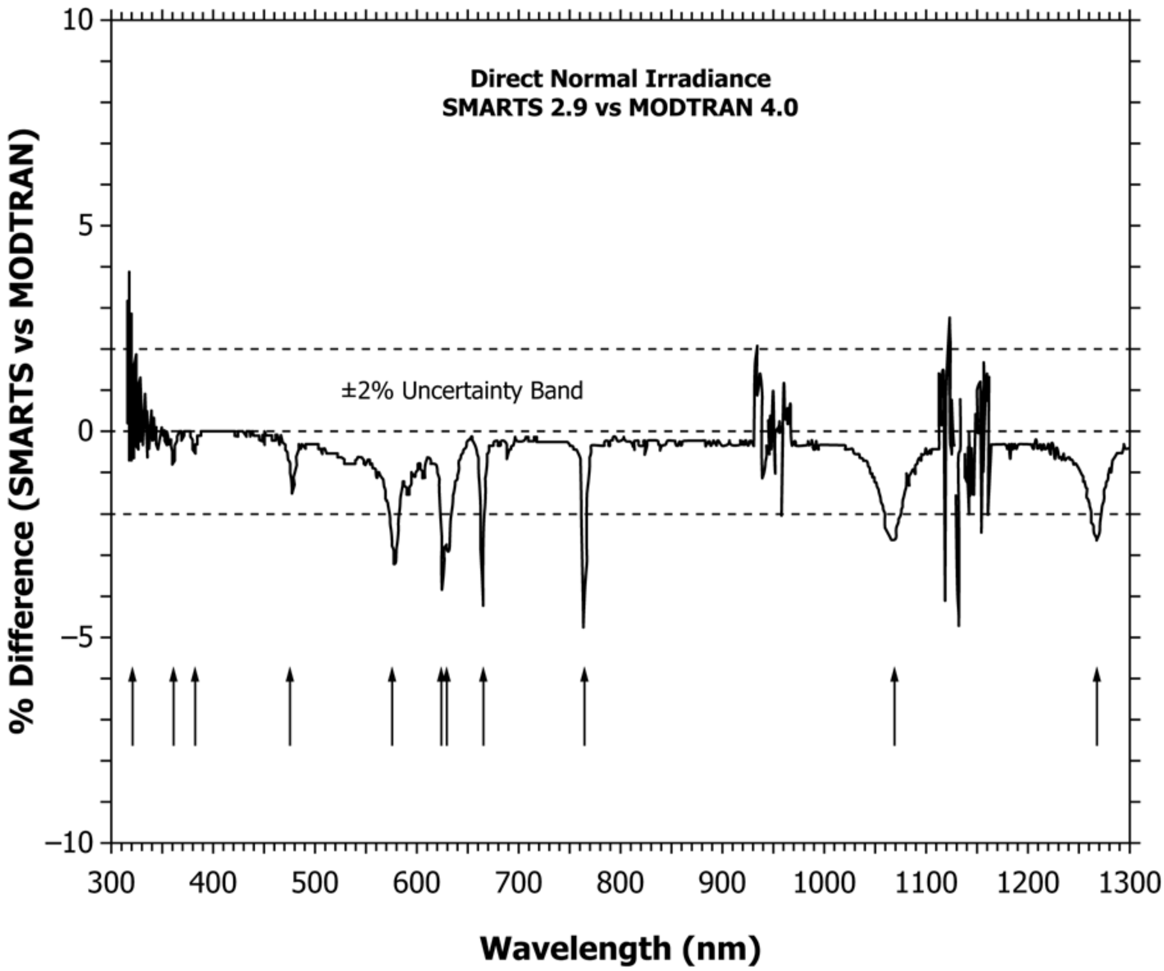
8.1 Comparisons of the SMARTS computer model with both MODTRAN model results and measured spectral data and other rigorous spectral models are reported in Gueymard (**1,2**). Fig. 2 is a plot of the relative magnitude of the spectral differences observed between MODTRAN version 4.0 and SMARTS for the direct spectrum. Results indicate that the two models agree well within ~2 % in spectral regions where significant energy is present.

8.2 Comparison of these reference spectra with clear sky solar spectral irradiance data obtained using various spectrometers under AM 1.5 and atmospheric conditions approximating those chosen for modeling this dataset are in agreement within the uncertainties of the spectral instrumentation calibration and measurement uncertainties. See (**1,2,8**). Fig. 3 compares SMARTS model output with spectra measured at Golden, CO, at three air mass conditions.

8.3 The values of direct normal irradiance presented are representative of measurements with a spectroradiometer or a normal incidence pyrheliometer with a field of view of 5.8°. A small amount of circumsolar (diffuse) radiation is included in the direct normal tables. For the atmospheric conditions selected, this circumsolar component adds 2.2 $W \cdot m^{-2}$ or approximately 0.25 % to the true direct beam irradiance, on average for the whole spectrum.

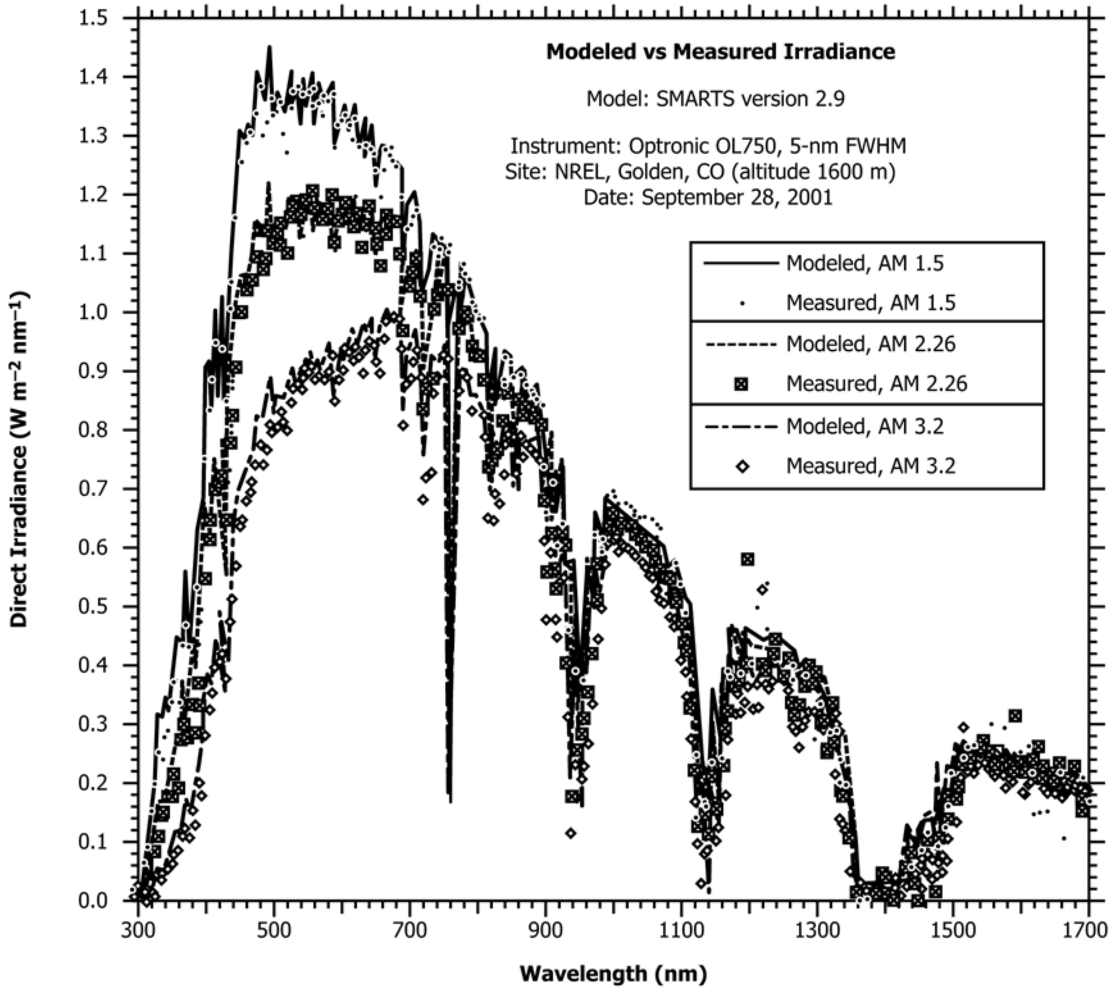
9. Keywords

9.1 direct normal; hemispherical; irradiance; solar constant; solar spectrum; terrestrial; wavelength



NOTE 1—Arrows indicate the center of gaseous absorption features considered in SMARTS but not in MODTRAN.

FIG. 2 Relative Difference in the Direct Normal Irradiance Predicted by SMARTS and MODTRAN



NOTE 1—Model results are within the calibration and measurement uncertainty limits of the spectroradiometer measurements.

FIG. 3 Comparison of 5-nm-Resolution Measured Spectra and SMARTS Model Results for Three Air Mass Conditions at Golden, CO., September 28, 2001

APPENDIX

(Nonmandatory Information)

X1. Aerosol Optical Depth

X1.1 Aerosol Optical Depth

X1.1.1 Aerosol optical depth is sometimes incorrectly referred to as "turbidity." The expression frequently used for extinction of solar radiation by aerosols in the atmosphere is:

$$\tau(\lambda) = \beta(\lambda/\lambda_o)^{-\alpha} \quad (X1.1)$$

where $\tau(\lambda)$ is the extinction coefficient, or optical depth, at wavelength λ. β (approximately 0.02 to 0.45 for clean and "turbid" atmospheres, respectively) is an extinction coefficient, related to the total atmospheric loading of the aerosols, generally called the "Ångström turbidity coefficient." Its value for the present spectra is 0.031. α, generally called the "Ångström turbidity exponent" or "wavelength exponent," is related to the size of the aerosol particles and normally ranges from −0.2 (very large particles) to +2.6 (very small particles) with values of 1.0 to 1.5 typical for a rural atmosphere. In the present spectra, its value varies slightly with wavelength and averages 1.19 over the whole spectrum. For $\lambda = \lambda_o = 1$ µm, $\tau(\lambda)$ equals the turbidity coefficient β, which is therefore identical to the AOD at 1 µm. Typical values for AOD at 500 nm (for example, tau(500) in X1.1) are 0.02 to 0.05 for extremely clean, 0.1 for clear, 0.2 for moderate, and 1.0 for extremely "turbid" or "hazy" cloudless skies. The value used here is 0.084.

X1.2 Selection Criteria for Aerosol Optical Depth

X1.2.1 The criterion chosen was to examine data for sites in the National Solar Radiation Data Base (NSRDB) with at least 6 kWh.m^{-2}/day annual direct normal irradiance. Table X1.1 lists the 15 sites meeting this criterion.

X1.2.2 The column "BB AOD" in the table reflects the "broadband" aerosol optical depth reported in the NSRDB data field for "turbidity." The BBAOD value was computed from the broadband direct beam irradiance in the data base. The equivalent monochromatic AOD was computed for Air Mass 1.5 (plane parallel atmosphere) using the SMARTS model, version 2.8.to achieve the equivalent integrated broadband direct normal irradiance.

X1.2.3 The mean monochromatic AOD at 500 nm for these sites is 0.085. The spectra were computed based on the same atmospheric conditions specified in previous versions of this standard, except the AOD at 500 nm be specified as 0.084. This slight deviation from the regional average in Table X1.1 is used since the integrated values of the hemispherical tilted spectrum is 1000.37 W/m^2, or essentially the 1000 W/m^2 representing SRC for flat plate Photovoltaic testing. The integral for the direct normal spectrum for these conditions is 900.14 W/m^2, or essentially 900 W/m^2. These results are obtained using the specific realistic spectral albedo file (included with the SMARTS model) for "light soil," rather than the artificial uniform albedo of 0.2 used in the previous standard. See X1.4.

X1.3 Atmospheric Constituents and Absorbers

X1.3.1 The 1976 U.S. Standard Atmosphere Model (8) with the rural Shettle and Fenn Aerosol (9) was used to produce the data in this standard. The atmospheric model exhibits the following parameters for a vertical path from sea level to the top of the atmosphere. Differences in the quoted values for precipitable water and ozone do not result from actual differences in their respective vertical profile, but reflect different numerical integration techniques and round-off precision.

X1.3.2 Atmospheric parameters, such as temperature, pressure, relative humidity, air density, and the density of nine molecular species are defined at 33 levels in the atmosphere. Atmospheric parameters vary exponentially between the 33 levels. The total abundance of all absorbing gases are obtained by integrating their concentrations throughout the 33 levels, from sea level to an altitude of 120 km.

TABLE X1.1 NSRDB Site Data for Sites With Annual Daily Mean DNI of at Least 6 kWh.m2^2/day

Station	Direct Beam kWh.m2^{-2} per day	AOD at 500 nm	BB AOD
Daggett, CA	7.50	0.087	0.058
Las Vegas, NV	7.10	0.105	0.068
Tucson, AZ	7.00	0.099	0.065
Phoenix, AZ	6.80	0.142	0.090
Prescott, AZ	6.80	0.074	0.050
Alamosa, CO	6.80	0.029	0.024
Albuquerque, NM	6.70	0.074	0.050
Tonopah, NV	6.70	0.082	0.055
El Paso, TX	6.70	0.118	0.076
Flagstaff, AZ	6.40	0.074	0.050
Reno, NV	6.20	0.091	0.060
Cedar City, UT	6.20	0.074	0.050
Pueblo, CO	6.10	0.074	0.050
Tucumcari, NM	6.10	0.099	0.065
Ely, NV	6.00	0.050	0.036
Regional Avg.	<6.61>	<0.085>	<0.056>

TABLE X1.2 U.S. Standard Atmosphere 1976 Constituents

Standard	Aerosol Optical Depth at 500 nm	Total Precipitable Water Vapor, cm	Total Ozone, atm-cm	Carbon Dioxide Volume Concentration, ppm
Historical Standard (G159)	0.270	1.42	0.34	330
Present Standard	0.084	1.4164	0.3438	370

X1.3.3 The USSA 1976 concentration of Carbon Dioxide (CO_2) is 330 parts per million (ppm). The value of this concentration in 2002 is known to be about 370 ppm. In order to accurately represent the current state of the atmosphere, the 370 ppm value is used to generate the reference spectra, as noted for card 6 in Table 1.

X1.3.4 The SMARTS Version 2.9.2 model calculates absorption for a total of 19 gases, some of which are not mentioned in USSA, nor treated in MODTRAN4 or the previous versions of the reference spectra. The SMARTS model allows the user to specify the relative loading of some of these gases at default concentrations representing standard, pristine, light pollution, moderate pollution, or severe pollution conditions. As noted in Table 1, conditions for the reference spectra were chosen to be for a standard atmosphere, that is, USSA without pollution. The total columnar abundances (in atm-cm) of all gases (except water vapor, see Table X1.2) treated in the standard spectra are shown in Table X1.3.

X1.3.5 The absorption and scattering properties of the aerosol are calculated based on parameterizations of the data from the Shettle and Fenn model (8), which is also used in the MODTRAN spectral modeling code developed at the Air Force Geophysical Laboratory (2,3,4,5). Complete input parameters for the spectral model are listed in Table 1.

X1.4 Spectral Reflectance

X1.4.1 To generate the spectra, the present standards utilize wavelength-dependent values of ground reflectance, representative of a light soil, combined with a slightly forward-enhanced reflectance pattern. Fig. X1.1 is a plot of the data, which have been slightly modified from the Jet Propulsion Laboratory ASTER Spectral Library (13). This realistic reflectance model adds about 12 W·m^{-2} to the integrated hemispherical irradiance on the 37° tilted surface, comparatively to a wavelength-independent and isotropic albedo of 0.2.

X1.5 Generating Approximation to Earlier Standard Spectra

X1.5.1 Previous versions of the reference spectra can be approximated using the input file shown in Table X1.4. The earlier standard spectra were based upon an AOD of 0.27 and a wavelength-independent albedo of 0.2. It is not possible to remove the gas elements that are considered in SMARTS but

TABLE X1.3 Gaseous Abundances for Standard Conditions Used to Compute Standard Spectra

Gas	Ammonia	Bromine monoxide	Carbon monoxide	Carbon dioxide	Chlorine nitrate	Formal-dehyde	Methane	Nitric acid	Nitric oxide
Symbol	NH3	BrO	CO	CO2	ClNO3	CH2O	CH4	HNO3	NO
Standard Abundance (atm-cm)	0.00013	0.0000025	0.08747	297.1	0.00012	0.0003	1.285	0.0003811	0.0003211
Gas	Ammonia	Bromine monoxide	Carbon monoxide	Carbon dioxide	Chlorine nitrate	Formal-dehyde	Methane	Nitric acid	Nitric oxide
Standard Abundance (atm-cm)	3.719	0.0002044	0.00005	0.0001	0.2385	16780	16780	0.3438	0.0001071

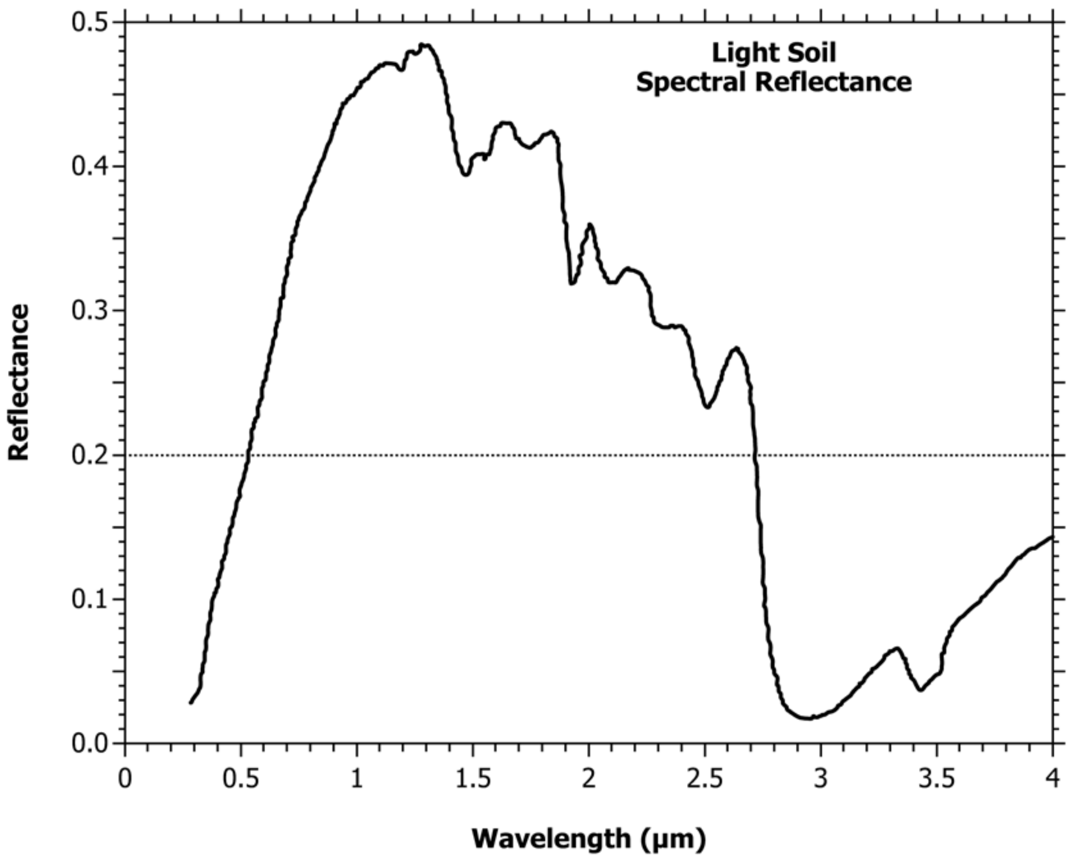


FIG. X1.1 Plot of the Data in the Albedo File (LITESOIL.DAT) Used to Compute the Standard Spectra

not in USSA or in the historical reference. However, this results in only minor difference in a few spectral bands, and negligible difference over the rest of the spectrum.

TABLE X1.4 SMARTS Version 2.9.2 Input File to Generate the Historical Reference Spectra (G159)

Card ID	Value	Parameter/Description/Variable Name
1	'G 159_Std_Spectra'	Header
2	0	Pressure input mode (1 = pressure and altitude): ISPR
2a	1013.25 0.	Station Pressure (mb) and altitude (km): SPR, ALT
3	1	Standard Atmosphere Profile Selection (1 = use default atmosphere): IATM1
3a	'USSA'	Default Standard Atmosphere Profile: ATM
4	1	Water Vapor Input (1 = default from Atmospheric Profile): IH2O
5	1	Ozone Calculation (1 = default from Atmospheric Profile): IO3
6	1	Pollution level mode (1 = standard conditions/no pollution): IGAS (see X1.3)
7	330	Carbon Dioxide volume mixing ratio (ppm): qCO2 (see X1.3)
7a	1	Extraterrestrial Spectrum (1 = SMARTS/Gueymard): ISPCTR
8	'S&F_RURAL'	Aerosol Profile to Use: AEROS
9	0	Specification for aerosol optical depth/turbidity input (0 = AOD at 500 nm): ITURB
9a	0.27	Aerosol Optical Depth @ 500 nm: TAU5
10	-1	Far field Spectral Albedo file to use (-1 = fixed albedo): IALBDX
10a	0.2	Fixed, spectrally constant albedo value: RHOX
10b	1	Specify tilt calculation (1 = yes): ITILT
10c	-1 37 180	Albedo and Tilt variables-Albedo file to use for near field, Tilt, and Azimuth: IALBDG, TILT, WAZIM
11	280 4000 1.0 1367.0	Wavelength Range-start, stop, mean radius vector correction, integrated solar spectrum irradiance: WLMN, WLMX, SUNCOR, SOLARC
12	2	Separate spectral output file print mode (2 = yes): IPRT
12a	280 4000 0.5	Output file wavelength-Print limits, start, stop, minimum step size: WPMN, WPMX, INTVL
12b	2	Number of output variables to print: IOTOT
12c	8 9	Code relating output variables to print (8 = Hemispherical tilt, 9 = direct normal + circumsolar): OUT(8), OUT(9)
13	1	Circumsolar calculation mode (1 = yes): ICIRC
13a	0 2.9 0	Receiver geometry-Slope, View, Limit half angles: SLOPE, APERT, LIMIT
14	0	Smooth function mode (0 = none): ISCAN
15	0	Illuminance calculation mode (0 = none) ILLUM
16	0	UV calculation mode (0 = none): IUV
17	2	Solar Geometry mode (2 = Air Mass): IMASS
17a	1.5	Air mass value: AMASS

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