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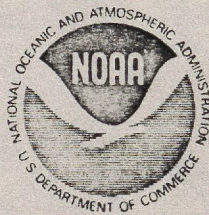
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THE SOLAR CONSTANT AND SOLAR SPECTRUM AND THEIR POSSIBLE VARIATION

Matthew P. Thekaekara
Goddard Space Flight Center
Greenbelt, Md.

Measurements made from high altitude platforms have yielded standard values of the solar constant and solar spectrum. Based on the extraterrestrial solar spectral irradiance data and the best available information in literature on atmospheric transmittance, detailed solar spectral curves at ground level for different sets of parameters have been derived. Programs currently under way for more precise determination of the solar constant and zero air mass solar spectrum and their possible variations will be described.

1. INTRODUCTION

For all solar energy conversion systems two parameters of primary importance are the total amount of energy available from the Sun and the distribution of this energy with wavelength. In this paper we shall review briefly the data currently available about these parameters, their possible variations and the plans now under way for a more precise determination of these parameters.

The solar constant and the extraterrestrial solar spectrum are of significance primarily for space borne energy conversion systems such as the solar panels of the satellites or the large solar power station in synchronous orbit envisioned by Peter Glaser. Secondly, they are of significance also for ground based solar energy uses. In locations where precise measurements of the energy reaching the ground are not feasible, a fairly good estimate can be made from the spectral distribution of solar energy outside the atmosphere and the absorbing and scattering properties of the atmosphere.

The solar constant is the total amount of energy received from the Sun per unit time per unit area exposed normally to the Sun's rays at the average Sun-Earth distance outside the Earth's atmosphere. The zero air mass solar spectral irradiance is the distribution of this energy as a function of wavelength. Earlier estimates of these parameters had been obtained from ground based measurements made at different solar zenith angles and extrapolation to zero air mass. Such measurements are subject to large errors because of the atmospheric pollutants and especially water vapor and aerosol which are highly absorbing and variable in the course of a day.

2. STANDARD VALUES OF SOLAR CONSTANT AND SOLAR SPECTRUM

Since the advent of satellites and high altitude research aircraft, several attempts were made to measure the solar constant and solar spectrum from above all or almost all of the atmosphere. An *ad hoc* committee on Solar Electromagnetic Radiation was appointed by the NASA Space Vehicles Design Criteria Office and by the Institute of Environmental Sciences to study the question. The Committee made a detailed study of all the available information and recommended proposed standard values of the solar constant and solar spectrum.

The solar constant was evaluated from nine series of measurements, all made from high altitude platforms, namely, Convair 990 and B-57B jet aircraft, X-15 rocket aircraft, balloons and Mariner Mars probe. These nine values are shown in figure 1. Each one is the result of many

SOLAR CONSTANT ON DIFFERENT RADIATION SCALES

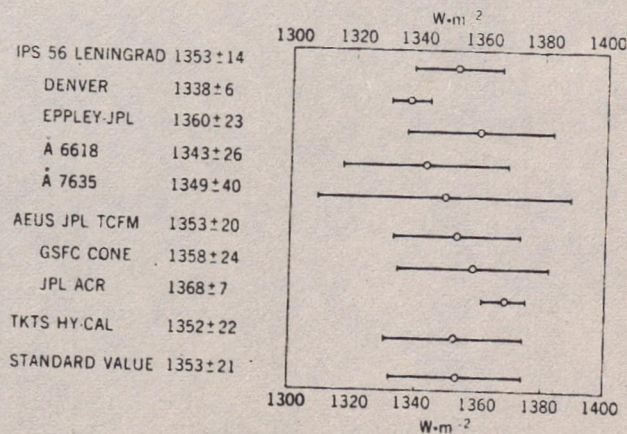


Figure 1. Values of the solar constant from which the standard values is derived. Horizontal lines indicate the uncertainty assigned by each author.

series of measurements. The uncertainties claimed by the authors are shown by the horizontal lines. The detectors included Ångström pyrheliometers, cavity radiometers and normal incidence pyrheliometers of different types and manufacturers. The value of the solar constant derived from these measurements is 1353 Wm^{-2} or $1.940 \text{ cal cm}^{-2} \text{ nm}^{-1}$. Drummond (1973) should be consulted for more detailed information about the different sets of measurements.

The values of zero air mass solar spectral irradiance were derived mainly from the measurements of NASA GSFC on board a Convair 990 and of Eppley-JPL on CV 990, B57B and X-15. The GSFC experimenters used two large prism monochromators, a filter radiometer (33 filters each of 100 Å bandwidth) and two interferometers, which made detailed spectral measurements covering the wavelength range 0.3 to 15 μm (Thekaekara, 1970). The Eppley-JPL team under the direction of the late Dr. A. J. Drummond used filter radiometers (Drummond and Hickey, 1968). Several narrow band pass filters covered the range 0.25 to 0.7 μm . The integral energy in the wavelength range $\lambda > 0.7 \mu\text{m}$ was determined from the difference between total radiation channels and cut-off filter channels. Data from other sources were used for the range $0.3 \mu\text{m} > \lambda > 15.0 \mu\text{m}$. The zero air mass solar spectral irradiance is shown in figure 2 and in

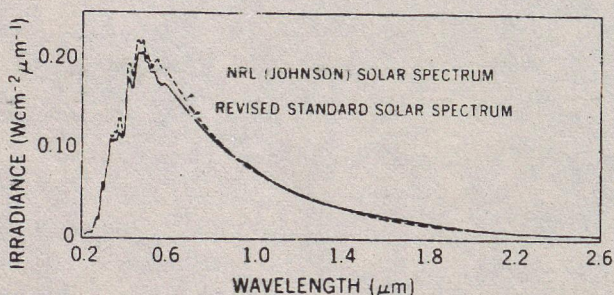


Figure 2. Standard solar spectrum (NASA, ASTM) compared to Johnson (NRL) spectrum.

table 1. Figure 2 covers the wavelength range 0.2 to 2.6 μm . The NRL (Johnson) curve (Johnson, 1954) is shown by dashed line for purposes of comparison; this had been used as a working standard in the U.S. for a long time.

Following the recommendation of the Committee on Solar Electromagnetic Radiation these values have received a wide circulation and have been extensively used as a standard of reference. A monograph published in the NASA Space Vehicles Design Criteria series recommends these values as the criteria to be applied in the design and testing of spacecraft systems (NASA-SP8005, 1971). These values have been adopted by the Solar Simulation Committee of the Institute of Environmental Sciences and the E-21 Committee of the American Society for Testing and Materials (ASTM) and have been issued as the ASTM "Engineering Standard for the Solar Constant and Solar Spectrum" (NASA-SP298, 1972).

The estimated error in the value of the solar constant is 1.5 percent or $\pm 21 \text{ Wm}^{-2}$. We believe this estimate is very conservative considering the large mass of high altitude measurements on which it is based. The estimated error in the spectral irradiance data is considerably greater partly because of the uncertainties in the spectral standards which were used for calibration. Over the range 0.3 to 2.6 μm the calibration standards were quartz iodine lamps issued by the NBS. They have an uncertainty of about 5 percent. Other reference standards with larger uncertainty were used for $0.3 \mu\text{m} > \lambda > 2.6 \mu\text{m}$.

Two other sets of spectral data which were developed on the basis of the standard table (table 1) should be briefly mentioned. In the standard table the irradiance values are given at 50 Å intervals for the visible and near UV and are averages over 100 Å bandwidths centered at the given wavelengths. This method of listing was chosen so as not to make the table too long and to give the solar irradiance independent of the Fraunhofer structure which different instruments show differently according to their wavelength resolution. For many of the applications a more detailed knowledge of the extraterrestrial solar spectrum was found to be necessary. In response to inquiries from users a project was undertaken recently to meet this need. For the range 3000 to 6100 Å tables and charts are now available which give the spectrum at 1 Å intervals. The charts are shown in figures 3 and 4. They are based on the measurements made with Perkin-Elmer monochromator on board CV 990. The P.-E. data were normalized so that in each 50 Å range the integral under the curve is equal to the values of table 1. The dashed line shows the standard curve.

3. SOLAR IRRADIANCE AT GROUND LEVEL

Another set of curves more directly applicable to solar energy conversion is given in figure 5. They give the solar spectral irradiance at ground level for air mass 0, 1, 4 and 7. Air mass is defined as the ratio of path length in the atmosphere for a given zenith angle of the Sun to the path length when the Sun is at the zenith. To a first degree of approximation the air mass is equal to the secant of the zenith angle. These curves are based on the computations made by D. Hoyt of NOAA, Boulder. The solar zenith angles corresponding to air mass 1, 4 and 7 are respectively 0° , 75° and 82° .

When the collecting system for solar energy is totally non-selective as to wavelength, that is, when it is a perfectly black absorber, the spectral distribution of the solar energy is not of any significance. The total incident energy alone need be considered. But all surfaces are wavelength selective to some extent. This is particularly so for conversion systems which use solar cells, parabolic energy concentrators, selective transmittance coatings and the like. In these cases the energy absorbed is an integral of the form

$$\int_0^{\infty} E_{\lambda} \tau_{\lambda} d\lambda$$

Table 1. Solar Spectral Irradiance at 1 AU (Solar Constant at 1353 Wm^{-2})

Wavelength λ (μm)	Average Irradiance** E_{λ} ($\text{Wm}^{-2} \mu\text{m}^{-1}$)	Area under curve, σ to λ $E_{0-\lambda}$ (Wm^{-2})	Portion of solar constant with wavelength $< \lambda$, $D_{0-\lambda}$ (%)	Wavelength λ (μm)	Average Irradiance** E_{λ} ($\text{Wm}^{-2} \mu\text{m}^{-1}$)	Area under curve, σ to λ $E_{0-\lambda}$ (Wm^{-2})	Portion of solar constant with wavelength $< \lambda$, $D_{0-\lambda}$ (%)
.115	.007	.0025	.0001	.410	1751	134.224	9.920
.120	.900	.0048	.0002	.415	1774	143.036	10.571
.125	.007	.0070	.0005	.420	1747	151.839	11.222
.130	.007	.0071	.0005	.425	1693	160.439	11.858
.140	.030	.0073	.0005	.430	1639	168.769	12.473
.150	.070	.0078	.0005	.435	1663	177.024	13.083
.160	.230	.0093	.0006	.440	1810	185.706	13.725
.170	.630	.0136	.0010	.445	1922	195.036	14.415
.180	1.250	.0230	.0016	.450	2006	204.856	15.140
.190	2.710	.0428	.0031	.455	2057	215.014	15.891
.200	10.7	.1098	.0081	.460	2066	225.321	16.653
.210	22.9	.2778	.0205	.465	2048	235.606	17.413
.220	57.5	.6798	.0502	.470	2033	245.809	18.167
.225	64.9	.9858	.0728	.475	2044	256.001	18.921
.230	66.7	1.3148	.0971	.480	2074	266.296	19.681
.235	59.3	1.6298	.1204	.485	2176	276.421	20.430
.240	63.0	1.9356	.1430	.490	1950	286.236	21.155
.245	72.3	2.2738	.1680	.495	1960	296.011	21.878
.250	70.4	2.6306	.1944	.500	1942	305.766	22.599
.255	104.0	3.0666	.2266	.505	1920	315.421	23.312
.260	130	3.6516	.269	.510	1882	324.926	24.015
.265	185	4.4391	.328	.515	1833	334.214	24.701
.270	232	5.4816	.405	.520	1833	343.379	25.379
.275	204	6.5716	.485	.525	1852	352.591	26.059
.280	222	7.6366	.564	.530	1842	361.826	26.742
.285	315	8.9791	.663	.535	1818	370.976	27.418
.290	482	10.9716	.810	.540	1783	379.979	28.084
.295	584	13.6366	1.007	.545	1754	388.821	28.737
.300	514	16.3816	1.210	.550	1725	397.519	29.380
.305	603	19.1741	1.417	.555	1720	406.131	30.017
.310	689	22.4041	1.655	.560	1695	414.669	30.648
.315	764	26.0366	1.924	.565	1705	423.169	31.276
.320	830	30.0216	2.218	.570	1712	431.711	31.907
.325	975	34.5341	2.552	.575	1719	440.289	32.541
.330	1059	39.6191	2.928	.580	1715	448.874	33.176
.335	1081	44.9691	3.323	.585	1712	457.441	33.809
.340	1074	50.3566	3.721	.590	1700	465.971	34.439
.345	1069	55.7141	4.117	.595	1682	474.426	35.064
.350	1093	61.1191	4.517	.600	1666	482.796	35.683
.355	1083	66.5591	4.919	.605	1647	491.079	36.295
.360	1068	71.9366	5.316	.61	1635	499.284	36.902
.365	1132	77.4366	5.723	.62	1602	515.469	38.098
.370	1181	83.2191	6.150	.63	1570	531.329	39.270
.375	1157	89.0641	6.582	.64	1544	546.899	40.421
.380	1120	94.7566	7.003	.65	1511	562.174	41.550
.385	1058	100.3016	7.413	.66	1486	577.159	42.657
.390	1048	105.7916	7.819	.67	1456	591.869	43.744
.395	1189	111.5091	8.241	.68	1427	606.284	44.810
.400	1429	118.0541	8.725	.69	1402	620.429	45.855
.405	1644	125.7366	9.293	.70	1369	634.284	46.879

* Horizontal lines indicate change in wavelength interval of integration.

** Spectral irradiance averaged over small bandwidth centered at λ :
0.3 to 0.75 μm (bandwidth, 10 nm)

Wavelength λ (μm)	Average Irradiance** E_{λ} ($\text{Wm}^{-2} \mu\text{m}^{-1}$)	Area under curve, σ to λ $E_{0-\lambda}$ (Wm^{-2})	Portion of solar constant with wavelength $< \lambda$, $D_{0-\lambda}$ (%)	Wavelength λ (μm)	Average Irradiance** E_{λ} ($\text{Wm}^{-2} \mu\text{m}^{-1}$)	Area under curve, σ to λ $E_{0-\lambda}$ (Wm^{-2})	Portion of solar constant with wavelength $< \lambda$, $D_{0-\lambda}$ (%)
.71	1344	647.849	47.882	2.1	48	1307.959	96.6710
.72	1314	661.139	48.864	2.7	43	1312.509	97.0073
.73	1290	674.159	49.826	2.8	39	1316.609	97.3103
.74	1260	686.909	50.769	2.9	35	1320.309	97.5838
.75	1235	699.384	51.691	3.0	31	1323.609	97.8277
.76	1211	711.614	52.595				
.77	1185	723.594	53.480	3.1	26.0	1326.459	98.0383
.78	1159	735.314	54.346	3.2	22.6	1328.889	98.2179
.79	1134	746.779	55.194	3.3	19.2	1330.979	98.3724
.80	1109	757.994	56.023	3.4	16.6	1332.769	98.5047
.81	1085	768.966	56.834	3.5	14.6	1334.329	98.6200
.82	1060	779.694	57.627	3.6	13.5	1335.734	98.7238
.83	1036	790.174	58.401	3.7	12.3	1337.024	98.8192
.84	1013	800.419	59.158	3.8	11.1	1338.194	98.9056
.85	990	810.434	59.899	3.9	10.3	1339.264	98.9847
.86	968	820.224	60.622	4.0	9.5	1340.254	99.0579
.87	947	829.799	61.330				
.88	926	839.164	62.022	4.1	8.70	1341.1641	99.12521
.89	908	848.334	62.700	4.2	7.80	1341.9891	99.18616
.90	891	857.329	63.365	4.3	7.10	1342.7341	99.24124
.91	880	866.184	64.019	4.4	6.50	1343.4141	99.29150
.92	869	874.929	64.665	4.5	5.92	1344.0351	99.33740
.93	858	883.564	65.304	4.6	5.35	1344.5986	99.37905
.94	847	892.089	65.934	4.7	4.86	1345.1091	99.41678
.95	837	900.509	66.556	4.8	4.47	1345.5757	99.45127
.96	820	908.794	67.168	4.9	4.11	1346.0049	99.48299
.97	803	916.909	67.768	5.0	3.79	1346.3999	99.51219
.98	785	924.849	68.355				
.99	767	932.609	68.928	6	1.8200	1349.2049	99.71950
1.00	748	940.184	69.488	7	.9900	1350.6099	99.82335
1.05	668	975.584	72.105	8	.5850	1351.3974	99.88155
1.10	593	1007.109	74.435	9	.3670	1351.8734	99.91673
1.15	535	1035.309	76.519	10	.2410	1352.1774	99.93920
1.20	485	1060.809	78.404	11	.1650	1352.3804	99.95200
1.25	438	1083.884	80.109	12	.1170	1352.5214	99.96462
1.30	397	1104.759	81.652	13	.0851	1352.6224	99.97209
1.35	358	1123.634	83.047	14	.0634	1352.6967	99.97758
1.40	337	1141.009	84.331	15	.0481	1352.7524	99.98170
1.45	312	1157.234	85.530				
1.50	288	1172.234	86.639	16	.037100	1352.7950	99.98485
1.55	267	1186.109	87.665	17	.029100	1352.8281	99.98730
1.60	245	1198.909	88.611	18	.022100	1352.8542	99.98923
1.65	223	1210.609	89.475	19	.018601	1352.8751	99.99077
1.70	202	1221.234	90.261	20	.015200	1352.8920	99.99202
1.75	180	1230.784	90.967				
1.80	159	1239.259	91.593	25	.006170	1352.9454	99.99596
1.85	142	1246.784	92.149	30	.002970	1352.9683	99.99765
1.90	126	1253.484	92.644	35	.001600	1352.9797	99.99850
1.95	114	1259.484	93.088	40	.000947	1352.9860	99.99897
2.00	103	1264.909	93.489	50	.000391	1352.9927	99.99946
				60	.00019000	1352.9956	99.99967
				80	.00006160	1352.9981	99.99986
				100	.00002570	1352.9990	99.99992
				120	.00001260	1352.9994	99.99995
				150	.00000523	1352.9997	99.99997
2.1	90	1274.559	94.2024	200	.00000165	1352.9998	99.99999
2.2	79	1283.009	94.8269	250	.00000070	1352.9999	99.99999
2.3	69	1290.409	95.3739	300	.00000034	1352.9999	99.99999
2.4	62	1296.959	95.8580	400	.00000011	1352.9999	99.99999
2.5	55	1302.809	96.2903	1000	.00000000	1353.0000	100.00000

** Spectral irradiance averaged over small bandwidth centered at λ :
0.75 to 1.0 μm (bandwidth, 50 nm)
1.0 to 5.0 μm (bandwidth, 100 nm)

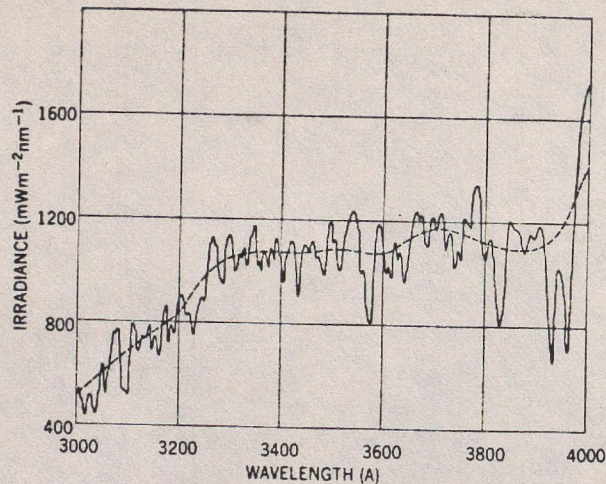


Figure 3. Solar irradiance, 3000 to 4000 Å, based on detailed spectrum at 1 Å intervals.

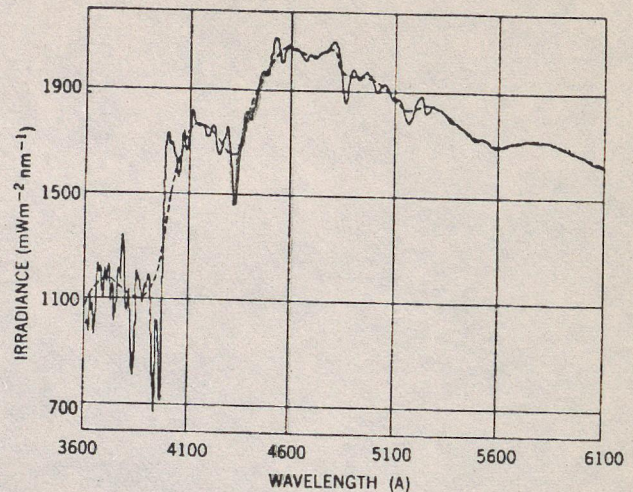


Figure 4. Solar irradiance, 3600 to 6100 Å, based on detailed spectrum at 1 Å intervals.

where E_λ is the solar spectral irradiance and τ_λ is a spectral transfer function characteristic of the system. But even for perfectly black absorbers, knowledge of the spectral distribution is important if direct measurements of the incident energy are not feasible. Since the atmosphere is highly wavelength selective in its absorbance and scattering, the total energy has to be determined by integrating the area under curves of the type shown in figure 5.

These curves are valid for one particular set of atmospheric parameters. The equations for generating these curves will be discussed briefly so that curves for other atmospheric conditions can be computed. These computations can be made easily with a small electronic pocket calculator. Since the general shape of the curve and the integral under the curve are known for several typical cases, for other cases with a different set of parameters, computations at a few selected wavelengths will suffice.

Let E_0 and E_m be the irradiance at a given wavelength for air mass 0 and m respectively.

$$E_m = E_0 e^{-\alpha m}, \quad (1)$$

where α is the extinction optical thickness. α is the sum of four parameters, α_1 due to Rayleigh scattering, α_2 due to ozone, α_3 due to turbidity (aerosol) and a fourth parameter, which may be α_4 , α_5 , or α_6 . α_1 and α_2 have been computed by Elterman for 22 wavelengths for $0.27 \mu\text{m} \leq \lambda \leq 4.0 \mu\text{m}$ (1968). Elterman refers to these parameters as Rayleigh optical thickness ($h - \infty$), symbol τ_r and ozone optical thickness ($h - \infty$), symbol τ_o . The values for altitude $h = 0$ km are taken. The total amount of ozone in the atmosphere is assumed to be 0.34 cm as was done by Elterman. For wavelengths not listed in Elterman's tables a linear interpolation is sufficiently accurate. α_3 is the optical thickness due to turbidity, and is given by

$$\alpha_3 = \frac{\beta}{\lambda^\alpha}$$

where β is the Ångström turbidity coefficient and α is an exponent for the wavelength. The values selected for the curves in figure 5 are $\alpha = 1.3$ and $\beta = 0.02$, which are typical of relatively clean air of rural background. Curves have been generated for other sets of values of α and β , more representative of urban areas but they are not reproduced here.

The fourth parameter represents the absorption due to water vapor, CO_2 and other molecules. Here no single expression applies to all the absorption bands. The experimental results of Gates and Harrop (1963) seem to be the most appropriate for handling the complex problem of molecular absorption. The molecular absorption is treated as

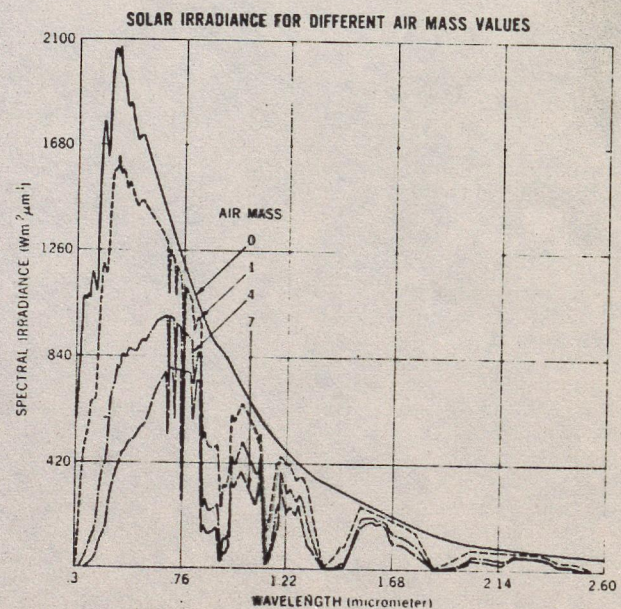


Figure 5. Solar spectrum outside the atmosphere and at ground level for air mass 1, 4, and 7.

belonging to one of three models with appropriate coefficients, c_1 for strong random band model, c_2 for weak random band model and c_5 for strong regular band model. The fourth parameter of the exponent depends on the model applicable for a given absorption line and is given by

$$\begin{aligned}\alpha_4 &= -c_1\sqrt{w}, \\ \alpha_5 &= -c_2 w, \text{ or} \\ \alpha_6 &= \ln(1 - c_5 m^{1/2})\end{aligned}$$

where m is the air mass and w is the amount of precipitable water vapor in millimeters. The value of w for these computations was chosen as 20 mm which is an annual average for mid latitudes.

These data on solar irradiance at ground level refer to the light received directly from the Sun on a surface exposed normally to the Sun's rays. They do not include diffuse radiation from the sky.

Spectral irradiance data (wavelength and spectral irradiance) discussed in these tables and graphs have been put on punched cards. User organizations which have need of such data for computer aided applications can obtain them from The National Space Science Data Center, Code 601, NASA, Goddard Space Flight Center, Greenbelt, Md., 20771. For zero air mass spectral irradiance the data are given at wavelengths listed in table 1. The more detailed table lists the values at 1 Å intervals for the limited range 3000 to 6100 Å. The tables of solar spectral irradiance at ground level are available at the same wavelengths as in table 1 and at all the flexion points of the curve. The wavelength range is 0.290 to 4.045 μm. The U.S. model atmosphere with 0.34 cm of ozone and 20 mm of precipitable water is assumed for all the tables.

Four sets of values of α and β (turbidity coefficients) and four values of air mass 1, 4, 7 and 10 have been chosen. Brief explanatory material is issued along with the punched card decks.

4. UNCERTAINTY AND POSSIBLE VARIABILITY

The solar spectral data, especially the zero air mass solar spectral irradiance, have received a wide circulation and are extensively being used in many areas of physics, meteorology, climate, solar energy applications, and related fields. However, it should be emphasized that these parameters are not known with an accuracy at all near what is desirable or attainable. At the turn of this century major evaluations of the solar constant were (in units of $\text{cal min}^{-1}\text{cm}^{-2}$) Pouillet's 1.76, Langley's 3.02 and Ångström's 4.0. Hann's standard work on meteorology published in 1901 quotes these and other values without preference. The margin of uncertainty has narrowed considerably since then, but the solar constant is not known with an accuracy comparable to that of most physical constants. The currently accepted value is 1353 W/m^{-2} ($1.940 \text{ cal min}^{-1}\text{cm}^{-2}$) and it is based on nine rather widely scattered values varying between 1338 and 1368 W/m^{-2} .

The uncertainty in spectral irradiance is even greater. The spectral curve of NASA and ASTM differs significantly from those of Johnson, Labs and Neckel, Makarova and Kharitonov and others which have been published in recent years. The NASA, ASTM curve is based on two sources, the GSFC CV 990 curve and the integral energy in 20 filter channels obtained by Eppley-JPL. The two sets of data showed differences of the order of 5 percent or more in some of the channels and there were similar differences between the spectral curves obtained from the different instruments used by GSFC.

There is also a major question about possible variations in the solar constant and solar spectrum. We are not concerned here with the seasonal change between 1399 W/m^{-2} and 1309 W/m^{-2} due to varying Sun-Earth distance. There are many features about the Sun which are known to change cyclically and sporadically. There are also many changes in the Earth-atmosphere system which have a correlation with the solar changes. The density of the ozone layer changes from day to night. Geomagnetic disturbances have a periodicity of 27 days superposed on the 11 year period of sunspot cycles. Other phenomena which probably are related to solar flux variations are annual frequency of Etesian winds in Athens, wintriness index of northern hemisphere sea-level pressure pattern, annual march of temperature in different cities of Europe, changes in meridional sea level pressure, water level in rivers and lakes, occurrence of drought in the U.S. (with a 22 year periodicity) annual growth rings of trees, advance and retreat of glaciers, etc.

Several attempts have been made to determine the variations in solar constant with the 11-year solar cycle. The most extensive data are those of the Smithsonian Institution. More recent data have been published by Kondratyev, Bossolaseo et al., by Johnson and Iriarte. But the difficulties due to atmospheric absorption and the changes in radiation scales prevent an exact evaluation of the magnitude of the change.

If there are changes in the solar constant, there is no reason to suppose that these changes affect uniformly all regions of the solar spectrum. Changes in the UV below 0.3 μm and in the microwave range 2 cm to 10 m have been well established. But changes, if any, in the near UV, visible and near IR which contains over 99 percent of the solar energy, are totally unknown and unexplored.

5. CURRENT PROGRAMS FOR SOLAR MEASUREMENTS

In conclusion we shall describe briefly a project now being developed for a more precise determination of the solar constant and solar spectrum. The objective is to monitor the solar constant with an accuracy of better than one percent and the solar spectral irradiance with an accuracy better than five percent. The variations of these parameters will be determined with a precision considerably greater than the absolute accuracy. The instrument package will be mounted in a U-2 aircraft which has a cruising altitude of 20 km. Observing time per flight will be about six hours.

6. REFERENCES

The instrument package will consist of a medium resolution prism monochromator for the spectrum and a thermopile detector for the total energy. It will be mounted in the Q-bay of the aircraft where a pressure of 350 millibars and a temperature range of 5°C to 25°C will be maintained. The residual atmosphere above the aircraft at 20 km is about 5 percent of what it is at sea level and the water vapor above the aircraft is 0.05 percent of the average amount of precipitable water in the atmosphere. About 50 percent or more of the ozone is above the aircraft so that the lower limit of the observable spectrum is about 0.27 mm. The upper limit is 2.6 mm with quartz optics and 4.0 mm with sapphire optics. Since there is a certain amount of residual atmosphere above the aircraft, extrapolation to zero air mass will be made by measuring the solar energy at zenith angles varying between 15° and 60°. The instrument will be sufficiently lightweight and compact so that it can be flown on all routine missions of the U-2 aircraft.

The U-2 measurements will permit the development of a more reliable and rugged instrument for deployment on the space shuttle which will be operational in the 80's. A floating laboratory above the ozonosphere and all other atmospheric absorbers, with manned instruments and onboard calibration, with few constraints as to weight, size and power, with long observation periods, total and spectral irradiance of the Sun can be determined with sufficient accuracy and resolution. This will provide an answer to many questions about the Sun's energy output which have often been raised but never adequately answered.

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DISCUSSION

Matthew P. Thekaekara

Q. *What is the variation of the solar constant, or the amount of solar energy at the outside of the atmosphere? Is it possible to assign an upper limit to this variability?*

A. A conservative estimate is 1 or 2 percent but Bos⁵folasco and his co-workers quote a 15 percent variability and Kondrat'yev showed a 3 or 4 percent variability. For sporadic events as when a large sunspot crosses the solar disk as was observed by Abbott, the variability may reach 4 or 5 percent. However, the degree of variability of the solar constant is not well known since there have been so few measurements of the value by the same technique.

Q. *What is your best estimate of the likely variation?*

A. About 2 percent but in certain spectral regions such as the 0.2 to 0.3 micrometer region the variability could lie in the 5 to 10 percent range.

Q. *Where do we get the IBM data cards?*

A. This information is contained in NASA monograph SP-8005. The address to write to is: NASA Goddard Space Science Data Center, Code 601, Greenbelt, Md., 20770.