Università degli Studi di Trieste
Dipartimento di Fisica Teorica

Cattedra di Fisica Terrestre e Climatologia

Franco Stravisi

FORTRAN PROGRAMS FOR COMPUTING THE CLEAR SKY SOLAR DIRECT AND DIFFUSE SPECTRAL IRRADIANCE AT THE GROUND

Presented at the
"Course on Physical Climatology and Meteorology
for Environmental Applications"
23 May - 17 June 1988
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
Trieste

Rapporto Interno
FTC 88/4

Trieste 1988

CONTENTS

FORTRAN PROGRAMS FOR COMPUTING THE CLEAR SKY SOLAR DIRECT AND DIFFUSE SPECTRAL IRRADIANCE AT THE GROUND

Franco Stravisi
University of Trieste,
Department of Theoretical Physics

ABSTRACT. The solar spectral irradiance (direct normal, diffuse and global on a horizontal surface) at the ground is computed according to the Bird and Riordan (1986) SPCTRAL2 model with some improvements. Spectra are defined at 122 wavelengths in the range from 0.3 to 4.0 micrometers. The extraterrestrial irradiance spectrum in the band above, accounting for 98 % of the solar constant (1339 of total 1367 W/m^2) is given according to WRR and Neckel and Labs (1981). A cloudless atmosphere is assumed. Fortran functions and subroutines are given for the computation of the physical quantities considered in the model and for the sun position. A BASIC program for plotting solar spectra on the PC screen is included.

1. DIRECT, DIFFUSE AND GLOBAL IRRADIANCE

The *direct spectral sun irradiance* I_D on a surface normal to the sun direction at ground level is defined as the extraterrestrial spectral irradiance H_o at the mean sun-earth distance corrected by the daily coefficient D (the square of the ratio between one astronomical unit and the actual earth-sun distance), depleted by the atmosphere with a spectral transmittance τ :

$$I_D = H_o D \tau .$$

The spectral atmospheric transmittance accounts for five independent processes: the Rayleigh scattering by the clean dry air molecules (τ_R), the attenuation (absorption and scattering) by the aerosol (suspended solid and liquid particles, size from about 10^{-3} to 10^2 µm) (τ_A), the absorption by the water vapor (τ_W), by the ozone (τ_O) and by the "uniformly mixed gas" (τ_U) :

$$\tau = \tau_R \, \tau_A \, \tau_W \, \tau_O \, \tau_U \, .$$

The *diffuse spectral irradiance* on a horizontal surface at the ground is given by the sum of three components:

$$I_S = I_R + I_A + I_G \, ,$$

that are respectively the irradiances down scattered (Rayleigh scattering) by the air molecules (I_R) and by the aerosol (I_A) and the component I_G resulting from multiple reflections between the ground and the atmosphere.

The *spectral global irradiance* on a horizontal surface at the ground is defined by:

$$I_T = I_D \cos\Theta + I_S \ ,$$

where Θ is the sun zenith angle, which can be computed, at a given site and time, according to Spencer (1971) or, if a higher accuracy is desired, according to Michalsky (1988).

2. NOTATIONS, UNITS AND FORMULAS

Basic data.

ϕ	latitude, north positive (°);
λ	longitude, east positive (°);
n	day number (1 to 365);
Θ	apparent sun zenith angle (°);
p	atmospheric pressure (hPa);
p_o	one standard atmosphere (101325 Pa);
θ	air (screen) temperature (°C);
T	air (screen) absolute temperature (K);
U	percentual (screen) relative humidity ;
V	horizontal visibility (km);
α	wavelength exponent;
r_G	ground albedo (cfr. Iqbal, 1983).

Physical quantities.

D . The daily value of the earth-sun distance factor is computed according to Spencer (1971) as a function of the day number n:

$$j = 2\pi\,(n\text{-}1)/365 \ ,$$
$$D = 1.00011 + 0.034221 \cos j + 0.00128 \sin j + 0.000719 \cos 2j + 0.000077 \sin 2j \ ;$$

D(n) is computed by the Fortran FUNCTION DISTES(NDAY). Values are shown in *Table 1.*

O_3 . The surface density of the volume of ozone contained in the vertical column, reduced at normal temperature and pressure, or the NTP ozone amount (units: centimeters), is computed for each day of the year, at a given site, according to the expression given by Van Heuklon (1979):

$$\begin{aligned} O_3 \ &= \ 0.235 + (0.150 + 0.040 \sin(2(n\text{-}30)\pi/365.25) \\ &\quad + 0.020 \sin(3(\lambda + 20)\pi/180)) \sin^2(1.28\, \phi\, \pi/180) \ ; \end{aligned}$$

the ozone amount is computed by the FUNCTION O3(LAT,LONG, NDAY). Daily values for Trieste are reported in *Table 2.*

M_A. The relative air mass (the ratio between the oblique optical path length to the vertical path in the zenith direction), a function of the sun zenith angle, is computed, as indicated by Kasten (1966):

$$M_A = (\cos\Theta + 0.15\,(93.885 - \Theta)^{-1.253})^{-1} ,$$

by the FUNCTION RAM(Z). The pressure corrected relative air mass

$$M'_A = M_A\; p/p_o$$

is also defined. $M_A(\Theta)$ is listed in *Table 3.*

M_W. The relative water vapor mass is computed as a function of Θ according to Kasten (1966). A small departure from M_A, increasing with Θ, is due to the fact that the water vapor is mainly concentrated in the lower troposphere:

$$M_W = (\cos\Theta + 0.0548\,(92.650 - \Theta)^{-1.452})^{-1} ;$$

it is given by FUNCTION RWVM(Z). $M_W(\Theta)$ is listed in *Table 3.*

M_O. The relative ozone mass is computed by FUNCTION ROM(Z) according to Robinson's expression as given by Iqbal (1983):

$$M_O = (1+R)\,(\cos^2\Theta + 2R)^{-1/2} ,$$

where $R = 22/6370$ is the ratio between the height of the ozone layer (assumed to be 22 km) and the earth's radius. $M_O(\theta)$ is given in *Table 3.*

W. The precipitable water vapor height (unit: centimeter) is computed by the FUNCTION WV(UR,TA) as a function of the percentual relative humidity and of the air temperature at the ground *(Table 4)*, using the expression given by Iqbal (1983):

$$W = 0.00493\; U\, e_S / T .$$

An approximate formula for the saturation water vapor pressure, given by Leckner (1978), is used (e_S in Pascal):

$$e_S = \exp(26.23 - 5416/T) .$$

The more accurate Goff-Gratch formula is reported by Stravisi (1988).

β. The Angstrom turbidity coefficient (unit: micrometer$^{\alpha}$) is computed as a function of the wavelength exponent α and of the meteorological range, or horizontal visibility V, according to the expression reported by Iqbal (1983):

$$\beta = 0.55^{\alpha}\,(3.912/V - 0.01162)(0.02472(V\text{-}5) + 1.132) ,$$

that holds for V greater than 5 km, by the FUNCTION BETA(ALFA,V). Values are given in *Table 5.*

F_S. This term, depending on the sun zenith angle, represents the fraction of irradiance downscattered by the aerosol. According to Bird and Riordan (1986):

$$F_S = 1 - 0.5\,\exp((0.176\,\cos\Theta - 1.83)\,\cos\Theta) ;$$

computations are performed by the FUNCTION FS(Z).

Spectral data.

A set of spectral quantities is now defined. The wavelength is denoted by w. These data are DIMENSION(122) vectors defined in the BLOCK DATA H0A122 and stored in COMMON /SPECTA/ (Bird and Riordan, 1986, Table 1).

w . A set of 122 wavelengths (unit: micrometer) in the range from 0.3 to 4 µm is stored in vector W(122).

H_o . The spectral irradiance (unit: watt per square meter per micrometer) at the top of the atmosphere at the mean sun-earth distance (one astronomical unit) is represented by the vector H0(122).

a_W . The spectral water vapor absorption coefficient (unit: square centimeter per gram) is stored in vector AW(122).

a_O . The spectral ozone absorption coefficient (unit: 1/centimeter) is stored in vector AO(122).

a_U . The spectral absorption coefficient for the uniformly mixed gas (unit: 1/kilometer) is defined by vector AU(122).

Spectral physical quantities.

τ_R . The spectral transmittance after Rayleigh scattering is computed by the FUNCTION TR(W,AM,P) according to Bird and Riordan (1986):

$$\tau_R = \exp(-M'_A/(w^4(115.6406 - 1.335\, w^{-2}))) .$$

τ_A . The spectral transmittance after the attenuation by the aerosol is computed by the FUNCTION TA(W,AM,ALFA,BETA) as follows:

$$\tau_A = \exp(-\, M_A\, \beta\, w^{-\alpha}) ;$$

the exponent is the air mass times the Angstrom turbidity.

τ_W . The spectral transmittance after the absorption by the atmospheric water vapor is given by the FUNCTION TW(AW,WM,PW) according to Leckner (1978):

$$\tau_W = \exp(-0.2385\, a_W\, W M_W/(1 + 20.07\, a_W\, W M_W)^{0.45} .$$

The relative water vapor, instead of air, mass, is here used: the difference is however small.

τ_O . The spectral transmittance after the absortion by the ozone layer is computed by the FUNCTION TO(AO,OM,OZ) according to Leckner (1978):

$$\tau_O = \exp(-\, a_O\, O_3\, M_O) .$$

τ_U. The spectral transmittance after the absorption of the uniformly mixed gas is also given according to Leckner (1978):

$$\tau_U = \exp(-1.41\ a_U M'_A/(1 + 118.3\ a_U M'_A)^{0.45}$$

by the FUNCTION TU(AU,AM,P).

A. The spectral aerosol single scattering albedo is computed by the FUNCTION ASCA(W) according to Bird and Riordan (1986):

$$A = 0.945 \exp(-0.095(\ln(w/0.4))^2\ .$$

τ_{AS}, τ_{AA}. The spectral transmittances for the aerosol scattering and absorption, defined by Bird and Riordan (1986),

$$\tau_{AS} = \tau_A{}^A\ , \qquad \tau_{AA} = \tau_A/\tau_{AS}\ ,$$

are computed in the SUBROUTINE SPCTRL, vectors TAS(122), TAA(122).

r_S. The spectral sky reflectivity is computed in the SUBROUTINE SPCTRL, vector RS(122), according to Bird and Riordan (1986):

$$r_S = \tau'_O\, \tau'_W\, \tau'_{AA}\ ((1-\tau'_R)/2 + 0.191\ \tau'_R\ (1-\tau'_{AS}))\ ;$$

here ( )' indicates that the corresponding transmittances are computed at $M_A = 1.8$.

C_S. This spectral correction coefficient for the total scattered irradiance (CS(122) in SUBROUTINE SPCTRL) is defined by Bird and Riordan (1986) as follows:

$$\begin{aligned} C_S &= (w + 0.55)^{1.8} && \text{for } w \leq 0.45\ \mu\text{m},\\ C_S &= 1.0 && \text{for } w > 0.45\ \mu\text{m}. \end{aligned}$$

3. SUBROUTINE SPCTRL

The input data to this Fortran subroutine are latitude and longitude, day number, sun zenith angle, pressure, temperature, relative humidity, visibility, ground albedo and α. A parameter INT different from zero allows for the computation of the integrated (broadband) irradiances, in the range from 0.3 to 4 µm, by calling the SUBROUTINE BROBAN. The output computed spectral direct, diffuse and global irradiances on the horizontal plane are given by the vectors DIR, DIF and GLO, index 1 to 122; index 123 contains the broadband values in the case that INT=1. Other output quantities are contained in the labelled COMMONs, as indicated in the subroutine list. Irradiances are computed as follows:

$$\begin{aligned} H_T &= H_o D\ \ \tau_W\, \tau_O\, \tau_U\ ,\\ I_D &= H_T\, \tau_R\, \tau_A\ ,\\ H_Z &= C_S H_T\ \tau_{AA}\ \cos\Theta\ ,\\ I_R &= 0.5\, H_Z\, (1 - \tau_R{}^{0.95})\ ,\\ I_A &= H_Z\, (1 - \tau_{A\,S})\, F_S\, \tau_R{}^{1.5}\ ,\\ I_G &= (C_S I_D \cos\Theta + I_R + I_A)\, r_S\, r_G/(1 - r_S\, r_G)\ ,\\ I_S &= I_R + I_A + I_G\ ,\\ I_T &= I_D \cos\Theta + I_S\ . \end{aligned}$$

4. PROGRAM SPECIR

This Fortran program calls for the input data (latitude, longitude, day number, sun zenith angle, pressure, temperature, humidity, visibility, alfa and ground albedo) from the keyboard. The name of a NEW file must be indicated: this will contain the input data above, the model wavelengths, the extraterrestrial and the computed spectral direct, diffuse and global irradiances, together with their broadband integrals. Data are in Ascii; the format is indicated in the program list.

5. PROGRAM PLOIRR

This BASIC program provides a graph (on the PC screen) of the spectral extraterrestrial, direct, diffuse and global irradiances. The spectral data are stored in an Ascii file written by the program SPECIR. The graph can be then directed to a printer by means of the PRINT SCREEN key. Some examples are here given for Trieste, June 21th, sun at the meridian (12 h, 6 min), normal climatic data. *Fig. 1,2* and *3* show the effect of the water vapor absorption by increasing the relative humidity (0 %, 50 % and 100 %); *Fig. 4* and *5* show the effect of the atmospheric turbidity by considering a horizontal visibility equal to 100 and 5 km respectively.

6. SUBROUTINE SUNDAZ

The Fortran subroutine SUNDAZ (RLAT,RLONG,RLF,NDAY,HOUR, ELE,AZI,K) can be used to compute the sun elevation ELE above the horizon and the sun azimuth AZI, clockwise from the north, for a given latitude and longitude (RLAT, RLONG), day number NDAY and time HOUR. RLF is the standard meridian, having a longitude equal to 0°, 15°, 30° if the local time is GMT + 0, 1, 2 ... hours. The sun declination DEC and the equation of time EQ are stored in COMMON /SUN/. The output angles are in degrees/radians if K = 0/1. A list of symbols and formulae is supplied for the user's convenience (Stravisi, 1986).

ϕ , λ	latitude, longitude,
λ_S	longitude of the standard meridian (0°,15°,30° ..),
δ	sun declination,
t_H	sun hour angle,
e	equation of time,
α	sun elevation above the horizon,
θ	sun azimuth, or true bearing, clockwise from north on the local horizon,
t_S	local apparent time or true solar time,
t_M	local mean time,
t	clock time,
Δt	longitude correction, positive east of the standard meridian,
t_σ	passage of the sun at the local meridian ($t_H = 0$),
g	length of light time, from sunrise to sunset,
$t_\sigma \pm g/2$	astronomical sunrise and sunset.

The local sun coordinates are related to the sun coordinates referred to the celestial equator by:

$$\begin{aligned} \sin\alpha &= \sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \cos t_H , \\ \cos\theta &= (\cos\phi\ \sin\delta - \sin\phi\ \cos\delta \cos t_H)/\cos\alpha . \\ \sin\theta &= -\cos\delta\ \sin t_H/\cos\alpha . \end{aligned}$$

If $\sigma = \pi$ rad = 180° = 12 h indicates the south, it is:

$$\begin{aligned} t_H &= t_S - \sigma , \\ t_S &= t_M + e , \\ t_M &= t + \Delta t , \\ \Delta t &= \lambda - \lambda_S \end{aligned}$$

and

$$t_S = t + \Delta t + e .$$

For $t_S = \sigma$ ($t_H = 0$), the local time at which the sun is south is:

$$t_\sigma = 12\text{ h} - \Delta t - e .$$

The expression for $\sin\alpha$ then yields (i) the maximum elevation α_σ of the sun, which varies during the year between $90° - (\phi \pm \delta)$, and (ii), for $\alpha = 0$, the length of the light time

$$g = 2 \arccos(-\mathrm{tg}\phi\ \mathrm{tg}\delta)$$

and the times of sunrise and sunset $t_\sigma \pm g/2$.

7. SENSITIVITY OF THE MODEL TO THE INPUT PARAMETERS

The following table reports the variations of the broadband diffuse, direct and global irradiance (unit: W/m^2) and of the percentual ratio between diffuse and global irradiance for typical variations of some model parameters. The average climatic conditions for Trieste (ϕ = 45.64° N, λ = 13.75° E), 21 September, have been used: p = 1015.7 hPa, θ = 20 °C, U = 60 %, V = 17 km (β = 0.14), r_G = 0.2, α = 1.3, Θ = 44.81° (M_A = 1.4). The broadband irradiances are respectively 186, 714 and 692 W/m^2, with R = I_S/I_T = 27 %.

	$\Delta\alpha = 0.1$	$\Delta\beta = 0.01$	Δp = 100 hPa	$\Delta\theta$ = 1 °C	ΔU = 10 %	$\Delta r_G = 0.1$
ΔI_S	+ 4	+ 8	+ 1	- 0	- 1	+ 7
ΔI_D	- 9	-15	- 7	- 2	- 6	0
ΔI_T	- 2	- 3	- 4	- 2	- 5	+ 7
ΔR	+ 1	+ 1	+ 0	+ 0	+ 0	+ 1

REFERENCES

Bird R.E. and Riordan C. (1986): *"Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the earth's surface for cloudless atmospheres"*. J. Climate Appl. Meteor., 25, 87-97.

Iqbal M. (1983): *"An introduction to solar radiation"*. Academic Press.

Kasten F. (1966): *"A new table and approximate formula for relative optical air mass"*. Arch. Meteor. Geophys. Bioklim. B14, 206-223.

Kneyzys F.X., Shettle E.P., Gallery W.O., Chetwynd Jr. J.H., Abrea L.W., Selby J.E.A., Fenn R.W. and McClatchey R.W. (1980): "*Atmospheric transmittance/radiance: computer code LOWTRAN5"*. Tech. Rep. AFGL-TR-80-0067, USAF Geophysics Laboratory, Hanscom AFB, MA.

Leckner B. (1978): *"The spectral distribution of solar radiation at the earth's surface - elements of a model"*. Solar Energy, 20, 143-150.

Michalsky J.J. (1988): *"The Astronomical Almanac's algorithm for approximate solar position (1950-2050)"*. Sol. Energy, 40, 227-235.

Neckel H. and Labs D. (1981): *"Improved data of solar spectral irradiance from 0.33 to 1.25 micrometers"*. Solar Phys., 74, 231-249.

Spencer J.W. (1971): *"Fourier series representation of the position of the sun"*. Search, 2, 172.

Stravisi F. (1986): *"Sun ephemerides for Trieste"*. CNR - Ist. Talassografico, Trieste, Internal rep. RF 2 (in italian).

Stravisi F. (1988): *"A BASIC program for psychrometric computations and mercury barometer corrections"*, FTC 88/3, 10 pp.

Van Heuklon T.K. (1979): *"Estimating atmospheric ozone for solar radiation models"*. Solar Energy, 22, 63-68.

```
      PROGRAM SPECIR
C-------------------------------------- Franco Stravisi 1988
C  Modified Bird & Riordan code for the computation of the
C  spectral sun irradiance at ground level.
C  INPUT:
C  latitude, longitude, day number, sun zenith angle,
C  atmospheric pressure, air temperature, rel. humidity,
C  visibility, Angstrom coefficient alfa, ground albedo.
C  OUTPUT:
C  ASCII file with above data plus ozone amount, relative
C  ozone, water vap and air mass, Angstrom coefficient beta,
C  precipitable water and sun distance factor. Furthermore:
C  vectors DIM(123) containing spectral extraterrestrial
C  irradiance, global, direct and diffuse ground irradiance
C  plus broadband integrated values. FORMAT:
C    RLAT    RLONG                     2F10.3
C    NDAY    D      Z                  I10,2F10.3
C    P       T      UR     VIS         4F10.3
C    ALFA    BETA   RG                 3F10.3
C    AM      WM     OM     OZ     PW          5F10.3
C    1    WL(  1)   H0(  1)   DIR(  1)   DIF(  1)   GLO(  1)
C    ........
C  122    WL(122)   H0(122)   DIR(122)   DIF(122)   GLO(122)
C  123             integral  integral   integral   integral
C   I5    5F10.3
C   I5    10X,4F10.3
C-----------------------------------------------------------
      DIMENSION DIR(123),DIF(123),GLO(123),F(123)
      DIMENSION WL(122),H0(122),AW(122),AO(122),AU(122)
      CHARACTER*30 ASCII
      CHARACTER*1 NORD,EST
      COMMON /SPECTA/WL,H0,AW,AO,AU
      COMMON /MASS/AM,WM,OM,OZ,PW
      COMMON /DISTA/D
      INT=1
      WRITE(*,1000)
 1000 FORMAT(1X,78('-'),/
     .' ICTP Climatology Laboratory  ------ ',
     .' Franco Stravisi 1988',/
     .' Spectral irradiance computations,',
     .' 122 wavelengths',/
     .' (modified Bird & Riordan 1986 code).',/
     .' INPUT: lat., long., day number, sun zenith angle,',/
     .' atmospheric pressure, screen air temperature and',/
     .' relative humidity, visibility (to compute beta),',/
     .' Angstrom coefficient alfa and ground albedo.',/
     .' OUTPUT: ASCII file with input data above,'/
     .' spectral irradiance (122 wavelengths),'/
     .' extraterrestrial, direct, diffuse, global'
     .' irradiance and corresponding integrals.',
     .  /1X,78('-'),/)
    1 WRITE(*,2)
    2 FORMAT(' Latitude  (degrees, N positive) ?  '\)
      READ(*,3,ERR=1) RLAT
    3 FORMAT(F10.5)
    4 WRITE(*,5)
    5 FORMAT(' Longitude (degrees, E positive) ?  '\)
      READ(*,3,ERR=4) RLONG
    6 WRITE(*,7)
    7 FORMAT(' Day number (INTEGER, 1 to 365)  ?  '\)
      READ(*,8,ERR=6) NDAY
    8 FORMAT(I5)
    9 WRITE(*,10)
   10 FORMAT(' Sun zenith angle (degrees)      ?  '\)
      READ(*,3,ERR=9) Z
   11 WRITE(*,12)
```

```
   12 FORMAT(' Atmospheric pressure /hPa       ?  '\)
      READ(*,3,ERR=11) P
   13 WRITE(*,14)
   14 FORMAT(' Screen air temperature /.C      ?  '\)
      READ(*,3,ERR=13) T
   15 WRITE(*,16)
   16 FORMAT(' Screen relative humidity /%     ?  '\)
      READ(*,3,ERR=15) UR
   17 WRITE(*,18)
   18 FORMAT(' Horizontal visibility /km       ?  '\)
      READ(*,3,ERR=17) VIS
   19 WRITE(*,20)
   20 FORMAT(' Angstrom coefficient alfa       ?  '\)
      READ(*,3,ERR=19) ALFA
   21 WRITE(*,22)
   22 FORMAT(' Ground albedo (0.1 - 0.9)       ?  '\)
      READ(*,3,ERR=21) RG
   23 WRITE(*,24)
   24 FORMAT(/' Name of NEW Ascii file for output   ?   '\)
      READ(*,25,ERR=23) ASCII
   25 FORMAT(A30)
      WRITE(*,30)
   30 FORMAT(//' Computing......'//)
C
      CALL SPCTRL(RLAT,RLONG,NDAY,Z,P,T,UR,VIS,RG,ALFA,INT,
     .            DIR,DIF,GLO)
      DO 80 I=1,122
   80 F(I)=H0(I)
      CALL BROBAN(F,122)
      SC=F(123)
      OPEN(1,FILE=ASCII,STATUS='NEW')
      WRITE(1,50) RLAT,RLONG
   50 FORMAT(2F10.3)
      WRITE(1,51) NDAY,D,Z
   51 FORMAT(I10,2F10.3)
      WRITE(1,52) P,T,UR,VIS
   52 FORMAT(4F10.3)
      BE=BETA(ALFA,VIS)
      WRITE(1,53) ALFA,BE,RG
   53 FORMAT(3F10.3)
      WRITE(1,54) AM,WM,OM,OZ,PW
   54 FORMAT(5F10.3)
      DO 100 I=1,122
  100 WRITE(1,55) I,WL(I),H0(I),DIR(I),DIF(I),GLO(I)
   55 FORMAT(I5,5F10.3)
      I=123
      WRITE(1,56) I,SC,DIR(123),DIF(123),GLO(123)
   56 FORMAT(I5,10X,4F10.3)
      CLOSE(1)
      NORD='N'
      EST='E'
      IF(RLAT.LT.0.) NORD='S'
      IF(RLAT.LT.0.) RLAT=-RLAT
      IF(RLONG.LT.0.) EST='W'
      IF(RLONG.LT.0.) RLONG=-RLONG
      WRITE(*,60) RLAT,NORD,RLONG,EST,NDAY
   60 FORMAT(' LAT =',F6.2,' deg ',A1,5X,'LONG =',F7.2,
     .       ' deg ',A1,'     DAY =',I4)
      WRITE(*,61) Z
   61 FORMAT(' Sun zenith angle =',F6.2)
      WRITE(*,62) P,T
   62 FORMAT(' Pressure =',F7.1,' hPa',5X,
     .       'Temperature =',F6.1,' deg C')
      WRITE(*,63) UR,VIS
   63 FORMAT(' Humidity =',F6.1,' %',8X,
     .       'Visibility  =',F6.1,' km')
```

```
      WRITE(*,64) ALFA,BE,RG
   64 FORMAT(' Alfa =',F6.2,3X,'Beta =',F6.3,
     .       '   Ground albedo =',F6.2)
      WRITE(*,65) AM,OM,WM
   65 FORMAT(' Rel. air mass =',F7.3,5X,
     .'Rel. O3 mass =',F7.3/' Rel. water vapor mass =',F7.3)
      WRITE(*,66) OZ,PW
   66 FORMAT(' Ozone =',F6.3,' cm NTP'/
     .       ' Precip. water =',F6.3,' cm')
      STOP
      END
```

```
      SUBROUTINE SPCTRL(RLAT,RLONG,NDAY,Z,P,T,UR,VIS,RG,
     .                  ALFA,INT,DIR,DIF,GLO)
C-----------------------------------------------------FS1988
C  Computes the spectral solar irradiance on an horizontal
C  surface at sea level according to the SPCTRL2 model by
C  BIRD R.E. and RIORDAN C. (J. Clim. Appl. Met., 25, 87-97, C  1986). Uses
C  122 wavelengths between 0.3 and 4
C  micrometers. Some modifications have been introduced.
C  -------- Input:
C  RLAT     latitude  in degrees (and fraction of degree)
C  RLONG    longitude        "
C  NDAY     day number between 1 and 365
C  Z        sun zenith angle in degrees
C  P        atmospheric pressure in hPa
C  T        air (screen) temperature in degrees Celsius
C  UR       percentual (0-100) rel. humidity (at the ground)
C  VIS      atmospheric horizontal visibility in kilometers
C  RG       ground albedo (see e.g. Iqbal, 1983, page 289)
C  ALFA     Angstrom coefficient alfa (usually  1.3 +- 0.5)
C  INT      parameter: if INT = 1  spectral integrals are
C                                  computed.
C  -------- Output:
C  DIR      vector containing the spectrum of the direct
C           normal solar irradiance (1 to 122) and its
C           integral (123),
C           if INT =1;
C  DIF      the same for the diffuse component;
C  GLO      the same for the global (direct + diffuse)
C           irradiance.
C  -------- Output in COMMON:
C  /TRANS/  there are 7 vectors, dim(122), describing the
C           transmittance functions at the wavelengths WV
C           related to Rayleigh, aerosol, water vapor, ozone
C           and uniformly mixed gas scattering/absorption
C           (TRAY, TAER, TWAV, TOZO, TGAS)   and the
C           transmittance terms TAA and TAS for aerosol
C           absorption and scattering.
C  /IRRAD/  DIFR, DIFA and DIFG contain the spectra of the
C           diffuse irradiance due to Rayleigh scattering,
C           aerosol scattering and multiple reflection
C           between ground and air (1 to 122) and the
C           related integrals (123, if INT = 1).
C  /RSOMC/  contains the ground albedo RS, the aerosol
C           single scattering albedo OME and the total
C           scattered irradiance coefficient CS as functions
C           of wavelength (1 to 122).
C  /MASS/   contains the relative air mass AM and water
C           vapor mass WM (Kasten 1966), the ozone mass OM,
C           the NTP ozone amount OZ in cm for that site and
C           day and the precipitable water vapor PW in cm.
C  /SPECTA/ contains data of Table 1. Vectors (122) define
C           the wavelengths WL, the extraterrestrial
C           spectrum H0, the absorption coefficient AW
```

```
C           (cm2/g), AO (1/cm) for water vapor and ozone and
C           the AU factors (1/km) for the uniform gas
C           transmittance.
C-----------------------------------------------------------------
C  ROUTINES required:
C  BLOCK DATA H0A122,
C  FUNCTION DISTES,O3,RAM,RWVM,ROM,TR,TA,TW,TO,TU,WV,BETA,
C           ASCA,FS
C  SUBROUTINE BROBAN(F,N)   performing integration
C-----------------------------------------------------------------
      DIMENSION DIR(123),DIF(123),GLO(123),DIFR(123),
     .          DIFA(123),DIFG(123)
      DIMENSION TRAY(122),TAER(122),TWAV(122),TOZO(122),
     .TGAS(122),TAA(122),TAS(122),RS(122),OME(122),CS(122)
      DIMENSION WL(122),H0(122),AW(122),AO(122),AU(122)
      COMMON /TRANS/TRAY,TAER,TWAV,TOZO,TGAS,TAA,TAS
      COMMON /IRRAD/DIFR,DIFA,DIFG
      COMMON /RSOMC/RS,OME,CS
      COMMON /MASS/AM,WM,OM,OZ,PW
      COMMON /SPECTA/WL,H0,AW,AO,AU
      COMMON /DISTA/D
      DIR(123)=0.
      DIF(123)=0.
      GLO(123)=0.
      DIFR(123)=0.
      DIFA(123)=0.
      DIFG(123)=0.
      CZ=COS(Z/57.29578)
      FSZ=FS(Z)
      PM=1.8
      BE=BETA(ALFA,VIS)
      AM=RAM(Z)
      WM=RWVM(Z)
      OM=ROM(Z)
      OZ=O3(RLAT,RLONG,NDAY)
      PW=WV(UR,T)
      D=DISTES(NDAY)
      DO 10 L=1,122
      W=WL(L)
      AWL=AW(L)
      AOL=AO(L)
      AUL=AU(L)
      TRAY(L)=TR(W,AM,P)
      TAER(L)=TA(W,AM,ALFA,BE)
      TWAV(L)=TW(AWL,WM,PW)
      TOZO(L)=TO(AOL,OM,OZ)
      TGAS(L)=TU(AUL,AM,P)
      OME(L)=ASCA(W)
      TAS(L)=TAER(L)**OME(L)
      TAA(L)=TAER(L)/TAS(L)
      TAP=TA(W,PM,ALFA,BE)
      TASP=TAP**OME(L)
      TAAP=TAP/TASP
      TRP=TR(W,PM,P)
      RS(L)=TO(AOL,PM,OZ)*TW(AWL,PM,PW)*TAAP*
     .     (0.5*(1.-TRP)+0.191*TRP*(1.-TASP))
      IF(W.LT.0.45) CS(L)=(W+0.55)**1.8
      IF(W.GE.0.45) CS(L)=1.0
      HDT=H0(L)*D*TWAV(L)*TOZO(L)*TGAS(L)
      DIR(L)=HDT*TRAY(L)*TAER(L)
      HDTZA=CS(L)*HDT*CZ*TAA(L)
      DIFR(L)=HDTZA*(1.-TRAY(L)**0.95)/2.
      DIFA(L)=HDTZA*(1.-TAS(L))*FSZ*TRAY(L)**1.5
      RSG=RS(L)*RG
      DIFG(L)=(CS(L)*DIR(L)*CZ+DIFR(L)+DIFA(L))*RSG/(1.-RSG)
      DIF(L)=DIFR(L)+DIFA(L)+DIFG(L)
```

```
      GLO(L)=DIR(L)*CZ+DIF(L)
   10 CONTINUE
      DIR(123)=0.
      DIFR(123)=0.
      DIFA(123)=0.
      DIFG(123)=0.
      DIF(123)=0.
      GLO(123)=0.
      IF(INT.EQ.0) RETURN
      CALL BROBAN(DIR,122)
      CALL BROBAN(DIFR,122)
      CALL BROBAN(DIFA,122)
      CALL BROBAN(DIFG,122)
      DIF(123)=DIFR(123)+DIFA(123)+DIFG(123)
      GLO(123)=DIR(123)*CZ+DIF(123)
      RETURN
      END


      SUBROUTINE BROBAN(F,N)
C-----------------------------------------------------------
C  Computes the integral (broad band) value of F by
C  summation over wavelengths (1 to 122). The integral is
C  stored in F(123).
C-----------------------------------------------------FS1988
      DIMENSION F(123),W(122),H0(122),AW(122),AO(122),
     .          AU(122)
      COMMON /SPECTA/W,H0,AW,AO,AU
      BB=0.
      DO 1 I=2,N
      J=I-1
    1 BB=BB+(W(I)-W(J))*(F(I)+F(J))*0.5
      F(123)=BB
      RETURN
      END


      FUNCTION DISTES(NDAY)
C-----------------------------------------------------------
C  Computes the the earth-sun distance factor, according to
C  Spencer (1971), for each day of the year.
C  NDAY  = 1 to 365
C-----------------------------------------------------FS1988
      X=6.2831853*FLOAT(NDAY-1)/365.
      X2=X*2.
      DISTES=1.00011+0.034221*COS(X) +0.00128 *SIN(X)
     .              +0.000719*COS(X2)+0.000077*SIN(X2)
      RETURN
      END


      FUNCTION O3(RLAT,RLONG,NDAY)
C-----------------------------------------------------------
C  Computes the ozone amount (in atm-cm) given by
C  Van Heuklon (1979), as a function of the day number NDAY C  (1 to 365),
C  latitude and longitude (in degrees).
C-----------------------------------------------------FS1988
      PI=3.1415927
C  Compute ozone amount:
      X=FLOAT(NDAY-30)
      O3=0.235+(0.150+0.040*SIN(X*2.*PI/365.25)
     .  +0.020*SIN((RLONG+20.)*3.*PI/180.))
     .  *SIN(1.28*RLAT*PI/180.)**2
      RETURN
      END
```

```
      FUNCTION RAM(Z)
C------------------------------------------------------------

C   Computes the relative air mass (Kasten, 1966) as
C   a function of the sun zenith angle in degrees.
C------------------------------------------------------FS1988
      RD=57.2957795
      ZR=Z/RD
      X=COS(ZR)+0.15/(93.885-Z)**1.253
      RAM=1./X
      RETURN
      END

      FUNCTION RWVM(Z)
C------------------------------------------------------------
C  Computes the relative water vapor mass (Kasten, 1966) as
C  a function of the sun zenith angle in degrees.
C------------------------------------------------------FS1988
      RD=57.2957795
      ZR=Z/RD
      X=COS(ZR)+0.0548/(92.650-Z)**1.452
      RWVM=1./X
      RETURN
      END


      FUNCTION ROM(Z)
C------------------------------------------------------------
C  Computes the Robinson relative ozone mass (Iqbal 1983) as
C  a function of the sun zenith angle (in degrees).
C  A maximum ozone concentration height of 22 km is assumed.
C------------------------------------------------------FS1988
      RD=57.2957795
      ZD=Z/RD
      HO=22./6370.
      ROM=(1.+HO)/SQRT(COS(ZD)**2+2.*HO)
      RETURN
      END

      FUNCTION WV(UR,TA)
C------------------------------------------------------------
C  Computes the precipitable water vapor in the vertical
C  column (in cm) (Iqbal 1983, page 94), as a function of
C  the percentual relative humidity UR and of the air
C  temperature at the ground (in Celsius).
C------------------------------------------------------FS1988
      T=TA+273.15
      ES=EXP(26.23-5416./T)
      WV=0.00493*UR*ES/T
      RETURN
      END

      FUNCTION BETA(AL,V)
C------------------------------------------------------------
C  Computes the Angstrom turbidity coefficient BETA
C  (in micrometers to alfa) as a function of the wavelength
C  exponent alfa  AL and of the horizontal atmospheric
C  visibility V (in kilometers), according to Mc Clatchey & C  Selby (1972)
C  is reported by Iqbal (1983).
C  Valid for   V > 5 km.
C------------------------------------------------------FS1988
      X=3.912/V-0.01162
      Y=0.02472*(V-5.)+1.132
      BETA=X*Y*0.55**AL
      RETURN
```

```
      END


      FUNCTION FS(Z)
C-----------------------------------------------------------
C  Computes the downward fraction of the aerosol scatter as

C  a function of the sun zenith angle Z (in degrees).
C-----------------------------------------------------FS1988
      C=COS(Z/57.29578)
      E=(0.176*C-1.83)*C
      FS=1.-0.5*EXP(E)
      RETURN
      END

      FUNCTION ASCA(W)
C-----------------------------------------------------------
C  Computes the aerosol single scattering albedo as a
C  function of wavelength W (in micrometers).
C-----------------------------------------------------FS1988
      E=-0.095*(ALOG(W/0.4))**2
      ASCA=0.945*EXP(E)
      RETURN
      END

FUNCTION TR(W,AM,P)
C-----------------------------------------------------------
C  Computes the atmospheric transmittance after Rayleigh
C  scattering as a function of wavelength W (in micro-
C  meters), relative air mass AM and air pressure P (in hPa)
C  (Kneizys et al., 1980).
C-----------------------------------------------------FS1988
      AC=AM*P/1013.25
      W2=W*W
      W4=W2*W2
      TR=EXP(-AC/(W4*(115.6406-1.335/W2)))
      RETURN
      END

      FUNCTION TA(W,AM,AL,BE)
C-----------------------------------------------------------
C  Computes the atmospheric transmittance after the aerosol
C  scattering and absorption as a function of the wavelength
C  W (in micrometers), the relative air mass AM and the
C  Angstrom turbidity coefficients AL, BE.
C-----------------------------------------------------FS1988
C  Angstrom turbidity:
      TAU=BE/W**AL
C
      TA=EXP(-TAU*AM)
      RETURN
      END

      FUNCTION TW(AW,WM,PW)
C-----------------------------------------------------------
C  Computes the atmospheric transmittance after absorption
C  by the water vapor (Leckner, 1978), as a function of the
C  wv absorption coefficient AW (in cm2/g) depending on the
C  wavelength (122 values are defined by BLOCK DATA H0A122),
C  the relative water vapor mass WM and the precipitable
C  water vapor PW (in cm).  Constants  C1, C2  are in g/cm3.
C-----------------------------------------------------FS1988
      AWM=AW*PW*WM
      C1=-0.2385
      C2=20.07
      TW=EXP(C1*AWM/(1+C2*AWM)**0.45)
```

```
      RETURN
      END
FUNCTION TO(AO,OM,OZ)
C-----------------------------------------------------------
C  Computes the atmospheric transmittance after ozone
C  absorption (Leckner 1978), using the  Robinson ozone mass
C  OM  (Iqbal 1983) and the ozone amount OZ (in cm at NTP)
C  given by Van Heuklon (1979), as a function of AO (1/cm),
C  the ozone absorption coefficient depending on wavelength
C  (122 AO values are given in BLOCK DATA H0A122).
C-----------------------------------------------------FS1988
      TO=EXP(-AO*OZ*OM)
      RETURN
      END

      FUNCTION TU(AU,AM,P)
C-----------------------------------------------------------
C  Computes the atmospheric transmittance after absorption
C  by uniformly mixed gas using Leckner's (1978) expression,
C  as a function of the wavelength dependent absorption
C  coefficient AU (in 1/km)  (122 values are given by BLOCK
C  DATA H0A122) and the relative air mass AM corrected by
C  the air pressure P (in hPa). Constants  C1, C2 are in km.
C-----------------------------------------------------FS1988
      A=AU*AM*P/1013.25
      C1=-1.41
      C2=118.3
      TU=EXP(C1*A/(1.+C2*A)**0.45)
      RETURN
      END

      BLOCK DATA H0A122

C-----------------------------------------------------------
C  Neckel and Labs (1981) revised extraterrestrial spectrum
C  and atmospheric absorption coefficients at 122
C  wavelengths (Bird & Riordan 1986, Tab. 1).
C  W   wavelength  (micrometers)
C  H0  extraterrestrial spectral irradiance
C      (W/m2 per micrometer)
C  AW  water vapor absorption coefficient (cm2/g)
C  AO  ozone       absorption coefficient (1/cm)
C  AU  uniformly mixed gas absorption coefficient times
C      gas amount (1/km)
C-----------------------------------------------------FS1988
      DIMENSION W(122),H0(122),AW(122),AO(122),AU(122)
C
      COMMON /SPECTA/W,H0,AW,AO,AU
C
      DATA W/0.3,0.305,0.310,0.315,0.320,0.325,0.330,0.335,
     .0.340,0.345,0.35,0.36,0.37,0.38,0.39,0.40,0.41,0.42,
     .0.43,0.44,0.45,0.46,0.47,0.48,0.49,0.50,0.51,0.52,
     .0.53,0.54,0.55,0.57,0.593,0.610,0.630,0.656,0.6676,
     .0.690,0.710,0.718,0.7244,0.740,0.7525,0.7575,0.7625,
     .0.7675,0.780,0.800,0.816,0.8237,0.8315,0.840,0.860,
     .0.880,0.905,0.915,0.925,0.930,0.937,0.948,0.965,0.980,
     .0.9935,1.04,1.07,1.10,.1.12,1.13,1.145,1.161,1.17,
     .1.20,1.24,1.27,1.29,1.32,1.35,1.395,1.4425,1.4625,
     .1.477,1.497,1.520,1.539,1.558,1.578,1.592,1.610,1.630,
     .1.646,1.678,1.740,1.80,1.860,1.920,1.960,1.985,2.005,
     .2.035,2.065,2.10,2.148,2.198,2.270,2.360,2.450,2.5,
     .2.6,2.7,2.8,2.9,3.0,3.1,3.2,3.3,3.4,3.5,3.6,3.7,
     .3.8,3.9,4.0/
C
      DATA H0/535.9,558.3,622.0,692.7,715.1,832.9,961.9,
     .931.9,900.6,911.3,975.5,975.9,1119.9,1103.8,1033.8,
```

```
     .1479.1,1701.3,1740.4,1587.2,1837.0,2005.0,2043.0,
     .1987.0,2027.0,1896.0,1909.0,1927.0,1831.0,1891.0,
     .1898.0,1892.0,1840.0,1768.0,1728.0,1658.0,1524.0,
     .1531.0,1420.0,1399.0,1374.0,1373.0,1298.0,1269.0,
     .1245.0,1223.0,1205.0,1183.0,1148.0,1091.0,1062.0,
     .1038.0,1022.0,998.7,947.2,893.2,868.2,829.7,830.3,
     .814.0,786.9,768.3,767.0,757.6,688.1,640.7,606.2,585.9,
     .570.2,564.1,544.2,533.4,501.6,477.5,442.7,440.0,416.8,
     .391.4,358.9,327.5,317.5,307.3,300.4,292.8,275.5,272.1,
     .259.3,246.9,244.0,243.5,234.8,220.5,190.8,171.1,144.5,
     .135.7,123.0,123.8,113.0,108.5,97.5,92.4,82.4,74.6,
     .68.3,63.8,49.5,48.5,38.6,36.6,32.0,28.1,24.8,22.1,
     .19.6,17.5,15.7,14.1,12.7,11.5,10.4,9.5,8.6/
C
      DATA AW/32*0.0,0.075,4*0.0,0.016,0.0125,1.80,2.5,
     .0.061,0.0008,0.0001,2*0.00001,0.0006,0.0360,1.60,2.5,
     .0.500,0.155,0.00001,0.0026,7.0,5.0,5.0,27.0,55.0,45.0,
     .4.0,1.48,0.1,0.00001,0.001,3.2,115.0,70.0,75.0,10.0,
     .5.0,2.0,0.002,0.002,0.1,4.0,200.0,1000.0,185.0,80.0,
     .80.0,12.0,0.16,0.002,0.0005,0.0001,0.00001,0.0001,
     .0.001,0.01,0.036,1.1,130.0,1000.0,500.0,100.0,4.0,2.9,
     .1.0,0.4,0.22,0.25,0.33,0.50,4.0,80.0,310.0,15000.0,
     .22000.0,8000.0,650.0,240.0,230.0,100.0,120.0,19.5,
     .3.6,3.1,2.5,1.4,0.17,0.0045/
C
      DATA AO/10.0,4.80,2.70,1.35,0.800,0.380,0.160,0.075,
     .0.040,0.019,0.007,9*0.0,0.003,0.006,0.009,0.014,0.021,
     .0.030,0.040,0.048,0.063,0.075,0.085,0.120,0.119,0.120,
     .0.090,0.065,0.051,0.028,0.018,0.015,0.012,0.010,0.008,
     .0.007,0.006,0.005,76*0.0/
C
      DATA AU/37*0.0,0.15,6*0.0,4.0,0.35,26*0.0,0.05,0.30,
     .0.02,0.0002,0.00011,0.00001,0.05,0.011,0.005,0.0006,
     .0.0,0.005,0.13,0.04,0.06,0.13,0.001,0.0014,0.0001,
     .0.00001,0.00001,0.0001,0.001,4.3,0.20,21.0,0.13,1.0,
     .0.08,0.001,0.00038,0.001,0.0005,0.00015,0.00014,
     .0.00066,100.0,150.0,0.13,0.0095,0.001,0.8,1.9,1.3,
     .0.075,0.01,0.00195,0.004,0.29,0.025/
      END
```

```
10 REM- PROGRAM PLOIRR. PLOTS SPECTRAL IRRADIANCE, 122 WAVELENGTHS
20 FS=.2
30 DIM W(122),H(122),DIR(122),DIF(122),GLO(122)
40 PRINT" ICTP Climatology Laboratory ------- Franco Stravisi 1988"
50 PRINT" This program plots spectral irradiances from  an ASCII file"
60 PRINT" created by the Fortran program SPECIR using a modified"
70 PRINT" version of the Bird & Riordan 1986 code."
80 PRINT" Spectra are defined at 122 wavelengths from 0.3 to 4.0 .m."
90 PRINT" Graphs represent: (i) extraterrestrial normal SI at average"
100 PRINT" earth-sun distance, (ii) direct (beam) normal SI at the ground,"
110 PRINT" (iii) diffuse and (iv) global SI at a ground horizontal urface."
120 PRINT" Use <PRINT SCREEN> for output on a printer."
   :PRINT
130 INPUT" File name"; NF$
140 OPEN "I", #1, NF$
150 INPUT #1, LAT,LONG,DAY,SD,Z,PA,TA,UR,VIS,ALFA,BETA,
              GRAL,RAM,RWM,ROM,O3,PW
160 N$="N": E$="E"
170 IF LAT < 0 THEN N$="S": IF LAT < 0 THEN LAT=-LAT
180 IF LONG < 0 THEN E$="W": IF LONG < 0 THEN LONG=-LONG
190 FOR I=1 TO 122
   :INPUT #1, Y,W(I),H(I),DIR(I),DIF(I),GLO(I)
200 W(I)=W(I)^FS
210 NEXT I
220 INPUT #1, Y, H0,ID,IS,IG
230 H0D=H0*SD: ID0=100*ID/H0D
240 SCREEN 3: CLS: KEY OFF
250 X1=.3^FS: X2=4^FS: D=X2-X1: XS=X1-D/9: XD=X2
260 Y1=0: Y2=2100: D=Y2-Y1: YD=Y1-D/8: YU=Y2+D/16
270 DX=5*(XD-XS)/640: DY=5*(YU-YD)/400
280 WINDOW(XS,YD)-(XD,YU)
290 FOR I=Y1 TO Y2 STEP 100: DX1=DX
   :IF I MOD 500 = 0 THEN DX1=DX*2
300 LINE(X1,I)-(X1-DX1,I): LINE(X2,I)-(X2-DX1,I): NEXT I
310 LINE(X1,Y1)-(X2,Y1): LINE-(X2,Y2)
   :LINE-(X1,Y2): LINE-(X1,Y1)
320 X0=.3
330 X0=X0+.1 : XF=X0^FS
340 LINE(XF,Y1)-(XF,Y1-DY): LINE(XF,Y2)-(XF,Y2-DY)
350 IF X0 >= 4 THEN GOTO 360 ELSE GOTO 330
360 DY=2*DY: FOR I=5 TO 35 STEP 5: X0=(I/10)^FS
370 LINE(X0,Y1)-(X0,Y1-DY): LINE(X0,Y2)-(X0,Y2-DY) :NEXT I
380 FOR I=1 TO 121: LINE(W(I),H(I))-(W(I+1),H(I+1)): NEXT I
390 FOR I=1 TO 121: LINE(W(I),DIR(I))-(W(I+1),DIR(I+1))
   :NEXT I
400 FOR I=1 TO 121: LINE(W(I),DIF(I))-(W(I+1),DIF(I+1))
   :NEXT I
410 FOR I=1 TO 121: LINE(W(I),GLO(I))-(W(I+1),GLO(I+1))
   :NEXT I
420 REM FOR I=1 TO 122: LINE(W(I),H(I))-(W(I),DIR(I))
   :NEXT I
430 REM PAINT(W(5),H(5)-10),1
440 FOR I=1 TO 122: CIRCLE(W(I),DIR(I)),.002: NEXT I
450 LOCATE 1,9: PRINT "Spectral irradiance / (W/m.)/.m";
460 LOCATE 1,42: PRINT"-  ICTP Climatology Laboratory, Trieste";
470 LOCATE 3,3: PRINT "2OOO";: LOCATE 8,3: PRINT "15OO";
480 LOCATE 13,3: PRINT "1OOO";: LOCATE 18,4: PRINT "5OO";
   :LOCATE 23,5:PRINT "O";
490 LOCATE 24,19: PRINT "O.5";: LOCATE 24,36: PRINT "1.O";
500 LOCATE 24,48: PRINT "1.5";: LOCATE 24,56: PRINT "2.O";
510 LOCATE 24,63: PRINT "2.5";: LOCATE 24,69: PRINT "3.O";
520 LOCATE 24,75: PRINT "3.5";: LOCATE 24,79
   :PRINT CHR$(230)+"m";
530 LOCATE 4,38: PRINT "----- Solar constant = 1367  W/m. -----";
540 LOCATE 5,38: PRINT "LAT = "; :PRINT USING "##.##"; LAT;
```

```
   :PRINT "."+N$;
550 LOCATE 5,61: PRINT "LONG = ";
   :PRINT USING "###.##"; LONG; :PRINT "."+E$;
560 LOCATE 6,38: PRINT "DAY = ";:PRINT USING "###"; DAY;
   :PRINT",  ";
570 PRINT "D ="; :PRINT USING "##.###"; SD; :PRINT ", O3 =";
580 PRINT USING "##.##"; O3;: PRINT " cm NTP";
590 LOCATE 7,38: PRINT "Z = ";: PRINT USING "##.#"; Z;
   :PRINT ".,";
600 LOCATE 7,56: PRINT "rel. O3  mass =";
   :PRINT USING "##.###"; ROM;
610 LOCATE 8,38: PRINT "p = ";
   :PRINT USING "####.#"; PA; :PRINT " hPa,   ";
620 PRINT "rel. air mass =";: PRINT USING "##.###"; RAM;
630 LOCATE 9,38: PRINT "t =";: PRINT USING "####.#"; TA;
   :PRINT ".C,  U =";
640 PRINT USING "###"; UR;: PRINT " %,  vis. =";
   :PRINT USING "###.#"; VIS;
650 PRINT " km";:LOCATE 10,38: PRINT ". =";
   :PRINT USING "##.##"; ALFA;
660 PRINT ",  . =";: PRINT USING "##.##"; BETA;
   :PRINT ",    gr. alb. =";
670 PRINT USING "##.##"; GRAL;
680 LOCATE 11,38: PRINT "rel. wv mass =";
   :PRINT USING"##.###"; RWM;
690 PRINT"   pr wat =";: PRINT USING"##.##"; PW;
   :PRINT" cm";
700 LOCATE 13,38: PRINT"-- Broadband (O.3-4.O .m) irradiance --";
710 LOCATE 14,41: PRINT"Ho =";:PRINT USING "#####"; H0;
   :PRINT" W/m.";
720 LOCATE 14,59: PRINT"HoD =";: PRINT USING "#####"; H0D;
   :PRINT" W/m.";
730 LOCATE 15,41: PRINT"Id =";:PRINT USING "#####"; ID; :PRINT" W/m.";
740 LOCATE 15,59: PRINT"Id/HoD =";: PRINT USING "###.#"; ID0;: PRINT" %";
750 LOCATE 16,41: PRINT"Is =";: PRINT USING "#####"; IS;
   :PRINT" W/m.";
760 LOCATE 16,59: PRINT"Ig  =";: PRINT USING "#####"; IG;
   :PRINT" W/m.";
770 LOCATE 1,1
780 END
```

```
      SUBROUTINE SUNDAZ(RLAT,RLONG,RLF,NDAY,HOUR,ELE,AZI,K)
C----------------------------------Franco Stravisi 1986,1988
C  Computes the sun elevation above the horizon and the sun
C  azimuth for a given site, day of the year and hour.
C  Reference: Spencer, 1971.
C  Accuracy : better than one degree.
C  Validity : an "average" year is represented.
C  INPUT   :  RLAT    latitude in degrees, N positive,
C             RLONG   longitude in degrees, E positive,
C             RLF     longitude in degrees of the local time
C                     meridian (0,15,30,..)
C             NDAY    day number (1 to 365),
C             HOUR    local time in hours (0.00 to 24.00).
C  OUTPUT  :  ELE     sun elevation above the horizon,
C             AZI     sun azimuth, clockwise from north.
C  Code    :  K = 0   output angles in degrees,
C             K = 1   output angles in radiants.
C  Output in COMMON /SUN/  :
C             DEC     sun declination,  deg or rad,
C             EQ      time equation,    minutes,
C             TMER    time of sun at south, in hours,
C             GG      daylight length in hours,
```

```
C             TSR     sunrise in hours,
C             TSS     sunset  in hours.
C-------------------------------------------------------------
      COMMON /SUN/ DEC,EQ,TMER,GG,TSR,TSS
      REAL*8 SA,CA
C Define longitude correction in hours
      DT=(RLONG-RLF)*24./360.
      PI=3.1415927
      P2=6.2831853
      RH=24./P2
      GR=360./P2
      FI=RLAT/GR
      T0=P2*(FLOAT(NDAY)-1.+HOUR/24.)/365.
      T02=2.*T0
      T03=3.*T0
      S0=SIN(T0)
      C0=COS(T0)
      S02=SIN(T02)
      C02=COS(T02)
C Compute DEC/rad  and  EQ/h
      DEC=0.006918-0.399912*C0+0.070257*S0-0.006758*C02
     .   +0.000907*S02-0.002697*COS(T03)+0.001480*SIN(T03)
      EQ=(0.0075+0.1868*C0-3.2077*S0-1.4615*C02-4.0849*S02)
     .   *RH/100.
C Compute time/h of sun at meridian
      TMER=12.-DT-EQ
C Compute light time; sunrise and sunset
      GG=RH*ABS(2.*ACOS(-TAN(FI)*TAN(DEC)))
      TSR=TMER-GG/2.
      TSS=TMER+GG/2.
      SF=SIN(FI)
      CF=COS(FI)
      SD=SIN(DEC)
      CD=COS(DEC)
C  Apparent local time/h
      TLA=HOUR+DT+EQ
C  Hour angle/rad
      TH=(TLA-12.)/RH
      CH=COS(TH)
      SE=SD*SF+CD*CF*CH
C  Elevation/rad
      ELE=DATAN(SE/DSQRT(1.D0-SE*SE))
      CE=COS(ELE)
      CA=(SD*CF-CD*SF*CH)/CE
      SA=-CD*SIN(TH)/CE
C  Azimuth/rad
      AZI=DATAN2(SA,CA)
      IF(AZI.LT.0.) AZI=AZI+P2
      EQ=EQ*60.
      IF(K.EQ.1) RETURN
      ELE=ELE*GR
      AZI=AZI*GR
      DEC=DEC*GR
      RETURN
      END
```

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1	1.0351	1.0306	1.0190	1.0014	0.9845	0.9717	0.9666	0.9700	0.9814	0.9977	1.0156	1.0292
2	1.0351	1.0303	1.0185	1.0008	0.9840	0.9714	0.9666	0.9703	0.9819	0.9983	1.0161	1.0295
3	1.0351	1.0300	1.0179	1.0002	0.9835	0.9711	0.9666	0.9705	0.9824	0.9988	1.0167	1.0299
4	1.0351	1.0297	1.0174	0.9996	0.9830	0.9709	0.9666	0.9708	0.9829	0.9994	1.0172	1.0302
5	1.0351	1.0294	1.0169	0.9990	0.9825	0.9706	0.9666	0.9711	0.9834	1.0000	1.0177	1.0305
6	1.0350	1.0290	1.0164	0.9985	0.9820	0.9703	0.9666	0.9714	0.9839	1.0006	1.0182	1.0308
7	1.0350	1.0287	1.0158	0.9979	0.9816	0.9701	0.9666	0.9717	0.9844	1.0012	1.0188	1.0311
8	1.0350	1.0283	1.0153	0.9973	0.9811	0.9698	0.9666	0.9720	0.9849	1.0018	1.0193	1.0314
9	1.0349	1.0279	1.0147	0.9967	0.9806	0.9696	0.9667	0.9723	0.9854	1.0024	1.0198	1.0316
10	1.0348	1.0276	1.0142	0.9961	0.9802	0.9694	0.9667	0.9726	0.9859	1.0030	1.0203	1.0319
11	1.0347	1.0272	1.0136	0.9955	0.9797	0.9691	0.9668	0.9729	0.9865	1.0036	1.0208	1.0322
12	1.0347	1.0268	1.0131	0.9950	0.9793	0.9689	0.9668	0.9733	0.9870	1.0042	1.0213	1.0324
13	1.0346	1.0264	1.0125	0.9944	0.9788	0.9687	0.9669	0.9736	0.9875	1.0047	1.0217	1.0326
14	1.0344	1.0260	1.0119	0.9938	0.9784	0.9685	0.9670	0.9739	0.9881	1.0053	1.0222	1.0329
15	1.0343	1.0256	1.0114	0.9932	0.9779	0.9684	0.9671	0.9743	0.9886	1.0059	1.0227	1.0331
16	1.0342	1.0251	1.0108	0.9927	0.9775	0.9682	0.9672	0.9747	0.9891	1.0065	1.0232	1.0333
17	1.0340	1.0247	1.0102	0.9921	0.9771	0.9680	0.9673	0.9750	0.9897	1.0071	1.0236	1.0335
18	1.0339	1.0243	1.0096	0.9915	0.9767	0.9679	0.9674	0.9754	0.9902	1.0077	1.0241	1.0336
19	1.0337	1.0238	1.0091	0.9910	0.9763	0.9677	0.9675	0.9758	0.9908	1.0083	1.0245	1.0338
20	1.0335	1.0234	1.0085	0.9904	0.9759	0.9676	0.9677	0.9762	0.9914	1.0088	1.0249	1.0340
21	1.0334	1.0229	1.0079	0.9898	0.9755	0.9674	0.9678	0.9766	0.9919	1.0094	1.0254	1.0341
22	1.0332	1.0224	1.0073	0.9893	0.9751	0.9673	0.9680	0.9770	0.9925	1.0100	1.0258	1.0343
23	1.0330	1.0220	1.0067	0.9888	0.9747	0.9672	0.9682	0.9774	0.9930	1.0106	1.0262	1.0344
24	1.0327	1.0215	1.0061	0.9882	0.9744	0.9671	0.9683	0.9778	0.9936	1.0111	1.0266	1.0345
25	1.0325	1.0210	1.0056	0.9877	0.9740	0.9670	0.9685	0.9783	0.9942	1.0117	1.0270	1.0346
26	1.0323	1.0205	1.0050	0.9871	0.9737	0.9669	0.9687	0.9787	0.9948	1.0123	1.0274	1.0347
27	1.0320	1.0200	1.0044	0.9866	0.9733	0.9669	0.9689	0.9791	0.9953	1.0128	1.0278	1.0348
28	1.0318	1.0195	1.0038	0.9861	0.9730	0.9668	0.9691	0.9796	0.9959	1.0134	1.0281	1.0349
29	1.0315		1.0032	0.9856	0.9727	0.9667	0.9693	0.9800	0.9965	1.0140	1.0285	1.0349
30	1.0312		1.0026	0.9850	0.9723	0.9667	0.9696	0.9805	0.9971	1.0145	1.0289	1.0350
31	1.0309		1.0020		0.9720		0.9698	0.9810		1.0151		1.0350
	1.0338	**1.0255**	**1.0107**	**0.9930**	**0.9778**	**0.9686**	**0.9676**	**0.9750**	**0.9890**	**1.0065**	**1.0227**	**1.0329**

Table. 1.- Correction factor for the earth-sun distance for each day of the year.

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1	3.442	3.591	3.724	3.833	3.871	3.832	3.727	3.579	3.432	3.328	3.291	3.331
2	3.446	3.596	3.729	3.835	3.871	3.829	3.723	3.574	3.428	3.326	3.291	3.334
3	3.451	3.601	3.733	3.838	3.871	3.827	3.718	3.569	3.423	3.324	3.291	3.336
4	3.455	3.606	3.737	3.840	3.871	3.824	3.714	3.564	3.419	3.321	3.291	3.339
5	3.460	3.611	3.741	3.842	3.871	3.821	3.709	3.559	3.415	3.319	3.292	3.342
6	3.464	3.616	3.745	3.844	3.870	3.818	3.705	3.554	3.411	3.317	3.292	3.345
7	3.469	3.621	3.749	3.846	3.870	3.815	3.700	3.549	3.407	3.315	3.293	3.348
8	3.474	3.626	3.754	3.848	3.869	3.812	3.696	3.544	3.403	3.313	3.293	3.351
9	3.478	3.631	3.758	3.850	3.869	3.809	3.691	3.539	3.399	3.311	3.294	3.354
10	3.483	3.636	3.761	3.852	3.868	3.806	3.686	3.534	3.395	3.309	3.295	3.357
11	3.488	3.640	3.765	3.854	3.867	3.803	3.682	3.529	3.391	3.308	3.296	3.360
12	3.493	3.645	3.769	3.855	3.866	3.800	3.677	3.525	3.388	3.306	3.297	3.363
13	3.497	3.650	3.773	3.857	3.865	3.796	3.672	3.520	3.384	3.304	3.298	3.367
14	3.502	3.655	3.777	3.858	3.864	3.793	3.668	3.515	3.380	3.303	3.299	3.370
15	3.507	3.660	3.780	3.860	3.863	3.790	3.663	3.510	3.377	3.302	3.300	3.374
16	3.512	3.665	3.784	3.861	3.862	3.786	3.658	3.505	3.373	3.300	3.302	3.377
17	3.517	3.669	3.787	3.863	3.861	3.783	3.653	3.500	3.370	3.299	3.303	3.381
18	3.521	3.674	3.791	3.864	3.859	3.779	3.648	3.495	3.366	3.298	3.305	3.384
19	3.526	3.679	3.794	3.865	3.858	3.775	3.644	3.491	3.363	3.297	3.306	3.388
20	3.531	3.684	3.798	3.866	3.856	3.772	3.639	3.486	3.360	3.296	3.308	3.392
21	3.536	3.688	3.801	3.867	3.855	3.768	3.634	3.481	3.357	3.295	3.310	3.396
22	3.541	3.693	3.804	3.868	3.853	3.764	3.629	3.477	3.353	3.294	3.311	3.400
23	3.546	3.697	3.807	3.868	3.851	3.760	3.624	3.472	3.350	3.293	3.313	3.403
24	3.551	3.702	3.810	3.869	3.849	3.756	3.619	3.467	3.347	3.293	3.315	3.407
25	3.556	3.707	3.813	3.870	3.847	3.752	3.614	3.463	3.344	3.292	3.317	3.411
26	3.561	3.711	3.816	3.870	3.845	3.748	3.609	3.458	3.342	3.292	3.319	3.416
27	3.566	3.715	3.819	3.870	3.843	3.744	3.604	3.454	3.339	3.291	3.322	3.420
28	3.571	3.720	3.822	3.871	3.841	3.740	3.599	3.449	3.336	3.291	3.324	3.424
29	3.576		3.825	3.871	3.839	3.735	3.594	3.445	3.333	3.291	3.326	3.428
30	3.581		3.828	3.871	3.837	3.731	3.589	3.440	3.331	3.291	3.329	3.432
31	3.586		3.830		3.834		3.584	3.436		3.291		3.437
	3.513	**3.657**	**3.782**	**3.857**	**3.859**	**3.786**	**3.657**	**3.506**	**3.377**	**3.304**	**3.304**	**3.380**

(Year: 3.581 mm)

Table 2.- Ozone amount in mm NTP for each day of the year at TRIESTE
($\phi = 45.64°$ N, $\lambda = 13.75°$ E)

Θ	air	water v.	ozone	Θ	air	water v.	ozone
1	1.000	1.000	1.000	**46**	1.437	1.439	1.434
2	1.000	1.001	1.001	**47**	1.464	1.466	1.461
3	1.001	1.001	1.001	**48**	1.492	1.494	1.488
4	1.002	1.002	1.002	**49**	1.521	1.524	1.517
5	1.003	1.004	1.004	**50**	1.553	1.555	1.548
6	1.005	1.005	1.005	**51**	1.586	1.588	1.581
7	1.007	1.007	1.007	**52**	1.621	1.624	1.615
8	1.009	1.010	1.010	**53**	1.658	1.661	1.652
9	1.012	1.012	1.012	**54**	1.697	1.701	1.690
10	1.015	1.015	1.015	**55**	1.739	1.743	1.731
11	1.018	1.019	1.019	**56**	1.783	1.787	1.775
12	1.022	1.022	1.022	**57**	1.831	1.835	1.821
13	1.026	1.026	1.026	**58**	1.881	1.886	1.871
14	1.030	1.031	1.030	**59**	1.935	1.940	1.923
15	1.035	1.035	1.035	**60**	1.993	1.999	1.980
16	1.040	1.040	1.040	**61**	2.055	2.061	2.040
17	1.045	1.046	1.045	**62**	2.121	2.128	2.105
18	1.051	1.051	1.051	**63**	2.193	2.201	2.174
19	1.057	1.058	1.057	**64**	2.270	2.279	2.249
20	1.063	1.064	1.064	**65**	2.354	2.364	2.330
21	1.070	1.071	1.071	**66**	2.445	2.456	2.417
22	1.078	1.078	1.078	**67**	2.544	2.556	2.512
23	1.086	1.086	1.086	**68**	2.651	2.666	2.615
24	1.094	1.094	1.094	**69**	2.770	2.786	2.728
25	1.102	1.103	1.103	**70**	2.900	2.919	2.851
26	1.112	1.112	1.112	**71**	3.044	3.066	2.986
27	1.121	1.122	1.121	**72**	3.204	3.229	3.136
28	1.132	1.132	1.131	**73**	3.382	3.412	3.301
29	1.142	1.143	1.142	**74**	3.582	3.618	3.485
30	1.154	1.155	1.153	**75**	3.808	3.851	3.691
31	1.165	1.166	1.165	**76**	4.066	4.118	3.923
32	1.178	1.179	1.178	**77**	4.361	4.426	4.184
33	1.191	1.192	1.191	**78**	4.704	4.784	4.482
34	1.205	1.206	1.204	**79**	5.105	5.207	4.821
35	1.219	1.221	1.219	**80**	5.580	5.714	5.212
36	1.235	1.236	1.234	**81**	6.153	6.330	5.665
37	1.251	1.252	1.250	**82**	6.853	7.095	6.190
38	1.267	1.269	1.266	**83**	7.728	8.071	6.803
39	1.285	1.286	1.284	**84**	8.847	9.353	7.514
40	1.304	1.305	1.302	**85**	10.323	11.110	8.332
41	1.323	1.325	1.322	**86**	12.340	13.651	9.248
42	1.344	1.345	1.342	**87**	15.219	17.615	10.217
43	1.365	1.367	1.363	**88**	19.540	24.520	11.132
44	1.388	1.390	1.386	**89**	26.310	38.737	11.816
45	1.412	1.414	1.409	**90**	36.510	75.123	12.074

Table 3.- Relative air, water vapor and ozone mass as a function of the sun zenith angle Θ (1° - 90°).

	-15	**-10**	**-5**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
2	0.007	0.011	0.015	0.022	0.031	0.042	0.058	0.078	0.105	0.140	0.183	0.239
4	0.015	0.021	0.031	0.044	0.061	0.085	0.116	0.157	0.210	0.279	0.367	0.478
6	0.022	0.032	0.046	0.065	0.092	0.127	0.174	0.235	0.315	0.419	0.550	0.717
8	0.029	0.043	0.061	0.087	0.122	0.169	0.232	0.314	0.421	0.558	0.734	0.956
10	0.036	0.053	0.077	0.109	0.153	0.212	0.290	0.392	0.526	0.698	0.917	1.195
12	0.044	0.064	0.092	0.131	0.183	0.254	0.348	0.471	0.631	0.837	1.101	1.434
14	0.051	0.074	0.107	0.152	0.214	0.296	0.406	0.549	0.736	0.977	1.284	1.673
16	0.058	0.085	0.123	0.174	0.244	0.338	0.463	0.628	0.841	1.117	1.468	1.912
18	0.066	0.096	0.138	0.196	0.275	0.381	0.521	0.706	0.946	1.256	1.651	2.151
20	0.073	0.106	0.153	0.218	0.305	0.423	0.579	0.785	1.052	1.396	1.835	2.390
22	0.080	0.117	0.169	0.239	0.336	0.465	0.637	0.863	1.157	1.535	2.018	2.629
24	0.087	0.128	0.184	0.261	0.366	0.508	0.695	0.942	1.262	1.675	2.202	2.868
26	0.095	0.138	0.199	0.283	0.397	0.550	0.753	1.020	1.367	1.814	2.385	3.107
28	0.102	0.149	0.215	0.305	0.427	0.592	0.811	1.098	1.472	1.954	2.569	3.346
30	0.109	0.160	0.230	0.327	0.458	0.635	0.869	1.177	1.577	2.093	2.752	3.585
32	0.116	0.170	0.245	0.348	0.489	0.677	0.927	1.255	1.683	2.233	2.935	3.824
34	0.124	0.181	0.260	0.370	0.519	0.719	0.985	1.334	1.788	2.373	3.119	4.063
36	0.131	0.191	0.276	0.392	0.550	0.761	1.043	1.412	1.893	2.512	3.302	4.302
38	0.138	0.202	0.291	0.414	0.580	0.804	1.101	1.491	1.998	2.652	3.486	4.542
40	0.146	0.213	0.306	0.435	0.611	0.846	1.159	1.569	2.103	2.791	3.669	4.781
42	0.153	0.223	0.322	0.457	0.641	0.888	1.217	1.648	2.208	2.931	3.853	5.020
44	0.160	0.234	0.337	0.479	0.672	0.931	1.274	1.726	2.314	3.070	4.036	5.259
46	0.167	0.245	0.352	0.501	0.702	0.973	1.332	1.805	2.419	3.210	4.220	5.498
48	0.175	0.255	0.368	0.522	0.733	1.015	1.390	1.883	2.524	3.350	4.403	5.737
50	0.182	0.266	0.383	0.544	0.763	1.058	1.448	1.962	2.629	3.489	4.587	5.976
52	0.189	0.277	0.398	0.566	0.794	1.100	1.506	2.040	2.734	3.629	4.770	6.215
54	0.197	0.287	0.414	0.588	0.824	1.142	1.564	2.118	2.839	3.768	4.954	6.454
56	0.204	0.298	0.429	0.610	0.855	1.184	1.622	2.197	2.945	3.908	5.137	6.693
58	0.211	0.308	0.444	0.631	0.885	1.227	1.680	2.275	3.050	4.047	5.321	6.932
60	0.218	0.319	0.460	0.653	0.916	1.269	1.738	2.354	3.155	4.187	5.504	7.171
62	0.226	0.330	0.475	0.675	0.947	1.311	1.796	2.432	3.260	4.326	5.688	7.410
64	0.233	0.340	0.490	0.697	0.977	1.354	1.854	2.511	3.365	4.466	5.871	7.649
66	0.240	0.351	0.506	0.718	1.008	1.396	1.912	2.589	3.470	4.606	6.054	7.888
68	0.247	0.362	0.521	0.740	1.038	1.438	1.970	2.668	3.576	4.745	6.238	8.127
70	0.255	0.372	0.536	0.762	1.069	1.481	2.028	2.746	3.681	4.885	6.421	8.366
72	0.262	0.383	0.552	0.784	1.099	1.523	2.085	2.825	3.786	5.024	6.605	8.605
74	0.269	0.394	0.567	0.805	1.130	1.565	2.143	2.903	3.891	5.164	6.788	8.844
76	0.277	0.404	0.582	0.827	1.160	1.607	2.201	2.982	3.996	5.303	6.972	9.083
78	0.284	0.415	0.598	0.849	1.191	1.650	2.259	3.060	4.101	5.443	7.155	9.322
80	0.291	0.425	0.613	0.871	1.221	1.692	2.317	3.138	4.207	5.583	7.339	9.561
82	0.298	0.436	0.628	0.893	1.252	1.734	2.375	3.217	4.312	5.722	7.522	9.800
84	0.306	0.447	0.644	0.914	1.282	1.777	2.433	3.295	4.417	5.862	7.706	10.039
86	0.313	0.457	0.659	0.936	1.313	1.819	2.491	3.374	4.522	6.001	7.889	10.278
88	0.320	0.468	0.674	0.958	1.343	1.861	2.549	3.452	4.627	6.141	8.073	10.517
90	0.328	0.479	0.689	0.980	1.374	1.904	2.607	3.531	4.732	6.280	8.256	10.756
92	0.335	0.489	0.705	1.001	1.405	1.946	2.665	3.609	4.838	6.420	8.440	10.995
94	0.342	0.500	0.720	1.023	1.435	1.988	2.723	3.688	4.943	6.559	8.623	11.234
96	0.349	0.511	0.735	1.045	1.466	2.031	2.781	3.766	5.048	6.699	8.806	11.473
98	0.357	0.521	0.751	1.067	1.496	2.073	2.839	3.845	5.153	6.839	8.990	11.712
100	0.364	0.532	0.766	1.088	1.527	2.115	2.897	3.923	5.258	6.978	9.173	11.951

Table 4.- Precipitable water vapor in centimeters as a function of the percentual relative humidity (2 - 100 %) for air temperature between -15 and 40 °C.

	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.0**
5	0.647	0.610	0.574	0.541	0.509	0.480	0.452	0.426	0.401	0.378	0.356	0.335	0.316	0.297	0.280	0.264
6	0.549	0.517	0.487	0.459	0.433	0.407	0.384	0.361	0.341	0.321	0.302	0.285	0.268	0.253	0.238	0.224
7	0.479	0.452	0.425	0.401	0.377	0.356	0.335	0.316	0.297	0.280	0.264	0.248	0.234	0.220	0.208	0.196
8	0.427	0.402	0.379	0.357	0.336	0.317	0.298	0.281	0.265	0.249	0.235	0.221	0.208	0.196	0.185	0.174
9	0.386	0.364	0.343	0.323	0.304	0.286	0.270	0.254	0.239	0.225	0.212	0.200	0.188	0.178	0.167	0.158
10	0.353	0.333	0.314	0.295	0.278	0.262	0.247	0.233	0.219	0.206	0.194	0.183	0.172	0.162	0.153	0.144
11	0.327	0.308	0.290	0.273	0.257	0.242	0.228	0.215	0.202	0.191	0.180	0.169	0.159	0.150	0.141	0.133
12	0.304	0.287	0.270	0.254	0.240	0.226	0.213	0.200	0.189	0.178	0.167	0.158	0.148	0.140	0.132	0.124
13	0.285	0.269	0.253	0.238	0.225	0.212	0.199	0.188	0.177	0.167	0.157	0.148	0.139	0.131	0.124	0.116
14	0.269	0.253	0.239	0.225	0.212	0.200	0.188	0.177	0.167	0.157	0.148	0.139	0.131	0.124	0.116	0.110
15	0.255	0.240	0.226	0.213	0.201	0.189	0.178	0.168	0.158	0.149	0.140	0.132	0.124	0.117	0.110	0.104
16	0.242	0.228	0.215	0.203	0.191	0.180	0.169	0.160	0.150	0.142	0.133	0.126	0.118	0.111	0.105	0.099
17	0.231	0.218	0.205	0.193	0.182	0.172	0.162	0.152	0.143	0.135	0.127	0.120	0.113	0.106	0.100	0.094
18	0.222	0.209	0.197	0.185	0.175	0.164	0.155	0.146	0.137	0.129	0.122	0.115	0.108	0.102	0.096	0.090
19	0.213	0.201	0.189	0.178	0.168	0.158	0.149	0.140	0.132	0.124	0.117	0.110	0.104	0.098	0.092	0.087
20	0.205	0.193	0.182	0.171	0.161	0.152	0.143	0.135	0.127	0.120	0.113	0.106	0.100	0.094	0.089	0.084
21	0.198	0.186	0.176	0.165	0.156	0.147	0.138	0.130	0.123	0.116	0.109	0.103	0.097	0.091	0.086	0.081
22	0.191	0.180	0.170	0.160	0.151	0.142	0.134	0.126	0.119	0.112	0.105	0.099	0.093	0.088	0.083	0.078
23	0.185	0.175	0.164	0.155	0.146	0.137	0.129	0.122	0.115	0.108	0.102	0.096	0.090	0.085	0.080	0.076
24	0.180	0.169	0.160	0.150	0.142	0.133	0.126	0.118	0.111	0.105	0.099	0.093	0.088	0.083	0.078	0.073
25	0.175	0.165	0.155	0.146	0.138	0.130	0.122	0.115	0.108	0.102	0.096	0.091	0.085	0.080	0.076	0.071
26	0.170	0.160	0.151	0.142	0.134	0.126	0.119	0.112	0.105	0.099	0.094	0.088	0.083	0.078	0.074	0.069
27	0.166	0.156	0.147	0.138	0.130	0.123	0.116	0.109	0.103	0.097	0.091	0.086	0.081	0.076	0.072	0.068
28	0.162	0.152	0.143	0.135	0.127	0.120	0.113	0.106	0.100	0.094	0.089	0.084	0.079	0.074	0.070	0.066
29	0.158	0.149	0.140	0.132	0.124	0.117	0.110	0.104	0.098	0.092	0.087	0.082	0.077	0.073	0.068	0.064
30	0.154	0.145	0.137	0.129	0.121	0.114	0.108	0.101	0.096	0.090	0.085	0.080	0.075	0.071	0.067	0.063
31	0.151	0.142	0.134	0.126	0.119	0.112	0.105	0.099	0.093	0.088	0.083	0.078	0.074	0.069	0.065	0.062
32	0.148	0.139	0.131	0.123	0.116	0.109	0.103	0.097	0.092	0.086	0.081	0.076	0.072	0.068	0.064	0.060
33	0.145	0.136	0.128	0.121	0.114	0.107	0.101	0.095	0.090	0.084	0.080	0.075	0.071	0.066	0.063	0.059
34	0.142	0.134	0.126	0.119	0.112	0.105	0.099	0.093	0.088	0.083	0.078	0.073	0.069	0.065	0.061	0.058
35	0.139	0.131	0.123	0.116	0.110	0.103	0.097	0.092	0.086	0.081	0.077	0.072	0.068	0.064	0.060	0.057
36	0.137	0.129	0.121	0.114	0.108	0.101	0.095	0.090	0.085	0.080	0.075	0.071	0.067	0.063	0.059	0.056
37	0.134	0.126	0.119	0.112	0.106	0.100	0.094	0.088	0.083	0.078	0.074	0.070	0.065	0.062	0.058	0.055
38	0.132	0.124	0.117	0.110	0.104	0.098	0.092	0.087	0.082	0.077	0.073	0.068	0.064	0.061	0.057	0.054
39	0.130	0.122	0.115	0.108	0.102	0.096	0.091	0.085	0.080	0.076	0.071	0.067	0.063	0.060	0.056	0.053
40	0.128	0.120	0.113	0.107	0.100	0.095	0.089	0.084	0.079	0.075	0.070	0.066	0.062	0.059	0.055	0.052
41	0.126	0.118	0.111	0.105	0.099	0.093	0.088	0.083	0.078	0.073	0.069	0.065	0.061	0.058	0.054	0.051
42	0.124	0.117	0.110	0.103	0.097	0.092	0.086	0.081	0.077	0.072	0.068	0.064	0.060	0.057	0.054	0.050
43	0.122	0.115	0.108	0.102	0.096	0.090	0.085	0.080	0.076	0.071	0.067	0.063	0.059	0.056	0.053	0.050
44	0.120	0.113	0.107	0.100	0.095	0.089	0.084	0.079	0.074	0.070	0.066	0.062	0.059	0.055	0.052	0.049
45	0.118	0.112	0.105	0.099	0.093	0.088	0.083	0.078	0.073	0.069	0.065	0.061	0.058	0.054	0.051	0.048
46	0.117	0.110	0.104	0.098	0.092	0.087	0.082	0.077	0.072	0.068	0.064	0.061	0.057	0.054	0.051	0.048
47	0.115	0.109	0.102	0.096	0.091	0.085	0.081	0.076	0.071	0.067	0.063	0.060	0.056	0.053	0.050	0.047
48	0.114	0.107	0.101	0.095	0.090	0.084	0.079	0.075	0.071	0.066	0.063	0.059	0.056	0.052	0.049	0.046
49	0.112	0.106	0.100	0.094	0.088	0.083	0.078	0.074	0.070	0.066	0.062	0.058	0.055	0.052	0.049	0.046
50	0.111	0.104	0.098	0.093	0.087	0.082	0.077	0.073	0.069	0.065	0.061	0.057	0.054	0.051	0.048	0.045

Table 5.- Angstrom coefficient β as a function of the atmospheric horizontal visibility (5 to 50 km) for α between 0.5 and 2.0 .

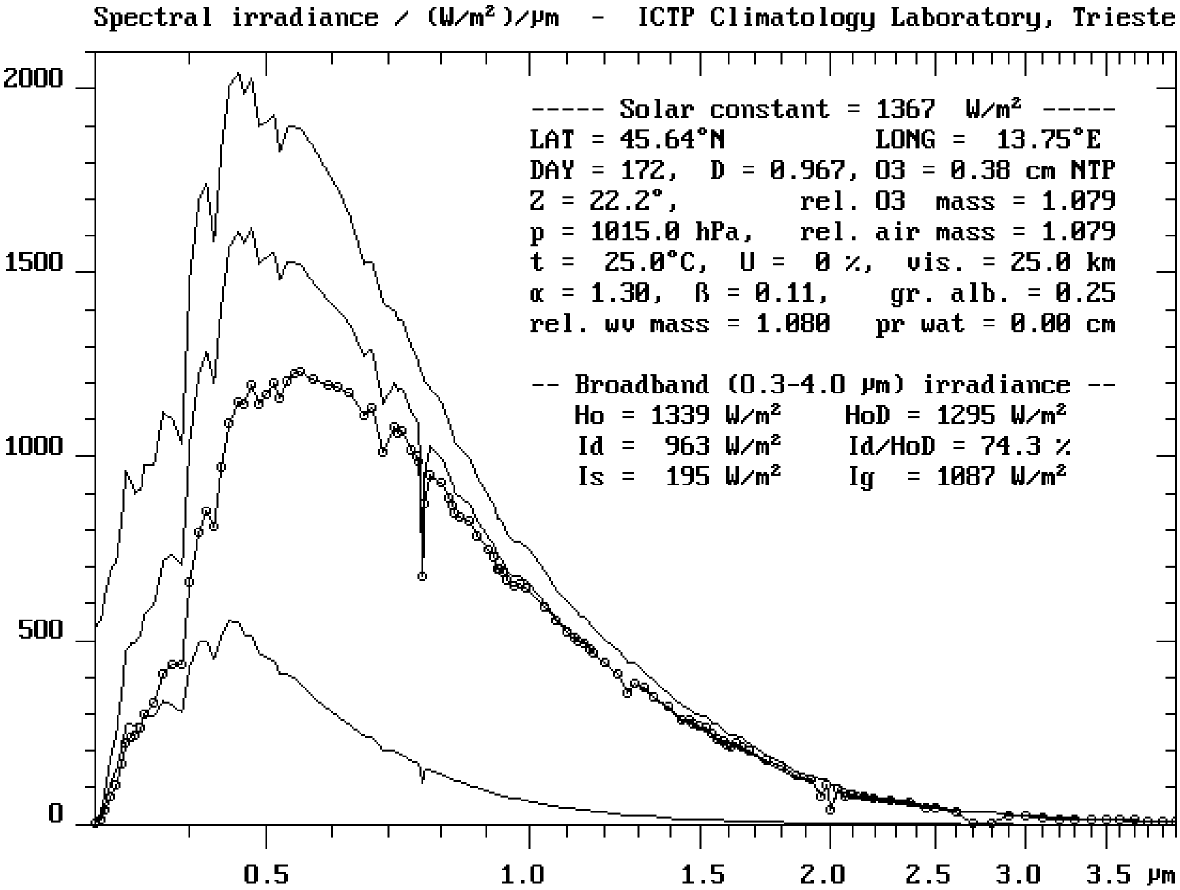
Spectral irradiance / (W/m²)/µm - ICTP Climatology Laboratory, Trieste
2000
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5 µm
----- Solar constant = 1367 W/m² -----
LAT = 45.64°N LONG = 13.75°E
DAY = 172, D = 0.967, O3 = 0.38 cm NTP
Z = 22.2°, rel. O3 mass = 1.079
p = 1015.0 hPa, rel. air mass = 1.079
t = 25.0°C, U = 0 %, vis. = 25.0 km
α = 1.30, ß = 0.11, gr. alb. = 0.25
rel. wv mass = 1.080 pr wat = 0.00 cm
-- Broadband (0.3-4.0 µm) irradiance --
Ho = 1339 W/m² HoD = 1295 W/m²
Id = 963 W/m² Id/HoD = 74.3 %
Is = 195 W/m² Ig = 1087 W/m²

Fig. 1

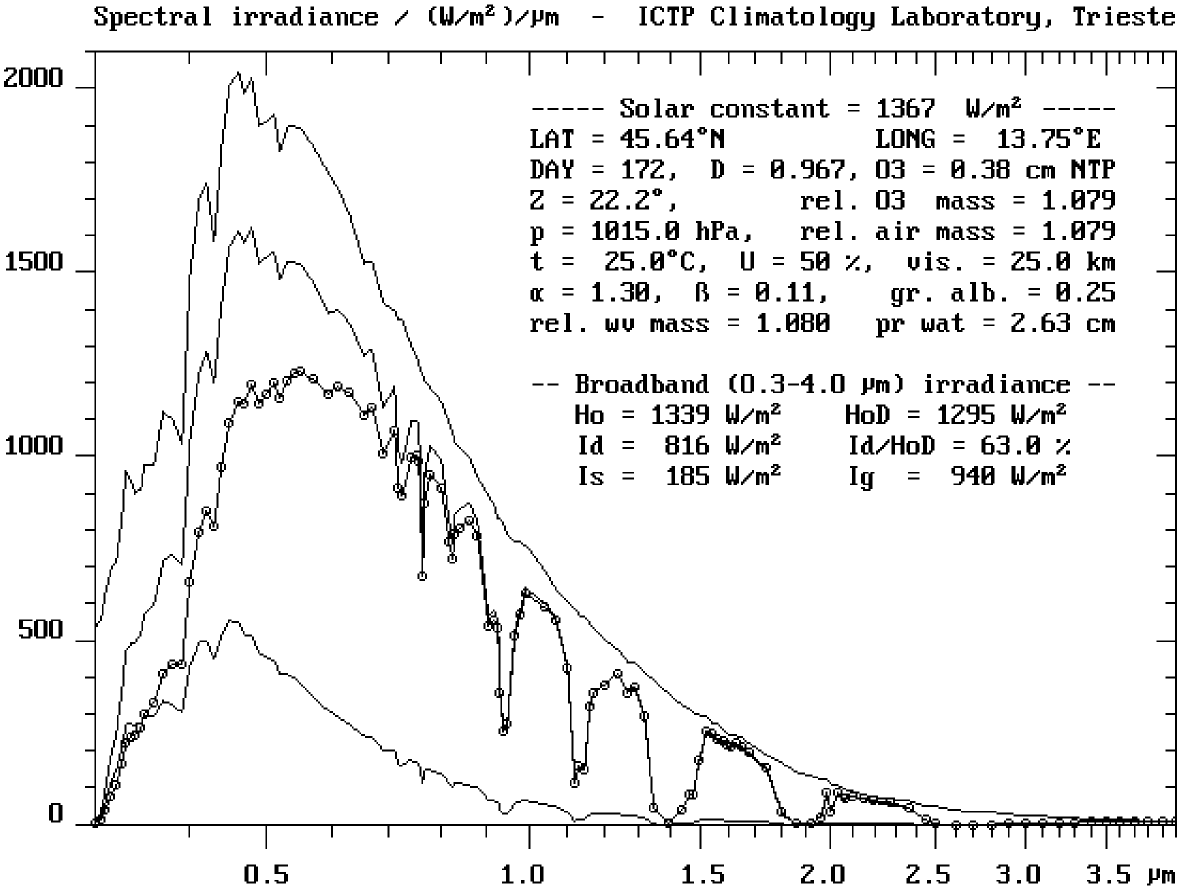
Spectral irradiance / (W/m²)/µm - ICTP Climatology Laboratory, Trieste
2000
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5 µm
----- Solar constant = 1367 W/m² -----
LAT = 45.64°N LONG = 13.75°E
DAY = 172, D = 0.967, O3 = 0.38 cm NTP
Z = 22.2°, rel. O3 mass = 1.079
p = 1015.0 hPa, rel. air mass = 1.079
t = 25.0°C, U = 50 %, vis. = 25.0 km
α = 1.30, ß = 0.11, gr. alb. = 0.25
rel. wv mass = 1.080 pr wat = 2.63 cm
-- Broadband (0.3-4.0 µm) irradiance --
Ho = 1339 W/m² HoD = 1295 W/m²
Id = 816 W/m² Id/HoD = 63.0 %
Is = 185 W/m² Ig = 940 W/m²

Fig. 2

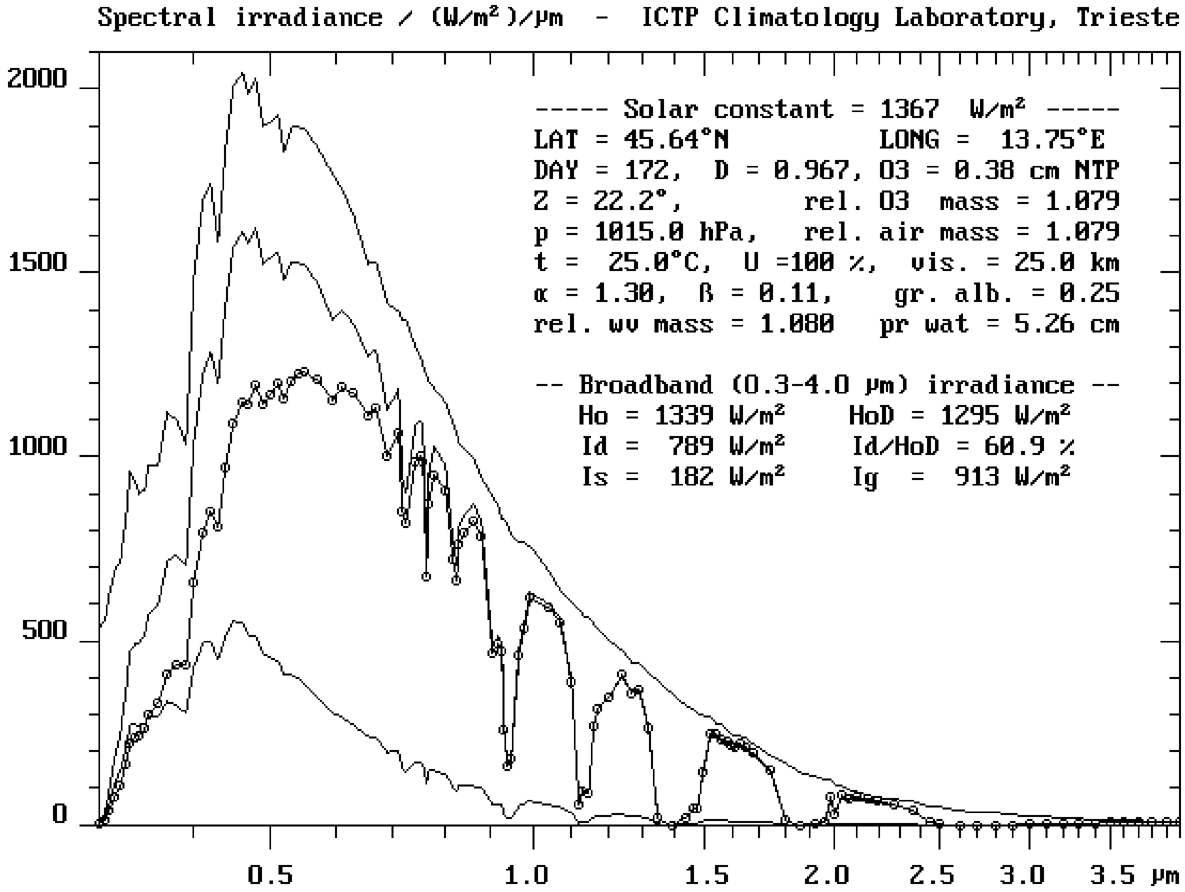
Spectral irradiance / (W/m²)/μm - ICTP Climatology Laboratory, Trieste
2000
1500
1000
500
0
----- Solar constant = 1367 W/m² -----
LAT = 45.64°N LONG = 13.75°E
DAY = 172, D = 0.967, O3 = 0.38 cm NTP
Z = 22.2°, rel. O3 mass = 1.079
p = 1015.0 hPa, rel. air mass = 1.079
t = 25.0°C, U =100 %, vis. = 25.0 km
α = 1.30, ß = 0.11, gr. alb. = 0.25
rel. wv mass = 1.080 pr wat = 5.26 cm
-- Broadband (0.3-4.0 μm) irradiance --
Ho = 1339 W/m² HoD = 1295 W/m²
Id = 789 W/m² Id/HoD = 60.9 %
Is = 182 W/m² Ig = 913 W/m²
0.5
1.0
1.5
2.0
2.5
3.0
3.5 μm

Fig. 3

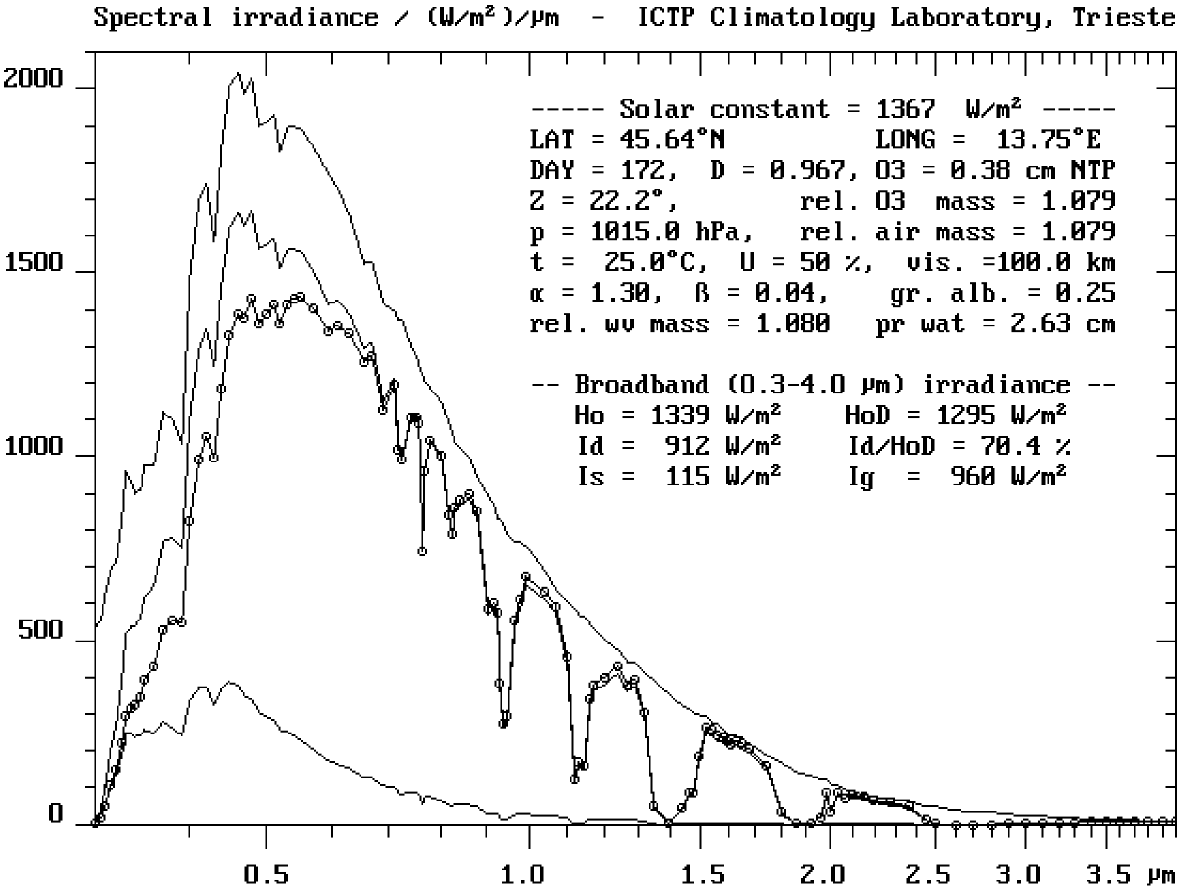
Spectral irradiance / (W/m²)/µm - ICTP Climatology Laboratory, Trieste
----- Solar constant = 1367 W/m² -----
LAT = 45.64°N LONG = 13.75°E
DAY = 172, D = 0.967, O3 = 0.38 cm NTP
Z = 22.2°, rel. O3 mass = 1.079
p = 1015.0 hPa, rel. air mass = 1.079
t = 25.0°C, U = 50 %, vis. =100.0 km
α = 1.30, ß = 0.04, gr. alb. = 0.25
rel. wv mass = 1.080 pr wat = 2.63 cm
-- Broadband (0.3-4.0 µm) irradiance --
Ho = 1339 W/m² HoD = 1295 W/m²
Id = 912 W/m² Id/HoD = 70.4 %
Is = 115 W/m² Ig = 960 W/m²
2000
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5 µm

Fig. 4

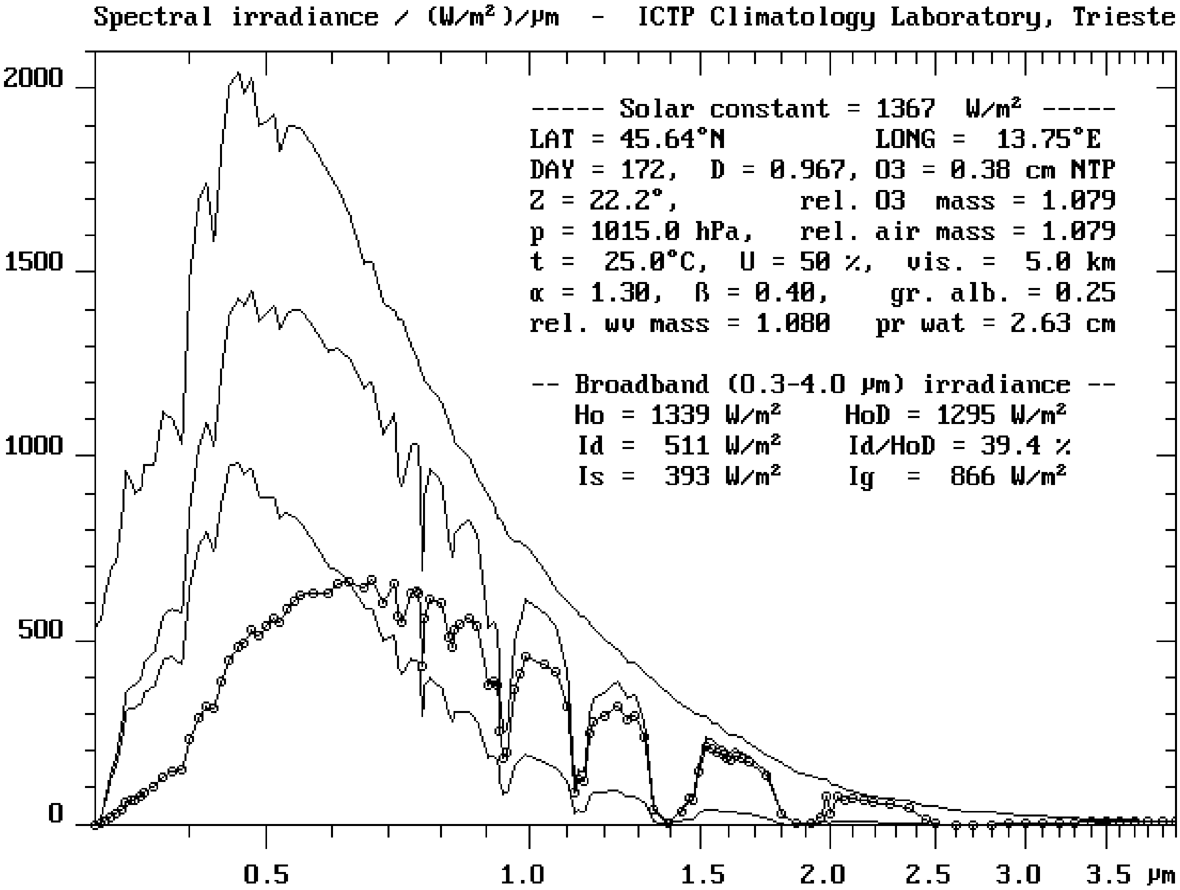
Spectral irradiance / (W/m²)/µm - ICTP Climatology Laboratory, Trieste
----- Solar constant = 1367 W/m² -----
LAT = 45.64°N LONG = 13.75°E
DAY = 172, D = 0.967, O3 = 0.38 cm NTP
Z = 22.2°, rel. O3 mass = 1.079
p = 1015.0 hPa, rel. air mass = 1.079
t = 25.0°C, U = 50 %, vis. = 5.0 km
α = 1.30, ß = 0.40, gr. alb. = 0.25
rel. wv mass = 1.080 pr wat = 2.63 cm
-- Broadband (0.3-4.0 µm) irradiance --
Ho = 1339 W/m² HoD = 1295 W/m²
Id = 511 W/m² Id/HoD = 39.4 %
Is = 393 W/m² Ig = 866 W/m²
2000
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5 µm

Fig. 5