#309

EXTRATERRESTRIAL SOLAR SPECTRAL IRRADIANCE

AT GROUND LEVEL

MS-21A

Table of Contents

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1. INTRODUCTION:

The documentation for this data set was originally on paper, kept in NSSDC's Data Set Catalogs (DSCs). The paper documentation in the Data Set Catalogs have been made into digital images, and then collected into a single PDF file for each Data Set Catalog. The inventory information in these DSCs is current as of July 1, 2004. This inventory information is now no longer maintained in the DSCs, but is now managed in the inventory part of the NSSDC information system. The information existing in the DSCs is now not needed for locating the data files, but we did not remove that inventory information.

The offline tape datasets have now been migrated from the original magnetic tape to Archival Information Packages (AIP’s).

A prior restoration may have been done on data sets, if a requestor of this data set has questions; they should send an inquiry to the request office to see if additional information exists.

2. ERRATA/CHANGE LOG:

NOTE: Changes are made in a text box, and will show up that way when displayed on screen with a PDF reader.

When printing, special settings may be required to make the text box appear on the printed output.

Version	Date	Person	Page	Description of Change
01				
02				

3 LINKS TO RELEVANT INFORMATION IN THE ONLINE NSSDC INFORMATION SYSTEM:

http://nssdc.gsfc.nasa.gov/nmc/

[NOTE: This link will take you to the main page of the NSSDC Master Catalog. There you will be able to perform searches to find additional information]

4. CATALOG MATERIALS:

a. Associated Documents — To find associated documents you will need to know the document ID number and then click here. http://nssdcftp.gsfc.nasa.gov/miscellaneous/documents/

b. Core Catalog Materials

REQ. AGENT	RAND #	ACQ. AGENT
DLB	RC3968	RHH
DAD		

EXTRATERRESTRIAL SOLAR SPECTRAL IRRADIANCE AT GROUND LEVEL

MS-21A

This data set is contained on 1 file on a 9-track, 1600 BPI, ASCII magnetic tape created on the MODCOMP IV computer from 18 decks of card image spectral irradiance values. The file consists of solar spectral irradiance at ground level covering the wavelength range 290 - 4045 nanometers. This data was originally created at 556 BPI, 7-track, BCD on the IBM 7094 computer but was converted to 9-track ASCII because of the phasing out of 7-track tape drives. The document number is B-23501-000A. The D and C numbers follow below:

D#	C#
D-18982	C-15783

B 23501-000A

ALTERNATE METHODS IN SOLARIMETRY: REMOTE SENSING AND COMPUTER MODELS

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R to RHH

Solarimetry Workshop, February 24-28, 1975
Energy Task Group
Financiadora de Estudos e Projetos — FINEP
Rio de Janeiro, Brazil

Paper presented at the Brazilian National Academy of Sciences,
February 24, 1975

DATA DECKS FOR SOLAR SPECTRAL IRRADIANCE AT GROUND LEVEL

DECK NUMBER	AIR MASS	α	β	COMMENTS
1	1	.66	.085	In decks 1 thru 16 there are 48 data cards and one title card. Each card gives 4 pairs of values of wavelength (nm) and irradiance ($m W cm^{-2} \mu m^{-1}$)
2	4	.66	.085	
3	7	.66	.085	
4	10	.66	.085	
5	1	.66	.17	
6	4	.66	.17	
7	7	.66	.17	Data of decks 1 thru 8 are reproduced in Table 2 and those of 9 thru 16 in Figures 13 to 14 of "Alternate methods in solarimetry."
8	10	.66	.17	
9	1	.02	1.3	
10	4	.02	1.3	
11	7	.02	1.3	
12	10	.02	1.3	
13	1	.04	1.3	In decks 17 and 18 there are 189 data cards, 2 title cards and 2 "area" cards. Area is total energy in $m W cm^{-2}$.
14	4	.04	1.3	
15	7	.04	1.3	
16	10	.04	1.3	
17	0.1 to 32	.02	1.3	Each card gives irradiance for 10 values of air mass for the wavelengths listed in first column
18	0.1 to 32	.02	-1.3	

See pp 17-28 of "Alternate Methods" for an explanation of these tables.

ALTERNATE METHODS IN SOLARIMETRY: REMOTE SENSING AND COMPUTER MODELS

by
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ABSTRACT

The Sun as a source of energy is receiving increased attention throughout the world. An important element in the design and location of solar energy conversion systems is knowing the amount of energy available. Direct measurement at all locations is expensive and not always feasible. Hence two alternate methods are presented in this paper. One is to make use of the telemetered data from satellites of Earth reflected solar irradiance and derive therefrom the insolation on the ground. The other is to develop by computer techniques the spectral irradiance of the direct solar beam from known values of the extraterrestrial solar spectral irradiance and of atmospheric absorption parameters and to obtain total direct solar irradiance by integration. The relevant mathematical theory is explained and some of the significant results are presented.

INTRODUCTION

The energy crisis and energy from the Sun is a topic which has received considerable attention in recent years. Two crises face mankind today, that of energy shortage and that of environmental pollution. The two are interconnected. The industrial age has been using in prodigal fashion the available sources of energy stored in the bowels of the Earth as fossil fuels, oil, gas and coal, and the supply is rapidly dwindling. The total amount of energy produced per year by all man-made systems in the world is slightly over 2×10^{20} joules. Of this all but 4 percent is from fossil fuels (which after all are stored solar energy). Increasing cost of such fuels and the need of importing fuels from other countries are having serious repercussions on the economy of many nations. Meanwhile this same industrial age is choking man with the wastes of energy usage. Air and water are polluted and the landscape is blighted.

Solar energy is the only form of non-polluting energy. Photons can be converted into energy useful to man without the Carnot's cycle and polluting effluents. But this is an area where research and development effort has been at a very low level. The fictional Russian philosopher, Kuzma Prutkov, decided that the Moon is more useful than the Sun, since it shines during the night when light is needed; while the Sun is of little use during daytime when there is light anyway. In like manner we too have decided to ignore the great outpouring of energy from the Sun.

The Earth-atmosphere system receives solar energy at the prodigious rate of over 5.4×10^{24} joules per year, that is, 27,000 times the energy produced by all man-made systems in the world. The supply is abundant, cost-free and inexhaustive. But it is thinly distributed over a wide area and is highly variable. As the energy crisis becomes worse and conventional fuels become more expensive, increased attention is being paid to systems for solar energy conversion. These systems are expensive to build and maintain; they have to be made cost effective. If the systems are not built for the available supply of solar energy, they will either be unable to deliver the required energy or cost unnecessary capital outlay. It will be necessary to conduct a careful evaluation of optimum sites for a large scale solar power plant. The ideal area to be selected should be most cloud-free, with longest hours of sunshine all year round.

Another major area of effort is small scale solar power generation for desalination, refrigeration, food processing, ice-making and other types of solar energy utilization which are of significance for a country like Brazil. Since solar energy is widely distributed, distribution of energy conversion systems to where energy will be used presents many advantages. Hence aside from selecting optimum sites for large installations, data should be available on solar irradiance for sub-regional to microclimate scales. The first and obvious method of determining the amount of available solar energy is to make direct measurements. A network of solarimetry stations is needed. This is one of the major questions to which this Solarimetry Workshop will address itself. Solarimetry stations require expensive instrumentation and manpower, and the coverage can never be complete. In a country of the size of Brazil (over 8.5 million sq. km) with a total of 50 stations, the average distance between stations will be over 400 km. Besides, there are vast areas which are relatively inaccessible. Hence we would inquire into alternate methods. We would like to explore two such methods in this paper: (1) using satellite data to derive ground insolation (remote sensing), and (2) using known values of extraterrestrial solar irradiance and of atmospheric parameters to compute solar irradiance at ground level (computer models).

REMOTE SENSING TECHNIQUES

A vast amount of data on radiation reflected from the Earth and the atmosphere is already available and will continue to be available from satellites. From these data information on solar irradiance at ground level can be extracted. Remote sensing provides an excellent means of obtaining the needed information about solar energy received on the ground. Remote sensing is superior to a finite number of ground stations in that it gives a continuous coverage over large areas with sufficient spatial resolution. Problems of manpower, differences in calibration factors of different stations, degradation of detectors, inaccessibility of certain locations, etc., can be eliminated by remote sensing techniques. The satellite data are being gathered and processed mainly for other objectives such as Earth resources survey, global radiation budget, etc. They can be used for a major problem of topical interest, namely, solar irradiance on the ground. Furthermore, satellite data can be used to monitor the vast sea surface which is very difficult, if not impossible, for in-situ measurements, but is important for sea thermal power generation and similar applications. The greater the insolation on the surface of the sea, the greater is the temperature gradient for a given depth and the efficiency of a sea thermal power generation plant.

A method developed by T. H. Von der Haar will first be briefly discussed here. There are three key factors which justify the derivation of ground insolation from satellite data. First, total insolation due to the Sun and sky at a given location is primarily dependent on cloud cover. Secondly, insolation data as derived from a single instrument (carried by a satellite) have advantages over those of many instruments from a network of ground stations. Thirdly, insolation is the (solar input) minus (energy scattered or reflected upwards + energy absorbed in the atmosphere).

THE ENERGY EQUATION

A schematic representation of the terms in the energy equation is shown in Figure 1. Q_O is the energy incident on the top of the atmosphere, the solar input. A part of this energy Q_A is absorbed in the atmosphere by ozone, water vapor, particulate matter, etc., and another part is scattered upwards. The part scattered upwards has three components, Q_R due to Rayleigh scattering, Q_H due to haze (also referred to as pollution, turbidity, particulate matter) and Q_C due to clouds. The balance of input energy and absorbed and scattered energy is Q_S, the insolation which reaches the ground. RQ_S (where R is the reflectance of the ground) is reflected upwards and the rest is absorbed by the ground. Q_a is the Earth albedo, the sum of the energy terms reflected and scattered upwards. This quantity Q_a is what is measured by the satellite.

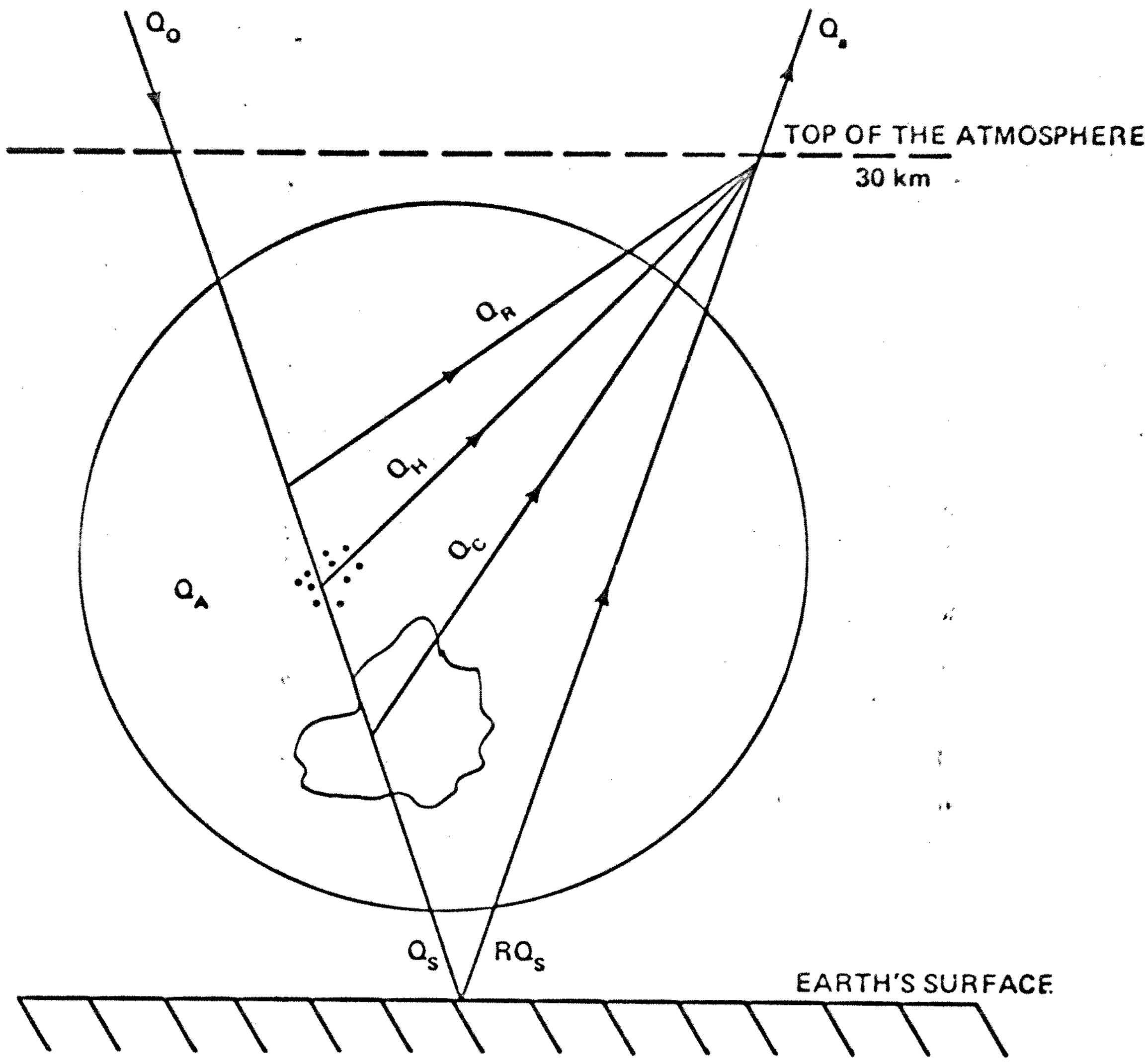

Figure 1. Schematic Representation of the Terms in the Energy Budget Equation

For the purposes of deriving insolation, Q_S, from albedo, Q_a, and cloud cover, we introduce two more terms, A_S the fractional area free of clouds and $Q_{a, min}$ the minimum value of albedo for a given location. The minimum value occurs when the atmosphere is free of haze or clouds, that is, when the two terms Q_H and Q_C tend to zero. Regrouping the terms (Ref. 1) it can be shown that

$$Q_S = Q_O - (Q_a - A_S\, Q_{a,\, min} + Q_A + A_S\, Q_R)\,. \quad (1)$$

All the terms on the right-hand side of equation (1) are known or can be determined. Q_O is the solar constant with due correction for the varying distance between the

Sun and the Earth. Q_a and $Q_{a, min}$ are the albedo measured by the satellite. The fractional area A_s free of clouds can be determined by electronic optical planimetry of satellite data. Q_A, the energy absorbed in the atmosphere, varies with location and seasons of the year, but is a smoothly varying function. It can be determined both from ground observations and from satellite data. Representative values are between 12 and 20 percent of Q_0 for continental United States and between 15 and 28 percent of Q_0 for Brazil. The final term, Q_R, that due to Rayleigh scattering is one which can be computed with a high degree of accuracy.

There are several approximations involved in deriving equation (1) and some of the terms cannot be determined with sufficient accuracy. Hence it will be necessary to check the insolation results derived from satellites against ground observations.

THE NASA PROGRAM

A program has recently been initiated by NASA to develop this method of obtaining ground insolation from satellite telemetry. Three parallel approaches are being planned under this program.

The first, with T. H. Von der Haar of Colorado State University as Principal Investigator, is to study the microclimate at the surface of the Earth over the continental United States, with special attention given to selected areas. Both the mean conditions and the space-time variations of total and direct solar beam energy will be derived using satellite observations with the aid of surface radiation network. Existing satellite data of the period 1969-1974 will first be used to derive the basic solar energy microclimate data set. This will be a space-time matrix of statistics describing the energy reaching the ground, archived on magnetic tape and punched cards. Next the satellite data of 1975-76 will be analyzed to check the earlier data set and more intensive study will be made of regions suggested by engineering priorities. The most up-to-date theoretical methods to study the transfer of solar energy through a cloudy atmosphere are at the disposal of the research project and will be used in the analysis of the observational results as needed. This approach is both empirical and theoretical, and aims at a high degree of accuracy over well-defined geographical regions (Ref. 2).

The second approach, with H. W. Hiser of the University of Miami as Principal Investigator, is mainly empirical. The area of study will be the continental United States and 40 km of coastal waters. The objective is to select optimum locations for large scale power generation. The data from satellites of the SMS (NASA) and GOES (NOAA) series will be analyzed. The number of daytime cloud free hours as shown by satellite data will be determined. Cloud opacity, time of day of minimum cloud cover and seasonal distribution will also be determined. The data will be compared to those from nearest existing weather stations. Equations will be developed relating hours of sunshine in a given geographic location and season to solar energy received at the surface of the Earth (Refs. 3 and 4).

Both these approaches require data from existing weather stations. Insolation data are available from over fifty locations as shown in Figure 2. The numbers in boxes are the mean of daily insolation due to Sun and sky received on a horizontal surface averaged over a five-year period. The units are calories per sq. cm. Monthly averages and daily totals are also available for the same stations. Another highly valuable piece of information is the number of cloud-free hours. Such data are available from the sunshine switch recorders of over 160 stations.

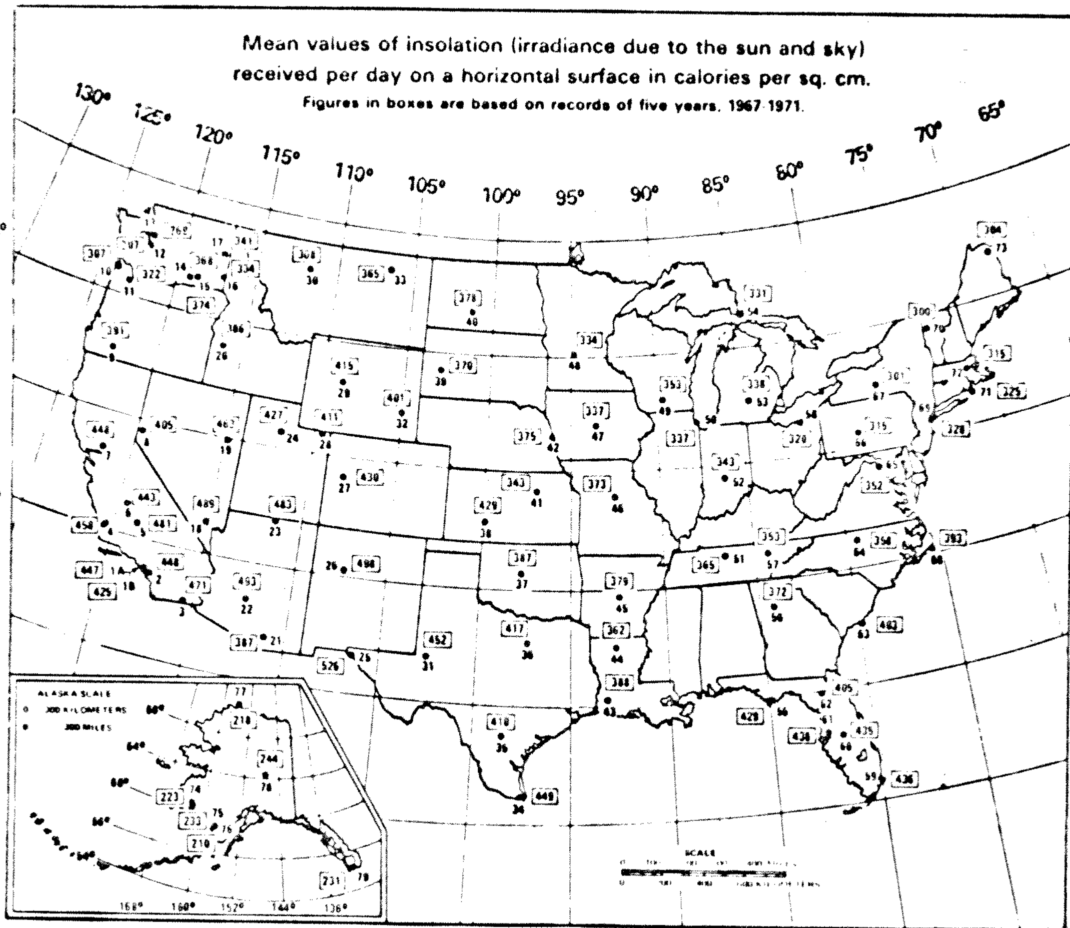

Figure 2. Daily Insolation in the U. S. at 79 Stations Based on Monthly Mean Value Records of the National Weather Service. 345 Monthly Means, 7.3% of Total, Were Missing from the Records and Were Supplied from Record of Same Place, Same Month, Adjacent Year

The third approach under the direction of M. P. Thekaekara of GSFC is to make detailed measurements at a selected ground station with the specific objective of checking out the insolation data derived from satellite telemetry. Such a station has been set up at Goddard Space Flight Center, Greenbelt, Md. The instrumentation consists of an Eppley normal incidence pyrheliometer (NIP) mounted on a Sun-tracker for direct solar irradiance, an Eppley pyranometer for irradiance of the Sun and sky and six thermopiles mounted on sloping surfaces for sky irradiance from six different directions. Sample data for two days, February 7 and 8, are shown in Figures 3 through 6. Figures 3 and 4 give the records of the NIP and the pyranometer for the two days. The pyranometer readings are lower than those of the NIP since it measures the irradiance on a horizontal surface and the zenith angle of the Sun at local noon on these days was nearly 54°. The charts are drawn from irradiance averaged over ten minute periods. Figures 5 and 6 show the irradiance on the same days on flat surfaces inclined at 45° to the horizontal and facing six points of the compass, N, W, SW, S, SE and E. The irradiance data of the eight detectors are stored on tape, one tape per month, and can be recalled as needed for a variety of graphical and tabular presentations. For solarimetry from remote sensing, these ground based records are of importance, since the insolation depends on a large number of variables, latitude, season of the year, time of day, cloud cover, azimuth and zenith angle of the receiving surface, atmospheric absorption parameters, etc. For cloud cover, not only the duration of cloudiness, but also the relative opacity of the clouds and the time of the day when they occur are of significance. The detailed records from each of the sensors stored on the computer tapes for every day of the year will be extremely valuable for a study of these parameters.

Measurements of reflected solar radiation (Earth albedo) have been made from several satellites, starting with Explorer 7 in 1959. These measurements were continued on spacecraft of the TIROS and NIMBUS series and other spacecraft. A NIMBUS 4 picture of the mouths of the Amazon is shown to the left of Figure 7, and a geographical map of the same area to the right. Continuous coverage and high spatial resolution over the western hemisphere are obtained from the telemetered data of the Synchronous Meteorological Satellites (SMS) 1 and 2 which are stationed at present over the equator at longitudes 75°W and 135°W respectively. The Geostationary Operational Environmental Satellites (GOES) A and B due to be launched by NOAA will also cover the same area with identical instruments. The instrument which scans the Earth is the VISSR, Visible Infrared Spin Scan Radiometer. The visible channels of the VISSR have a selective response in the wavelength range 0.52 μm to 0.85 μm. There are eight visible channels which scan the Earth in 14,568 scan lines during a period of 18.2 min. The satellite relays complete pictures of its field of view every half hour. The field of view of SMS 1 extends in longitude from 0°W to 140°W and in latitude 70°N and 70°S. Brazil is close to the nadir point of SMS 1 and is also in the field of view of SMS 2. The

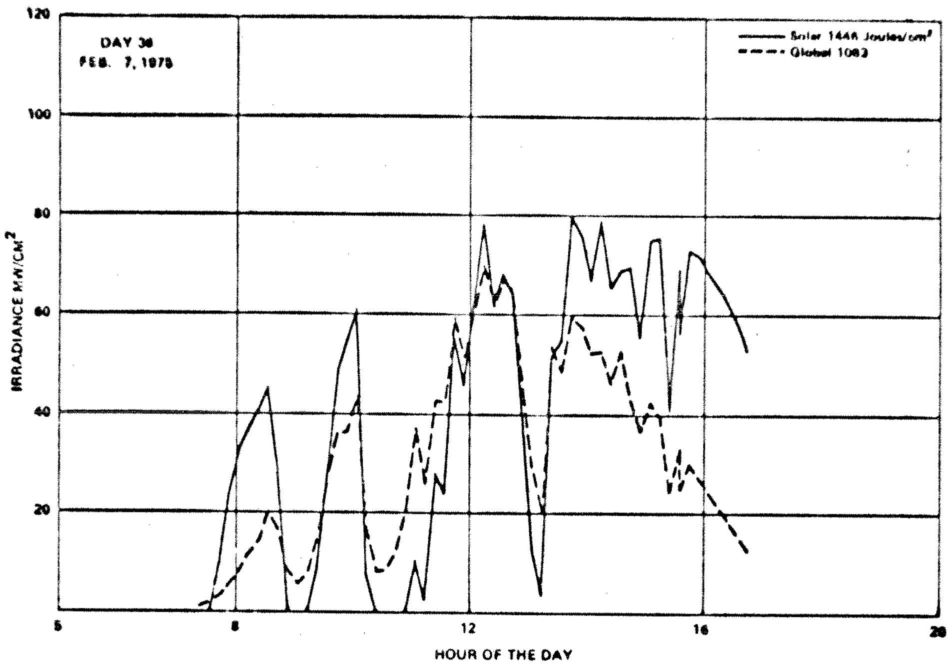

Figure 3. Ten Minute Averages of Direct Solar and Global Irradiance at GSFC on Feb. 7, 1975

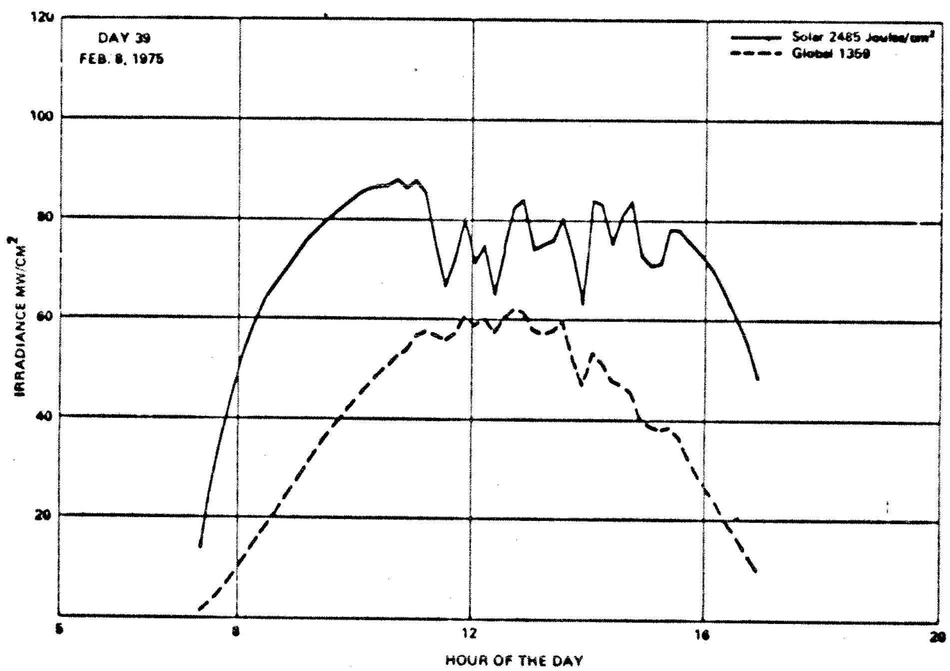

Figure 4. Ten Minute Averages of Direct Solar and Global Irradiance at GSFC on Feb. 8, 1975

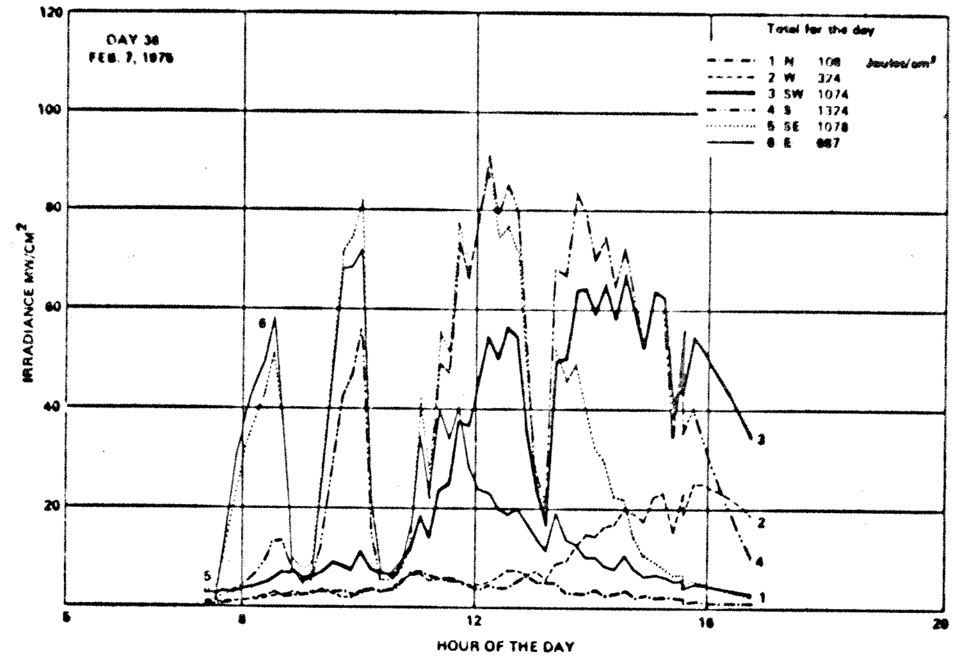

Figure 5. Ten Minute Averages of Sky Irradiance from Different Directions at GSFC on Feb. 7, 1975

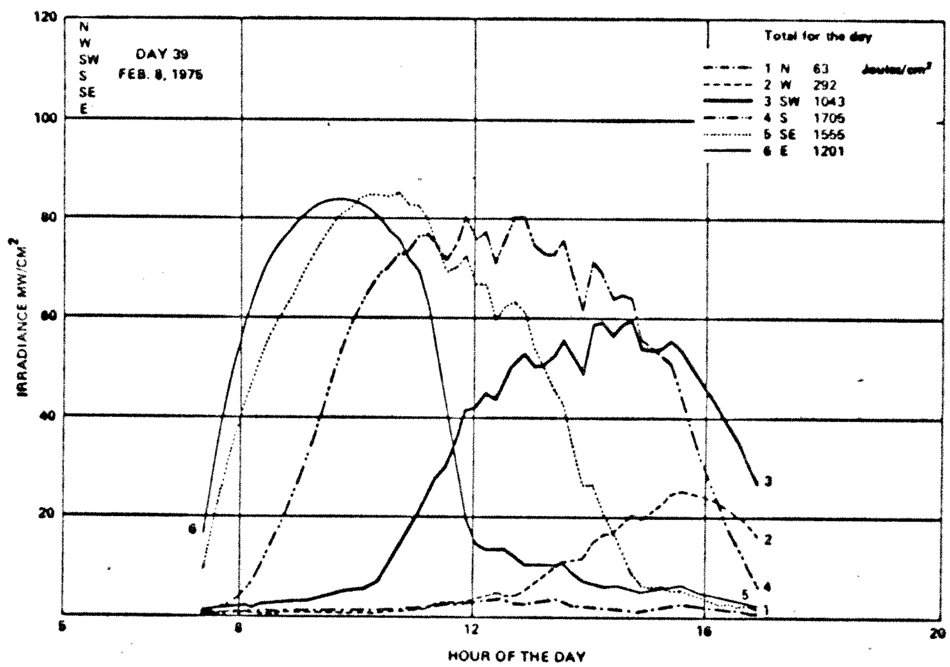

Figure 6. Ten Minute Averages of Sky Irradiance from Different Directions at GSFC on Feb. 8, 1975

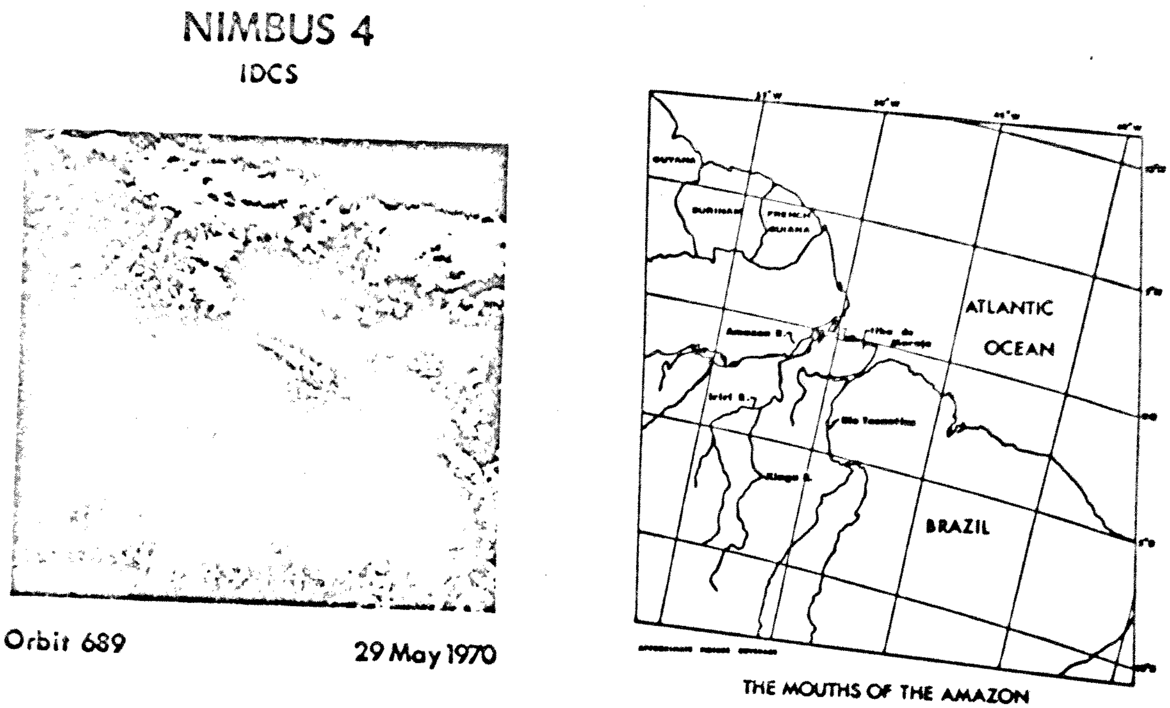

Figure 7. The Mouths of the Amazon Viewed from Nimbus 2 on May 29, 1970

spatial resolution is about 0.8 km near the nadir. The first full Earth disc photo released by NASA/Goddard Space Flight Center from SMS 1 telemetry is shown in Figure 8. This picture was taken on May 28, 1974. Most of Brazil is under cloud cover but the coastline of South and Central America is clearly visible. The original digital tapes from which this and similar halftone pictures are made permit extraction of cloud cover data with considerably higher spatial resolution and finer gradations of cloud transparency.

This research on solarimetry by remote sensing has just started and will continue for a two-year period. It is expected that as a result of this research a relatively simple but sufficiently accurate method will be developed for deriving from remote sensor data of satellites, the information on solar irradiance on any geographical location and at any time which is essential for solar energy conversion systems.

COMPUTER MODELS

Computer models provide an alternate means of solarimetry. The computation is based primarily on known values of the solar constant and the extraterrestrial solar spectrum. The solar constant is the energy received per unit area exposed normally to the Sun's rays at the average Sun-Earth distance in the absence of the Earth's atmosphere. The distribution of this energy as a function of wavelength

Figure 8. First Full Earth Disc Picture from SMS 1 VISSR Camera Telescope Released by GSFC. Picture Taken on May 28, 1974

is the extraterrestrial solar spectrum. These parameters may seem at first to be of little importance for solar energy conversion systems. Most of these systems are on the ground below the atmosphere and the energy which reaches the ground is quite different from what is available outside the atmosphere. However a closer examination of the problem shows that the extraterrestrial values are of great practical significance.

The solar constant and the extraterrestrial solar spectrum are of importance primarily for spaceborne solar energy conversion systems. There are such systems on all satellites. Large energy conversion systems have been envisioned by P. Glaser and have elicited considerable interest from the news media and the public. Since solar cells are spectrally sensitive, the important parameter is not the solar constant itself but the distribution of solar energy in the visible and near infrared portions of the spectrum. The extraterrestrial values are also of significance, though indirectly, for ground based systems. In many cases solar energy parameters of sufficient accuracy can be obtained by computing the fractional loss due to the absorbing and scattering properties of the atmosphere. The extraterrestrial solar spectrum is the important input parameter for such computer programs.

THE SOLAR CONSTANT AND SOLAR SPECTRUM

The NASA/ASTM standard value (Refs. 5, 6 and 7) of the solar constant is 1353 W m^{-2} or 1.940 cal cm^{-2} min^{-1}. The estimated error in this value is ±1.5 percent. The value is based on nine long series of measurements, all made from high altitude platforms, Convair 990, balloons, X-15 aircraft, and Mariner-Mars probe, during the period 1967 to 1970. Different types of instruments were used, cavity radiometers, normal incidence pyrheliometers, Ångström pyrheliometers, etc., and the calibration of the instruments was referred to three scales of radiometry, the absolute electrical units scale, the international pyrheliometric scale, IPS 56, and the thermodynamic Kelvin temperature scale.

The extraterrestrial solar spectrum in the wavelength range 0.2 to 2.6 μm is shown in Figure 9. The spectral irradiance values are given in tabular form in Table 1. These data are based on detailed measurements made from a Convair 990 jet aircraft at an altitude of 11.6 km. In the wavelength range 0.3 to 2.6 μm which contains over 95 percent of the solar energy, four spectroradiometric instruments were used: a Perkin Elmer Monochromator with lithium fluoride prism (1 P28 photomultiplier tube and thermocouple detectors), a quartz double prism monochromator (EMI 9558 QA and lead sulfide detectors), a filter radiometer and a polarization type interferometer. The range of the Perkin Elmer Monochromator extended to 4 μm. A Michelson type infrared interferometer was used for the wavelength range 2.6 to 15 μm. The spectral irradiance curve obtained by these measurements was modified slightly in the visible and near IR in the light of the extensive filter radiometer data obtained by the Eppley-JPL team under the direction of A. J. Drummond (Ref. 8). Data from other sources were used for the two extreme ends of the solar spectrum, below 0.3 μm and beyond 15 μm. The spectral irradiance values given in Table 1 are averages over 10 nm bandwidths for the range 0.3 to 0.75 μm. Wider bandwidths for averaging were used for longer wavelengths. The estimated accuracy of these values is ±5 percent.

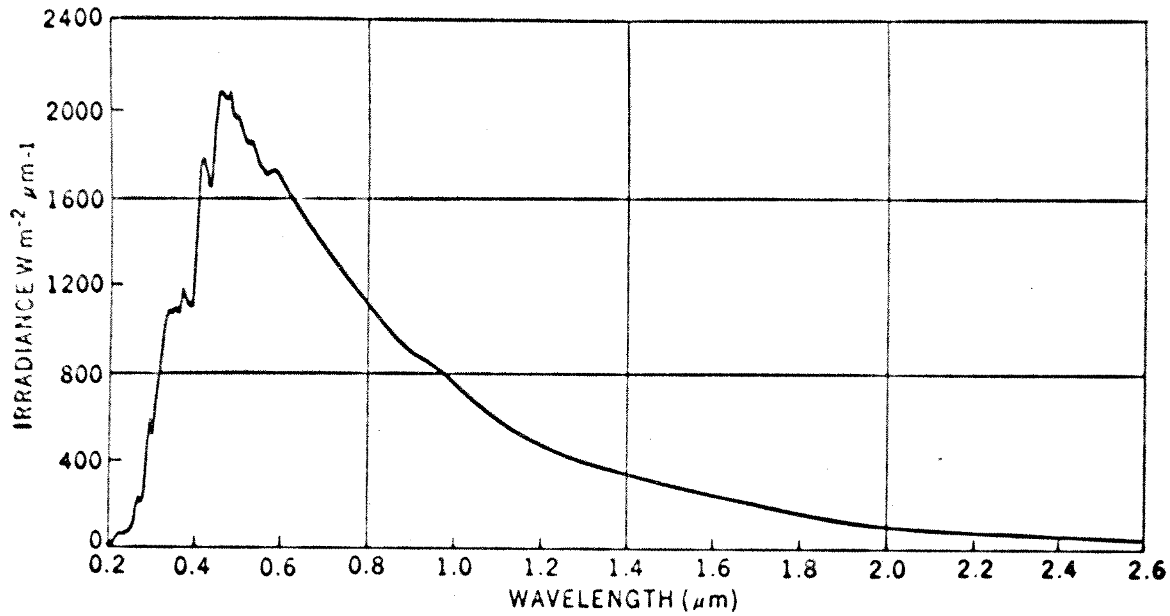

Figure 9. Extraterrestrial Solar Spectral Irradiance at Sun-Earth Distance of One Astronomical Unit, NASA/ASTM Standard Curve. Solar Constant = 1353 W m^{-2}

The solar constant and the extraterrestrial solar spectrum are defined for the average Sun-Earth distance of one astronomical unit, equal to 1.496×10^{13} cm. According to the well known Kepler's law, the Earth like all other planets of the solar system moves along an elliptical orbit with the Sun at one of the foci of the ellipse. Hence the Sun-Earth distance varies according to the seasons of the year, being a minimum around January 3 and a maximum around July 4. These seasonal variations are known with considerably higher precision than the absolute value of the solar constant.

SOLAR ENERGY AT GROUND LEVEL

The problem of extraterrestrial solar irradiance is quite relevant to the problem of more immediate interest, the irradiance, total and spectral, at ground level. The variability of energy incident on a collector surface on the ground is considerably greater than that of the extraterrestrial solar energy. On days of clear sunshine the energy increases from zero at sunrise to a maximum at solar noon and decreases to zero at sunset. At any moment clouds may intercept the Sun and decrease the energy to a low value, that due to the diffuse sky radiation. Figures 10 and 11 based on measurements made on two consecutive days illustrate the wide variations which can be expected. These measurements were made as part of the GSFC international comparison of working standard pyranometers

Table 1

SOLAR SPECTRAL IRRADIANCE - STANDARD CURVE

λ - Wavelength in micrometers

E_λ - Solar spectral irradiance averaged over small bandwidth centered at λ, in W m^{-2} μm^{-1}

$F_{o-\lambda}$ - Integrated solar irradiance in the wavelength range o to λ, in W m^{-2}

$D_{o-\lambda}$ - Percentage of solar constant associated with wavelengths shorter than λ

Solar constant - 1353 W m^{-2}

Note: lines indicate change in wavelength interval of integration

λ	E_λ	$F_{o-\lambda}$	$D_{o-\lambda}$
.115	.007	.0025	.0001
.120	.900	.0048	.0003
.125	.007	.0070	.0005
.130	.007	.0071	.0005
.140	.030	.0073	.0005
.150	.070	.0078	.0005
.160	.230	.0093	.0006
.170	.630	.0136	.0010
.180	1.250	.0230	.0016
.190	2.710	.0428	.0031
.200	10.7	.1098	.0081
.210	22.9	.2778	.0205
.220	[illegible]	.6798	.0502
.225	[illegible]	.9858	.0728
.230	66.7	1.3148	.0971
.235	59.3	1.6[illegible]	.1204
.240	63.0	1.9356	.1430
.245	72.3	2.2738	.1680
.250	70.4	2.6306	.1944
.255	104.0	3.0606	.2266
.260	130	3.6516	.269
.265	185	4.4391	.328
.270	232	5.4816	.405
.275	204	6.5716	.485
.280	222	7.6366	.564
.285	315	8.9791	.663
.290	482	10.9716	.810
.295	584	13.6366	1.007
.300	514	16.3816	1.210
.305	603	19.1741	1.417
.310	689	22.4041	1.655
.315	764	26.0366	1.924
.320	830	30.0216	2.218
.325	975	34.5341	2.552
.330	1059	39.6191	2.928
.335	1081	44.9691	3.323
.340	1074	50.3566	3.721
.345	1069	55.7141	4.117
.350	1093	61.1191	4.517
.355	1083	66.5591	4.919
.360	1068	71.9366	5.316
.365	1132	77.4366	5.723
.370	1181	83.2191	6.150
.375	1157	89.0641	6.582
.380	1120	94.7566	7.003
.385	1098	100.3016	7.413
.390	1098	105.7916	7.819
.395	1189	111.5091	8.241
.400	1429	118.0541	8.725
.405	1644	125.7366	9.293
.410	1751	134.224	9.920
.415	1774	143.036	10.571
.420	1747	151.839	11.222
.425	1693	160.439	11.858
.430	1639	168.769	12.473
.435	1663	177.024	13.083
.440	1810	185.706	13.725
.445	1922	195.036	14.415
.450	2006	204.856	15.140
.455	2057	215.014	15.891
.460	2066	225.321	16.653
.465	2048	235.606	17.413
.470	2033	245.809	18.167
.475	2044	256.001	18.921
.480	2074	266.296	19.681
.485	1976	276.421	20.430
.490	1950	286.236	21.155
.495	1960	296.011	21.878
.500	1942	305.766	22.599
.505	1920	315.421	23.312

λ	E_λ	$F_{o-\lambda}$	$D_{o-\lambda}$
.510	1882	324.926	24.015
.515	1833	334.214	24.701
.520	1833	343.379	25.379
.525	1852	352.591	26.059
.530	1842	361.826	26.742
.535	1818	370.976	27.418
.540	1783	379.979	28.084
.545	1754	388.821	28.737
.550	1725	397.519	29.380
.555	1720	406.131	30.017
.560	1695	414.669	30.648
.565	1705	423.169	31.276
.570	1712	431.711	31.907
.575	1719	440.289	32.541
.580	1715	448.874	33.176
.585	1712	457.441	33.809
.590	1700	465.971	34.439
.595	1682	474.426	35.064
.600	1666	482.796	35.683
.605	1647	491.079	36.295
.61	1635	499.284	36.902
.62	1602	515.469	38.098
.63	1570	531.329	39.270
.64	1544	546.899	40.421
.65	1511	562.174	41.550
.66	1486	577.159	42.657
.67	1456	591.869	43.744
.68	1427	606.284	44.810
.69	1402	620.429	45.855
.70	1369	634.284	46.879
.71	1344	647.849	47.882
.72	1314	661.139	48.864
.73	1290	674.159	49.826
.74	1260	686.909	50.769
.75	1235	699.384	51.691
.76	1211	711.614	52.595
.77	1185	723.594	53.480
.78	1159	735.314	54.346
.79	1134	746.779	55.194
.80	1109	757.994	56.023
.81	1085	768.966	56.834
.82	1060	779.694	57.627
.83	1036	790.174	58.401
.84	1013	800.419	59.158
.85	990	810.434	59.899
.86	968	820.224	60.622
.87	947	829.799	61.330
.88	926	839.164	62.022
.89	908	848.334	62.700
.90	891	857.329	63.365
.91	880	866.184	64.019
.92	869	874.929	64.665
.93	858	883.564	65.304
.94	847	892.089	65.934
.95	837	900.509	66.556
.96	820	908.794	67.168
.97	803	916.909	67.768
.98	785	924.849	68.355
.99	767	932.609	68.928
1.00	748	940.184	69.488
1.05	668	975.584	72.105
1.10	593	1007.109	74.435
1.15	535	1035.309	76.519
1.20	485	1060.809	78.404
1.25	438	1083.884	80.109
1.30	397	1104.759	81.652
1.35	358	1123.634	83.047
1.40	337	1141.009	84.331
1.45	312	1157.234	85.530
1.50	288	1172.234	86.639

λ	E_λ	$F_{o-\lambda}$	$D_{o-\lambda}$
1.55	267	1186.109	87.665
1.60	245	1198.909	88.611
1.65	223	1210.609	89.475
1.70	202	1221.234	90.261
1.75	180	1230.784	90.967
1.80	159	1239.259	91.593
1.85	142	1246.784	92.149
1.90	126	1253.484	92.644
1.95	114	1259.484	93.088
2.00	103	1264.909	93.489
2.1	90	1274.559	94.2024
2.2	79	1283.009	94.8269
2.3	69	1290.409	95.3739
2.4	62	1296.959	95.8580
2.5	55	1302.809	96.2903
2.6	48	1307.959	96.6710
2.7	43	1312.509	97.0073
2.8	39	1316.609	97.3103
2.9	35	1320.309	97.5838
3.0	31	1323.609	97.8277
3.1	26.0	1326.459	98.0383
3.2	22.6	1328.889	98.2179
3.3	19.2	1330.979	98.3724
3.4	16.6	1332.769	98.5047
3.5	14.6	1334.329	98.6200
3.6	13.5	1335.734	98.7238
3.7	12.3	1337.024	98.8192
3.8	11.1	1338.194	98.9056
3.9	10.3	1339.264	98.9847
4.0	9.5	1340.254	99.0579
4.1	8.70	1341.1641	99.12521
4.2	7.80	1341.9891	99.18618
4.3	7.10	1342.7341	99.24124
4.4	6.50	1343.4141	99.29150
4.5	5.92	1344.0351	99.33740
4.6	5.35	1344.5986	99.37905
4.7	4.86	1345.1091	99.41678
4.8	4.47	1345.5757	99.45127
4.9	4.11	1346.0049	99.48299
5.0	3.79	1346.3999	99.51219
6	1.8200	1349.2049	99.71950
7	.9900	1350.6099	99.82335
8	.5850	1351.3974	99.88155
9	.3670	1351.8734	99.91673
10	.2410	1352.1774	99.93920
11	.1650	1352.3804	99.95420
12	.1170	1352.5214	99.96462
13	.0851	1352.6224	99.97209
14	.0634	1352.6967	99.97758
15	.0481	1352.7524	99.98170
16	.037100	1352.7950	99.98485
17	.029100	1352.8281	99.98730
18	.023100	1352.8542	99.98923
19	.018600	1352.8751	99.99077
20	.015200	1352.8920	99.99202
25	.006170	1352.9454	99.99596
30	.002970	1352.9683	99.99765
35	.001600	1352.9797	99.99850
40	.000942	1352.9860	99.99897
50	.000391	1352.9927	99.99946
60	.00019100	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
200	.00000169	1352.9998	99.99999
250	.00000070	1352.9999	99.99999
300	.00000034	1352.9999	99.99999
400	.00000011	1352.9999	99.99999
1000	.00000000	1353.0000	100.00000

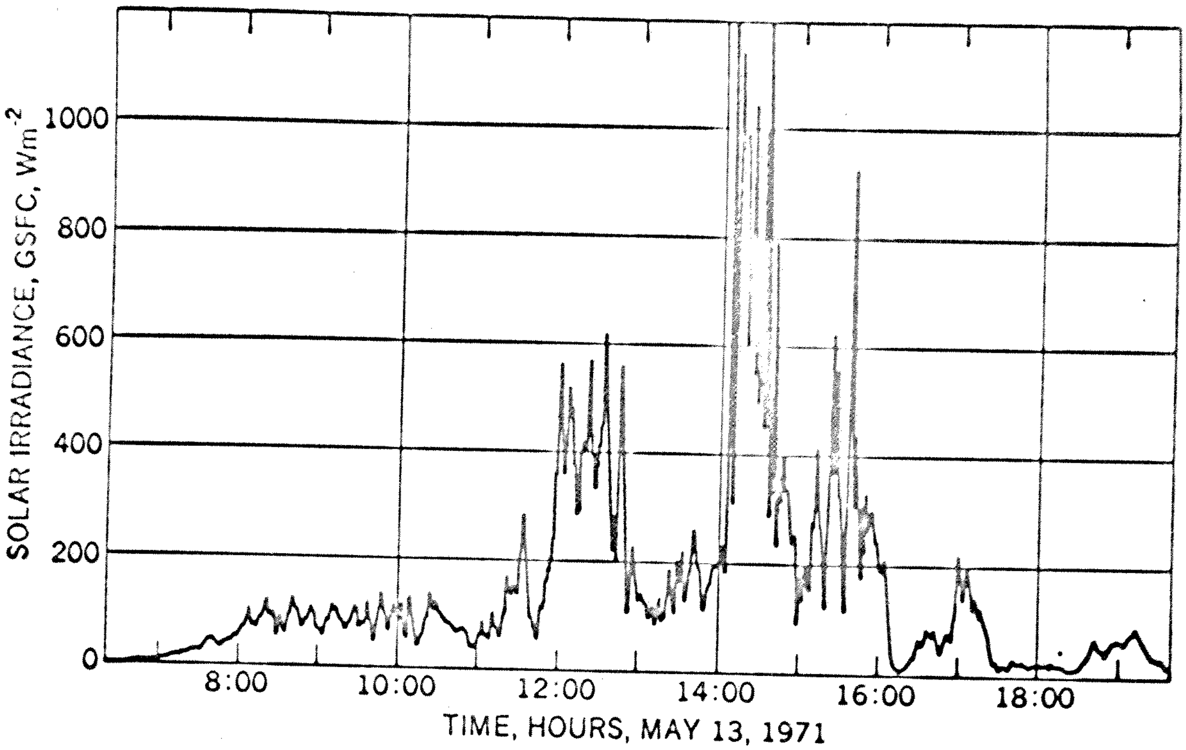

Figure 10. Global Irradiance Due to the Sun and Sky on a Horizontal Surface, Measured at GSFC on May 13, 1971. Total Energy Received During the Day, 175 cal cm^{-2} (732 joules cm^{-2})

(Ref. 9). The instrument was an Eppley pyranometer, model 2, mounted on a roof top. The readings were taken every 4 seconds. The x-axis shows hours in Eastern daylight saving time and the y-axis shows total irradiance. May 13th (Figure 10) was heavily overcast during most of the morning. A short interval of sunshine in the afternoon was followed by a heavy cloudburst at 18:00. The next day was one of relatively clear sunshine with a few passing clouds. The high value, near 1200 W m^{-2}, after 14:00 on May 13, is 30 percent higher than might be expected on a clear day for the given solar elevation; this is obviously due to reflection from the clouds. Such abnormally high values are of short duration.

There is also the familiar variation of solar energy with the seasons of the year. If the rotation axis of the earth were normal to the ecliptic plane (the plane in which the Earth rotates around the Sun), sunrise and sunset would occur at the same time daily at all latitudes, and the inclination of the local vertical to the Sun-Earth line at local noon time would be equal to the latitude of the place. The rotation axis is tilted by an angle of 23.5° from the normal to the ecliptic. Hence arise the seasonal variations of solar irradiance. Further, collecting surfaces

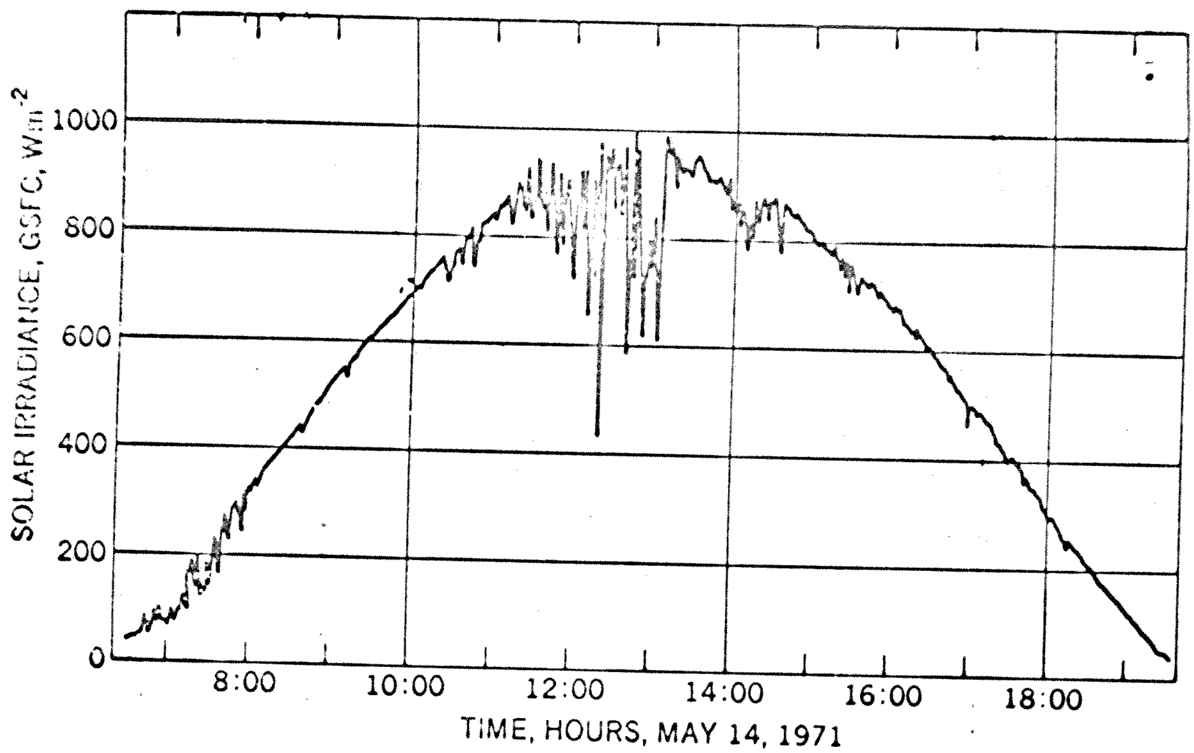

Figure 11. Global Irradiance Due to the Sun and Sky on a Horizontal Surface, Measured at GSFC on May 14, 1971. Total Energy Received During the Day, 647 cal cm^{-2} (2707 joules cm^{-2})

for solar energy conversion systems are not necessarily horizontal nor are they fixed to an equatorial mount so as to be always perpendicular to the solar rays. The slope of the receiving surface is another factor to be considered. Some of these factors are amenable to precise computations; others have to be treated statistically.

The main component of solar irradiance on a surface on a clear day is that due to direct sunlight attenuated by the atmosphere. The atmospheric attenuation is dependent on the path length of the solar rays through the atmosphere. It is least where the Sun is at the zenith and increases as the solar zenith angle increases. The solar zenith angle is the angle between the vertical at a point on the Earth and the line joining that point to the Sun. The path length is conveniently defined in terms of the relative optical air mass, more briefly referred to as the air mass. The air mass is the ratio of the mass of air in a column of unit cross section along the path of the solar rays to the mass of air in a vertical column of unit cross section. In a first approximation,

$$m = \sec z \qquad (2)$$

where m is the air mass and z is the zenith angle. Equation (1) is not strictly true for large values of z, where account has to be taken of the curvature of the solar ray due to refraction in increasingly denser atmospheric layers. Various approximation formulae are available in literature for computing air mass for large values of z (Refs. 10 and 11).

The zenith angle can be directly measured with a sextant or by measuring the length of the shadow cast by a vertical pole on a horizontal surface. It can also be computed from the equation

$$\cos z = \sin \theta \sin \delta + \cos \theta \cos \delta \cos h, \tag{3}$$

where θ is the latitude of the place, δ is the solar declination for the day and h is the hour angle of the Sun. Where $h = 0$, that is, at local noon, Equation (3) reduces to $z = \theta - \delta$, an expression which leads to a simple explanation of declination. (By local noon is meant the time the Sun crosses the meridian; it is not 12 noon standard time or daylight saving time.) On two days in the year, the vernal and autumnal equinoxes, Z at noon time is equal to the latitude of the place. On other days in places south of the equator noon time Z is greater for March through September and less for September through March; the difference is the declination. It is the angle between two planes passing through an observer, one in which the Sun apparently moves and the other parallel to the equator, positive if the solar plane is to the north and negative if it is to the south. Values of declination for each day of the year are available in the American Ephemeris and Nautical Almanac and also in other more readily available almanacs and year books.

The hour angle is an angle measured in the plane in which the Sun apparently moves; it is the angle between two lines from the observer, to the position of the Sun at local noon, and to the actual position of the Sun. Since the Sun's apparent rotation is 15° per hour, the hour angle in degrees is $h = 15(t - t_n)$, where t is the time of observation and t_n is the time of local noon. It is convenient to express t and t_n in Greenwich Mean Time (GMT). The value of t_n at Greenwich for each day of the year is given in the American Ephemeris and Nautical Almanac. For any other location local noon (or ephemeris transit) is 4 minutes of time later for each degree of longitude west (one hour for 15 degrees of longitude).

Values of solar declination and ephemeris transit for 1975 are given in Figure 12. The variation from year to year is quite negligible for the present purpose.

ATMOSPHERIC ATTENUATION OF SOLAR ENERGY

Through most of the solar spectrum the absorption of a monochromatic beam of light is governed by the logarithmic decrement law known also as Beer's Law or Bouguer's Law.

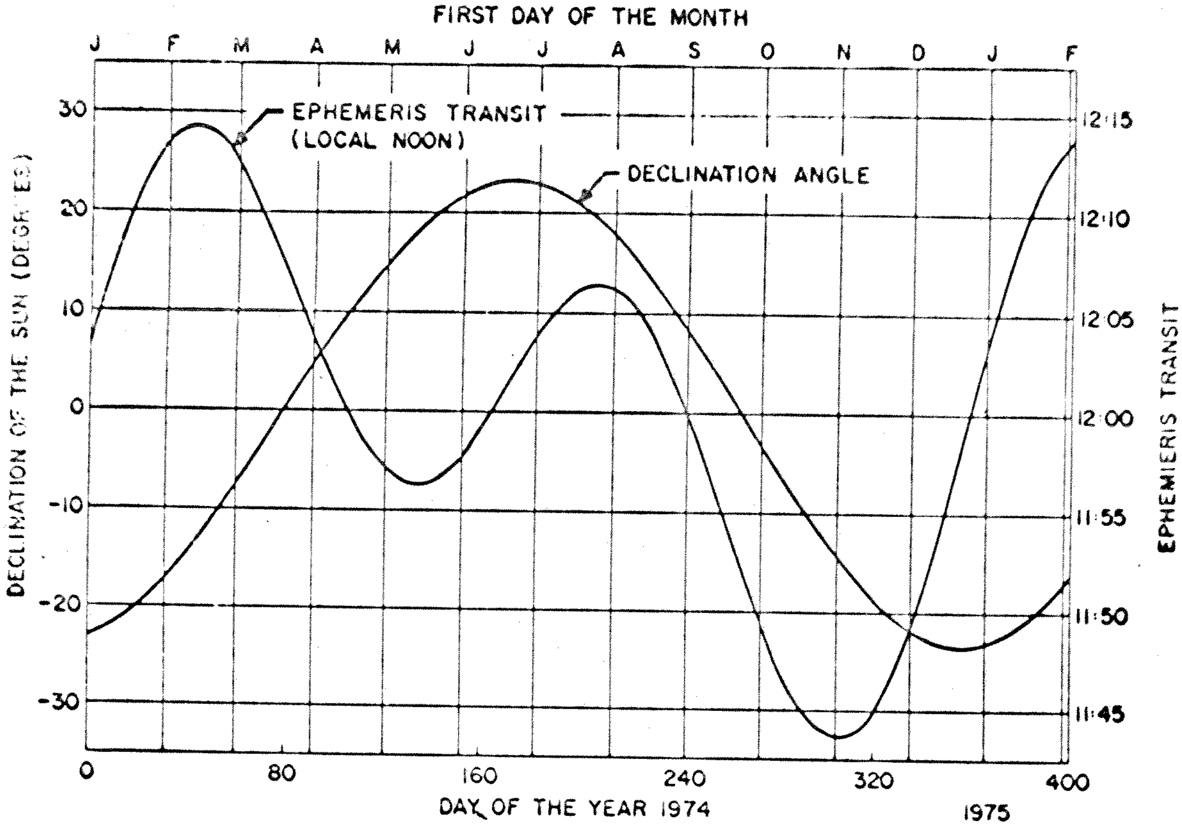

Figure 12. Variation of Solar Declination and Ephemeris Transit During the Year. Figures Along the Y-Axis on Left and Right Give Respectively the Declination in Degrees and the Ephemeris Transit in Hours and Minutes, Greenwich Mean Time

$$E_\lambda = E_\lambda^0 \, e^{-c_\lambda m} , \qquad (4)$$

where E_λ^0 and E_λ are irradiance at a given wavelength λ outside the atmosphere and after transmittance through air mass m respectively. C_λ is an attenuation factor, often referred to as the extinction optical thickness. The coefficient C_λ is the sum of three terms, C_1 due to Rayleigh scattering, C_2 due to ozone and C_3 due to aerosols or atmospheric turbidity. In the infrared ($\lambda > 0.69\ \mu m$) there is also selective absorption by the polyatomic gaseous constituents of the atmosphere, mainly, water vapor and carbon dioxide, and continuum attenuation due to scattering and absorption by particulate matter and water droplets. The selective absorption is characterized by many thousands of lines of the vibration-rotation spectrum of the molecules, as will be shown by a high dispersion ($\lambda/\Delta\lambda > 10^5$)

spectrograph. The total effect over finite bandwidths is not simple enough to be expressed by Equation (4). Nor is it correct to assume that the total energy at ground level can be expressed by an integral over all wavelengths of the right hand side of Equation (4).

There is a considerable amount of literature on atmospheric attenuation. Some of the attempts to solve the problem require elaborate mathematical tools and a great deal of computer time. A simpler approach is presented here. Solar irradiance spectra at ground level are computed on the basis of the standard NASA/ASTM curve, assuming atmospheric attenuation parameters which are considered to be highly reliable. The computer program was developed by Douglas Hoyt of NOAA, Boulder, Colorado and adapted by Reginald Mitchell of NASA/GSFC.

The Rayleigh attenuation coefficient C_1 and the ozone attenuation coefficient C_2 are based on the data developed by L. Elterman (Ref. 12). They are valid for the U. S. standard atmosphere. The total amount of ozone in a vertical path is assumed to be 0.34 cm (at NTP). Other values of ozone density can be introduced if needed. In Elterman's notation these constants C_1 and C_2 are respectively τ'_r, Rayleigh optical thickness (h - ∞) and τ'_3, ozone optical thickness (h - ∞). The values for h = 0 (i. e., at sea level) were used for the present computation. Elterman's tables list the values for 22 discrete wavelengths. For other wavelengths of the standard table a linear interpolation for C_1 and C_2 was found to be sufficiently accurate.

For atmospheric turbidity instead of using Elterman's coefficients, an equation of the form developed by A. Ångström is used.

$$C_3 = \frac{\beta}{\lambda^{\alpha}} \tag{5}$$

where β is the Ångström β coefficient, α the wavelength exponent and λ is wavelength in μm. This permits a greater flexibility in choosing α and β parameters corresponding to different levels of atmospheric pollution.

In the infrared, as stated earlier, a fourth parameter to account for the molecular absorption bands is required. Here no single expression applies to all the absorption bands. The experimental results of Gates and Harrop (Refs. 13 and 14) seem to be most appropriate for handling this complex problem. The expressions are relatively simple; the accuracy is adequate; and the parameters are based on actual measurements of solar irradiance. The experimental results were interpreted in the light of the random model theory (disordered distribution of many lines within a band) developed by Goody (Ref. 15) for water vapor and the regular model theory (regular distribution of absorption lines) developed by Elsasser (Ref. 16) for carbon dioxide. Thus, in the infrared, Equation (4) has to be modified as

$$E_\lambda = E_\lambda^0 \, e^{-c_\lambda m} \cdot T_{\lambda i}, \tag{6}$$

where $T_{\lambda i}$ is a transmittance factor which can have one of three values,

$$T_{\lambda 1} = e^{-c_4 \sqrt{w m}}; T_{\lambda 2} = e^{-c_5 w m}; \text{or } T_{\lambda 3} = (1 - c_6 \sqrt{m}). \tag{7}$$

c_4, c_5 and c_6 are respectively coefficients $-c_1$, $-c_2$ and c_5 of Reference 13; m is the air mass; and w is the amount of precipitable water vapor (the height in cm of the liquid layer if all the water vapor in a vertical column of unit cross section were condensed into liquid). For the present computation w was assumed to be 2 cm which is a global annual average for mid-latitudes. Other values can be introduced if needed.

The expression $T_{\lambda 1}$ is for the strong random model, and holds true in the main body of the absorption band. The expression $T_{\lambda 2}$ is for the weak random model and holds true for the wings of the bands and for small optical depth. The third expression $T_{\lambda 3}$ holds true where the effect of water vapor is negligible, but where other molecular species in the atmosphere influence the transmission.

TOTAL AND SPECTRAL SOLAR IRRADIANCE AT GROUND LEVEL

Computations of solar spectral irradiance at ground level have been made for different sets of parameters for ozone density, precipitable water vapor, turbidity coefficients and air mass. The spectral irradiance outside the atmosphere, E_λ^0, is assumed to be that given in the NASA/ASTM standard.

Some of the results are presented here in graphical and tabular form. Figures 13 and 14 give the spectral curves for air mass 1, 4, 7 and 10. These correspond respectively to solar zenith angles 0°, 75.5°, 81.8° and 84.3°. The continuous curve on top is the extraterrestrial spectrum same as Figure 9. Figure 13 is for $\alpha = 1.3$ and $\beta = 0.02$, and corresponds to a relatively clear atmosphere. A higher value of $\beta = 0.04$, that is, a more turbid atmosphere, is assumed for the curves of Figure 14. The integral values of irradiance are given in the inset.

Spectral irradiance at ground level in tabular form is given in Table 2 for the range 0.29 μm to 0.93 μm and in Table 3 for the range 0.94 μm to 4.045 μm. These values

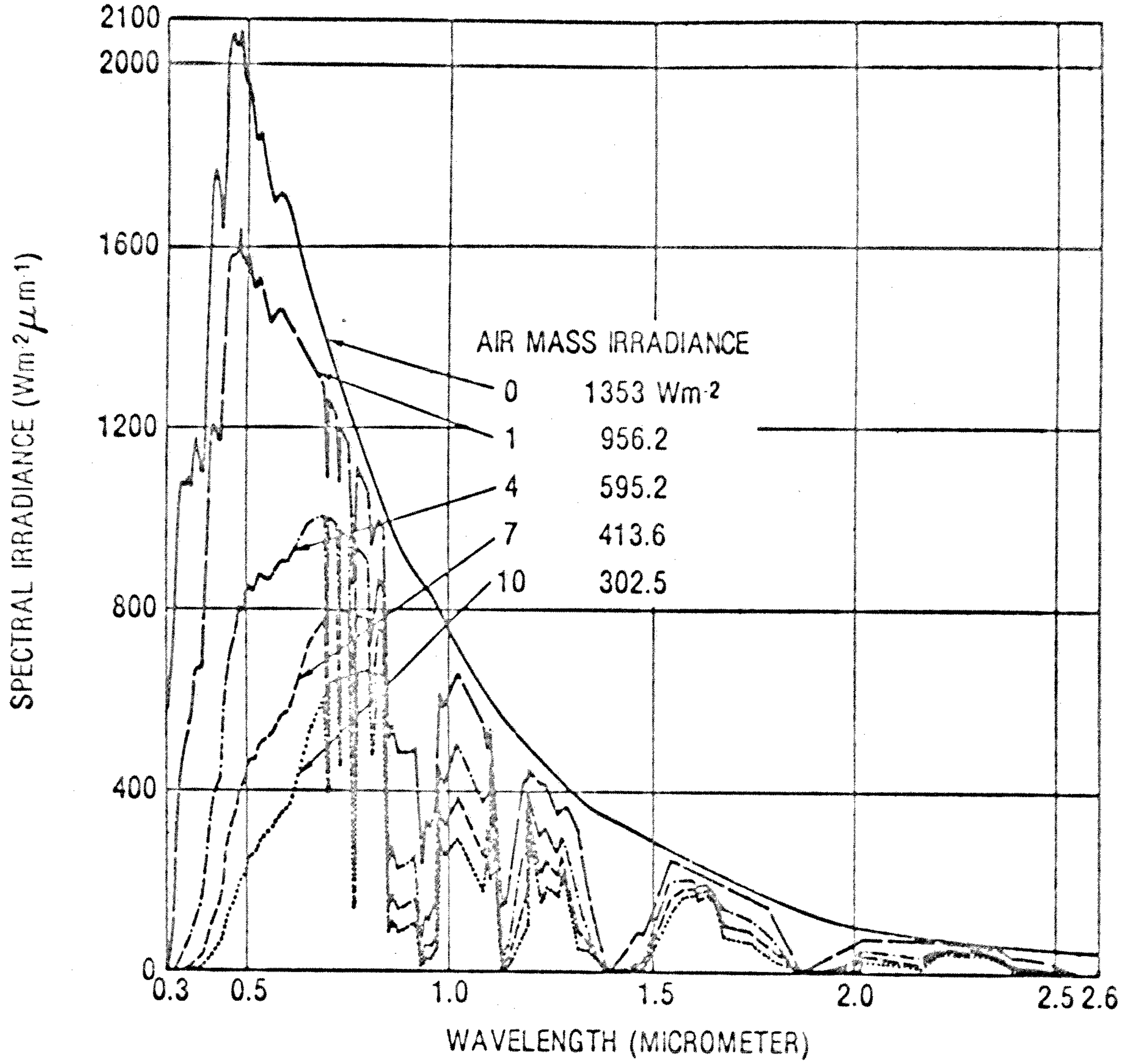

Figure 13. Solar Spectral Irradiance for Different Air Mass Values, Assuming U. S. Standard Atmosphere, 20 mm of Precipitable Water Vapor, 3.4 mm of ozone, very clear air ($\alpha = 1.3$, $\beta = 0.02$)

correspond to a considerably higher level of atmospheric pollution, as is the case in large cities and industrial centers. Column 2 gives the extraterrestrial values; columns 3 to 6 give values at ground level for $\alpha = 0.66$ and $\beta = 0.085$; and columns 7 to 9 give values at ground level for $\alpha = 0.66$ and $\beta = 0.17$.

It is instructive to compare these computed spectral curves with one obtained by direct measurements. During the course of the ground calibration of the VISSR of SMS spacecraft a series of measurements of the total and spectral irradiance of the Sun was made on Table Mountain, CA. One of the spectral curves generated

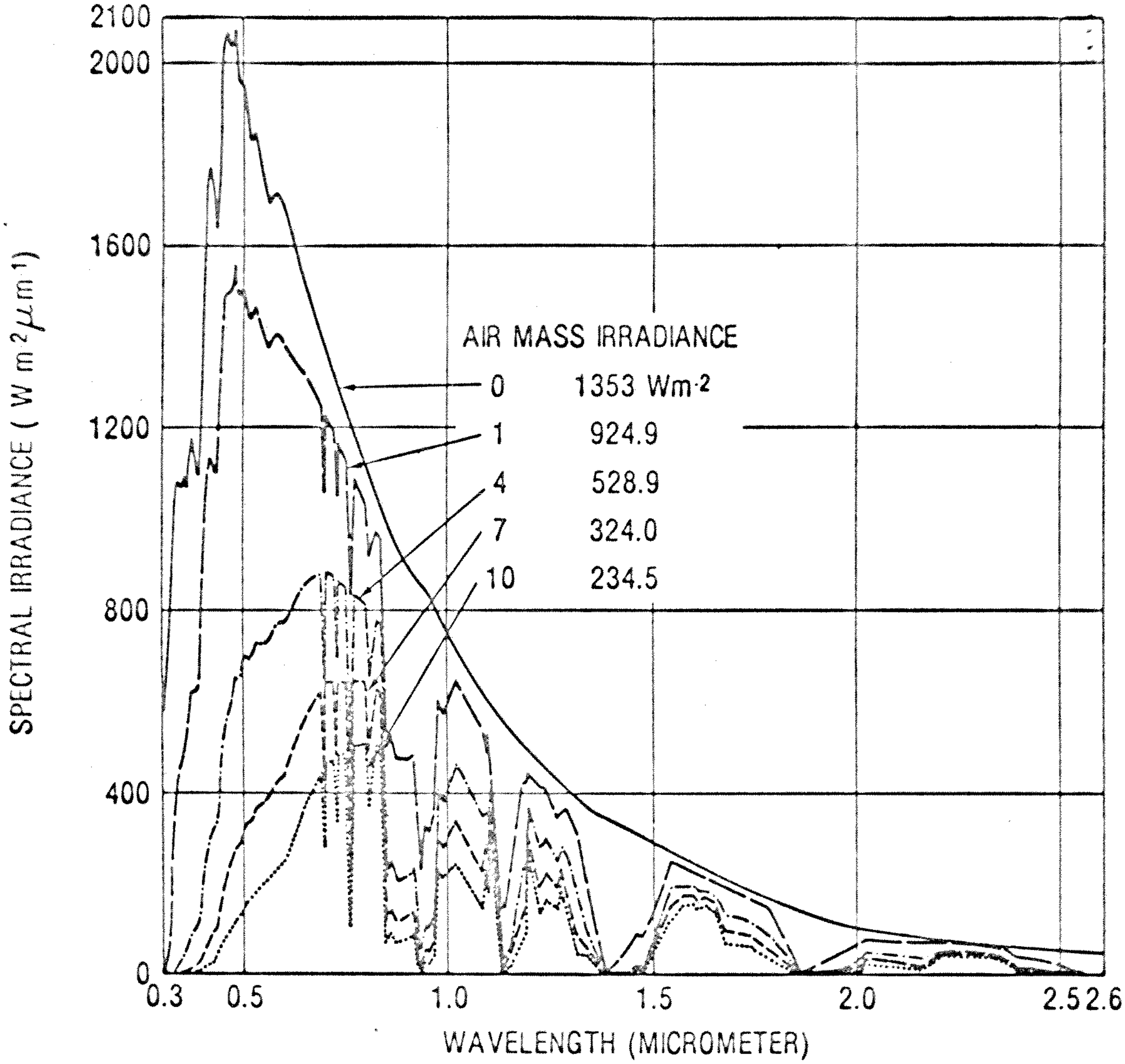

Figure 14. Solar Spectral Irradiance for Different Air Mass Values, Assuming U. S. Standard Atmosphere, 20 mm of Precipitable Water Vapor, 3.4 mm of ozone, relatively clear air ($\alpha = 1.3$, $\beta = 0.04$)

during these measurements is shown in Figure 15. The instrument was a Perkin Elmer monochromator, the same which was used on the CV990 aircraft for determination of the extraterrestrial solar spectral irradiance. The secant of the solar zenith angle was 1.5, but since the altitude of the Table Mountain test site is 2.19 km, this corresponds to an absolute air mass of 1.15 (referred to zenith Sun at sea level as air mass 1). Several of the absorption lines of Figures 13 and 14 are masked here because of the finite resolution of the monochromator.

Table 2

Computed Values of Solar Spectral Irradiance (in $Wm^{-2}\,\mu m^{-1}$) on the Ground for Different Air Masses, Two Values of Turbidity and H_2O 2.0 cm, O_3 0.34 cm (spectral range 0.29 to 0.93 μm)

AIR MASS / WAVE LENGTH	0	α 0.66 β 0.085				α 0.66 β 0.170			
		1	4	7	10	1	4	7	10
0.290	482.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.295	584.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.300	514.0	4.1	0.0	0.0	0.0	3.4	0.0	0.0	0.0
0.305	603.0	11.4	0.0	0.0	0.0	9.4	0.0	0.0	0.0
0.310	689.0	30.5	0.0	0.0	0.0	25.4	0.0	0.0	0.0
0.315	764.0	79.4	0.1	0.0	0.0	66.2	0.0	0.0	0.0
0.320	830.0	202.6	2.4	0.0	0.0	169.2	1.4	0.0	0.0
0.325	975.0	269.5	5.7	0.1	0.0	225.5	2.8	0.0	0.0
0.330	1059.0	331.6	10.2	0.3	0.0	277.9	5.0	0.1	0.0
0.335	1081.0	383.4	17.1	0.8	0.0	321.8	8.5	0.2	0.0
0.340	1074.0	431.3	27.9	1.8	0.1	362.7	14.0	0.5	0.0
0.345	1089.0	449.2	33.3	2.5	0.2	378.4	16.8	0.7	0.0
0.350	1093.0	480.5	40.8	3.5	0.3	405.4	20.7	1.1	0.1
0.355	1083.0	498.0	44.4	4.7	0.5	420.8	24.7	1.4	0.1
0.360	1068.0	513.7	57.2	6.4	0.7	434.8	29.3	2.0	0.1
0.365	1132.0	561.3	68.4	8.3	1.0	475.7	35.3	2.6	0.2
0.370	1181.0	603.5	80.5	10.7	1.4	512.3	41.8	3.4	0.3
0.375	1157.0	609.4	89.8	13.0	1.9	518.8	48.5	4.2	0.4
0.380	1120.0	608.0	97.2	15.6	2.5	517.6	51.1	5.0	0.5
0.385	1098.0	609.8	104.5	17.9	3.1	519.9	55.2	5.9	0.6
0.390	1098.0	623.9	114.5	21.0	3.9	532.6	60.8	6.9	0.8
0.395	1189.0	691.2	135.8	26.7	5.2	590.8	72.5	8.9	1.1
0.400	1429.0	849.9	170.8	37.6	7.9	727.4	95.9	12.7	1.7
0.405	1644.0	992.8	218.7	48.2	10.6	850.8	117.9	16.3	2.3
0.410	1751.0	1073.7	247.5	57.1	13.2	921.3	134.2	19.5	2.8
0.415	1774.0	1104.5	266.5	64.3	15.5	948.8	145.2	22.2	3.4
0.420	1747.0	1104.3	278.9	70.4	17.8	949.8	152.7	24.5	3.9
0.425	1693.0	1086.5	287.2	75.9	20.1	935.6	157.9	26.7	4.5
0.430	1639.0	1067.9	295.4	81.7	22.6	920.7	163.2	28.9	5.1
0.435	1663.0	1100.1	318.4	92.2	26.7	949.5	176.7	32.9	6.1
0.440	1810.0	1215.5	368.2	111.5	33.8	1050.3	205.2	40.1	7.8
0.445	1922.0	1310.4	415.3	131.6	41.7	1133.5	232.5	47.7	9.8
0.450	2006.0	1388.4	448.3	152.6	50.6	1202.7	258.8	55.7	12.9
0.455	2057.0	1434.8	480.9	165.2	56.1	1243.7	274.9	60.8	13.4
0.460	2066.0	1452.2	504.4	175.2	60.8	1260.1	285.9	64.9	14.7
0.465	2048.0	1450.7	515.7	183.3	65.1	1260.1	293.5	68.4	15.9
0.470	2033.0	1451.2	527.9	192.0	69.8	1261.8	301.6	72.1	17.2
0.475	2044.0	1470.3	547.3	203.7	75.8	1279.6	313.9	77.0	18.9
0.480	2074.0	1503.4	572.6	210.1	83.1	1309.6	324.7	83.0	20.9
0.485	1976.0	1443.3	562.4	219.2	85.4	1258.5	325.1	88.0	21.7
0.490	1950.0	1435.2	572.2	228.2	91.0	1252.6	332.0	88.8	23.3
0.495	1960.0	1453.6	592.9	241.9	98.7	1269.8	345.3	93.9	25.5
0.500	1942.0	1451.2	605.6	252.7	105.5	1268.8	353.9	98.7	27.5
0.505	1920.0	1440.1	607.6	256.4	108.2	1260.2	356.3	100.8	28.5
0.510	1882.0	1416.8	604.4	257.8	110.0	1240.9	355.7	101.9	29.2
0.515	1833.0	1384.9	597.3	257.6	111.1	1214.0	352.7	102.5	29.8
0.520	1833.0	1390.0	608.1	264.3	115.2	1219.5	359.1	105.7	31.1
0.525	1852.0	1409.5	621.3	273.9	120.7	1237.6	369.3	110.2	32.9
0.530	1842.0	1406.9	626.9	279.4	124.5	1236.4	373.9	113.1	34.2
0.535	1818.0	1393.8	627.7	282.8	127.4	1225.6	375.5	115.1	35.3
0.540	1783.0	1371.7	624.5	284.4	129.5	1207.3	374.8	116.4	36.1
0.545	1754.0	1354.2	623.2	286.8	132.0	1192.8	375.2	118.0	37.1
0.550	1725.0	1336.6	621.7	289.2	134.5	1178.2	375.4	119.6	38.1
0.555	1720.0	1335.7	625.5	293.0	137.2	1178.3	378.8	121.8	39.2
0.560	1695.0	1319.2	622.0	293.3	138.3	1164.7	377.8	122.6	39.8
0.565	1705.0	1330.0	631.3	299.6	142.2	1175.0	384.6	125.9	41.2
0.570	1712.0	1339.4	639.5	305.6	146.0	1183.3	390.7	129.0	42.6
0.575	1719.0	1346.9	647.8	311.6	149.9	1191.6	396.9	132.2	44.0
0.580	1715.0	1346.7	652.0	315.7	152.8	1192.3	400.6	134.6	45.2
0.585	1712.0	1347.3	656.6	320.0	156.0	1193.6	404.5	137.1	46.5
0.590	1700.0	1340.7	657.7	322.6	158.3	1188.6	406.3	138.9	47.5
0.595	1682.0	1329.4	656.4	324.1	160.0	1179.4	406.6	140.2	48.3
0.600	1666.0	1319.6	655.8	325.9	162.0	1171.5	407.3	141.6	49.2
0.605	1647.0	1311.0	661.3	333.8	168.2	1164.6	411.6	145.6	51.5
0.610	1635.0	1307.9	669.6	342.8	175.5	1167.6	418.0	150.3	54.0
0.620	1602.0	1294.2	682.4	359.9	189.7	1151.9	428.2	159.2	59.2
0.630	1570.0	1280.9	695.6	377.8	205.2	1141.4	438.8	168.5	64.8
0.640	1544.0	1272.1	711.4	397.9	222.5	1134.9	450.7	179.0	71.1
0.650	1511.0	1257.1	723.9	416.9	240.1	1122.8	460.8	189.1	77.6
0.660	1486.0	1244.2	730.2	428.8	251.6	1112.5	466.9	195.9	82.2
0.670	1456.0	1226.8	733.8	438.9	262.5	1098.2	471.2	202.2	86.8
0.680	1427.0	1209.9	737.4	449.5	273.9	1084.3	475.6	208.6	91.5
0.690	1402.0	1196.2	742.9	461.3	286.5	1073.1	481.1	215.7	96.7
0.698	1379.0	1010.3	546.1	311.8	181.6	907.1	354.9	148.7	61.8
0.700	1369.0	1175.3	743.7	470.6	297.7	1055.4	483.6	221.6	101.6
0.710	1344.0	1157.4	734.2	472.1	301.5	1040.4	482.7	223.9	103.9
0.720	1314.0	1135.1	731.7	471.6	304.0	1021.3	479.6	225.2	105.8
0.728	1295.5	1003.1	582.3	351.7	215.5	903.3	382.4	168.8	75.5
0.730	1290.0	1117.8	727.1	473.9	307.7	1006.7	478.5	227.4	108.1
0.740	1260.0	1095.1	718.9	471.9	309.8	987.2	474.8	228.4	109.9
0.750	1235.0	1076.6	713.2	472.4	313.0	971.4	472.8	230.1	112.0
0.762	1205.5	744.0	357.1	163.6	69.1	717.2	237.8	80.3	25.6
0.770	1185.0	1039.2	700.4	472.7	318.4	939.4	467.9	233.1	116.1
0.780	1159.0	1019.4	693.6	472.0	321.1	922.3	464.7	234.1	118.0
0.790	1134.0	1000.3	686.7	471.4	323.6	905.6	461.6	235.2	119.9
0.800	1109.0	981.2	679.4	470.5	325.8	889.1	458.2	236.1	121.7
0.806	1095.1	874.4	547.7	355.9	236.4	792.7	370.0	179.2	88.0
0.825	1048.0	931.6	654.3	459.6	322.8	845.9	444.8	233.9	123.0
0.830	1036.0	921.8	649.3	457.3	322.1	837.3	442.0	233.3	123.2
0.835	1024.5	912.4	644.4	455.2	321.5	829.1	439.4	232.9	123.4
0.846	998.1	476.2	181.0	65.9	24.2	433.1	123.8	44.2	17.1
0.860	969.0	508.4	212.8	107.6	58.3	461.8	145.8	55.6	22.8
0.870	947.0	453.8	174.7	88.0	43.6	413.4	120.4	43.7	17.2
0.875	936.5	449.2	173.6	83.6	43.7	409.4	119.6	43.6	17.3
0.887	912.5	448.6	178.3	87.7	48.7	409.2	123.4	46.1	18.6
0.900	891.0	448.9	183.7	92.3	50.8	409.0	127.6	48.8	20.1
0.907	882.8	455.2	190.9	97.6	53.7	415.6	132.9	51.8	21.7
0.915	874.5	461.5	198.5	103.2	57.5	421.8	138.4	54.9	23.4
0.925	863.5	279.0	73.6	26.0	12.1	255.1	51.5	14.9	5.0
0.930	858.0	221.8	46.9	15.4	6.0	202.9	32.8	8.3	2.4

Table 3

Computed Values of Solar Spectral Irradiance (in $Wm^{-2}\ \mu m^{-1}$) on the Ground for Different Air Masses, Two Values of Turbidity and H_2O 2.0 cm, O_3 0.34 cm (spectral range 0.94 to 4.045 μm)

AIR MASS / WAVE LENGTH	0	α 0.66 β 0.085				α 0.66 β 0.170			
		1	4	7	10	1	4	7	10
0.940	847.0	313.4	95.0	34.6	18.5	286.9	66.7	21.3	7.6
0.950	837.0	296.5	86.3	35.0	16.0	271.6	60.7	18.9	6.7
0.955	828.5	321.1	102.3	44.1	21.2	294.2	77.1	23.9	8.8
0.965	811.5	344.4	120.4	55.1	27.8	315.7	85.0	30.9	11.6
0.975	794.0	576.9	368.0	224.6	150.1	529.1	264.9	122.7	81.7
0.985	776.0	544.6	316.1	201.2	132.4	499.8	224.2	110.3	58.1
1.018	719.2	617.5	391.0	247.5	156.7	567.8	274.4	137.5	67.6
1.082	620.0	512.9	290.4	164.4	93.1	473.1	210.3	83.5	41.5
1.094	602.0	464.1	303.1	210.8	149.9	428.6	220.0	120.3	67.3
1.098	596.0	503.7	304.1	183.6	110.9	465.0	220.9	105.0	49.9
1.101	591.8	504.8	362.7	267.3	198.4	466.1	263.6	153.0	89.5
1.128	560.5	135.1	27.7	9.1	3.6	124.9	20.2	5.3	1.6
1.131	557.0	152.2	35.3	12.6	5.3	140.7	25.8	7.3	2.9
1.137	550.1	143.1	31.7	11.0	4.5	132.4	23.2	6.4	2.1
1.144	542.0	191.2	57.4	24.2	11.6	176.9	42.1	14.1	5.3
1.147	538.5	174.5	48.2	19.3	8.8	161.5	35.3	11.2	4.1
1.178	507.0	399.3	195.1	93.4	46.6	370.0	141.8	55.9	21.7
1.189	496.0	402.2	214.5	114.4	61.0	372.8	158.4	67.3	26.5
1.193	492.0	424.0	310.8	233.3	176.6	393.1	229.7	137.4	82.9
1.222	464.3	391.8	235.3	141.3	84.9	363.6	174.7	83.9	40.3
1.236	451.2	390.8	254.1	165.2	107.4	363.0	189.3	98.5	51.3
1.264	426.5	329.2	209.7	140.0	94.3	306.1	156.7	84.1	45.5
1.276	416.7	342.6	238.6	172.6	126.1	318.7	178.6	104.0	61.2
1.288	406.8	347.3	216.1	134.4	83.7	323.2	162.1	81.3	40.7
1.314	386.1	298.3	137.0	63.5	29.3	277.9	103.6	38.6	14.4
1.335	369.7	190.6	85.0	46.7	27.7	177.6	64.2	28.6	13.7
1.384	343.7	5.7	0.1	0.0	0.0	5.3	0.1	0.0	0.0
1.432	321.0	44.6	5.4	1.3	0.4	41.7	4.1	0.8	0.2
1.457	308.6	85.4	20.6	7.7	3.3	80.0	15.8	4.8	1.7
1.472	301.4	77.4	17.4	6.2	2.6	72.4	13.3	3.9	1.3
1.542	270.4	239.3	165.9	115.0	79.7	224.5	128.5	73.6	42.1
1.572	257.3	222.6	168.1	130.4	102.1	209.0	130.7	83.9	54.4
1.599	245.4	216.0	166.7	131.5	104.5	203.0	129.9	85.0	56.0
1.608	241.5	208.5	157.4	122.1	95.7	195.9	122.7	79.1	51.4
1.626	233.6	206.7	160.7	127.5	101.9	194.3	125.6	82.8	55.0
1.644	225.6	197.9	152.4	120.1	95.5	186.1	119.3	78.3	51.8
1.650	223.0	195.7	150.9	119.1	94.7	184.1	118.2	77.6	51.4
1.676	212.1	181.9	114.8	72.4	45.7	171.2	90.1	47.5	25.0
1.732	187.9	161.5	102.5	65.1	41.3	152.2	80.9	43.0	22.9
1.782	166.6	136.7	75.6	41.8	23.1	129.0	59.9	27.4	12.9
1.862	138.2	4.0	0.1	0.0	0.0	3.8	0.1	0.0	0.0
1.955	112.9	42.7	14.5	6.0	3.6	40.5	11.6	4.6	2.1
2.008	102.0	69.4	35.6	17.7	6.4	65.7	28.9	12.2	3.8
2.014	101.2	74.7	45.5	26.8	17.8	70.8	36.7	19.8	10.4
2.057	95.6	69.5	41.3	25.3	14.0	66.0	33.4	17.5	8.7
2.124	87.4	70.0	35.9	18.4	9.5	66.4	29.2	12.8	5.6
2.156	83.8	66.0	32.3	15.8	7.7	62.7	26.3	11.0	4.6
2.201	78.9	66.1	49.1	38.0	29.7	62.8	40.1	26.7	17.9
2.266	72.4	61.6	46.8	36.8	29.3	58.6	38.4	26.0	17.9
2.320	67.6	57.2	43.2	33.8	26.8	54.4	35.5	24.0	16.5
2.338	66.3	54.7	39.9	30.4	23.4	52.1	32.8	21.6	14.4
2.356	65.1	52.5	35.3	26.5	19.6	49.5	29.9	18.9	12.1
2.388	62.8	36.0	18.7	11.7	7.8	34.3	15.5	8.3	4.8
2.415	61.0	32.5	15.8	9.4	6.0	31.0	13.0	6.7	3.7
2.453	58.3	29.6	13.7	7.9	5.0	28.2	11.3	5.7	3.1
2.494	55.4	20.3	6.8	3.2	1.7	19.4	5.6	2.3	1.1
2.537	52.4	4.6	0.4	0.1	0.0	4.4	0.3	0.1	0.0
2.900	35.0	2.9	0.2	0.0	0.0	2.6	0.2	0.0	0.0
2.941	33.4	6.0	1.0	0.3	0.1	5.7	0.8	0.2	0.1
2.954	32.8	5.7	0.9	0.3	0.1	5.5	0.6	0.2	0.1
2.973	32.1	8.7	2.2	0.9	0.4	8.4	1.8	0.6	0.3
3.005	30.8	7.8	1.8	0.7	0.3	7.5	1.6	0.5	0.2
3.045	28.8	4.7	0.7	0.2	0.1	4.5	0.6	0.1	0.0
3.056	28.2	4.9	0.8	0.2	0.1	4.7	0.7	0.2	0.1
3.097	26.2	3.2	0.4	0.1	0.0	3.1	0.3	0.1	0.0
3.132	24.9	6.8	1.7	0.7	0.3	6.5	1.5	0.5	0.2
3.156	24.1	18.7	12.6	8.9	6.3	17.9	10.7	6.7	4.2
3.204	22.5	2.1	0.2	0.0	0.0	2.0	0.2	0.0	0.0
3.214	22.1	3.4	0.5	0.1	0.0	3.3	0.4	0.1	0.0
3.245	21.1	3.9	0.7	0.2	0.1	3.8	0.6	0.2	0.1
3.260	20.6	3.7	0.6	0.2	0.1	3.5	0.5	0.1	0.0
3.285	19.7	14.2	8.5	5.1	2.8	13.7	7.3	3.9	1.9
3.317	18.8	12.9	6.9	3.5	1.3	12.4	5.9	2.7	0.9
3.344	18.1	4.2	0.9	0.3	0.1	4.1	0.8	0.2	0.1
3.403	16.5	12.3	7.8	5.1	3.2	11.9	6.7	3.9	2.2
3.450	15.6	12.5	8.9	6.7	5.0	12.0	7.7	5.1	3.5
3.507	14.5	12.5	9.9	8.1	6.7	12.1	8.5	6.2	4.6
3.538	14.2	11.8	8.8	6.9	5.5	11.3	7.6	5.3	3.8
3.573	13.8	10.9	5.4	2.6	1.3	10.5	4.6	2.0	0.9
3.633	13.1	10.8	8.3	6.7	5.5	10.4	7.1	5.2	3.8
3.673	12.6	9.1	6.1	4.6	3.5	8.8	5.3	3.5	2.5
3.696	12.3	10.4	8.2	6.7	5.6	10.1	7.1	5.2	3.9
3.712	12.2	10.9	9.0	7.6	6.5	10.5	7.8	5.9	4.6
3.765	11.5	9.5	7.2	5.9	4.8	9.1	6.3	4.6	3.4
3.812	11.0	8.9	6.7	5.4	4.4	8.6	5.8	4.2	3.1
3.888	10.4	8.1	5.6	4.0	2.9	7.8	4.8	3.1	2.0
3.923	10.1	8.0	5.6	4.2	3.1	7.7	4.9	3.3	2.2
3.948	9.9	7.8	5.5	4.0	3.0	7.6	4.8	3.2	2.1
4.045	9.1	6.7	4.1	2.6	1.5	6.5	3.6	2.0	1.1
TOTAL Wm^{-2}	1363	889.2	448.7	256.2	153.6	800.2	303.1	133.3	63.4

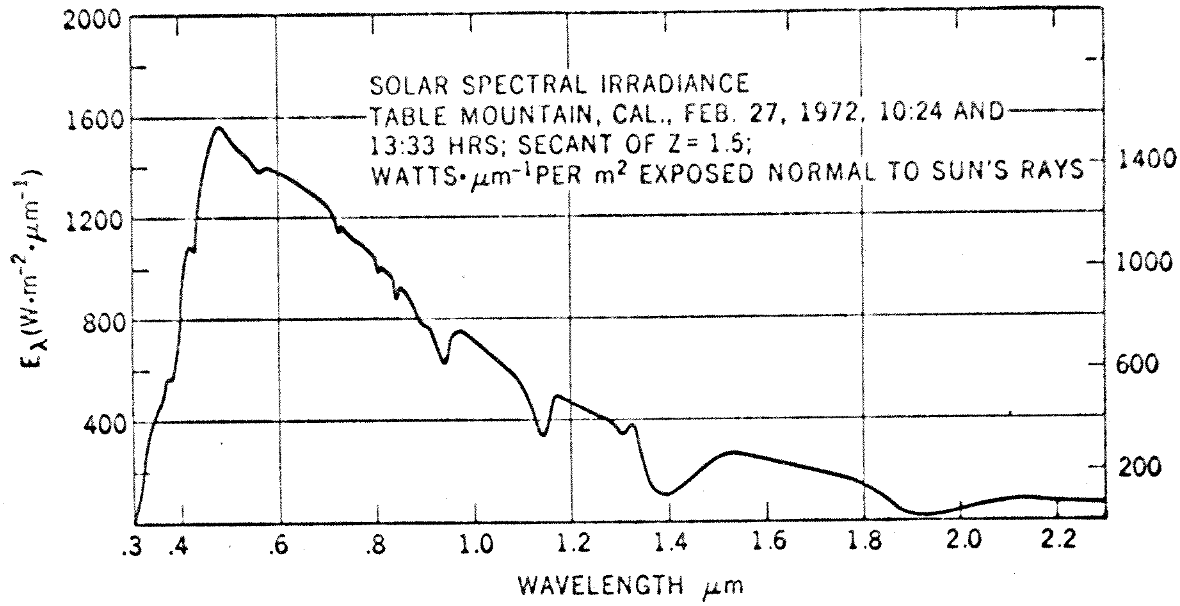

Figure 15. Solar Spectral Irradiance Measured by a Perkin Elmer Monochromator at Table Mountain Test Site on Feb. 27, 1972

While the solar spectral irradiance is of importance for photovoltaic conversion, for most applications of solar energy the absorbers are nonselective and hence the significant parameter is the total solar irradiance. The total irradiance is determined by integrating the area under curves of the type shown in Figures 13 and 14. The integration is performed as part of the computer program for evaluating the spectral irradiance as defined by Equation (6). Table 4 gives data on total irradiance at ground level for the four air mass values and the four sets of turbidity parameters. The partition of energy between the UV, visible and IR ranges of the spectrum is also shown. It is significant that as the air mass increases or as the turbidity increases, the relative amount of energy in the infrared increases and that in the visible and UV decreases. The variation of total irradiance as a function of air mass is shown in Figure 16 for the four sets of α and β. The y-axis is on the log scale. For monochromatic radiation where Equation (4) holds the plot of log E_λ versus air mass m is a straight line and the slope of the line gives the coefficient C_λ. But the linear relation does not at all hold for total irradiance, contrary to what is stated in some Handbooks (Ref. 17).

The values of solar irradiance derived above are for unit area exposed normally to the Sun's rays. Energy incident on a horizontal surface is obtained by multiplying these values by cos z or the reciprocal of the air mass.

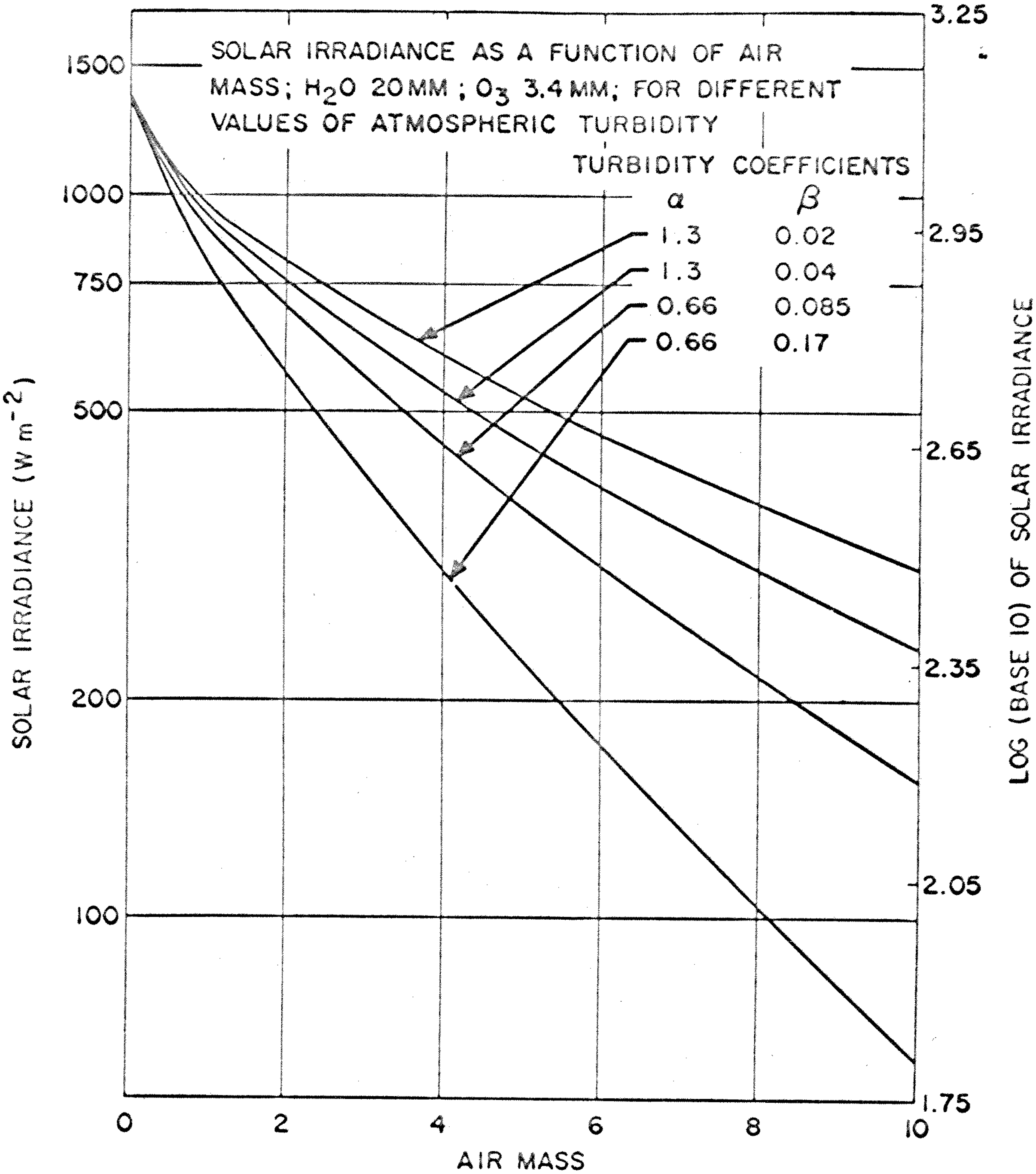

Figure 16. Semilog Plots of Irradiance versus Air Mass. Curves Show the Variation of Total Energy Received Directly from Sun by Unit Area Exposed Normally to the Sun's Rays for Different Values of Solar Zenith Angle and Atmospheric Turbidity

Table 4
Computed Values of Solar Irradiance (Wm^{-2}) on the Ground for Different Air Masses and Turbidity, H_2O 2.0 cm, O_3 0.34 cm

AIR MASS	SOLAR ZENITH ANGLE (DEGREES)	TURBIDITY FACTORS α	β	TOTAL IRRADIANCE $W m^{-2}$	RATIO OF TOTAL IRRADIANCE TO SOLAR CONSTANT %	FRACTION OF THE TOTAL ENERGY IN THE UV, $\lambda < 0.4 \mu m$ %	VISIBLE $0.4 \mu m < \lambda < 0.72 \mu m$ %	INFRARED $\lambda > 0.72 \mu m$ %
0	0			1363.0	100.0	8.7	40.1	51.1
1	0	1.30	0.02	956.2	70.7	4.8	46.9	48.3
4	75.5	1.30	0.02	695.2	44.0	1.23	44.2	54.5
7	81.8	1.30	0.02	413.6	30.6	0.35	39.4	60.3
10	84.3	1.30	0.02	302.5	22.4	0.102	34.7	65.2
1	0	1.30	0.04	924.9	68.4	4.6	46.4	49.0
4	75.6	1.30	0.04	528.9	39.1	1.04	42.1	56.9
7	81.8	1.30	0.04	342.0	25.3	0.26	35.9	63.8
10	84.3	1.30	0.04	234.5	17.3	0.065	30.3	69.6
1	0	0.66	0.085	889.2	65.7	4.7	46.4	48.9
4	75.5	0.66	0.085	448.7	33.2	1.14	42.4	56.5
7	81.8	0.66	0.085	255.2	18.9	0.30	36.3	63.4
10	84.3	0.66	0.085	153.8	11.4	0.08	30.7	69.2
1	0	0.66	0.17	800.2	59.1	4.5	45.4	50.1
4	75.5	0.66	0.17	303.1	22.4	0.88	38.3	60.8
7	81.8	0.66	0.17	133.3	9.85	0.14	30.0	69.8
10	84.3	0.66	0.17	63.4	4.69	0.039	22.9	77.1

EMPIRICAL EQUATION FOR SOLAR IRRADIANCE

From the above discussion it is clear that to determine total solar irradiance at ground level from known values of atmospheric parameters a rather elaborate computer program is required. On the other hand, the curves of Figure 16 are all concave up and seem to belong to a family of curves of second degree equations of the type

$$y = A + Bm + Cm^2 \tag{8}$$

where y is logarithm to the base e of the total irradiance, m is the air mass and A, B and C are constants. A search was made to find an empirical equation which would give the value of y or ln E for any given set of values of atmospheric parameters. The results will be briefly discussed.

In Table 4 are given values of E for one set of values of H_2O and O_3, four values of α and β and four values of m. Similar values were computed for 28 sets of values of H_2O, O_3 and α, β and each case for 10 values of m. The values of H_2O (cm of precipitable water) were 0.5, 1.0, 2.0 and 5. The values of O_3 (height in cm of total ozone in a vertical path reduced to NTP) were 0.2, 0.34, 0.4 and 0.7. The same four values of α, β as in Table 4 were used. It was found that for m between 0.6 and 5, a curve fitting method (least squares parabolic non-linear regression) yielded a quadratic equation

$$\ln E_i = A_i + B_i m + C_i m^2 \qquad (9)$$

which gave values of $\ln E_i$ with about a ±2% accuracy. For air mass greater than 5 a quadratic equation did not give a reasonable fit. This is not a serious restriction since for air mass 5, the solar zenith angle is 78.5° and the corresponding irradiance on a horizontal surface is very low. In the case of H_2O 2.0 cm, O_3 0.34 cm, α 1.3 and β 0.02, the equation is

$$\ln E_i = 7.06969 - 0.21640\, m + 0.01098\, m^2 \qquad (10)$$

The values of A_i, B_i and C_i are obviously different according to the atmospheric parameters. A set of 28 equations of the type of (9) and (10) were generated. It was also found that the following empirical equation in matrix form is valid for all values of the atmospheric parameters.

$$\begin{vmatrix} A \\ B \\ C \end{vmatrix} = \begin{vmatrix} \overline{A} \\ \overline{B} \\ \overline{C} \end{vmatrix} + \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} \times \begin{vmatrix} W \\ O \\ T \end{vmatrix} \qquad (11)$$

Where W and O are respectively the amount of precipitable water vapor and ozone (in cm), $T = \frac{\beta}{\lambda^{\alpha}}$ with $\lambda = 0.7$. The numerical values of the vector and matrix on the right-hand side of Equation (11) are

$$\begin{vmatrix} \overline{A} \\ \overline{B} \\ \overline{C} \end{vmatrix} = \begin{vmatrix} 7.07254 \\ -0.28439 \\ 0.01161 \end{vmatrix} \text{ and } \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = \begin{vmatrix} -0.02183 & 0.04254 & 0.27799 \\ -0.01223 & 0.37192 & -1.10980 \\ 0.00520 & -0.02277 & -0.02213 \end{vmatrix} \qquad (12)$$

The value of total solar irradiance, E, for any set of values of W, O and T is given by

$$\ln E = A + Bm + Cm^2 \qquad (13)$$

where A, B and C are computed by Equation (11) with the numerical values of Equation (12). Equation (13) is not applicable for extreme values of W and O which occur but rarely and the accuracy is not better than ±10%.

DIFFUSE RADIATION FROM THE SKY

Direct solar irradiance is the major term in the total irradiance on a surface. The next most significant term is the diffuse irradiance due to the sky. This problem has been treated extensively in literature (Ref. 18), both theoretically and experimentally. The diffuse sky radiation is a function of all the atmospheric parameters discussed earlier, but cannot be expressed in a simple mathematical expression. The ratio of the diffuse radiation to direct solar radiation (for air mass one) is very high in the UV but drops rapidly in the visible and IR. Representative values of this ratio (based on Ref. 18) are (ratio in percentage and wavelength in μm) 72 at 0.3, 42 at 0.35, 23 at 0.4, 8 at 0.5, 1 at 0.7. The ratio is high, above 25 percent in the UV where the direct sunlight energy is less than 5 percent of the total. Experimental data, though widely varying with Sun angle and location, tend to confirm these values of the ratio. The irradiance on a horizontal surface over all wavelengths due to the sky is about 20 percent of that due to direct sunlight. The sky irradiance on a surface sloping at an angle B is related to the irradiance on a horizontal surface by the ratio $\cos^2(B/2)$.

Two other terms in the total irradiance received by a surface is the radiation scattered from the Earth and the surrounding objects like trees or buildings and the long wave radiation emitted by the atmosphere. The former varies with location and the latter is not of significance for most energy collecting systems. Both terms are relatively small.

SOLAR IRRADIANCE ON A SLOPING SURFACE

The slope of a surface is another factor of importance. The surface of the collecting system is rarely horizontal or normal to the solar rays. The irradiance E_s on a sloping surface is related to the irradiance E_n on a surface normal to the solar rays by the equation

$$E_s = E_n \cos C, \qquad (14)$$

where C is the angle between the surface normal and the Sun-Earth line. For a horizontal surface C is obviously equal to the solar zenith angle. The angle C can be evaluated in terms of the three angles, latitude θ, declination δ, hour angle h, and two other angles which define the slope (Ref. 19). A slope can be effected by first tilting a normal fixed to a horizontal surface towards the north through an angle B and then rotating the normal about the vertical in the clockwise direction through an angle A. A is the azimuth of the surface measured from north through east (range of A is 0 to 360°) and B is the zenith angle of the surface. It can be shown that

$$\cos C = \cos \delta [(\sin\theta \cos h)(-\cos A \sin B) - \sin h (\sin A \cos B) + (\cos\theta \cos h) \cos B] + \sin\delta [\cos\theta (\cos A \sin B) + (\sin\theta \cos B)] \qquad (15)$$

The equation seems formidable, but can be readily solved by a programmable electronic calculator. The hour angle is measured from east to west, with zero at local noon, so that the values are negative before noon. The angle can obviously be determined directly by measuring the length of a shadow. A rod is fixed normal to the surface and the shadow is cast by the Sun on the slope. For design purposes it is necessary to know C for different hours of the day and different seasons of the year. Equation (15) can be used for this purpose. For a horizontal surface, A and B are zero, and Equation (15) reduces to Equation (3).

For optimum efficiency of the collector plate, it is advantageous to have low angles of incidence especially around solar noon when the air mass is least. For year round operation a surface facing south with slope B equal to the latitude is desirable. For winter heating, but no air conditioning, a greater slope and for summer heating, of swimming pools, for example, a smaller slope is indicated. The difference between the slope and the local latitude should be equal to the weighted average of solar declination during the heating period. In cases where architectural or other reasons dictate less than optimum values of A and B, the variations in values of C can help in making a rough estimate of the loss in efficiency.

CONCLUSION

An obvious drawback of the computer model presented above is that it is applicable only for clear sky conditions. But in certain parts of the Earth clear sky conditions prevail most days of the year and they are the optimum sites for large scale solar energy conversion systems. Relative amount of cloud cover can be obtained from the telemetered pictures of satellites. Thus it is seen that the two methods, remote sensing and computer models are complementary to each other.

With the increased interest in solar energy conversion, the quantitative data on available solar energy will become more accurate and abundant. Research and development programs in heating and cooling, photovoltaic conversion, etc., need such data for determining the efficiency of the system. Spectral distribution data are as important as total irradiance data for most applications. Theoretical computations of ground level irradiance have become easier through a better understanding of atmospheric processes and greater availability of computers. Satellite data are beginning to be used for the determination of monthly and yearly totals of insolation at specific locations. Current research efforts in improving solar energy data are in many directions: greater accuracy in extraterrestrial measurements, improvement of instruments, definition of radiation scales and standards, spectral and total irradiance monitoring at a larger number of stations, studies of atmospheric processes and pollution. These research efforts are of interest not only for solar energy applications but many related fields.

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DECK NUMBER 1   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
  189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 20
      290.0   0.00000     295.0   0.00000     300.0   0.00041     305.0   0.00114
      310.0   0.00305     315.0   0.00794     320.0   0.02026     325.0   0.02695
      330.0   0.03316     335.0   0.03834     340.0   0.04313     345.0   0.04492
      350.0   0.04805     355.0   0.04980     360.0   0.05137     365.0   0.05613
      370.0   0.06035     375.0   0.06094     380.0   0.06080     385.0   0.06098
      390.0   0.06239     395.0   0.06912     400.0   0.08499     405.0   0.09928
      410.0   0.10737     415.0   0.11045     420.0   0.11043     425.0   0.10865
      430.0   0.10679     435.0   0.11001     440.0   0.12155     445.0   0.13104
      450.0   0.13884     455.0   0.14348     460.0   0.14522     465.0   0.14507
      470.0   0.14512     475.0   0.14703     480.0   0.15034     485.0   0.14433
      490.0   0.14352     495.0   0.14536     500.0   0.14512     505.0   0.14401
      510.0   0.14168     515.0   0.13849     520.0   0.13900     525.0   0.14095
      530.0   0.14069     535.0   0.13936     540.0   0.13717     545.0   0.13542
      550.0   0.13366     555.0   0.13357     560.0   0.13192     565.0   0.13300
      570.0   0.13384     575.0   0.13469     580.0   0.13467     585.0   0.13473
      590.0   0.13407     595.0   0.13294     600.0   0.13196     605.0   0.13110
      610.0   0.13079     620.0   0.12942     630.0   0.12809     640.0   0.12721
      650.0   0.12571     660.0   0.12442     670.0   0.12258     680.0   0.12099
      690.0   0.11962     698.3   0.10103     700.0   0.11753     710.0   0.11574
      720.0   0.11351     727.7   0.10031     730.0   0.11178     740.0   0.10951
      750.0   0.10766     762.1   0.07940     770.0   0.10392     780.0   0.10194
      790.0   0.10003     800.0   0.09812     805.9   0.08744     825.0   0.09316
      830.0   0.09218     835.0   0.09124     846.5   0.04762     860.0   0.05064
      870.0   0.04538     875.0   0.04492     887.5   0.04486     900.0   0.04489
      907.5   0.04552     915.0   0.04615     925.0   0.02790     930.0   0.02218
      940.0   0.03134     950.0   0.02965     955.0   0.03211     965.0   0.03444
      975.0   0.05769     985.0   0.05446    1018.0   0.06175    1082.0   0.05129
     1094.0   0.04641    1098.0   0.05037    1101.0   0.05048    1128.0   0.01351
     1131.0   0.01522    1137.0   0.01431    1144.0   0.01912    1147.0   0.01745
     1178.0   0.03993    1189.0   0.04022    1193.0   0.04240    1222.0   0.03918
     1236.0   0.03908    1264.0   0.03292    1276.0   0.03426    1288.0   0.03473
     1314.0   0.02983    1335.0   0.01906    1384.0   0.00037    1432.0   0.00446
     1457.0   0.00854    1472.0   0.00774    1542.0   0.02393    1572.0   0.02226
     1599.0   0.02160    1608.0   0.02085    1626.0   0.02067    1644.0   0.01979
     1650.0   0.01957    1676.0   0.01819    1732.0   0.01615    1782.0   0.01367
     1862.0   0.00040    1955.0   0.00427    2008.0   0.00694    2014.0   0.00747
     2057.0   0.00695    2124.0   0.00700    2156.0   0.00660    2201.0   0.00661
     2266.0   0.00616    2320.0   0.00572    2338.0   0.00547    2356.0   0.00520
     2388.0   0.00360    2415.0   0.00325    2453.0   0.00296    2494.0   0.00303
     2537.0   0.00046    2900.0   0.00029    2941.0   0.00060    2954.0   0.00057
     2973.0   0.00087    3005.0   0.00078    3045.0   0.00047    3056.0   0.00049
     3097.0   0.00032    3132.0   0.00068    3156.0   0.00187    3204.0   0.00021
     3214.0   0.00034    3245.0   0.00039    3260.0   0.00037    3285.0   0.00142
     3317.0   0.00129    3344.0   0.00042    3403.0   0.00123    3450.0   0.00125
     3507.0   0.00125    3538.0   0.00118    3573.0   0.00109    3633.0   0.00108
     3673.0   0.00091    3696.0   0.00104    3712.0   0.00109    3765.0   0.00098
     3812.0   0.00089    3888.0   0.00081    3923.0   0.00080    3948.0   0.00078
     4045.0   0.00067       0.0   0.00000       0.0   0.00000       0.0   0.00000
DECK NUMBER 2   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
  189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10
      290.0   0.00000     295.0   0.00000     300.0   0.00000     305.0   0.00000
      310.0   0.00000     315.0   0.00001     320.0   0.00029     325.0   0.00057
      330.0   0.00102     335.0   0.00171     340.0   0.00279     345.0   0.00333
      350.0   0.00408     355.0   0.00484     360.0   0.00572     365.0   0.00684
      370.0   0.00805     375.0   0.00890     380.0   0.00972     385.0   0.01045
      390.0   0.01145     395.0   0.01358     400.0   0.01788     405.0   0.02187
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410.0	0.02475	415.0	0.02665	420.0	0.02789	425.0	0.02872
430.0	0.02954	435.0	0.03184	440.0	0.03682	445.0	0.04153
450.0	0.04603	455.0	0.04869	460.0	0.05044	465.0	0.05157
470.0	0.05279	475.0	0.05473	480.0	0.05726	485.0	0.05624
490.0	0.05722	495.0	0.05929	500.0	0.06056	505.0	0.06076
510.0	0.06044	515.0	0.05973	520.0	0.06061	525.0	0.06213
530.0	0.06269	535.0	0.06277	540.0	0.06245	545.0	0.06232
550.0	0.06217	555.0	0.06255	560.0	0.06220	565.0	0.06313
570.0	0.06395	575.0	0.06478	580.0	0.06520	585.0	0.06566
590.0	0.06577	595.0	0.06564	600.0	0.06558	605.0	0.06613
610.0	0.06696	620.0	0.06824	630.0	0.06956	640.0	0.07114
650.0	0.07239	660.0	0.07302	670.0	0.07338	680.0	0.07374
690.0	0.07429	698.3	0.05461	700.0	0.07437	710.0	0.07392
720.0	0.07317	727.7	0.05823	730.0	0.07271	740.0	0.07189
750.0	0.07132	762.1	0.03571	770.0	0.07008	780.0	0.06936
790.0	0.06867	800.0	0.06794	805.9	0.05477	825.0	0.06543
830.0	0.06493	835.0	0.06444	846.5	0.01810	860.0	0.02120
870.0	0.01747	875.0	0.01734	887.5	0.01783	900.0	0.01837
907.5	0.01909	915.0	0.01985	925.0	0.00736	930.0	0.00469
940.0	0.00950	950.0	0.00863	955.0	0.01023	965.0	0.01204
975.0	0.03460	985.0	0.03161	1018.0	0.03910	1082.0	0.02904
1094.0	0.03031	1098.0	0.03041	1101.0	0.03627	1128.0	0.00277
1131.0	0.00353	1137.0	0.00317	1144.0	0.00574	1147.0	0.00482
1178.0	0.01951	1189.0	0.02145	1193.0	0.03108	1222.0	0.02353
1236.0	0.02541	1264.0	0.02097	1276.0	0.02386	1286.0	0.02161
1314.0	0.01376	1335.0	0.00850	1384.0	0.00001	1432.0	0.00054
1457.0	0.00206	1472.0	0.00174	1542.0	0.01659	1572.0	0.01681
1599.0	0.01667	1608.0	0.01574	1626.0	0.01607	1644.0	0.01524
1650.0	0.01509	1676.0	0.01148	1732.0	0.01025	1782.0	0.00756
1862.0	0.00001	1955.0	0.00145	2008.0	0.00358	2014.0	0.00455
2057.0	0.00413	2124.0	0.00359	2156.0	0.00323	2201.0	0.00491
2266.0	0.00468	2320.0	0.00432	2338.0	0.00399	2356.0	0.00363
2388.0	0.00187	2415.0	0.00158	2453.0	0.00137	2494.0	0.00068
2537.0	0.00004	2900.0	0.00002	2941.0	0.00010	2954.0	0.00009
2973.0	0.00022	3005.0	0.00018	3045.0	0.00007	3056.0	0.00008
3097.0	0.00004	3132.0	0.00017	3156.0	0.00126	3204.0	0.00002
3214.0	0.00005	3245.0	0.00007	3260.0	0.00006	3285.0	0.00085
3317.0	0.00069	3344.0	0.00009	3403.0	0.00078	3450.0	0.00089
3507.0	0.00099	3538.0	0.00088	3573.0	0.00054	3633.0	0.00083
3673.0	0.00061	3696.0	0.00082	3712.0	0.00090	3765.0	0.00072
3812.0	0.00067	3888.0	0.00056	3923.0	0.00056	3948.0	0.00055
4045.0	0.00041	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 3 THEKAEKARA SOLAR IRRADIANCE AT GROUND LEVEL

189 SCLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00000	305.0	0.00000
310.0	0.00000	315.0	0.00000	320.0	0.00000	325.0	0.00001
330.0	0.00003	335.0	0.00008	340.0	0.00018	345.0	0.00025
350.0	0.00035	355.0	0.00047	360.0	0.00064	365.0	0.00083
370.0	0.00107	375.0	0.00130	380.0	0.00156	385.0	0.00179
390.0	0.00210	395.0	0.00267	400.0	0.00376	405.0	0.00482
410.0	0.00571	415.0	0.00643	420.0	0.00704	425.0	0.00759
430.0	0.00817	435.0	0.00922	440.0	0.01115	445.0	0.01316
450.0	0.01526	455.0	0.01652	460.0	0.01752	465.0	0.01833
470.0	0.01920	475.0	0.02037	480.0	0.02191	485.0	0.02192
490.0	0.02282	495.0	0.02419	500.0	0.02527	505.0	0.02564
510.0	0.02578	515.0	0.02576	520.0	0.02643	525.0	0.02739
530.0	0.02794	535.0	0.02828	540.0	0.02844	545.0	0.02868
550.0	0.02892	555.0	0.02930	560.0	0.02933	565.0	0.02996

570.0	0.03056	575.0	0.03116	580.0	0.03167	585.0	0.03200
590.0	0.03226	595.0	0.03241	600.0	0.03259	605.0	0.03336
610.0	0.03428	620.0	0.03599	630.0	0.03778	640.0	0.03979
650.0	0.04169	660.0	0.04286	670.0	0.04383	680.0	0.04495
690.0	0.04613	698.3	0.03118	700.0	0.04706	710.0	0.04721
720.0	0.04716	727.7	0.03517	730.0	0.04730	740.0	0.04719
750.0	0.04724	762.1	0.01636	770.0	0.04727	780.0	0.04720
790.0	0.04714	800.0	0.04705	805.9	0.03559	825.0	0.04596
830.0	0.04573	835.0	0.04552	846.5	0.00855	860.0	0.01074
870.0	0.00840	875.0	0.00836	887.5	0.00877	900.0	0.00923
907.5	0.00976	915.0	0.01032	925.0	0.00280	930.0	0.00154
940.0	0.00396	950.0	0.00350	955.0	0.00441	965.0	0.00551
975.0	0.02246	985.0	0.02012	1018.0	0.02475	1082.0	0.01644
1094.0	0.02108	1098.0	0.01836	1101.0	0.02673	1128.0	0.00091
1131.0	0.00126	1137.0	0.00110	1144.0	0.00242	1147.0	0.00193
1178.0	0.00954	1189.0	0.01144	1193.0	0.02333	1222.0	0.01413
1236.0	0.01652	1264.0	0.01400	1276.0	0.01726	1288.0	0.01344
1314.0	0.00635	1335.0	0.00467	1384.0	0.00000	1432.0	0.00013
1457.0	0.00077	1472.0	0.00062	1542.0	0.01150	1572.0	0.01304
1595.0	0.01315	1608.0	0.01221	1626.0	0.01275	1644.0	0.01201
1650.0	0.01191	1676.0	0.00724	1732.0	0.00651	1782.0	0.00418
1862.0	0.00000	1955.0	0.00068	2008.0	0.00177	2014.0	0.00288
2057.0	0.00253	2124.0	0.00184	2156.0	0.00158	2201.0	0.00380
2266.0	0.00368	2320.0	0.00338	2338.0	0.00304	2356.0	0.00265
2388.0	0.00117	2415.0	0.00094	2453.0	0.00079	2494.0	0.00032
2537.0	0.00001	2900.0	0.00000	2941.0	0.00003	2954.0	0.00003
2973.0	0.00009	3005.0	0.00007	3045.0	0.00002	3056.0	0.00002
3097.0	0.00001	3132.0	0.00007	3156.0	0.00089	3204.0	0.00000
3214.0	0.00001	3245.0	0.00002	3260.0	0.00002	3285.0	0.00051
3317.0	0.00035	3344.0	0.00003	3403.0	0.00051	3450.0	0.00057
3507.0	0.00081	3538.0	0.00069	3573.0	0.00026	3633.0	0.00067
3673.0	0.00046	3696.0	0.00067	3712.0	0.00076	3765.0	0.00059
3812.0	0.00054	3888.0	0.00040	3923.0	0.00042	3948.0	0.00040
4045.0	0.00026	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 4 THEKAEKARA SOLAR IRRADIANCE AT GROUND LEVEL

189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00000	305.0	0.00000
310.0	0.00000	315.0	0.00000	320.0	0.00000	325.0	0.00000
330.0	0.00000	335.0	0.00000	340.0	0.00001	345.0	0.00002
350.0	0.00003	355.0	0.00005	360.0	0.00007	365.0	0.00010
370.0	0.00014	375.0	0.00019	380.0	0.00025	385.0	0.00031
390.0	0.00039	395.0	0.00052	400.0	0.00079	405.0	0.00106
410.0	0.00132	415.0	0.00155	420.0	0.00178	425.0	0.00201
430.0	0.00226	435.0	0.00267	440.0	0.00339	445.0	0.00417
450.0	0.00506	455.0	0.00561	460.0	0.00608	465.0	0.00651
470.0	0.00698	475.0	0.00758	480.0	0.00831	485.0	0.00854
490.0	0.00910	495.0	0.00987	500.0	0.01055	505.0	0.01082
510.0	0.01100	515.0	0.01111	520.0	0.01152	525.0	0.01207
530.0	0.01245	535.0	0.01274	540.0	0.01295	545.0	0.01320
550.0	0.01345	555.0	0.01372	560.0	0.01383	565.0	0.01422
570.0	0.01460	575.0	0.01499	580.0	0.01528	585.0	0.01550
590.0	0.01583	595.0	0.01600	600.0	0.01620	605.0	0.01682
610.0	0.01755	620.0	0.01897	630.0	0.02052	640.0	0.02225
650.0	0.02401	660.0	0.02516	670.0	0.02625	680.0	0.02739
690.0	0.02865	698.3	0.01816	700.0	0.02977	710.0	0.03015
720.0	0.03040	727.7	0.02155	730.0	0.03077	740.0	0.03098
750.0	0.03130	762.1	0.00691	770.0	0.03188	780.0	0.03211
790.0	0.03236	800.0	0.03258	805.9	0.02344	825.0	0.03228

830.0	0.03221	835.0	0.03215	846.5	0.00442	860.0	0.00583
870.0	0.00438	875.0	0.00437	887.5	0.00467	900.0	0.00500
907.5	0.00537	915.0	0.00575	925.0	0.00121	930.0	0.00060
940.0	0.00185	950.0	0.00160	955.0	0.00212	965.0	0.00278
975.0	0.01501	985.0	0.01324	1018.0	0.01567	1082.0	0.00931
1094.0	0.01499	1098.0	0.01109	1101.0	0.01988	1128.0	0.00036
1131.0	0.00053	1137.0	0.00045	1144.0	0.00116	1147.0	0.00088
1178.0	0.00466	1189.0	0.00610	1193.0	0.01766	1222.0	0.00849
1236.0	0.01074	1264.0	0.00943	1276.0	0.01263	1288.0	0.00837
1314.0	0.00293	1335.0	0.00277	1384.0	0.00000	1432.0	0.00004
1457.0	0.00033	1472.0	0.00026	1542.0	0.00797	1572.0	0.01021
1599.0	0.01045	1608.0	0.00957	1626.0	0.01019	1644.0	0.00955
1650.0	0.00947	1676.0	0.00457	1732.0	0.00413	1782.0	0.00231
1862.0	0.00000	1955.0	0.00036	2008.0	0.00064	2014.0	0.00178
2057.0	0.00148	2124.0	0.00095	2156.0	0.00077	2201.0	0.00297
2266.0	0.00293	2320.0	0.00268	2338.0	0.00234	2356.0	0.00196
2388.0	0.00078	2415.0	0.00060	2453.0	0.00050	2494.0	0.00017
2537.0	0.00000	2900.0	0.00000	2941.0	0.00001	2954.0	0.00001
2973.0	0.00004	3005.0	0.00003	3045.0	0.00001	3056.0	0.00001
3097.0	0.00000	3132.0	0.00003	3156.0	0.00063	3204.0	0.00000
3214.0	0.00000	3245.0	0.00001	3260.0	0.00001	3285.0	0.00028
3317.0	0.00013	3344.0	0.00001	3403.0	0.00032	3450.0	0.00050
3507.0	0.00067	3538.0	0.00055	3573.0	0.00013	3633.0	0.00055
3673.0	0.00035	3696.0	0.00056	3712.0	0.00065	3765.0	0.00048
3812.0	0.00044	3888.0	0.00029	3923.0	0.00031	3948.0	0.00030
4045.0	0.00015	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 5 THEKAEKARA SOLAR IRRADIANCE AT GROUND LEVEL
189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00034	305.0	0.00094
310.0	0.00254	315.0	0.00662	320.0	0.01692	325.0	0.02255
330.0	0.02779	335.0	0.03218	340.0	0.03627	345.0	0.03784
350.0	0.04054	355.0	0.04208	360.0	0.04348	365.0	0.04757
370.0	0.05123	375.0	0.05180	380.0	0.05176	385.0	0.05199
390.0	0.05326	395.0	0.05908	400.0	0.07274	405.0	0.08508
410.0	0.09213	415.0	0.09488	420.0	0.09498	425.0	0.09356
430.0	0.09207	435.0	0.09495	440.0	0.10503	445.0	0.11335
450.0	0.12022	455.0	0.12437	460.0	0.12601	465.0	0.12601
470.0	0.12618	475.0	0.12796	480.0	0.13096	485.0	0.12585
490.0	0.12526	495.0	0.12698	500.0	0.12688	505.0	0.12602
510.0	0.12409	515.0	0.12140	520.0	0.12195	525.0	0.12376
530.0	0.12364	535.0	0.12256	540.0	0.12073	545.0	0.11928
550.0	0.11782	555.0	0.11783	560.0	0.11647	565.0	0.11750
570.0	0.11833	575.0	0.11916	580.0	0.11923	585.0	0.11936
590.0	0.11886	595.0	0.11794	600.0	0.11715	605.0	0.11646
610.0	0.11626	620.0	0.11519	630.0	0.11414	640.0	0.11349
650.0	0.11228	660.0	0.11125	670.0	0.10982	680.0	0.10843
690.0	0.10731	698.3	0.09071	700.0	0.10554	710.0	0.10404
720.0	0.10213	727.7	0.09033	730.0	0.10067	740.0	0.09872
750.0	0.09714	762.1	0.07172	770.0	0.09394	780.0	0.09223
790.0	0.09058	800.0	0.08891	805.9	0.07927	825.0	0.08459
830.0	0.08373	835.0	0.08291	846.5	0.04331	860.0	0.04610
870.0	0.04134	875.0	0.04094	887.5	0.04092	900.0	0.04098
907.5	0.04158	915.0	0.04218	925.0	0.02551	930.0	0.02029
940.0	0.02869	950.0	0.02716	955.0	0.02942	965.0	0.03157
975.0	0.05291	985.0	0.04998	1018.0	0.05678	1082.0	0.04731
1094.0	0.04284	1098.0	0.04650	1101.0	0.04661	1128.0	0.01249
1131.0	0.01407	1137.0	0.01324	1144.0	0.01765	1147.0	0.01615
1178.0	0.03700	1189.0	0.03728	1193.0	0.03931	1222.0	0.03636

1236.0	0.03630	1264.0	0.03061	1276.0	0.03187	1288.0	0.03232
1314.0	0.02779	1335.0	0.01776	1384.0	0.00053	1432.0	0.00417
1457.0	0.00800	1472.0	0.00724	1542.0	0.02245	1572.0	0.02090
1599.0	0.02030	1608.0	0.01959	1626.0	0.01943	1644.0	0.01861
1650.0	0.01841	1676.0	0.01712	1732.0	0.01522	1782.0	0.01290
1862.0	0.00038	1955.0	0.00405	2008.0	0.00657	2014.0	0.00708
2057.0	0.00660	2124.0	0.00664	2156.0	0.00627	2201.0	0.00628
2266.0	0.00586	2320.0	0.00544	2338.0	0.00521	2356.0	0.00495
2388.0	0.00343	2415.0	0.00310	2453.0	0.00282	2494.0	0.00194
2537.0	0.00044	2900.0	0.00028	2941.0	0.00057	2954.0	0.00055
2973.0	0.00084	3005.0	0.00075	3045.0	0.00045	3056.0	0.00047
3097.0	0.00031	3132.0	0.00065	3156.0	0.00179	3204.0	0.00020
3214.0	0.00033	3245.0	0.00038	3260.0	0.00035	3285.0	0.00137
3317.0	0.00124	3344.0	0.00041	3403.0	0.00119	3450.0	0.00120
3507.0	0.00121	3538.0	0.00113	3573.0	0.00105	3633.0	0.00104
3673.0	0.00088	3696.0	0.00101	3712.0	0.00105	3765.0	0.00091
3812.0	0.00086	3888.0	0.00078	3923.0	0.00077	3948.0	0.00076
4045.0	0.00065	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 6   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL

189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00000	305.0	0.00000
310.0	0.00000	315.0	0.00000	320.0	0.00014	325.0	0.00028
330.0	0.00050	335.0	0.00085	340.0	0.00140	345.0	0.00168
350.0	0.00207	355.0	0.00247	360.0	0.00293	365.0	0.00353
370.0	0.00418	375.0	0.00465	380.0	0.00511	385.0	0.00552
390.0	0.00608	395.0	0.00725	400.0	0.00959	405.0	0.01179
410.0	0.01342	415.0	0.01452	420.0	0.01527	425.0	0.01579
430.0	0.01632	435.0	0.01767	440.0	0.02052	445.0	0.02325
450.0	0.02588	455.0	0.02749	460.0	0.02859	465.0	0.02935
470.0	0.03016	475.0	0.03139	480.0	0.03297	485.0	0.03251
490.0	0.03320	495.0	0.03453	500.0	0.03539	505.0	0.03563
510.0	0.03557	515.0	0.03527	520.0	0.03591	525.0	0.03693
530.0	0.03739	535.0	0.03755	540.0	0.03748	545.0	0.03752
550.0	0.03754	555.0	0.03788	560.0	0.03778	565.0	0.03846
570.0	0.03907	575.0	0.03969	580.0	0.04006	585.0	0.04045
590.0	0.04063	595.0	0.04066	600.0	0.04073	605.0	0.04118
610.0	0.04180	620.0	0.04282	630.0	0.04386	640.0	0.04507
650.0	0.04608	660.0	0.04669	670.0	0.04712	680.0	0.04756
690.0	0.04811	698.3	0.03549	700.0	0.04836	710.0	0.04827
720.0	0.04796	727.7	0.03828	730.0	0.04785	740.0	0.04748
750.0	0.04728	762.1	0.02378	770.0	0.04679	780.0	0.04647
790.0	0.04616	800.0	0.04582	805.9	0.03700	825.0	0.04448
830.0	0.04420	835.0	0.04394	846.5	0.01238	860.0	0.01456
870.0	0.01204	875.0	0.01196	887.5	0.01234	900.0	0.01276
907.5	0.01329	915.0	0.01384	925.0	0.00515	930.0	0.00328
940.0	0.00667	950.0	0.00607	955.0	0.00721	965.0	0.00850
975.0	0.02449	985.0	0.02242	1018.0	0.02794	1082.0	0.02103
1094.0	0.02200	1098.0	0.02209	1101.0	0.02636	1128.0	0.00202
1131.0	0.00258	1137.0	0.00232	1144.0	0.00421	1147.0	0.00353
1178.0	0.01438	1189.0	0.01584	1193.0	0.02297	1222.0	0.01747
1236.0	0.01891	1264.0	0.01567	1276.0	0.01786	1288.0	0.01621
1314.0	0.01036	1335.0	0.00642	1384.0	0.00001	1432.0	0.00041
1457.0	0.00158	1472.0	0.00133	1542.0	0.01285	1572.0	0.01307
1599.0	0.01299	1608.0	0.01227	1626.0	0.01256	1644.0	0.01193
1650.0	0.01182	1676.0	0.00901	1732.0	0.00809	1782.0	0.00599
1862.0	0.00001	1955.0	0.00116	2008.0	0.00289	2014.0	0.00357
2057.0	0.00334	2124.0	0.00292	2156.0	0.00263	2201.0	0.00401
2266.0	0.00384	2320.0	0.00355	2338.0	0.00328	2356.0	0.00299

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      2388.0   0.00155   2415.0   0.00130   2453.0   0.00113   2494.0   0.00056
      2537.0   0.00003   2900.0   0.00002   2941.0   0.00008   2954.0   0.00008
      2973.0   0.00018   3005.0   0.00016   3045.0   0.00006   3056.0   0.00007
      3097.0   0.00003   3132.0   0.00015   3156.0   0.00107   3204.0   0.00002
      3214.0   0.00004   3245.0   0.00006   3260.0   0.00005   3285.0   0.00073
      3317.0   0.00059   3344.0   0.00008   3403.0   0.00067   3450.0   0.00077
      3507.0   0.00085   3538.0   0.00076   3573.0   0.00046   3633.0   0.00071
      3673.0   0.00053   3696.0   0.00071   3712.0   0.00079   3765.0   0.00063
      3812.0   0.00058   3888.0   0.00048   3923.0   0.00049   3948.0   0.00048
      4045.0   0.00036      0.0   0.00000      0.0   0.00000      0.0   0.00000
 DECK NUMBER 7   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
   189 SCLAR SPECTRUM,AIR MASS 1,4,7 AND 10
       290.0   0.00000    295.0   0.00000    300.0   0.00000    305.0   0.00000
       310.0   0.00000    315.0   0.00000    320.0   0.00000    325.0   0.00000
       330.0   0.00001    335.0   0.00002    340.0   0.00005    345.0   0.00007
       350.0   0.00011    355.0   0.00014    360.0   0.00020    365.0   0.00026
       370.0   0.00034    375.0   0.00042    380.0   0.00050    385.0   0.00059
       390.0   0.00069    395.0   0.00089    400.0   0.00127    405.0   0.00163
       410.0   0.00195    415.0   0.00222    420.0   0.00245    425.0   0.00267
       430.0   0.00289    435.0   0.00329    440.0   0.00401    445.0   0.00477
       450.0   0.00557    455.0   0.00608    460.0   0.00649    465.0   0.00684
       470.0   0.00721    475.0   0.00770    480.0   0.00830    485.0   0.00840
       490.0   0.00880    495.0   0.00939    500.0   0.00987    505.0   0.01008
       510.0   0.01019    515.0   0.01025    520.0   0.01057    525.0   0.01102
       530.0   0.01131    535.0   0.01151    540.0   0.01164    545.0   0.01180
       550.0   0.01196    555.0   0.01218    560.0   0.01226    565.0   0.01259
       570.0   0.01290    575.0   0.01322    580.0   0.01346    585.0   0.01371
       590.0   0.01389    595.0   0.01402    600.0   0.01416    605.0   0.01456
       610.0   0.01503    620.0   0.01592    630.0   0.01685    640.0   0.01790
       650.0   0.01891    660.0   0.01959    670.0   0.02022    680.0   0.02086
       690.0   0.02157    698.3   0.01467    700.0   0.02216    710.0   0.02239
       720.0   0.02252    727.7   0.01688    730.0   0.02274    740.0   0.02284
       750.0   0.02301    762.1   0.00803    770.0   0.02331    780.0   0.02341
       790.0   0.02352    800.0   0.02361    805.9   0.01792    825.0   0.02339
       830.0   0.02333    835.0   0.02329    846.5   0.00442    860.0   0.00556
       870.0   0.00437    875.0   0.00436    887.5   0.00461    900.0   0.00488
       907.5   0.00518    915.0   0.00549    925.0   0.00149    930.0   0.00083
       940.0   0.00213    950.0   0.00189    955.0   0.00239    965.0   0.00300
       975.0   0.01227    985.0   0.01103   1018.0   0.01375   1082.0   0.00935
      1094.0   0.01203   1098.0   0.01050   1101.0   0.01530   1128.0   0.00053
      1131.0   0.00073   1137.0   0.00064   1144.0   0.00141   1147.0   0.00112
      1178.0   0.00559   1189.0   0.00673   1193.0   0.01374   1222.0   0.00839
      1236.0   0.00985   1264.0   0.00841   1276.0   0.01040   1288.0   0.00813
      1314.0   0.00386   1335.0   0.00286   1384.0   0.00000   1432.0   0.00008
      1457.0   0.00048   1472.0   0.00039   1542.0   0.00736   1572.0   0.00839
      1599.0   0.00850   1608.0   0.00791   1626.0   0.00828   1644.0   0.00783
      1650.0   0.00776   1676.0   0.00475   1732.0   0.00430   1782.0   0.00279
      1862.0   0.00000   1955.0   0.00046   2008.0   0.00122   2014.0   0.00198
      2057.0   0.00175   2124.0   0.00128   2156.0   0.00110   2201.0   0.00267
      2266.0   0.00260   2320.0   0.00240   2338.0   0.00216   2356.0   0.00189
      2388.0   0.00083   2415.0   0.00067   2453.0   0.00057   2494.0   0.00023
      2537.0   0.00001   2900.0   0.00000   2941.0   0.00002   2954.0   0.00002
      2973.0   0.00006   3005.0   0.00005   3045.0   0.00001   3056.0   0.00002
      3097.0   0.00001   3132.0   0.00005   3156.0   0.00067   3204.0   0.00000
      3214.0   0.00001   3245.0   0.00002   3260.0   0.00001   3285.0   0.00039
      3317.0   0.00027   3344.0   0.00002   3403.0   0.00039   3450.0   0.00051
      3507.0   0.00062   3538.0   0.00053   3573.0   0.00020   3633.0   0.00052
      3673.0   0.00035   3696.0   0.00052   3712.0   0.00059   3765.0   0.00046
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      3812.0   0.00042    3888.0   0.00031    3923.0   0.00033    3948.0   0.00032
      4045.0   0.00020       0.0   0.00000       0.0   0.00000       0.0   0.00000
 DECK NUMBER 8   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
    189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10
       290.0   0.00000     295.0   0.00000     300.0   0.00000     305.0   0.00000
       310.0   0.00000     315.0   0.00000     320.0   0.00000     325.0   0.00000
       330.0   0.00000     335.0   0.00000     340.0   0.00000     345.0   0.00000
       350.0   0.00001     355.0   0.00001     360.0   0.00001     365.0   0.00002
       370.0   0.00003     375.0   0.00004     380.0   0.00005     385.0   0.00006
       390.0   0.00008     395.0   0.00011     400.0   0.00017     405.0   0.00023
       410.0   0.00028     415.0   0.00034     420.0   0.00039     425.0   0.00045
       430.0   0.00051     435.0   0.00061     440.0   0.00078     445.0   0.00098
       450.0   0.00120     455.0   0.00134     460.0   0.00147     465.0   0.00159
       470.0   0.00172     475.0   0.00189     480.0   0.00209     485.0   0.00217
       490.0   0.00233     495.0   0.00255     500.0   0.00275     505.0   0.00285
       510.0   0.00292     515.0   0.00298     520.0   0.00311     525.0   0.00329
       530.0   0.00342     535.0   0.00353     540.0   0.00361     545.0   0.00371
       550.0   0.00381     555.0   0.00392     560.0   0.00398     565.0   0.00412
       570.0   0.00426     575.0   0.00440     580.0   0.00452     585.0   0.00465
       590.0   0.00475     595.0   0.00483     600.0   0.00492     605.0   0.00515
       610.0   0.00540     620.0   0.00592     630.0   0.00648     640.0   0.00711
       650.0   0.00776     660.0   0.00822     670.0   0.00868     680.0   0.00915
       690.0   0.00967     698.3   0.00618     700.0   0.01016     710.0   0.01039
       720.0   0.01058     727.7   0.00755     730.0   0.01081     740.0   0.01099
       750.0   0.01120     762.1   0.00250     770.0   0.01161     780.0   0.01180
       790.0   0.01199     800.0   0.01217     805.9   0.00880     825.0   0.01230
       830.0   0.01232     835.0   0.01234     846.5   0.00171     860.0   0.00228
       870.0   0.00172     875.0   0.00173     887.5   0.00186     900.0   0.00201
       907.5   0.00217     915.0   0.00234     925.0   0.00050     930.0   0.00024
       940.0   0.00076     950.0   0.00067     955.0   0.00088     965.0   0.00116
       975.0   0.00632     985.0   0.00561    1018.0   0.00676    1082.0   0.00415
      1094.0   0.00673    1098.0   0.00499    1101.0   0.00895    1128.0   0.00016
      1131.0   0.00024    1137.0   0.00021    1144.0   0.00053    1147.0   0.00041
      1178.0   0.00217    1169.0   0.00286    1193.0   0.00829    1222.0   0.00403
      1236.0   0.00513    1264.0   0.00455    1276.0   0.00612    1288.0   0.00407
      1314.0   0.00144    1335.0   0.00137    1384.0   0.00000    1432.0   0.00002
      1457.0   0.00017    1472.0   0.00013    1542.0   0.00421    1572.0   0.00544
      1599.0   0.00560    1608.0   0.00514    1626.0   0.00550    1644.0   0.00518
      1650.0   0.00514    1676.0   0.00250    1732.0   0.00229    1782.0   0.00129
      1862.0   0.00000    1955.0   0.00021    2008.0   0.00038    2014.0   0.00104
      2057.0   0.00087    2124.0   0.00056    2156.0   0.00046    2201.0   0.00179
      2266.0   0.00179    2320.0   0.00165    2338.0   0.00144    2356.0   0.00121
      2388.0   0.00048    2415.0   0.00037    2453.0   0.00031    2494.0   0.00011
      2537.0   0.00000    2900.0   0.00000    2941.0   0.00001    2954.0   0.00001
      2973.0   0.00003    3005.0   0.00002    3045.0   0.00000    3056.0   0.00001
      3097.0   0.00000    3132.0   0.00002    3156.0   0.00042    3204.0   0.00000
      3214.0   0.00000    3245.0   0.00001    3260.0   0.00000    3285.0   0.00019
      3317.0   0.00009    3344.0   0.00001    3403.0   0.00022    3450.0   0.00035
      3507.0   0.00046    3538.0   0.00038    3573.0   0.00009    3633.0   0.00036
      3673.0   0.00025    3696.0   0.00039    3712.0   0.00046    3765.0   0.00034
      3812.0   0.00031    3888.0   0.00020    3923.0   0.00022    3948.0   0.00021
      4045.0   0.00011       0.0   0.00000       0.0   0.00000       0.0   0.00000
 DECK NUMBER 9   THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
    189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10
       290.0   0.00000     295.0   0.00000     300.0   0.00045     305.0   0.00125
       310.0   0.00335     315.0   0.00871     320.0   0.02222     325.0   0.02956
       330.0   0.03636     335.0   0.04203     340.0   0.04729     345.0   0.04924
       350.0   0.05266     355.0   0.05457     360.0   0.05629     365.0   0.06148
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       370.0   0.06610    375.0   0.06673     380.0   0.06656     385.0   0.06675
       390.0   0.06828    395.0   0.07563     400.0   0.09297     405.0   0.10859
       410.0   0.11740    415.0   0.12074     420.0   0.12070     425.0   0.11873
       430.0   0.11667    435.0   0.12015     440.0   0.13273     445.0   0.14306
       450.0   0.15154    455.0   0.15656     460.0   0.15843     465.0   0.15822
       470.0   0.15824    475.0   0.16028     480.0   0.16384     485.0   0.15726
       490.0   0.15634    495.0   0.15830     500.0   0.15801     505.0   0.15675
       510.0   0.15418    515.0   0.15068     520.0   0.15119     525.0   0.15327
       530.0   0.15296    535.0   0.15147     540.0   0.14905     545.0   0.14712
       550.0   0.14517    555.0   0.14504     560.0   0.14322     565.0   0.14435
       570.0   0.14523    575.0   0.14611     580.0   0.14605     585.0   0.14608
       590.0   0.14534    595.0   0.14408     600.0   0.14299     605.0   0.14202
       610.0   0.14165    620.0   0.14010     630.0   0.13860     640.0   0.13758
       650.0   0.13590    660.0   0.13444     670.0   0.13250     680.0   0.13062
       690.0   0.12909    698.3   0.10899     700.0   0.12678     710.0   0.12460
       720.0   0.12234    727.7   0.10808     730.0   0.12042     740.0   0.11793
       750.0   0.11589    762.1   0.08543     770.0   0.11178     780.0   0.10961
       790.0   0.10752    800.0   0.10541     805.9   0.09392     825.0   0.10000
       830.0   0.09892    835.0   0.09790     846.5   0.05108     860.0   0.05429
       870.0   0.04864    875.0   0.04813     887.5   0.04804     900.0   0.04806
       907.5   0.04872    915.0   0.04939     925.0   0.02984     930.0   0.02372
       940.0   0.03351    950.0   0.03169     955.0   0.03432     965.0   0.03679
       975.0   0.06161    985.0   0.05814    1018.0   0.06587    1082.0   0.05461
      1094.0   0.04940   1098.0   0.05361    1101.0   0.05372    1128.0   0.01436
      1131.0   0.01618   1137.0   0.01521    1144.0   0.02032    1147.0   0.01855
      1178.0   0.04241   1189.0   0.04270    1193.0   0.04501    1222.0   0.04156
      1236.0   0.04145   1264.0   0.03489    1276.0   0.03630    1288.0   0.03679
      1314.0   0.03158   1335.0   0.02017    1384.0   0.00060    1432.0   0.00471
      1457.0   0.00902   1472.0   0.00816    1542.0   0.02522    1572.0   0.02345
      1599.0   0.02275   1608.0   0.02195    1626.0   0.02175    1644.0   0.02082
      1650.0   0.02059   1676.0   0.01913    1732.0   0.01697    1782.0   0.01435
      1862.0   0.00042   1955.0   0.00447    2008.0   0.00726    2014.0   0.00782
      2057.0   0.00727   2124.0   0.00731    2156.0   0.00690    2201.0   0.00690
      2266.0   0.00643   2320.0   0.00596    2338.0   0.00570    2356.0   0.00542
      2388.0   0.00375   2415.0   0.00339    2453.0   0.00308    2494.0   0.00212
      2537.0   0.00048   2900.0   0.00030    2941.0   0.00062    2954.0   0.00059
      2973.0   0.00090   3005.0   0.00081    3045.0   0.00048    3056.0   0.00051
      3097.0   0.00033   3132.0   0.00071    3156.0   0.00193    3204.0   0.00022
      3214.0   0.00035   3245.0   0.00041    3260.0   0.00038    3285.0   0.00147
      3317.0   0.00134   3344.0   0.00044    3403.0   0.00127    3450.0   0.00129
      3507.0   0.00129   3538.0   0.00121    3573.0   0.00113    3633.0   0.00111
      3673.0   0.00094   3696.0   0.00108    3712.0   0.00112    3765.0   0.00098
      3812.0   0.00092   3888.0   0.00084    3923.0   0.00083    3948.0   0.00081
      4045.0   0.00069      0.0   0.00000       0.0   0.00000       0.0   0.00000
 DECK NUMBER 10  THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
   189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10
       290.0   0.00000    295.0   0.00000     300.0   0.00000     305.0   0.00000
       310.0   0.00000    315.0   0.00001     320.0   0.00043     325.0   0.00082
       330.0   0.00147    335.0   0.00247     340.0   0.00404     345.0   0.00481
       350.0   0.00589    355.0   0.00698     360.0   0.00824     365.0   0.00985
       370.0   0.01159    375.0   0.01280     380.0   0.01397     385.0   0.01500
       390.0   0.01642    395.0   0.01947     400.0   0.02561     405.0   0.03129
       410.0   0.03539    415.0   0.03807     420.0   0.03980     425.0   0.04095
       430.0   0.04208    435.0   0.04532     440.0   0.05235     445.0   0.05899
       450.0   0.06533    455.0   0.06903     460.0   0.07144     465.0   0.07296
       470.0   0.07462    475.0   0.07729     480.0   0.08078     485.0   0.07927
       490.0   0.08057    495.0   0.08341     500.0   0.08511     505.0   0.08531
       510.0   0.08477    515.0   0.08369     520.0   0.08484     525.0   0.08688
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     530.0   0.08758     535.0   0.08761      540.0   0.08708      545.0   0.08681
     550.0   0.08652     555.0   0.08696      560.0   0.08639      565.0   0.08759
     570.0   0.08865     575.0   0.08972      580.0   0.09021      585.0   0.09076
     590.0   0.09083     595.0   0.09056      600.0   0.09039      605.0   0.09107
     610.0   0.09212     620.0   0.09372      630.0   0.09535      640.0   0.09734
     650.0   0.09888     660.0   0.09956      670.0   0.09986      680.0   0.10019
     690.0   0.10075     698.3   0.07397      700.0   0.10069      710.0   0.09992
     720.0   0.09873     727.7   0.07848      730.0   0.09796      740.0   0.09669
     750.0   0.09577     762.1   0.04786      770.0   0.09392      780.0   0.09271
     790.0   0.09164     800.0   0.09053      805.9   0.07291      825.0   0.08686
     830.0   0.08613     835.0   0.08543      846.5   0.02395      860.0   0.02801
     870.0   0.02304     875.0   0.02286      887.5   0.02346      900.0   0.02413
     907.5   0.02506     915.0   0.02602      925.0   0.00564      930.0   0.00613
     940.0   0.01242     950.0   0.01126      955.0   0.01335      965.0   0.01568
     975.0   0.04501     985.0   0.04108     1018.0   0.05060     1082.0   0.03731
    1094.0   0.03889    1098.0   0.03901     1101.0   0.04651     1128.0   0.00354
    1131.0   0.00452    1137.0   0.00405     1144.0   0.00733     1147.0   0.00614
    1178.0   0.02482    1189.0   0.02725     1193.0   0.03947     1222.0   0.02980
    1236.0   0.03214    1264.0   0.02645     1276.0   0.03007     1288.0   0.02720
    1314.0   0.01728    1335.0   0.01066     1384.0   0.00001     1432.0   0.00067
    1457.0   0.00256    1472.0   0.00215     1542.0   0.02047     1572.0   0.02070
    1599.0   0.02048    1608.0   0.01933     1626.0   0.01971     1644.0   0.01867
    1650.0   0.01848    1676.0   0.01403     1732.0   0.01249     1782.0   0.00918
    1862.0   0.00001    1955.0   0.00174     2008.0   0.00430     2014.0   0.00546
    2057.0   0.00494    2124.0   0.00429     2156.0   0.00385     2201.0   0.00584
    2266.0   0.00555    2320.0   0.00511     2338.0   0.00472     2356.0   0.00429
    2388.0   0.00221    2415.0   0.00186     2453.0   0.00161     2494.0   0.00080
    2537.0   0.00004    2900.0   0.00003     2941.0   0.00011     2954.0   0.00011
    2973.0   0.00025    3005.0   0.00021     3045.0   0.00008     3056.0   0.00009
    3097.0   0.00004    3132.0   0.00020     3156.0   0.00145     3204.0   0.00002
    3214.0   0.00006    3245.0   0.00008     3260.0   0.00007     3285.0   0.00097
    3317.0   0.00079    3344.0   0.00010     3403.0   0.00089     3450.0   0.00102
    3507.0   0.00113    3538.0   0.00101     3573.0   0.00061     3633.0   0.00094
    3673.0   0.00070    3696.0   0.00093     3712.0   0.00102     3765.0   0.00082
    3812.0   0.00076    3888.0   0.00063     3923.0   0.00064     3948.0   0.00062
    4045.0   0.00047       0.0   0.00000        0.0   0.00000        0.0   0.00000
DECK NUMBER 11  THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL
  189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10
     290.0   0.00000     295.0   0.00000      300.0   0.00000      305.0   0.00000
     310.0   0.00000     315.0   0.00000      320.0   0.00001      325.0   0.00002
     330.0   0.00006     335.0   0.00015      340.0   0.00034      345.0   0.00047
     350.0   0.00066     355.0   0.00089      360.0   0.00121      365.0   0.00158
     370.0   0.00203     375.0   0.00246      380.0   0.00293      385.0   0.00337
     390.0   0.00395     395.0   0.00501      400.0   0.00705      405.0   0.00902
     410.0   0.01067     415.0   0.01200      420.0   0.01313      425.0   0.01412
     430.0   0.01518     435.0   0.01709      440.0   0.02064      445.0   0.02432
     450.0   0.02816     455.0   0.03044      460.0   0.03221      465.0   0.03365
     470.0   0.03519     475.0   0.03727      480.0   0.03983      485.0   0.03996
     490.0   0.04153     495.0   0.04395      500.0   0.04584      505.0   0.04642
     510.0   0.04661     515.0   0.04649      520.0   0.04761      525.0   0.04925
     530.0   0.05015     535.0   0.05067      540.0   0.05087      545.0   0.05123
     550.0   0.05157     555.0   0.05214      560.0   0.05211      565.0   0.05315
     570.0   0.05411     575.0   0.05509      580.0   0.05572      585.0   0.05639
     590.0   0.05676     595.0   0.05692      600.0   0.05715      605.0   0.05839
     610.0   0.05991     620.0   0.06269      630.0   0.06560      640.0   0.05867
     650.0   0.07194     660.0   0.07373      670.0   0.07527      680.0   0.07685
     690.0   0.07864     698.3   0.05302      700.0   0.07997      710.0   0.08000
     720.0   0.07968     727.7   0.05929      730.0   0.07969      740.0   0.07928
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750.0	0.07914	762.1	0.02732	770.0	0.07874	780.0	0.07841
790.0	0.07810	800.0	0.07775	805.9	0.05872	825.0	0.07545
830.0	0.07498	835.0	0.07454	846.5	0.01402	860.0	0.01747
870.0	0.01363	875.0	0.01355	887.5	0.01418	900.0	0.01488
907.5	0.01571	915.0	0.01658	925.0	0.00448	930.0	0.00247
940.0	0.00632	950.0	0.00558	955.0	0.00701	965.0	0.00875
975.0	0.03560	985.0	0.03181	1018.0	0.03887	1082.0	0.02549
1094.0	0.03260	1098.0	0.02838	1101.0	0.04130	1128.0	0.00140
1131.0	0.00194	1137.0	0.00168	1144.0	0.00371	1147.0	0.00295
1178.0	0.01453	1189.0	0.01739	1193.0	0.03544	1222.0	0.02137
1236.0	0.02492	1264.0	0.02102	1276.0	0.02586	1288.0	0.02011
1314.0	0.00945	1335.0	0.00694	1384.0	0.00000	1432.0	0.00019
1457.0	0.00112	1472.0	0.00090	1542.0	0.01661	1572.0	0.01876
1599.0	0.01885	1608.0	0.01749	1626.0	0.01822	1644.0	0.01714
1650.0	0.01697	1676.0	0.01030	1732.0	0.00920	1782.0	0.00588
1862.0	0.00000	1955.0	0.00094	2008.0	0.00244	2014.0	0.00396
2057.0	0.00347	2124.0	0.00251	2156.0	0.00214	2201.0	0.00514
2266.0	0.00496	2320.0	0.00454	2338.0	0.00407	2356.0	0.00355
2388.0	0.00156	2415.0	0.00125	2453.0	0.00105	2494.0	0.00042
2537.0	0.00001	2900.0	0.00001	2941.0	0.00004	2954.0	0.00003
2973.0	0.00011	3005.0	0.00009	3045.0	0.00003	3056.0	0.00003
3097.0	0.00001	3132.0	0.00009	3156.0	0.00114	3204.0	0.00000
3214.0	0.00002	3245.0	0.00003	3260.0	0.00002	3285.0	0.00065
3317.0	0.00045	3344.0	0.00004	3403.0	0.00065	3450.0	0.00084
3507.0	0.00102	3538.0	0.00087	3573.0	0.00033	3633.0	0.00084
3673.0	0.00057	3696.0	0.00084	3712.0	0.00096	3765.0	0.00073
3812.0	0.00067	3888.0	0.00050	3923.0	0.00052	3948.0	0.00050
4045.0	0.00032	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 12 THEKAEKARA SOLAR IRRADIANCE AT GROUND LEVEL
189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00000	305.0	0.00000
310.0	0.00000	315.0	0.00000	320.0	0.00000	325.0	0.00000
330.0	0.00000	335.0	0.00001	340.0	0.00003	345.0	0.00005
350.0	0.00007	355.0	0.00011	360.0	0.00018	365.0	0.00025
370.0	0.00036	375.0	0.00047	380.0	0.00062	385.0	0.00076
390.0	0.00095	395.0	0.00129	400.0	0.00194	405.0	0.00260
410.0	0.00322	415.0	0.00378	420.0	0.00433	425.0	0.00487
430.0	0.00547	435.0	0.00645	440.0	0.00814	445.0	0.01003
450.0	0.01214	455.0	0.01342	460.0	0.01453	465.0	0.01552
470.0	0.01659	475.0	0.01797	480.0	0.01964	485.0	0.02014
490.0	0.02140	495.0	0.02315	500.0	0.02469	505.0	0.02526
510.0	0.02562	515.0	0.02582	520.0	0.02671	525.0	0.02792
530.0	0.02872	535.0	0.02931	540.0	0.02972	545.0	0.03023
550.0	0.03073	555.0	0.03127	560.0	0.03143	565.0	0.03225
570.0	0.03303	575.0	0.03383	580.0	0.03442	585.0	0.03503
590.0	0.03547	595.0	0.03578	600.0	0.03615	605.0	0.03744
610.0	0.03896	620.0	0.04193	630.0	0.04513	640.0	0.04873
650.0	0.05234	660.0	0.05460	670.0	0.05673	680.0	0.05894
690.0	0.06138	698.3	0.03877	700.0	0.06351	710.0	0.06405
720.0	0.06431	727.7	0.04544	730.0	0.06483	740.0	0.06500
750.0	0.06540	762.1	0.01438	770.0	0.06609	780.0	0.06632
790.0	0.06657	800.0	0.06677	805.9	0.04793	825.0	0.06554
830.0	0.06528	835.0	0.06504	846.5	0.00890	860.0	0.01158
870.0	0.00874	875.0	0.00871	887.5	0.00927	900.0	0.00989
907.5	0.01058	915.0	0.01132	925.0	0.00238	930.0	0.00117
940.0	0.00361	950.0	0.00312	955.0	0.00411	965.0	0.00538
975.0	0.02897	985.0	0.02548	1018.0	0.02585	1082.0	0.01741
1094.0	0.02796	1098.0	0.02065	1101.0	0.03700	1128.0	0.00066

1131.0	0.00098	1137.0	0.00083	1144.0	0.00213	1147.0	0.00162
1178.0	0.00850	1189.0	0.01110	1193.0	0.03210	1222.0	0.01532
1236.0	0.01932	1264.0	0.01685	1276.0	0.02251	1288.0	0.01487
1314.0	0.00517	1335.0	0.00488	1384.0	0.00000	1432.0	0.00007
1457.0	0.00057	1472.0	0.00044	1542.0	0.01348	1572.0	0.01717
1599.0	0.01748	1608.0	0.01599	1626.0	0.01697	1644.0	0.01586
1650.0	0.01572	1676.0	0.00756	1732.0	0.00677	1782.0	0.00376
1862.0	0.00000	1955.0	0.00057	2008.0	0.00101	2014.0	0.00280
2057.0	0.00232	2124.0	0.00147	2156.0	0.00120	2201.0	0.00458
2266.0	0.00449	2320.0	0.00408	2338.0	0.00356	2356.0	0.00297
2388.0	0.00118	2415.0	0.00091	2453.0	0.00075	2494.0	0.00025
2537.0	0.00000	2900.0	0.00000	2941.0	0.00002	2954.0	0.00001
2973.0	0.00006	3005.0	0.00004	3045.0	0.00001	3056.0	0.00001
3097.0	0.00000	3132.0	0.00004	3156.0	0.00089	3204.0	0.00000
3214.0	0.00001	3245.0	0.00001	3260.0	0.00001	3285.0	0.00040
3317.0	0.00018	3344.0	0.00002	3403.0	0.00045	3450.0	0.00070
3507.0	0.00093	3538.0	0.00076	3573.0	0.00018	3633.0	0.00077
3673.0	0.00049	3696.0	0.00078	3712.0	0.00090	3765.0	0.00067
3812.0	0.00060	3888.0	0.00039	3923.0	0.00042	3948.0	0.00040
4045.0	0.00021	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 13 THEKAEKARA   SOLAR IRRADIANCE AT GROUND LEVEL

189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00041	305.0	0.00114
310.0	0.00306	315.0	0.00797	320.0	0.02035	325.0	0.02712
330.0	0.03341	335.0	0.03869	340.0	0.04360	345.0	0.04546
350.0	0.04869	355.0	0.05054	360.0	0.05220	365.0	0.05709
370.0	0.06146	375.0	0.06212	380.0	0.06204	385.0	0.06229
390.0	0.06379	395.0	0.07074	400.0	0.08705	405.0	0.10178
410.0	0.11015	415.0	0.11340	420.0	0.11347	425.0	0.11172
430.0	0.10988	435.0	0.11327	440.0	0.12524	445.0	0.13509
450.0	0.14322	455.0	0.14808	460.0	0.14997	465.0	0.14989
470.0	0.15002	475.0	0.15206	480.0	0.15555	485.0	0.14941
490.0	0.14863	495.0	0.15060	500.0	0.15041	505.0	0.14932
510.0	0.14695	515.0	0.14370	520.0	0.14428	525.0	0.14635
530.0	0.14613	535.0	0.14479	540.0	0.14256	545.0	0.14078
550.0	0.13899	555.0	0.13893	560.0	0.13726	565.0	0.13841
570.0	0.13932	575.0	0.14023	580.0	0.14024	585.0	0.14033
590.0	0.13968	595.0	0.13853	600.0	0.13754	605.0	0.13667
610.0	0.13637	620.0	0.13498	630.0	0.13364	640.0	0.13275
650.[illegible]	[illegible].13123	660.0	0.12991	670.0	0.12812	680.0	0.12638
[illegible]	[illegible]2497	698.3	0.10557	700.0	0.12281	710.0	0.12096
[illegible]	[illegible].11865	727.7	0.10486	730.0	0.11685	740.0	0.11449
[illegible]	0.11257	762.1	0.08303	770.0	0.10868	780.0	0.10662
[illegible].0	0.10464	800.0	0.10263	805.9	0.09147	825.0	0.09746
830.0	0.09644	835.0	0.09546	846.5	0.04983	860.0	0.05298
870.0	0.04748	875.0	0.04700	887.5	0.04694	900.0	0.04697
907.5	0.04763	915.0	0.04829	925.0	0.02919	930.0	0.02320
940.0	0.03279	950.0	0.03102	955.0	0.03360	965.0	0.03603
975.0	0.06035	985.0	0.05697	1018.0	0.06439	1082.0	0.05363
1094.0	0.04853	1098.0	0.05267	1101.0	0.05278	1128.0	0.01412
1131.0	0.01591	1137.0	0.01496	1144.0	0.01998	1147.0	0.01824
1178.0	0.04173	1189.0	0.04203	1193.0	0.04430	1222.0	0.04092
1236.0	0.04082	1264.0	0.03437	1276.0	0.03578	1288.0	0.03626
1314.0	0.03114	1335.0	0.01989	1384.0	0.00060	1432.0	0.00465
1457.0	0.00891	1472.0	0.00807	1542.0	0.02493	1572.0	0.02319
1599.0	0.02250	1608.0	0.02171	1626.0	0.02152	1644.0	0.02060
1650.0	0.02037	1676.0	0.01893	1732.0	0.01680	1782.0	0.01422
1862.0	0.00041	1955.0	0.00444	2008.0	0.00720	2014.0	0.00775

2057.0	0.00722	2124.0	0.00726	2156.0	0.00685	2201.0	0.00685
2266.0	0.00638	2320.0	0.00592	2338.0	0.00566	2356.0	0.00538
2388.0	0.00373	2415.0	0.00336	2453.0	0.00306	2494.0	0.00210
2537.0	0.00048	2900.0	0.00030	2941.0	0.00062	2954.0	0.00059
2973.0	0.00090	3005.0	0.00081	3045.0	0.00048	3056.0	0.00051
3097.0	0.00033	3132.0	0.00070	3156.0	0.00192	3204.0	0.00022
3214.0	0.00035	3245.0	0.00041	3260.0	0.00038	3285.0	0.00147
3317.0	0.00133	3344.0	0.00043	3403.0	0.00127	3450.0	0.00129
3507.0	0.00129	3538.0	0.00121	3573.0	0.00112	3633.0	0.00111
3673.0	0.00094	3696.0	0.00107	3712.0	0.00112	3765.0	0.00097
3812.0	0.00091	3888.0	0.00083	3923.0	0.00082	3948.0	0.00080
4045.0	0.00069	0.0	0.00000	0.0	0.00000	0.0	0.00000

DECK NUMBER 14 THEKAEKARA SOLAR IRRADIANCE AT GROUND LEVEL

189 SOLAR SPECTRUM,AIR MASS 1,4,7 AND 10

290.0	0.00000	295.0	0.00000	300.0	0.00000	305.0	0.00000
310.0	0.00000	315.0	0.00001	320.0	0.00030	325.0	0.00058
330.0	0.00105	335.0	0.00177	340.0	0.00292	345.0	0.00350
350.0	0.00430	355.0	0.00513	360.0	0.00609	365.0	0.00732
370.0	0.00866	375.0	0.00962	380.0	0.01054	385.0	0.01137
390.0	0.01251	395.0	0.01490	400.0	0.01968	405.0	0.02415
410.0	0.02742	415.0	0.02962	420.0	0.03109	425.0	0.03211
430.0	0.03311	435.0	0.03579	440.0	0.04148	445.0	0.04691
450.0	0.05212	455.0	0.05525	460.0	0.05736	465.0	0.05876
470.0	0.06027	475.0	0.06261	480.0	0.06563	485.0	0.06458
490.0	0.06582	495.0	0.06832	500.0	0.06989	505.0	0.07023
510.0	0.06996	515.0	0.06924	520.0	0.07035	525.0	0.07222
530.0	0.07297	535.0	0.07315	540.0	0.07287	545.0	0.07280
550.0	0.07270	555.0	0.07322	560.0	0.07288	565.0	0.07404
570.0	0.07508	575.0	0.07613	580.0	0.07669	585.0	0.07729
590.0	0.07749	595.0	0.07740	600.0	0.07738	605.0	0.07809
610.0	0.07912	620.0	0.08075	630.0	0.08241	640.0	0.08438
650.0	0.08596	660.0	0.08679	670.0	0.08728	680.0	0.08779
690.0	0.08851	698.3	0.06511	700.0	0.08866	710.0	0.08819
720.0	0.08734	727.7	0.06954	730.0	0.08685	740.0	0.08590
750.0	0.08526	762.1	0.04271	770.0	0.08385	780.0	0.08301
790.0	0.08220	800.0	0.08135	805.9	0.06558	825.0	0.07838
830.0	0.07778	835.0	0.07721	846.5	0.02169	860.0	0.02541
870.0	0.02094	875.0	0.02078	887.5	0.02137	900.0	0.02201
907.5	0.02288	915.0	0.02378	925.0	0.00882	930.0	0.00562
940.0	0.01139	950.0	0.01033	955.0	0.01226	965.0	0.01442
975.0	0.04144	985.0	0.03786	1018.0	0.04679	1082.0	0.03471
1094.0	0.03622	1098.0	0.03634	1101.0	0.04334	1128.0	0.00330
1131.0	0.00422	1137.0	0.00378	1144.0	0.00685	1147.0	0.00575
1178.0	0.02327	1189.0	0.02556	1193.0	0.03704	1222.0	0.02802
1236.0	0.03024	1264.0	0.02494	1276.0	0.02837	1288.0	0.02568
1314.0	0.01634	1335.0	0.01009	1384.0	0.00001	1432.0	0.00064
1457.0	0.00244	1472.0	0.00205	1542.0	0.01955	1572.0	0.01980
1599.0	0.01961	1608.0	0.01851	1626.0	0.01899	1644.0	0.01790
1650.0	0.01772	1676.0	0.01347	1732.0	0.01201	1782.0	0.00884
1862.0	0.00001	1955.0	0.00168	2008.0	0.00416	2014.0	0.00529
2057.0	0.00479	2124.0	0.00416	2156.0	0.00373	2201.0	0.00568
2266.0	0.00540	2320.0	0.00497	2338.0	0.00459	2356.0	0.00417
2388.0	0.00215	2415.0	0.00181	2453.0	0.00157	2494.0	0.00078
2537.0	0.00004	2900.0	0.00002	2941.0	0.00011	2954.0	0.00010
2973.0	0.00025	3005.0	0.00021	3045.0	0.00008	3056.0	0.00009
3097.0	0.00004	3132.0	0.00019	3156.0	0.00142	3204.0	0.00002
3214.0	0.00005	3245.0	0.00008	3260.0	0.00007	3285.0	0.00096
3317.0	0.00078	3344.0	0.00010	3403.0	0.00088	3450.0	0.00100