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A User's Manual for: A Clear Sky Solar Radiation Generator for the Personal Computer

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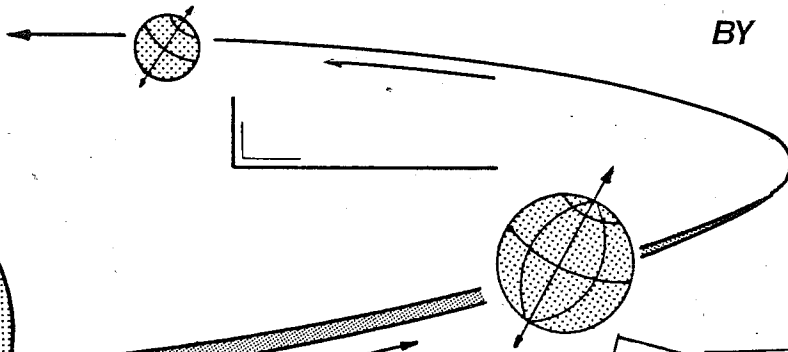
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A USER'S MANUAL
FOR:
A CLEAR SKY SOLAR RADIATION
GENERATOR FOR THE PERSONAL
COMPUTER

——— # ———

BY KEITH R. MOUNTAIN



USER SUPPLIED OPT*

Latitude of site -
Declination of site
Time increment for
Earth/sun correct
Atmospheric trans-
Precipitable wat
Atmospheric pre
Estimated elev
Inclination of
azimuth of sit
Albedo of sit
Elevation of
Elevation of
Atmospheric
Backscatter
Time of SUN
Time of SU

TIME	DIRECT	DIFFUSE	IRRADIANCE (W/m ²)
5.00	.00	.00	.00
5.30	3.47	.00	3.47
6.00	22.31	.00	22.31
6.30	86.75	.00	86.75
7.00	169.58	.00	169.58
7.30	259.69	.00	259.69
8.00	348.21	.00	348.21
8.30	434.14	.00	434.14
9.00	513.59	.00	513.59
9.30	584.33	.00	584.33
10.00	644.56	.00	644.56
10.30	692.86	.00	692.86
11.00	728.13	.00	728.13
11.30	749.60	.00	749.60
12.00	756.81	.00	756.81
12.30	749.60	.00	749.60
13.00	728.13	.00	728.13
13.30	692.86	.00	692.86
14.00	644.56	.00	644.56
14.30	584.33	.00	584.33
15.00	513.59	.00	513.59
15.30	434.14	.00	434.14
16.00	348.21	.00	348.21
16.30	259.69	.00	259.69
17.00	169.58	.00	169.58
17.30	86.75	.00	86.75
18.00	22.31	.00	22.31
18.30	3.47	.00	3.47
19.00	.00	.00	.00

77.11	.00	.00	.00
67.83	.00	.00	.00
54.48	141.2c	.00	.00
33.63	53.94	.00	.00
8.25	11.72	.00	.00
.00	.00	.00	.00

DAILY TOTAL OF DIFFUSE RADIATION --- = 3.82 MJ/m**2
DAILY TOTAL OF DIRECT RADIATION --- = 28.21 MJ/m**2
DAILY TOTAL OF GLOBAL RADIATION --- = 34.03 MJ/m**2
DAILY TOTAL OF REFLECTED RADIATION --- = 6.01 MJ/m**2
DAILY TOTAL OF NET SHORTWAVE RAD. --- = 18.02 MJ/m**2
DAILY TOTAL OF EXTRATERRESTRIAL RAD. --- = 34.59 MJ/m**2

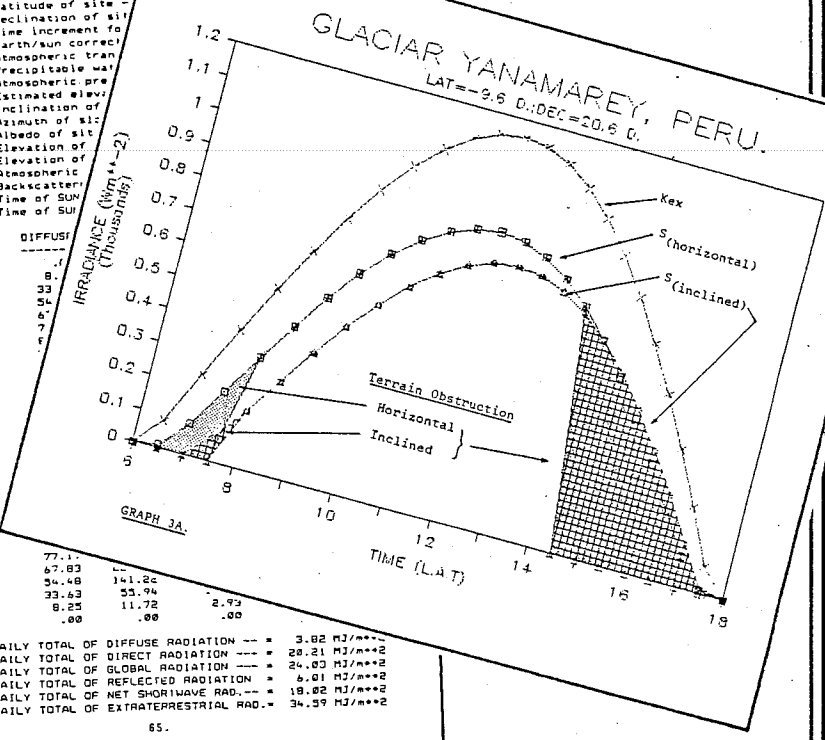
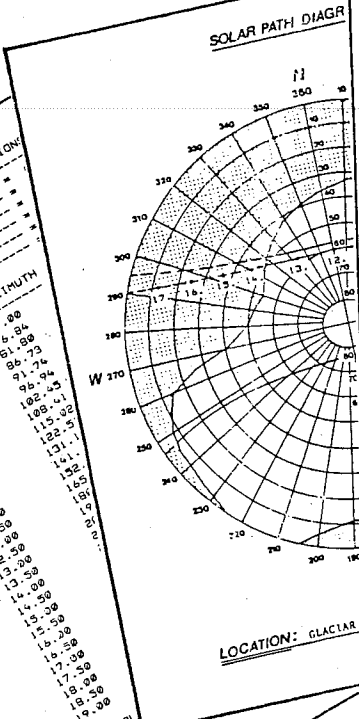
SOLAR PATH CALCULATION

Latitude -----
Declination -----
Azimuth of sunrise -----
Azimuth of sunset -----
Time of sunrise -----
Time of sunset -----

SOLAR AZIMUTH

TIME	76.84
5.00	81.89
5.30	86.74
6.00	91.94
6.30	96.94
7.00	102.41
7.30	108.41
8.00	115.02
8.30	122.51
9.00	131.11
9.30	141.11
10.00	152.11
10.30	163.11
11.00	174.11
11.30	185.11
12.00	196.11
12.30	207.11
13.00	218.11
13.30	229.11
14.00	240.11
14.30	251.11
15.00	262.11
15.30	273.11
16.00	284.11
16.30	295.11
17.00	306.11
17.30	317.11
18.00	328.11
18.30	339.11
19.00	350.11


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Portland State University. Department of Geography.

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QC912.2

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The included data disk contains both executable code compiled using the Microsoft Fortran Compiler Version 3.2 and FORTRAN 77 source code. Purchase of this diskette entitles the owner to make archival copies and to utilize it on one machine at a time. No warranty is given regarding the suitability of this software for a particular purpose. If the diskette proves defective a replacement copy will be provided to the user at no cost.

For any questions regarding the use of this software contact: Keith Mountain, c/o Department of Geography, Portland State University, P.O. Box 751, Portland, OR 97207. We would be pleased to receive any advice regarding possible improvements in the program or documentation.

A Clear Sky Solar
Radiation Generator for
the Personal Computer.

By:

Keith Richard Mountain

Department of Geography Portland State University.
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Note to Readers.

This manual can be divided into three fundamental and distinct units. Sections 1-7 discuss the overall construction of the program, user options and presents the governing equations as used within the radiation program. Section 8 details the commands and syntax necessary to initialize the computer program and explicitly develops the data entry sequence and procedures. The last primary division, Section 9, presents a variety of worked examples that hopefully provide some indication of the range of climatological problems to which the generated data can be applied. Contingent upon the specific needs and experience of the user, each basic unit is designed to be self-contained and can be consulted directly. For example, the first-time user may choose to go directly to Section 8 to gain a basic working knowledge of the computer operations and the mechanics of running the program. The more experienced user may be primarily concerned with applications of the generated data. Thus, Section 9 becomes more meaningful.

If necessary, the user should consult the Table of Contents and move to the section of the manual that meets their specific requirements. Hopefully, however, with increasing experience in using the FORTRAN package and greater familiarity with the model operation, this document will serve as an integrated reference for those aspects of radiation climatology as presented and applied within this program.

PREFACE.

This program is primarily designed as an interactive instructional aid for students concerned with select aspects of shortwave radiation climatology. On the basis of user supplied temporal and geographic information the algorithm will produce instantaneous values of diffuse, direct, global, reflected, net shortwave and extraterrestrial radiation. Daily totals are also generated by numerical approximation of the area under the curve as described by each of these quantities. In addition, an optional routine to compute the instantaneous values of solar elevations and azimuths is included to further define the nature of astronomical relationships for the site under investigation. The overall structure of the program is such that the appropriate variables can be easily and conveniently manipulated to provide an accurate estimate of the shortwave radiative balance at a given point with a minimal knowledge of the relevant mathematics and of FORTRAN computer programming. It is hoped that the interested student will investigate the range of possibilities offered by this routine and use it as a stepping stone to the understanding of the many fundamental concepts involved in shortwave radiative transfer and its geographical distribution.

The syntax used in the construction of this program is MICROSOFT FORTRAN which, for certain statements, differs from conventional ANSI FORTRAN 77 and its derivatives. Should this program be modified to run on systems other than the IBM PC (or equivalent systems) the IBM FORTRAN manual should be consulted. In addition, Microsoft Fortran by Paul M. Chirilian and Programming the IBM Personal Computer: Fortran 77 by Robert Rouse and Thomas Bugnitz are explicit references for programmers.

The executable file for the solar radiation program (SOLAR.EXE) has been included on the enclosed diskette and will run on any IBM compatible system simply by entering the code, SOLAR. However, if necessary, the minimum system requirements to successfully edit, compile and link this program under MICROSOFT FORTRAN are 256 K. of computer RAM (128 K of which is required by the FORTRAN compiler for Version 1.0 and 150 K for Version 3.3), two disk drives, a video display and/or a printer as the data is not stored on disk at the time of generation. Approximately 10 minutes are required to compile and link this program on the IBM PC although this can be expected to vary according to system capacity. Although no graphics routines are built directly into the radiation program, minimal knowledge of the data organization and graphics routines of LOTUS 1-2-3 (or an equivalent data base management program) enables the FORTRAN generated results to be easily manipulated and plotted. The routines inherent in LOTUS 1-2-3 allow data to be graphically presented even if no on-screen display is possible (i.e. in the case of a monochrome display without a graphics card) as the generated graphics can be passed directly to almost any dot matrix printer. The advantages of being able to conveniently and accurately plot the data are substantial and the delays involved in hand-plotting or the generalizations

that can accrue from the direct interpretation of data columns are avoided.

The following documentation and program description is not intended as a discussion on radiative transfer or solar geometry but rather to outline and define the techniques used within this program that lead to the successful integration of the relevant components. Derivations of the selected equations have been included only where considered necessary as have the many assumptions that lie behind the theoretical construct of radiative transfer. It is left to the user to become familiar with the assumptions and limitations of the individual program elements (a complete bibliography used in the construction of this program is provided on page 99). In addition, the author does not necessarily claim originality in most of the mathematics that comprise this program; these are conventional formulae that are well developed in a great variety of standard texts as well as concepts explored in advanced courses in climatology with the Department of Geography at The Ohio State University. In particular, the author gratefully acknowledges the expertise of Dr. A. John Arnfield of this Department. It is, however, instructive for the user to see how the equations are numerically approximated and the direct relationship that exists between all the relevant variables. In addition, as the information within this manuscript has been compiled from a wide variety of sources the documentation represents a rather complete synthesis of the many governing equations and principles. It is also recognized that the solutions presented in this program may not represent the best possible choice in terms of programming syntax or in selection of the governing equations. It is, however, designed to be user oriented and straightforward in its operation; the program statements are explicit and internally well documented and it is hoped that the interested student will be able to conveniently trace the programming steps.

During the construction and proofing of this program a great variety of inputs and variables were tested. It is, however, difficult to ensure that the algorithm will successfully function for all possible geographic and climatic scenarios. Should any legitimate input generate obviously incorrect data or result in compiler error the author would appreciate learning of the problem.

The author would also like to express appreciation to the Department of Geography at Portland State University for making possible the publication of this manuscript and to Dr. Richard Lycan for many helpful suggestions.

Keith R. Mountain.

LIST OF RELEVANT SYMBOLS.

Standard Symbol	FORTTRAN Name	DESCRIPTION	UNITS.
(Ah/A) _{s/p}	SHAPE	correction factor for radiation received on an inclined surface	(dimensionless)
As	AZSUN	solar azimuth angle	(computed in radians)
Az	AZMITH	user specified site azimuth angle	(entered in deg.)
D	DIFUSE	diffuse beam solar radiation	(Wm ⁻²)
(d/d̄) ²	EDIST	earth/sun correction factor.....	(dimensionless)
Db	DIFHAY	backscattered diffuse solar radiation ...	(Wm ⁻²)
h	HOUR	hour angle	(computed in radians)
H	HOUR	hour angle when cos(Z)=0..	(computed in radians)
i	SLOPE	user supplied site inclination	(entered in deg.)
Io	IO	solar constant.....	(1353 Wm ⁻²)
K	K	atmospheric transmission (turbidity) factor	
K↓	GLOBAL	total (global) incoming shortwave radiation	(Wm ⁻²)
K*	NET	net shortwave radiation (K* = K↓ - K↑) ..	(Wm ⁻²)
K↑	REF	reflected shortwave radiation (K↑ = K↓ (1 - α)	(Wm ⁻²)
Kex	KEXINS	instantaneous extraterrestrial radiation	(Wm ⁻²)
m	M	optical air mass	(dimensionless)
Nt	DAYLTH	total daylength (Sunrise to Sunset)	(Hrs)
Nh	-	half the total daylength	(Hrs)
p	PRES	atmospheric pressure	(millibars)
S	DIRECT	direct beam solar radiation	(Wm ⁻²)
t	TINC	user supplied time increment	(minutes)

List of Symbols Cont'd

Standard Symbol	FORTTRAN Name	Description
t	TINC	user supplied time increment(minutes)
z	Z	solar zenith angle ... (computed in radians)
∅ or hor		where provided the subscript indicates sea level value and horizontal surface.

GREEK.

β	BETA	solar elevation (computed in radians)
α	ALBEDO	site albedo (dimensionless)
Γ_1	TOPM	user supplied skyline elevation for a.m. (entered in deg.)
Γ_2	TOPE	user supplied skyline elevation for p.m. (entered in deg.)
ϕ	PHI	site latitude (entered in deg.)
γ	DEC	site declination (entered in deg.)
Ψ_{ws}	PSIWS	water vapor scattering
Ψ_{rs}	PSIRS	Rayleigh scattering
Ψ_{ds}	PSIDS	aerosol scattering
Ψ_{da}	PSIDA	aerosol absorption
Ψ_{wa}	PSIWA	water vapor absorption

INTRODUCTION.

The application of concepts involved in radiative transfer and its diurnal, seasonal and geographic distribution clearly extends beyond the limits of that particular to climatology and into the many subfields of geography. In addition, many other disciplines require some understanding of the physical aspects of radiative loading; architecture, geology, glaciology, urban and landscape planning, among many others, at some stage deal with the concepts of shortwave radiation climatology but may not explicitly develop the mathematical, theoretical and conceptual framework unique to shortwave radiative transfer. Typically, the lack of familiarity of the appropriate theory often leads to the use of generalized radiative data and results in equally general conclusions. Thus, it is hoped that the structure and concepts that comprise this program will provide a link between these two extremes and enable the student to develop an appreciation of the very dynamic nature of shortwave radiative transfer.

The mathematics that form the basis of this program are those most commonly applied to problems in shortwave radiative geometry. The documentation that follows is not intended to discuss all possibilities that exist or to justify the use of one set of equations in preference to another. The intent is to simply present the selected equations in their standard mathematical format, develop the hierarchy of their position within the computer program, to express their FORTRAN equivalents and the procedures by which the algorithm integrates these equations. To facilitate understanding of these relationships a listing of the relevant program variables, their conventional mathematical symbols and FORTRAN names have been provided on pages 33 and 34. A generalized flow chart and a partial program listing is provided on pages 32 and 35 - 45 respectively. In addition, a variety of worked examples and their graphical representation (with LOTUS 1-2-3 graphics syntax) is provided in Section 9.

The equations that define the geometrical relationships between the earth and the sun are definitively presented in a great variety of standard texts. Paltridge and Platt (1976), Kondratyev (1969), and Sellers (1972) are perhaps those most commonly referenced and all provide detailed derivations and discussions on the appropriate equations *. The basic solar radiation generator is directly traceable to the model proposed by Davies, Schertzer and Nunez (1975). This model is generally considered to be one of the more versatile schemes and is known to consistently generate reliable results for a wide range of

* The inputs required for the FORTRAN program as well as the generated results conform to the Systeme International units of measurement. This system has been adopted as a standardization procedure by the World Meteorological Organization. A table of S.I units and their equivalents has been included in the Appendix (page 101).

conditions. Although in its original format, a cloud parameterization scheme was included, it has not been incorporated into this radiation program. To the basic Davies (et. al.) model has been added a variety of user options. The adjustment of radiative receipt due to site inclination and azimuth, the additional contribution to the diffuse receipt by first order backscatterance as suggested by Suckling and Hay (1976), the effects of atmospheric refraction (Kasten, 1966), the shielding effects of the direct beam due to site topography and several other options enable the user to generate results that are both realistic and environmentally sensitive. All of these options will be defined and their positions within the computer routine established in the following discussion.

Above all, this program has been constructed to enable convenient, straightforward manipulation of one or several variables that are known to influence the shortwave radiative balance at a given site. This provides an opportunity for the user to develop a solid understanding and appreciation of the relative effects upon radiative receipt of the generally accepted influential components. It is also strongly recommended that the user become familiar with the great variety of applications to which the output generated by this program can be applied. Aside from the above references Monteith (1973), Gates (1981), Oke (1978), Outcalt (1971), Goodison (1972), Wendler and Ishikawa (1974), Terjung and Louie (1974), Terjung and O'Rourke (1984) and Ohmura (1982), represent just a few references that indicate of the range of possibilities to which information on the shortwave radiative balance can be applied.

SECTION 1.

SOLAR GEOMETRY AND EARTH/SUN RELATIONSHIPS.

The instantaneous value of the extraterrestrial radiation at the edge of the earth's atmosphere can be expressed

$$K_{ex} = I_0 \left(\frac{d}{\bar{d}} \right)^2 \cos Z \quad 1.1$$

where $(d/\bar{d})^2$ is the correction factor for the obliquity of the earth's orbit around the sun. The numerical value of this term can be obtained by taking the inverse of the orbital radius vector as compiled in the ephemeris of the sun tables (List, 1966, 495). A modified copy of these tables has been included in the Appendix (page 102). Thus, the value of $(d/\bar{d})^2$ will vary from 1.017045 on January the 4th (perigee) to 0.983565 on July the 4th (apogee). If this variable is not explicitly required within the program a default value of 1.000000 should be entered. This assumes that the earth's orbit around the sun is circular and, therefore, represents the average condition of the earth/sun orbital relationships over the course of one year. The solar constant, I_0 , is specified as 1353.0 Wm^{-2} following Thekaekarra and Drummond (1971) and is perhaps the most conventionally accepted value.

Expanding the cosine of the zenith angle

$$\cos(Z) = \sin \phi \sin \gamma + \cos \phi \cos \gamma \cos h \quad 1.2$$

where ϕ is the user supplied site latitude and γ , the declination, also obtained from the ephemeris tables. The hour angle, h , can be determined by

$$h = (12.0 - t) 15.0 \quad (\text{Units: hr} * \text{deg hr}^{-1} \rightarrow \text{deg}) \quad 1.3$$

The hour angle is defined as the angle through which the earth must rotate to bring the meridian of the site directly under the sun (solar noon). By convention, h is considered positive for all times prior to solar noon and negative for all times past solar noon. The time, t , as used within the program is local apparent time (L.A.T). If necessary, the zonal mean time (Z.M.T) can be converted to L.A.T by

$$t_{[L.A.T]} = t_{[Z.M.T]} + c + e \quad 1.4$$

where

$$c = (\lambda_s - \lambda) 4.0$$

and

$$\begin{array}{l} \lambda_s \text{ standard meridian} \\ \lambda \text{ meridian of site} \end{array}$$

The equation of time, e , can be taken directly from the ephemeris tables for the appropriate time of the year. Thus, the result generated by 1.4 is not constant for a specific site as the equation of time will vary due to differences in the speed at which the earth revolves around the sun throughout one complete orbit. Also, if this program is used to compare computed results to measured data an adjustment for daylight savings may be required.

From equation 1.2 the zenith angle is obtained by

$$Z = \arccos(Z) \quad 1.5$$

The zenith is defined as that point on the sky hemisphere directly above the site. The zenith angle is, therefore, the angle from this point to some other point on the sky hemisphere. It is the opposite of the angle of that point above the horizon. Should the value of the zenith angle as computed by 1.5 be less than zero the sun lies below the horizon and all components of the radiative balance must be set to zero. This relationship can be used to establish the exact times of astronomical sunrise and sunset. From 1.2

$$\cos Z = 0 = \sin \phi \sin \gamma + \cos \phi \cos \gamma \cos H$$

where $H = h$ for the special case of $\cos(z)=0.0$

solving for H

$$\cos H = - \frac{\sin \phi \sin \gamma}{\cos \phi \cos \gamma} = - \tan \phi \tan \gamma$$

$$H = \arccos(-\tan \phi \tan \gamma) \quad 1.6$$

The total number of hours that the sun is positioned above the horizon over a 24 hour period can be determined by

$$\text{Daylength} = Nt = \left\{ \arccos(-\tan \phi \tan \gamma) \right\} / 7.5 \quad 1.7$$

And the half-day length, Nh , centered around solar noon, becomes

$$Nh = \left\{ \arccos(-\tan \phi \tan \gamma) \right\} / 15.0 \quad 1.8$$

Thus, the time of astronomical sunrise (i.e. not including the effects of atmospheric refraction) is simply

$$\text{Sunrise } SR = 12.0 - Nh \quad 1.9a$$

and for sunset

$$\text{Sunset } SS = 12.0 + Nh \quad 1.9b$$

The computer program capitalizes upon the relationships that exist between 1.6, 1.7 and 1.9 to both initialize and terminate calculations. The time of sunrise as established by 1.9 is set to its integer value (i.e. if $SR = 5.79$ hrs "computational" sunrise is fixed at 5 a.m). This ensures that the program will always be initialized prior to sunrise and that for the first iteration all components of the radiative balance will be set to zero. In addition, if the time increment selected by the user is natural divisor of 60 (ie. 1,5,10,15, etc.) this allows the routine to isolate solar noon ensuring that the computed radiative quantities will always be centered around solar noon. For programming purposes and, as the primary solar radiation generator lies within a DO LOOP, these associations are further used to establish the number of program iterations required over the period from sunrise to sunset (see lines 690-697 and lines 771-777 of the FORTRAN program).

However, for certain astronomical and geographical scenarios the above equations (hence their computer equivalents) are not strictly applicable. For example, consider a site at 85 degrees north latitude at the June solstice (declination of +23.5 degrees). In this instance the sun remains above the horizon for the 24 hour period and the times of sunrise and sunset are, therefore, undefined. From 1.6

$$\chi = -\tan \phi \tan \gamma > \pm 1.0 \quad \therefore \arccos \chi \rightarrow \infty$$

Thus, direct application of 1.6 is restricted to $\phi = 66.5$ degrees and $\gamma = 23.5$ at the June solstice (northern hemisphere) and -66.5 and -23.5 at the December solstice in the southern hemisphere. Of course, as this relationship depends upon both the declination and the latitude the geographical position at which equation 1.6 holds will vary, i.e. for 75 degrees north with a declination of +10.0 degrees (Aug. 9th) the times of sunrise and sunset can be calculated. For sites where the sun remains above the horizon throughout the day the times of sunrise and sunset are set to zero and the number of iterations determined by simply dividing 24 hours by the user specified time increment. In this

instance calculations will always begin at the 0000 hours terminating at its equivalent of 2400 hours.

In terms of FORTRAN programming it is important to note that all the appropriate variables must at some point in the program be converted to their radian equivalents. Thus

$$X_{[\text{deg}]} * \pi / 180 = X_{[\text{rad}]}$$

However, as no intrinsic function for π exists within the FORTRAN compiler its numerical value must be specified. In this program the value is given to 9 decimal places (3.141592654) which is considered adequate for computational purposes. However, as π is an irrational number all the converted variables will be subject to some truncation. On occasion this rounding can lead to compiler error as an exact solution to many of the trigonometric functions will not exist. The potential problems generated by this inconsistency are overcome by specifying upper and lower limits on the results generated by the trigonometric functions. For example, in lines 171 to 174 of the FORTRAN program, the value of $\cos(z)$ (the solar zenith angle) is set to a maximum of 1.57079 for if the rounding errors generated by previous calculations result in $\cos(z)$ exceeding this value compiler error will occur. This problem does not appear to be significant with larger computer systems and could possibly be reduced in microsoft FORTRAN by specifying the appropriate variables as DOUBLE PRECISION.

It is also interesting to note that there are certain conditions for which the trigonometric associations identified above do not always hold. For example, with $\phi = 90.0$ degrees the tangent function is undefined. Thus, equations such as 1.6 do not strictly hold for the North and South Poles. Again, potential complications are overcome by specifying that the radian value of 90 degrees cannot exceed 1.57079. Thus, in reality, 90 degrees is set equal to 89.999637 which is accurate enough for computational purposes. Another interesting inconsistency is generated for an equatorial site during the equinox at solar noon. In this specific instance the variables take on the following values

$$z = 0; \phi = 0 \text{ \& } \gamma = 0$$

However, to establish the solar azimuth angle (equation 2.1) we require division by the result of $\sin(z)$ which is not possible if $z=0.0$. If, however, z is some positive number the equation will be executed satisfactorily; in this instance z is set equal to 0.0001 radians (0.0057 degrees) which is so small a value that no inconsistencies will appear in the generated radiative values (see program lines 173-174).

END OF SECTION 1.

SECTION 2.

SOLAR PATH CALCULATIONS.

The equations that generate the solar azimuth angle and the solar altitude are required within the primary solar radiation program and could have been integrated into the previous section. However, these constructs have been isolated as they explicitly form the basis of the optional routine for solar path calculations and the relationships that exist between these equations are perhaps more easily established. The computer code for this user option can be found in the FORTRAN program between lines 955 to 1036.

The solar azimuth angle, A_s , is the angle formed between grid north and the instantaneous position of the sun and is specified by a north through east rotation. Thus, east is given as 90 degrees, south as 180, west as 270 and north as 0 or 360 degrees (see page 107). The instantaneous value of the solar azimuth angle is conventionally expressed

$$\cos(A_s) = (\sin \gamma \cos \phi - \sin \phi \cos \gamma \cos h) / \sin Z \quad 2.1$$

where h has been previously defined by Equation 1.3 and the zenith angle, z , by 1.5. Thus

$$A_s = \arccos(A_s)$$

At solar noon the hour angle goes to zero and

$$A_s = \arccos \left\{ (\sin \gamma \cos \phi - \sin \phi \cos \gamma) / \sin Z \right\} \quad 2.2$$

Applying the standard trigonometric identity

$$\sin(x-y) = \sin x \cos y - \sin y \cos x$$

and, if the latitude of the site is greater than the declination

$$\sin Z = \sin(\phi - \gamma) = \sin \phi \cos \gamma - \sin \gamma \cos \phi$$

Eqn. cont'd

$$\cos(A_s) = \frac{\sin \gamma \cos \phi - \cos \gamma \sin \phi}{\cos \phi \sin \gamma - \sin \phi \cos \gamma}$$

$$\cos(A_s) = -1.0$$

$$A_s = 180.0 \text{ (South)}$$

2.3

For this particular relationship the position of the sun is due south as can be seen from the solar path diagram and data output generated for Example 1 (pages 66 and 67). However, for any geographical point that lies to the south of 23.5 degrees north, there will be a time of the year that the solar path will lie to the north of the site and will describe a curve similar to that presented in the solar path diagram for Example 3A (page 74). Of course, for a site south of 23.5 degrees south, at no time of the year will the sun be positioned to the south and solar trajectories over all declinations would be consistently described by curves to the north. Thus

$$(\phi - \gamma) < 0 \quad \& \quad A_s = 0 \text{ or } 360 \text{ (North)} \quad 2.4$$

It is also necessary to distinguish between solar azimuths for times prior to and past solar noon. When $t \leq 12.0$ the numerical value of the azimuth as computed by 2.2 is directly applicable and the sun is positioned at some point to the east of due south (or north). However, for $t > 12.0$ the solar azimuth is determined by $A_s = (360.0 - A_s)$ and the sun lies to the west.

The times of sunrise and sunset have been previously established by equation 1.9. The azimuths of sunrise and sunset are computed by setting the zenith angle in Equation 2.1 to 90 degrees. Thus as

$$Z = 90.0 \longrightarrow \sin(90) = 1.0$$

and

$$\cos A_s = \sin \gamma \cos \phi - \cos \gamma \sin \phi \cos h \quad 2.5$$

solving for $\cos(h)$

$$\cos h = \frac{\sin \gamma \sin \phi}{\cos \gamma \cos \phi}$$

therefore

$$\cos A_s = \sin \gamma \cos \phi - \cos \gamma \sin \phi \left\{ \frac{\sin \gamma \sin \phi}{\cos \gamma \cos \phi} \right\}$$

From the identity

$$\sin^2 \chi = 1.0 - \cos^2 \chi$$

Substituting and factoring yields

$$\cos A_s = \frac{\sin \gamma}{\cos \phi} \quad 2.6$$

Thus, the exact azimuth of sunrise is simply

$$A_s(SR) = \arccos(A_s) \quad 2.7a$$

and the azimuth of sunset

$$A_s(SS) = 360 - \arccos(A_s) \quad 2.7b$$

As previously stated, the solar altitude, β , is the angle of the sun above the horizon. Thus, after establishing the zenith angle from 1.2 and 1.5, the solar altitude is simply

$$\beta = 90 - Z \quad 2.8$$

The above mathematical relationships are conventionally summarized in solar path diagrams of the type presented in this manual. List (1966, 497-505) provides similar diagrams for all latitudes at 5 degree increments north of the equator over all declinations. Note, that for the southern hemisphere the described curves for equivalent south latitudes would be directly opposite (i.e rotated 180 degrees). However, while these diagrams are most often used to illustrate solar relationships they are not the only possibility. Wendler and Ishikawa (1974) provide an alternative that is both interesting and instructive particularly when site topography (skyline) is superimposed on the solar trajectory.

END OF SECTION 2

SECTION 3

GEOMETRIC ADJUSTMENTS FOR NON-HORIZONTAL SURFACES.

Where necessary, meaningful determination of the radiative balance at a given site must involve compensation for site slope and orientation (azimuth). This conventionally involves the modification of the radiative receipt computed for the horizontal by a geometrically derived correction factor, called the shape factor, which is a number that can be greater or less than unity including zero. The FORTRAN model allows adjustment of both the direct, S, and diffuse beam, D, using the procedures outlined and derived by Monteith (1973, Chap.4).

3A. SHAPE FACTOR FOR DIFFUSE BEAM RADIATION.

For the diffuse beam, assuming an isotropic (independent of direction) radiance distribution, the shape factor, $(Ah/A)_D$, can be determined by

$$(Ah/A)_D = \cos(i/2)^2 D_{hor} + \sin(i/2)^2 \propto K \downarrow \quad 3.1$$

and the total diffuse beam irradiance becomes

$$D = D_{hor} * (Ah/D)$$

Thus, the result generated by 3.1 represents the association between site slope and the total diffuse irradiance from the sky hemisphere, and includes the contribution of diffuse beam radiation reflected from the surrounding terrain. Qualitatively, it can be envisioned that as the slope increases less and less of the sky hemisphere can be "seen" from the site for which we require radiative data. The minimum view of the sky hemisphere will occur when the inclination reaches its maximum, 90 degrees. Conversely, as the slope increases, greater portions of the hemispheric field of view from the site are occupied by the ground. Again, with an inclination of 90 degrees and no skyline obstruction (mountains, buildings, etc.), one half of the hemispheric field of view would be occupied by ground and the other by sky.

The first term on the right of Equation 3.1 represents the adjustment of the sky diffuse irradiance on the horizontal due solely to site inclination. As the site is effectively angled away from the sky the actual diffuse beam receipt is proportionately reduced from the maximum that is available for the horizontal. The second term accounts for the additional diffuse radiation received at the site due to reflectance from

the surrounding terrain. The albedo of the terrain, α , must be specified by the user and, as the reflection is considered specular, must involve the total shortwave receipt on the horizontal (i.e both S and D as $K_{\downarrow} = S + D$). Generally, the contribution of reflected diffuse radiation to the shortwave balance at a given site is small. However, there are certain instances when this component can become significant. For example, conditions experienced over a high elevation glacial site where K_{\downarrow} is large and α high. Note also, that the isotropic assumption for the diffuse beam eliminates the need to compensate for azimuthal variations.

From the relationships inherent equation 3.1 it can be seen that if the site is specified as horizontal

$$i = 0 \longrightarrow \left\{ \cos(i/2)^2 \right\} D_{\text{hor}} = 1.0 * D_{\text{hor}}$$

and

$$\left\{ \sin(i/2)^2 \right\} = 0 \quad \therefore \sin(i/2)^2 \propto K_{\downarrow} = 0$$

reducing 3.1 to

$$D = D_{\text{hor}} + 0$$

In addition, if no direct beam radiation, (S) is received at the site

$$K_{\downarrow} = S + D = D$$

and the second term of 3.1 can be given as

$$\sin(i/2)^2 \propto D_{\text{hor}}$$

In this instance, even if the diffuse radiation was large, the contribution attributable to this component of the shape factor would be small (i.e. for $i = 45$ degrees, $D = 150 \text{ Wm}^{-2}$ and $= 0.40$ the total contribution would be only 8.78 Wm^{-2}).

3B. SHAPE FACTOR FOR DIRECT BEAM RADIATION.

Again, following Monteith (1973), the shape factor for the direct beam at a specified azimuth can be expressed

$$\left(\frac{Ah}{A}\right)_S = \cos i - \sin i \cotan \beta \cos (As - Az) \quad 3.2$$

and the total direct irradiance

$$S = S_{\text{hor}} * \left(\frac{Ah}{A}\right)_S$$

Thus, the magnitude of this correction depends upon the relationships that exist between the site inclination, i , the solar altitude, β , the solar azimuth angle, As (determined by equation 2.1), and the user supplied site azimuth angle, Az . In a qualitative sense we can consider the components of 3.2 to be such that they precisely determine the relationships that exist between the instantaneous position of the solar disk and the specific characteristics of the site. Thus, even though the sun may lie above the astronomical horizon, should the slope and user specified azimuth be such that the solar disk is not visible from the site as defined by the geometry of 3.2 (i.e, for the obvious case of a 90 degree west facing slope when the solar disk is positioned due east), then the direct beam receipt must be set to zero. Of course, if the slope faces toward the solar disk then the site is radiatively loaded and the computed direct beam receipt can be expected to exceed that for the horizontal. The manner in which these elements interact is explicitly developed in Example 2 (page 70).

Thus, from 3.2 it is apparent that if the site is horizontal

$$i = 0 \quad \text{then} \quad \cos i = 1; \sin i = 0$$

thus

$$\left(\frac{Ah}{A}\right)_S = 1.0 \quad \& \quad S = S_{\text{hor}} * 1.0$$

and should

$$\sin i \cotan \beta \cos (As - Az) < 0 \quad \longrightarrow \quad \left(\frac{Ah}{A}\right)_S = 0$$

and the direct beam must be set to zero (see lines 870 - 878 of the FORTRAN program). The cotangent function is determined by

$$\cotan \beta = 1.0 / \tan \beta$$

which is necessary as no intrinsic function for the cotangent

exists within the FORTRAN compiler.

From the above relationships there are circumstances that can generate some interesting computational instabilities when the zenith angle is large (i.e. small β). For example, consider a site at 70 degrees North on July 24 ($\gamma = +20$). In this instance the times of sunrise and sunset are defined but the solar trajectory is such that the sun maintains small solar altitudes for a considerable time period (see the solar path diagram provided by List, 1966, 504). Thus, as the sun lies just above the horizon, the extraterrestrial flux is small and the global radiative receipt on the horizontal correspondingly reduced. However, assuming a small solar altitude, for example, of 0.2 degrees (zenith angle of 89.8 deg.) and a site inclination of 90 degrees facing toward the sun, i.e. east at sunrise, the tangent of this angle is very small. Consequently, the cotangent function defines a very large number, and when the numerical value of the shape factor is determined and multiplied to the direct beam received on the horizontal, the result is a value that exceeds the extraterrestrial flux which, of course, is not possible. Thus, the solar disk needs to be positioned at least 1 to 2 degrees above the horizon (at $i = 90$ deg.) for 3.2 to execute satisfactorily. For the rare instances when this particular set of relationships develop, these idiosyncrasies are overcome by not allowing the result of the cotangent function to exceed a value of 9 and by specifying that the computed direct beam received at the surface cannot be greater than the extraterrestrial flux.

END OF SECTION 3.

SECTION 4.

INTEGRATED DAILY TOTALS OF SOLAR RADIATION.

The daily totals are obtained by summation of the area under the curve as described by the computed values of $K\downarrow$, D , S , K^* , $K\uparrow$ and K_{ex} . The summation interval is the time increment (TINC) selected by the user for the computation of instantaneous values. The conventional backward differencing summation procedure for determining the area contained within a specific curve is graphically presented in Diagram 1.

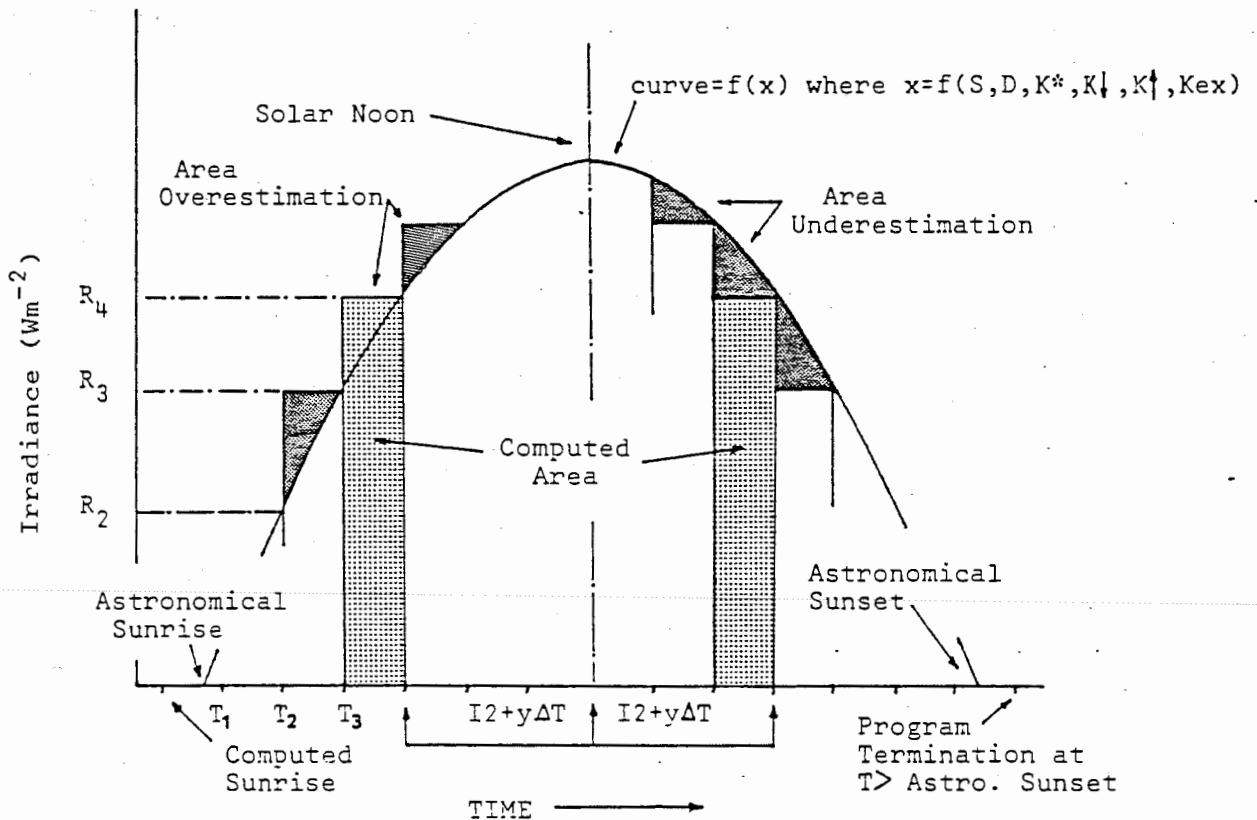


DIAGRAM 1.

Thus, for the total area:
$$= \sum_{i=1}^n f(x_i) \Delta t$$

From the above diagram, however, it can be seen that direct application of this procedure would lead to an overestimation of the exact area during the morning hours and underestimation for all times past solar noon. Should the curve be symmetrical around solar noon this over- and underestimation error would be offsetting and the generated result reliable. However, there are several conditions under which this procedure could lead to substantial error. For example, if the computed curve were

asymmetric such as that generated for a site with an inclination and azimuth of 60 and 270 degrees respectively, the bulk of the radiant receipt would occur in the hours following solar noon and the integrated daily total would effectively be an underestimate. Similarly, should the site be topographically confined and the curve truncated such as Examples 3A and 3B (page 73), again, the result could be erroneous. Note also, that the diffuse component will remain unaffected by this summation error as the assumption of isotropy ensures that the diurnal distribution of diffuse radiation is always symmetrical around solar noon.

To reduce the magnitude of this possible error the computer routine estimates an intermediate value between consecutive instantaneous values (i.e. point P'4 on Diagram 2 where $P'4 = (P3 + P4) / 2.0$). This approximated point is given as R'4 on the ordinate. Thus, for each column, part of the area is effectively overestimated and part underestimated generating a result that is perhaps more sensitive to the specific characteristics of the computed curves.

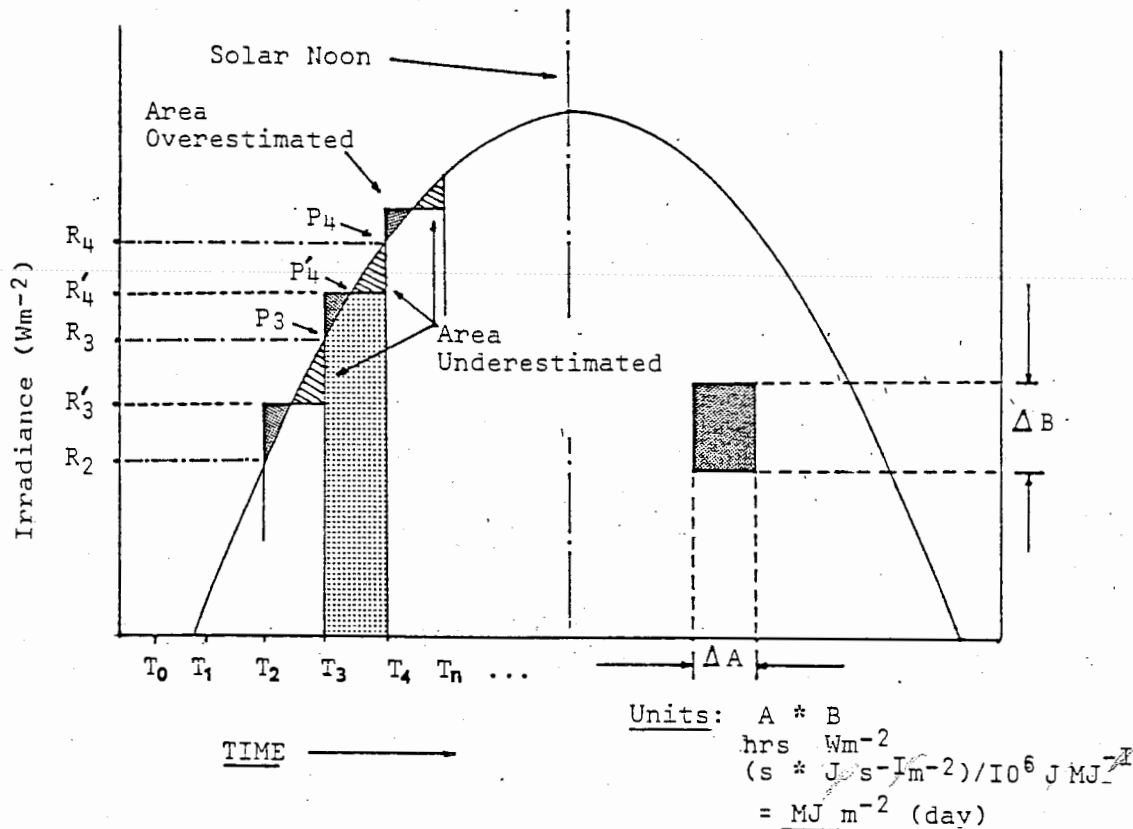


DIAGRAM 2.

It should also be apparent that summation error can be reduced through the selection of a small time increment (hence

iteration interval). The smallest unit of time that the program will accept is 1 minute (maximum not to exceed 60 mins). However, this leads to a lengthy execution and printout time. In addition, the resolution of the generated data would likely be in excess of that required by the user for most purposes. It should also be noted that the units of output are Megajoules per square meter per day and not watts per square meter as for instantaneous values.

As an analytical solution to the equations that govern the daily total of extraterrestrial radiation exist, it is possible to gauge the accuracy of the computer generated daily totals. From Eqn. 1.1

$$K_{ex} = I_0 \left(\frac{d}{\bar{d}} \right)^2 \cos Z$$

integrating from sunrise to sunset yields

$$\int_{SR}^{SS} K_{ex} dt = I_0 \left(\frac{d}{\bar{d}} \right)^2 \int_{SR}^{SS} \cos Z dt$$

As the values of both I_0 and $\left(\frac{d}{\bar{d}} \right)^2$ are constant they can be placed outside the integral. In integrated form

$$K_{ex}(\text{total}) = \frac{I_0 \left(\frac{d}{\bar{d}} \right)^2}{3.64 \times 10^{-5}} \left\{ H \sin \phi \sin \gamma + \cos \phi \cos \gamma \sin H \right\}$$

4.1

where the numerical value of the denominator is half the angular velocity of the earth and, H has been previously determined by Eqn. 1.6 and must be specified in radians for the first position within the parenthesis (see Sellers, 1971, 16).

Comparison of the computed result for Example 1. (page 65) to the analytical solution (4.1) indicates only a 0.017 Megajoule difference for an iteration interval of 30 minutes. Thus, for most purposes, the summation procedure as used within this program appears adequate and can be expected to generate reliable results for all but the smallest of areas bounded by a specific curve.

END OF SECTION 4.

SECTION 5.

THE DAVIES, SCHERTZER AND NUNEZ RADIATION MODEL.

The following discussion on the Davies, et.al. (1975) shortwave radiation model is intended to present only the most elementary components of this scheme. The theory, development and testing of this radiative transfer model is definitively presented in the original publication and will not be reiterated in this section. The user is strongly advised to consult this reference to understand the nature and limitations of this particular model.

The model proposed by Davies, et.al (1975) has been selected as the basis of this program for its apparent reliability over a wide range of geographical and atmospheric conditions. In addition, the ease to which a variety of user options can be incorporated into the basic construct makes this an excellent format for a user oriented instructional computer program.

Developed and initially tested for stations on and around Lake Ontario, Canada, this model expresses the surface radiative receipt as the product of atmospheric transmissions. Based largely upon the earlier work of Houghton (1954), three primary expressions are used to determine the amount of radiation received at a given site. For the diffuse, direct and global radiation these expressions take the form

$$D = I_0 \left(\frac{d}{\bar{d}} \right)^2 \cos Z \Psi_{wa} \Psi_{da} (1.0 - \Psi_{ws} \Psi_{rs} \Psi_{ds}) / 2.0 \quad 5.1$$

$$S = I_0 \left(\frac{d}{\bar{d}} \right)^2 \cos Z \Psi_{wa} \Psi_{da} \Psi_{rs} \Psi_{ds} \Psi_{ws} \quad 5.2$$

$$K_{\downarrow \text{hor}} = I_0 \left(\frac{d}{\bar{d}} \right)^2 \cos Z \Psi_{wa} \Psi_{da} (\Psi_{rs} \Psi_{ws} \Psi_{ds} + 1) / 2.0 \quad 5.3$$

where

$$\Psi \begin{cases} \text{ws} & \text{water vapor scattering} \\ \text{wa} & \text{water vapor absorption} \\ \text{da} & \text{aerosol absorption} \\ \text{ds} & \text{aerosol scattering} \\ \text{rs} & \text{Rayleigh scattering} \end{cases}$$

The quantity $(d/\bar{d})^2$ was not presented in the original equations but its inclusion here is considered expedient. In addition, the global radiation (K_{\downarrow}) is that received on the

horizontal and, should any adjustment to the direct or diffuse beam (i.e. allowance for site inclination) be required, the value of K_{\downarrow} as determined by 5.3 is inappropriate. However, due to the direct relationships that exist between the components of these particular equations it can be seen that the value of K_{\downarrow} as determined by the sum of Eqn. 5.1 and 5.2 is equally reliable. Thus, Equation 5.3 has not been explicitly included in the FORTRAN program and for all values of global radiation the relationship $K_{\downarrow} = (S + D)$ is applied.

Primary assumptions inherent in the Davies et.al. model include: absorption prior to scattering, half of the scattered radiation reaches the surface and half the dust depletion is due to absorption (Davies, et.al, 1975, 3). Approximating Houghton's transmission curves the values of these variables are given as

$$\Psi_{ws} = 1.0 - 0.025wm$$

$$\Psi_{rs} = 0.972 - 0.08262m + 0.000933m^2 - 0.00095m^3 + 0.0000437m^4$$

$$\Psi_{wa} = 1.0 - 0.077(wm)^{0.3}$$

where m is the optical air mass
 w the precipitable water

For the dust transmission

$$\Psi_D = \Psi_{da} \Psi_{ds} = K^m$$

where the turbidity (transmission) factor, K , was allowed to vary between 0.88 and 0.98.

To these fundamental equations have been added a variety of theoretical constructs necessary to generate reliable and realistic estimates of solar radiation at a specified site. Although several of these options have been included in the initial work of Davies, et.al.(1975), for purposes of discussion and information continuity, they have been isolated and included in the following section.

END OF SECTION 5.

SECTION 6.

MODEL USER OPTIONS.

In addition to the inclusion of the earth/sun correction factor and adjustment due to site inclination and azimuth, a variety of user options have been integrated into the basic radiative transfer scheme. These options are expressions that have been developed to account for the known physical properties of the radiative environment and their inclusion into the program provides the user with the capacity to test the sensitivity of these elements through the generated results. As these options do not necessarily occupy any specific hierarchy within the FORTRAN program they are not preferentially listed.

A more basic body of information for each of these variables has been included in the solar radiation program and can be invoked by selecting Option 2 of the data entry sequence. This option and other user facilities are explicitly discussed in Section 8 of this manual.

6A. TIME INCREMENT. (Option 4.)

The user selected time increment determines the number of times the radiative data will be computed over the time from sunrise to sunset. For example, if the daylength is 10 hours and calculations are required at 5 minute intervals then the model will iterate 120 times. The minimum input that the model will accept is 1 minute and any value can be entered up to and including 60 minutes. It should also be noted that for increments of 5 minutes (i.e. 1,5,10,15,20 ... 60) the computed values will always be centered around solar noon.

6B. PRECIPITABLE WATER. (Option 6.)

If all the water vapor in a column of air directly above the study site could be condensed, the actual depth of water obtained defines the precipitable water. Various chart methods have been developed to provide a general measure of the precipitable water if appropriate information about the state of the atmosphere is available (see List, 1966, 327; Berry et.al., 1973, 392 and 1020). Also, if radiosonde data is available an exact measure of the atmospheric moisture can be obtained. Generally, under conditions of clear sky, the amount of precipitable water can reasonably be expected to vary between 0.2 to 10.0 centimeters. Davies et.al (1975, 43) found the precipitable water to vary between 0.2 and 3.0 centimeters for over 90% of the clear sky days monitored during the study period from which the basic radiation model was developed.

Various expressions have been developed that use more readily available data to obtain a measure of the precipitable water. Reitan (1963) developed a well-used expression that

relates precipitable water to the surface dew point temperature (useful if monthly climatological summaries are available). Also, as Reitan's regression equation was developed using data gathered from 15 stations over the continental United States, it is possible to obtain an indication of the geographic variability and ranges of precipitable water from this reference. Other investigators such as Idso (1970) and Hay (1970) have attempted to relate precipitable water to surface humidity. Again, the user should consult these references if the necessary data is available and some absolute measure of the precipitable is required.

It should also be noted that the radiation model can be used to determine the value of a single variable. For example, if measured radiative data exists and the other variables required for model input are known with some confidence, the value of the variable (i.e. precipitable water) is isolated when the measured and computed curves converge.

6C. ATMOSPHERIC TRANSMISSION. (Option 5.)

The atmospheric transmission factor, K, can be expected to vary between 0.75 and 0.98. Davies evaluated the model over a range of transmissivities (0.88 to 0.98) with best results achieved as the transmissivity approached 0.88 (Davies, et.al., 1975,38). The original value accepted by Houghton for the determination of the transmission curves was 0.95 (see Davies et.al, 38). However, this variable can be expected to vary considerably in time and space and, therefore, represents one of the less definable inputs to the FORTRAN program. As previously suggested, it is possible to use the FORTRAN program to converge upon an appropriate value.

6D. ADJUSTMENT FOR SITE ELEVATION. (Options 7 & 8.)

The effects of site elevation (or pressure) are incorporated somewhat indirectly, although very effectively, into the radiation model through adjustment of the optical air mass by the ratio of the site pressure to the average sea level pressure. Thus

$$m = m_0 * \left(\frac{p}{p_0} \right)$$

6.1

where m adjusted value of the optical air mass
 m_0 sea level optical air mass (computed by 6.5 or 6.6)
 p atmos. pressure (mb) of the site under investigation
 p_0 average sea level pressure (1013.25 mb)

Although only a measure of the pressure is required as model input this quantity can also be considered a surrogate for site elevation. The relationships that exist between elevation (height) and pressure are conventionally developed through appropriate substitution into the hydrostatic equation. In standard form

$$dp/dz = - \rho g = - \frac{gP}{RT}$$

where P atmospheric pressure 6.2
 z height (meters)
 T air temperature (Kelvin)
 R Universal gas constant (288 J kg⁻¹ K⁻¹)
 g acceleration of gravity (9.80665 m s⁻²)
 ρ density of the atmosphere

By making certain assumptions about the "average" state of the atmosphere and accepting general values for the constants, the association between the elements expressed in Eqn. 6.2 gives rise to what is known as the U.S. Standard Atmosphere. For complete derivation of the following equations and determination of the constants the user should consult Berry et.al (1970, 371-374). By integrating Eqn. 6.2 the relationships between pressure and temperature can take the form

$$p = p_0 \left(1.0 - \frac{\dot{n} z}{T_0} \right)^{g/R\dot{n}}$$

6.3

where P₀ average surface pressure (1013.25 mb)
 T₀ are average surface temperature (288 K)
 ṅ the dry adiabatic lapse rate (0.65 deg. m⁻¹)
 z the elevation in meters of the point for which an estimate of the pressure is required.

Solving for pressure at height, z, and with standard values for the variables

$$p = 1013.25 \left(1.0 - \frac{0.0065z}{288} \right)^{\left(\frac{9.8066}{287 * 0.0065} \right)}$$

Thus, for an elevation of 3,000 meters the atmospheric pressure becomes

$$p = 1013.25 \left(1.0 - \frac{0.0065 * 3000}{288} \right)^{5.2568} \longrightarrow \underline{\underline{700.87 mb.}}$$

By solving equation 6.3 for height (z) we can use this general construct to compute site elevation using pressure as input. Thus:

$$z = \frac{T_0 \left(\frac{g}{R\dot{n}} \sqrt{\frac{p}{p_0}} - 1.0 \right)}{\dot{n}}$$

6.4

By using equations 6.3 and 6.4 the solar radiation program gives the user the option of entering either the site elevation or site pressure. The computer will, in turn, compute an estimated elevation or pressure depending upon the input (see output of user options on pages 65 and 73).

If necessary, the conversion from feet to meters can be undertaken by setting 12 inches equal to 0.3047 meters. Thus 3000 meters is equivalent to 9843 feet. For general reference a table of pressure/height values computed using Eqn.6.7 has been included in the Appendix (page 105).

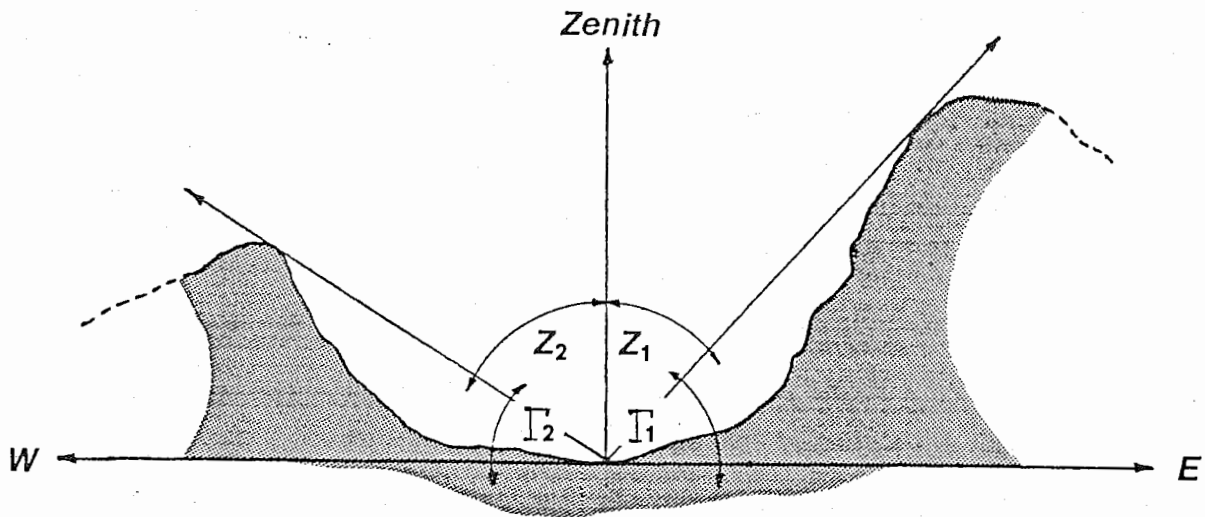
6E. SURFACE ALBEDO. (Option 11.)

A measure of the surface albedo (or surface reflection coefficient) is essential in determining the net shortwave radiation (K*) and for the additional radiative contribution due to backscatterance. If measured data is not available many standard texts provide a listing of generally accepted values and ranges of the albedo for various surface types (i.e. Monteith, 1973, Chap.5; Oke, 1978, 15; Sellers, 1972, 29). Perhaps the most complete compilation is that of List (1966, 442-443). For user convenience a listing of surface reflection coefficients for a variety of surface types has been included in the Appendix (page 103).

6F. TERRAIN OBSTRUCTION. (Options 12 & 13.)

The shielding effects of the surrounding terrain are incorporated into the model through the relationships that exist between the user-specified terrain elevation (TOPM and TOPE) and the time-dependent computer generated zenith angle. Only the direct beam receipt is altered as the isotropic assumption for diffuse radiation results in a diurnal distribution that remains unaffected by obstruction of the solar disk. The diagram below is intended to approximate the conditions presented in Example 3 (page 73) and the FORTRAN syntax can be found between lines 835 and 841 of the computer program.

Example cont'd

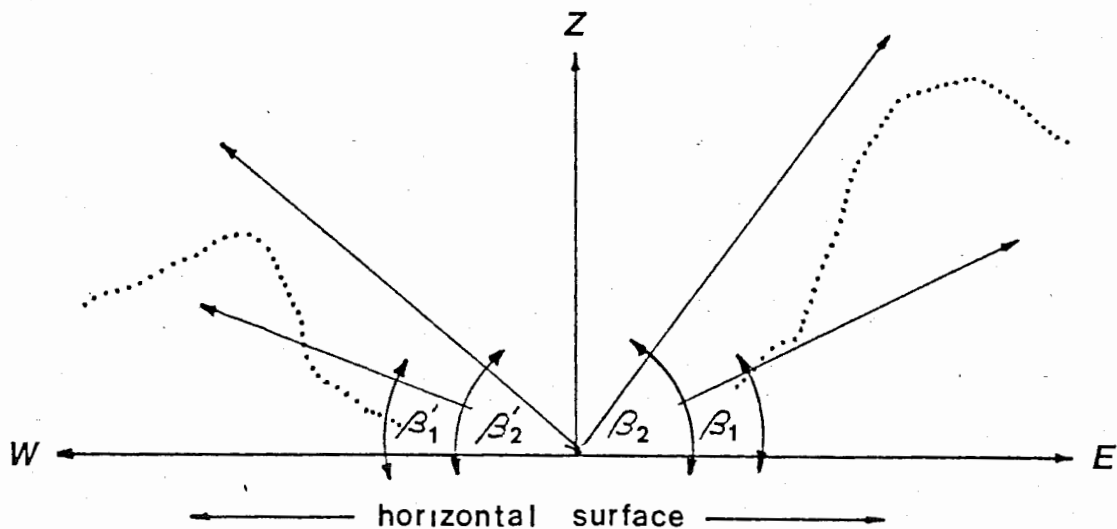


where the angles

- Γ_1 skyline elevation for sunrise (TOPM)
- Γ_2 skyline elevation for sunset (TOPE)
- Z_1 zenith angle for times prior to solar noon
- Z_2 zenith angle for times past solar noon

The position of the solar disk in the sky is defined by the solar zenith angle. At solar noon the the zenith angle is zero and increases as the solar disk approaches the horizon for both sunrise and sunset. The opposite of the zenith angle, β , is the actual angle of the sun above the astronomical horizon (i.e. horizontal surface without surrounding terrain). Thus from the above diagram it is clear that if the zenith angles, centered around solar noon, are greater than either Γ_1 or Γ_2 then the solar disk lies below the visible horizon.

From the above diagram and with reference to the solar path diagram included with Example 3, the computer iteration procedure can be generalized as follows



Therefore, if

$$\left. \begin{array}{l} \beta_1 > \Gamma_1 \quad S = 0 \\ \beta_2 < \Gamma_1 \quad S = 0 \\ \beta'_2 < \Gamma_2 \quad S = 0 \\ \beta'_1 > \Gamma_2 \quad S = 0 \end{array} \right\} \begin{array}{l} \text{- Sunrise to Noon} \\ \text{- Noon to sunset} \end{array}$$

Thus, for the morning hours, the direct beam radiation is set to zero as long as the computed angle of the solar elevation is less than the angle specified by the user for the skyline of the surrounding terrain (TOPM). Similarly, for times past solar noon, the direct beam is set to zero only when the solar elevation is less than the user specified skyline (TOPE).

It should also be noted that, if the effects of the surrounding terrain upon radiative receipt are required, the user selected time increment (TINC) is important in determining in the computed time of direct beam receipt on the surface. For example, if the time increment selected was 60 minutes, the range of zenith angles through which the sun would move between consecutive instantaneous computations is greater than for a time increment of 10 minutes. Thus, a smaller time increment will produce results that are more sensitive to the exact specifications of the skyline elevations (consult Example 3A).

6G. ATMOSPHERIC REFRACTION (Optical Air Mass). (Option 14.)

The optical depth (or optical thickness) of the atmosphere can generally be interpreted as the path length from the edge of the atmosphere to the site for which calculations are being made as taken by the direct solar beam. Thus, this "length" is related to the zenith angle, for when the sun is low on the horizon the depth of the atmosphere through which the direct beam must travel is greater than if the sun were positioned directly overhead. The most straightforward and conventional expression for the optical air mass is

$$m = \sec Z = \frac{1.0}{\cos Z} \quad 6.5$$

The latter expression is necessary as no intrinsic function for the secant exists within the FORTRAN compiler. Thus, the "length" is in reality a ratio of the actual path length at some point in time (as determined by the zenith angle) to the value of this function when the sun is directly overhead. The optical air mass is, therefore, a dimensionless quantity for when the sun is directly above the site (zenith angle of zero)

$$m = \sec 0 = \frac{1.0}{\cos 0} = 1.0$$

The numerical value of the optical air mass is, therefore, greater when the sun is positioned near the horizon. However, at

large zenith angles the value of m as determined by Eqn. 6.5 becomes unrealistically large and, to avoid computational instability in the FORTRAN model, an upper limit of 10.0 is specified.

An alternative to the somewhat simple construct of Eqn. 6.5 has been presented by Kasten (1966). As the secant format is purely geometric, no allowance is made for the known effects of atmospheric refraction which effectively makes the solar disk appear above the horizon prior to the time of computed astronomical sunrise and past the time of computed sunset. To include refractive effects the expression for the optical air mass becomes

$$m = \left\{ \cos Z + 0.15 (93.885 - Z)^{-1.253} \right\}^{-1.0} \quad 6.6$$

Again, to avoid computational instability, an upper limit of 10.0 is specified. The FORTRAN syntax for the above expressions and their position in the computer program can be found between lines 809 and 822 of the program listing.

6H. BACKSCATTERED RADIATION. (Option 15.)

Suckling and Hay (1976) suggested that the diffuse component of the radiative balance is augmented by a small but, on occasion, significant component of diffuse radiation that is effectively scattered back from the atmosphere toward the surface after initial surface reflection. That is, a proportion of the reflected radiation (K_{\uparrow}) is in turn scattered back toward the surface and becomes part of the total diffuse irradiance. In keeping with the Davies et.al format, this additional term can be expressed

$$Db = \alpha (S + D) \left\{ \Psi_{wa} \Psi_{da} (1.0 - \Psi_{ws} \Psi_{rs} \Psi_{ds}) \right\} / 2.0 \quad 6.7$$

Where all the Ψ 's have been defined through Eqns. 5a and 5b but are evaluated with the optical air mass, m , fixed at a value of 1.66. Although this approach has the potential for multiple reflections only the first component of this backward directed radiation is accounted for. Thus

$$Db = (S + D) \dot{\rho} / (1.0 - \dot{\rho})$$

where

$$\dot{\rho} = \left\{ \alpha \Psi_{wa} \Psi_{da} (1.0 - \Psi_{ws} \Psi_{rs} \Psi_{ds}) \right\} / 2.0 \quad 6.8$$

The total diffuse radiation received at the site, therefore, becomes the sum of the diffuse component initially determined by 5.1 and the additional contribution as determined by 6.8. Thus

$$D_{\text{tot}} = D + D_b$$

and

$$K_{\downarrow} = D_{\text{tot}} + S$$

6.9

This user option is positioned in the FORTRAN program between lines 842 and 856.

END OF SECTION 6.

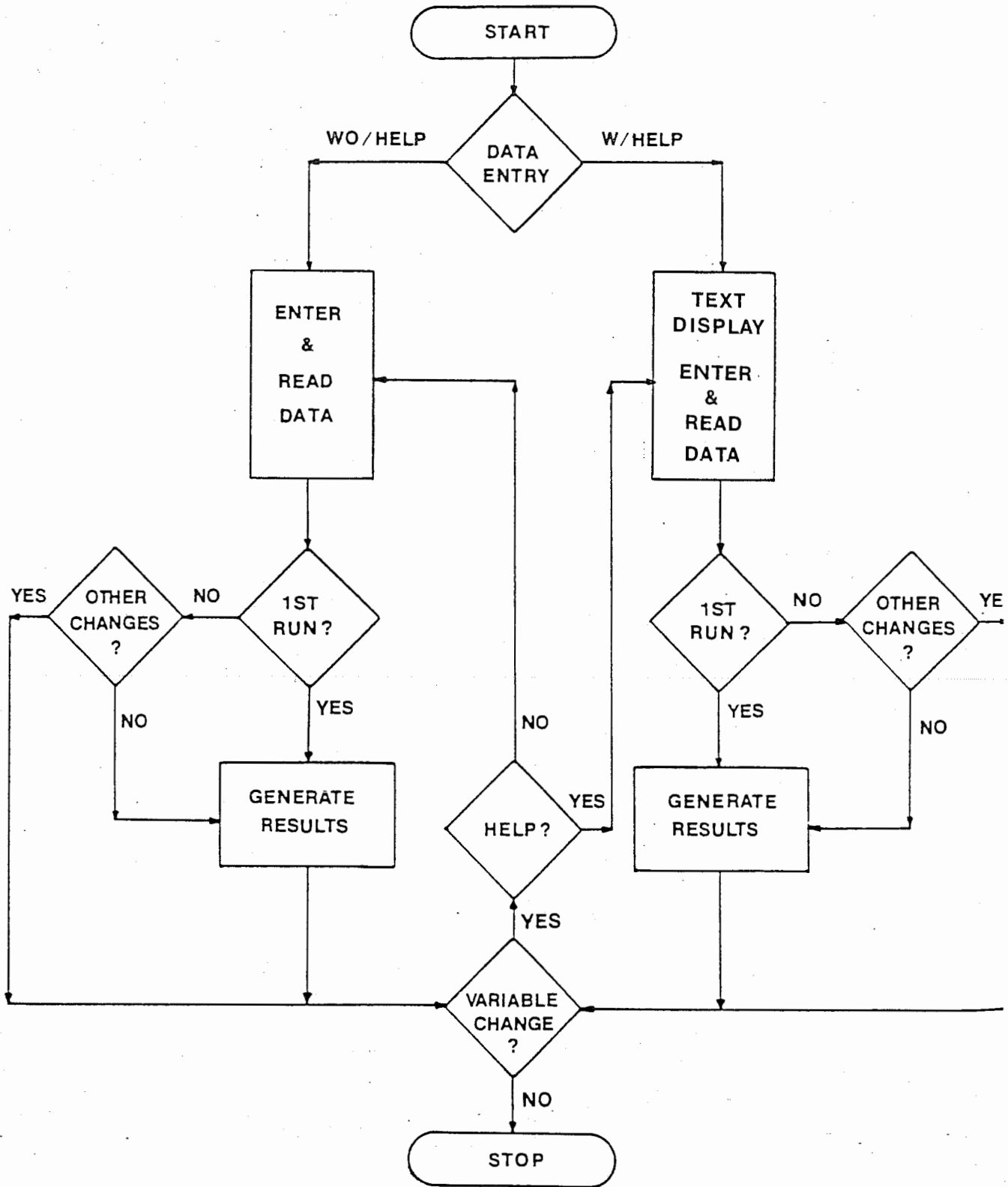
SECTION 7.

The FORTRAN solar radiation program.

Filename = SOLAR.FOR

Only a partial listing of the solar radiation program has been included in this manuscript. The intention is to present only the FORTRAN statement lines that involve the primary solar radiation generator. The total program consists of 1294 statement lines and requires 27 pages for a complete listing. Should a program printout be required the user should refer to the technical information provided on page 108 or the appropriate section of the MICROSOFT FORTRAN manual.

GENERALIZED FLOW CHART.



SHORTWAVE RADIATION MODEL

Data Input Sequence, Symbols and Field Length

Variable	Symbol	Variable FORTRAN Name	Field Type & Length	Units
Latitude -----	ϕ	PHI (PHIR)+ *	F6.2	Deg.
Declination -----	γ	DEC (DECR) *	F5.1	Deg.
Earth/Sun correction -	$(d/\bar{d})^2$	EDIST	F8.6	-
Time increment -----	t	TINC	I2	Mins.
Atmos. Transmission --	K	K	F4.2	-
Precipitable water ---	w	W	F4.2	Cm.
Atmospheric Pressure -	p	PRES	F7.2	Mb.
Site Elevation -----	z	ELEV	F6.2	M.
Slope of Site -----	i	ASLOPE (SLOPE)	F4.1	Deg.
Azimuth of Site -----	Az	AZZ (AZIMTH) #	F5.1	Deg.
Site Albedo -----	α	ALBEDO	F4.2	10ths
Horizon Elevation at Sunrise -----	-	TOPM (TOPMR)	F4.1	Deg.
Horizon Elevation at Sunset -----	-	TOPE (TOPER)	F4.1	Deg.
Backscattered radiation -	-	IHAY ^	I1	-
Atmospheric refraction -	-	KAST ^	I1	-
Solar Path Calculation -	-	ISOL ^	I1	-
Time Increment for Solar Path Calculation -	-	ISOLT	I2	Mins.

+ Variable names in parenthesis are radian equivalents as created within the program.

* All values south of the equator are to be preceded by a negative sign.

Cont'd

Specified as clockwise from north (360 or 0) through east (90).

^ Options: 0=NO; 1=YES.

Upon data entry the field type and length should be strictly adhered to or compiler error can result. Should an entry error be made the system prompt, B >, will appear. At this point the complete data entry sequence will need to be repeated. A complete printout of the data entry sequence is provided on pages 49 and 50. Error codes and reentry procedures are outlined on page 53 of Section 8.

For each user option the field type and length is identified at the point of entry. The variable to be entered will additionally be indicated by a line that will appear as "----.-" which serves to specifically define the variable length, the number of decimal places and the position of the decimal point. An entry specified, for example, by F6.2 (F denotes a real number; I for integer) six positions have been allocated for the input. The last two positions contain decimal places, the third for the decimal point and the remainder for all other data including the negative sign where necessary. Note also that the input is always right justified and, for those positions not required to contain a value, a zero or a blank (usually indicated by b) is the only acceptable input.

D Line# 1 7 Microsoft FORTRAN77 V3.30 March 1985

```

1 $title:'Solar Radiation Model. Mountain (1986)'
2 $storage:2
3 PROGRAM Solar
4 REAL KEX,IO,K,M,KEXINS,PRES,PHI,PHIR
5 REAL H,NETOT,NLGH,NAREA,NET,NETP,KEXP
6 INTEGER ATINC, HELP, START, OPT
7 C SET UP PROGRAM HEADINGS
8 WRITE(*,5)
9 5 FORMAT(2X,71('-') //10X,'A CLEAR SKY SOLAR RADIATION GENERATOR'/
10 *16X,'FOR THE PERSONAL COMPUTER' //40X,'Created by: KEITH R. MOUNTA
11 *IN. '//40X,'(C) Department of Geography'/
12 *39X,'Portland State University. 1986.'//2x,71('-')//)
13 WRITE(*,8)
14 8 FORMAT(' ',10X,'There are two ways to enter this program:'//
15 *15x,'1. If you are familiar with the data entry sequence and'/
16 *18x,'the nature of the variables then just ENTER the NUMBER 1.'//
17 *15x,'2. If you would like additional information on the'/
18 *18x,'variables and how to enter your choice ENTER the NUMBER 2.')
19 WRITE(*,9)
20 9 FORMAT(1x,14X,'_'//1X,'ENTRY NUMBER ='\\)
21 READ(*,4) START
22 4 FORMAT(I1)
23 IF( START.EQ.1) GO TO 670
24 IF(START.EQ.2) GO TO 671
25 670 WRITE(*,3)
26 3 FORMAT(1X,71('-')//)
27 WRITE (*,10)
28 10 FORMAT (2X,'Enter site latitude (F6.2).'/8X,'_____'//1x,'ENTRY ='

```

} *Input options & help routines*

```

661 WRITE(*,594)
662 594 FORMAT(15X,'To PRINT the data:'//
663 *15x,'Press the CONTROL (CTRL) key and, while holding it down,'/
664 *15x,'press the PRINT SCREEN (PRTSC) key. Release both keys and'/
665 *15x,'press the ENTER key. Make sure the printer is switched ON.'//
666 */15x,'To STOP PRINTING repeat the above sequence.'//8x,'_',
667 */1x,'ENTRY..'\\)
668 READ(*,336) IRUN
669 336 FORMAT(I1)
670 C SET UP CONSTANTS AND RADIAN CONVERSIONS
671 555 CONTINUE
672 C

```

```

D Line# 1      7
673          API = 3.141592654
674          RAD = API / 180.0
675          APID = 180.0/API
676          PHIR = PHI * RAD
677          DECR = DEC * RAD
678          IO = 1353.0
679          IP = 0
680          HELP = 0
681          OPT = 2
682          TOPMR = TOPM * RAD
683          TOPER = TOPE * RAD
684          DHOURL = 15.0 * RAD
685          BETAP = 0.0
686          SLOPE = ASLOPE * RAD
687          AZIMTH = (AZZ * RAD) - API
688 C
689          IF(PHIR.GT.1.57079) PHIR = 1.57079
690          IF(PHIR.LT.-1.57079) PHIR = -1.57079
691 C          CALCULATE TIMES OF SUNRISE AND SUNSET
692          AC = - TAN(PHIR) * TAN (DECR)
693          IF(AC.LE.-1.0) GO TO 110
694          IF(AC.GE.1.0) GO TO 110
695          AC = ACOS(AC)
696          SR = 12.0 - ((AC * APID) / 15.0)
697          SS = 12.0 + ((AC * APID) / 15.0)
698          GO TO 120
699 110 SR = 0.0
700          SS = 0.0
701 C
702 C          ROUTINES TO COMPUTE PRESSURE OR ELEVATION
703 120 continue
704 880 IF(IOPT.EQ.1) GO TO 606
705 C          COMPUTE ESTIMATED ELEVATION
706          ELEV = ((PRES/1013.25)**0.19303)-1.0
707          ELEV = (ELEV * 288.0)/0.0065
708          ELEV = ELEV * (-1.0)
709          GO TO 615
710 C
711 606 CONTINUE
712 C          COMPUTE ESTIMATED PRESSURE
713          PRES = 1.0 - ((0.0065 * ELEV) / 288.0)
714          PRES = PRES ** 5.2568
715          PRES = 1013.25 * PRES
716 615 CONTINUE
717          IF(OPT.LT.2) GO TO 222
718 C
719 C          WRITE OUT INPUTS
720          WRITE (*,50)
721          50 FORMAT(24X,'USER SUPPLIED OPTIONS'/24X,21('-'))
722          WRITE(*,51) PHI
723          51 FORMAT('0',20X,'Latitude of site ----- = ',F6.2,' Deg')
724          WRITE(*,52) DEC
725          52 FORMAT(21X,'Declination of site ----- = ',F6.2,' Deg.')
726          WRITE(*,53) ATINC
727          53 FORMAT(21X,'Time increment for calculations = ',I2 , ' Mins.')
728          WRITE(*,54) EDIST

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
729      54 FORMAT(21X,'Earth/sun correction factor ---- = ', F8.6,)
730      WRITE(*,55) K
731      55 FORMAT(21X,'Atmospheric transmission ----- = ', F5.2,' 10ths')
732      WRITE(*,56) W
733      56 FORMAT(21X,'Precipitable water ----- = ', F5.2,' Cm.>')
734      IF(IOPT.EQ.1) GO TO 607
735      WRITE(*,57) PRES
736      57 FORMAT(21X,'Atmospheric pressure ----- = ', F7.2,' Mb.>')
737      WRITE(*,608) ELEV
738      608 FORMAT(21X,'Estimated elevation ----- = ', F6.1,' Meters')
739      GO TO 610
740      607 WRITE(*,611) ELEV
741      611 FORMAT(21X,'Elevation of site ----- = ', F6.1,' Meters')
742      WRITE(*,612) PRES
743      612 FORMAT(21X,'Estimated site pressure ----- = ', F7.2,' Mb')
744      610 CONTINUE
745      WRITE(*,58) ASLOPE
746      58 FORMAT(21X,'Inclination of slope ----- = ', F5.1,' Deg.>')
747      WRITE (*,59) AZZ
748      59 FORMAT(21X,'Azimuth of slope ----- = ', F5.1,' Deg.>')
749      WRITE(*,60) ALBEDO
750      60 FORMAT(21X,'Albedo of site ----- = ', F4.2,' 10ths')
751      WRITE(*,62) TOPM
752      62 FORMAT(21X,'Elevation of skyline for sunrise = ', F5.1,' Deg.>')
753      WRITE(*,63) TOPE
754      63 FORMAT(21X,'Elevation of skyline for sunset = ', F5.1,' Deg.>')
755      WRITE (*,64) KAST
756      64 FORMAT(21X,'Atmospheric refraction ----- = ', I3)
757      WRITE (*,66) IHAY
758      66 FORMAT(21X,'Backscattered radiation ----- = ', I3 )
759      WRITE(*,67) SR
760      67 FORMAT(21X,'Time of SUNRISE ----- = ',F6.2,1X,'Hrs')
761      WRITE(*,68) SS
762      68 FORMAT(21X,'Time of SUNSET ----- = ',F6.2,1X,'Hrs')/
763 C
764      IF(IX.EQ.18) GO TO 222
765      IF(IRUN.EQ.1) GO TO 222
766 C      WRITE OUT HEADINGS
767      WRITE(*,69)
768      69 FORMAT(' ', 5X,'TIME',4X,'DIRECT',4X,'DIFFUSE',4X,'GLOBAL',4X,
769      *'REFLECTED',5X,'NET',5X,'EX.TERR.']/6X,4(' '),4X,6(' '),4X,
770      *7(' '),4X,6(' '),4X,9(' '),5X,3(' '),5X,8(' '))
771 C
772 C      INITIALIZE TIME INCREMENT - VALUES WILL PASS THRO. SOLAR NOON
773      SR = IFIX(SR)
774      DAYLTH = (12 - SR) * 2
775      ITER =(DAYLTH * (60/ATINC)) + 1
776      AA = FLOAT(ATINC)
777      TINC = AA/60.0
778      AB = SR - TINC
779 C
780      DO 888 I = 1,ITER
1 781      TIME = AB + TINC
1 782 C      CALCULATE THE HOUR ANGLE AND CONVERT TO RADIANS
1 783      H = ((12.0 - TIME) * 15.0 ) * RAD
1 784 C      CALCULATE COSINE OF THE ZENITH ANGLE

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
1  785      COZ = (SIN(PHIR)* SIN(DECR))+ (COS(PHIR)*COS(DECR)*COS(H))
1  786      IF(COZ.LE.0.0) GOTO 900
1  787 C
1  788 C      CALCULATE INSTANTANEOUS VALUES OF KEX
1  789      KEXINS = IO * EDIST* COZ
1  790      AKEXL = TINC * 3600.0
1  791      AKEXA = AKEXL * ((KEXINS + KEXP)/2.0)
1  792      KEX = AKEXA + KEX
1  793      KEXP = KEXINS
1  794 C
1  795 C      REQUIRE THE ZENITH ANGLE
1  796      IF(COZ.GT.1.0) COZ = 1.0
1  797      Z = ACOS( COZ)
1  798      IF( Z.LE.0.0) Z = 0.0001
1  799 C      COMPUTE SOLAR AZIMUTH ANGLE
1  800      A = SIN(DECR) * COS(PHIR)
1  801      B = COS(DECR) * SIN(PHIR) * COS(H)
1  802      C = (A - B)/ SIN(Z)
1  803      IF(C.GE.1.0) C = 1.0
1  804      IF(C.LE.-1.0) C = -1.0
1  805      AZSUN = ACOS(C)
1  806 C      TEST FOR AZIMUTH AT TIME LESS THAN 12.0
1  807      IF(TIME.LE.12.0) GOTO 130
1  808      AZSUN = (2.0 * API) - AZSUN
1  809      130 CONTINUE
1  810 C      OPTICAL AIR MASS BY THE EQUATION OF KASTEN (1966)
1  811      IF(KAST.EQ.0) GO TO 140
1  812      M = COZ + 0.15 * (93.885 - ( Z * APID)) ** (-1.253)
1  813      M = M **(-1.0)
1  814      IF(M.GT.10.0) M = 10.0
1  815      GO TO 150
1  816 C
1  817 C      COMPUTATION OF OPTICAL AIR MASS AS FUNCT. ZENITH ANGLE
1  818      140 M = 1.0/COZ
1  819      150 CONTINUE
1  820 C      ADJUST OPTICAL AIR MASS FOR ATMOSPHERIC PRESSURE
1  821      M = M * (PRES/1013.25)
1  822      IF(M.GT.10.0) M = 10.0
1  823 C
1  824 C      BEGIN DAVIES ET.AL. COMPUTATION
1  825      PSIRS= 0.972 - 0.08262*M+0.00933*M*M-0.00095*M*M*M +
1  826      *0.0000437*M*M*M*M
1  827      PSIWA = 1.0 - 0.077 *(W*M) **0.3
1  828      PSIWS = 1.0 - (0.0225 * W * M)
1  829      Q      = K ** M
1  830      ALPHA = SQRT (Q)
1  831      PSIDS = ALPHA
1  832      PSIDA = ALPHA
1  833      DIRECT= IO * EDIST * COZ * PSIWA * PSIDA * PSIWS*PSIRS*PSIDS
1  834      DIFUSE=0.5*IO*EDIST*COZ*PSIWA*PSIDA*(1.0-PSIRS*PSIWS*PSIDS)
1  835 C
1  836 C      TERRAIN OBSTRUCTION (DETERMINES IF DIRECT BEAM IS SET TO ZERO)
1  837 C      CALCULATE ANGLE BETWEEN SUN AND HORIZON (BETA)
1  838      BETA = (API/2.0) - Z
1  839      IF(TOPMR.GE.BETA) DIRECT = 0.0
1  840      IF(TIME.LE.12.0) GO TO 155

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
1  841      IF(TIME.GT.12.0) TOPMR = 0.0
1  842      IF(TOPER.GE.BETA) DIRECT = 0.0
1  843 C
1  844 C      SUCKLING AND HAY MODEL (OPTIONAL)
1  845      155 IF(IHAY.EQ.0) GOTO 160
1  846      M = 1.66 * (PRES/1013.25)
1  847      PSIRS = 0.972 - 0.08262*M + 0.00933*M**2 - 0.00095*M**3 + 0.000437*M**4
1  848      PSIWA = 1.0 - 0.077*(W*M)**0.3
1  849      PSIWS = 1.0 - (0.0225*W*M)
1  850      Q = K ** M
1  851      ALPHA = SQRT(Q)
1  852      PSIDS = ALPHA
1  853      PSIDA = ALPHA
1  854      RHO = 0.5 * ALBEDO * PSIWA * PSIDA * (1.0 - PSIWS * PSIRS * PSIDS)
1  855      DIFHAY = (DIRECT + DIFUSE) * RHO / (1.0 - RHO)
1  856      DIFUSE = DIFHAY + DIFUSE
1  857 C
1  858 C      BEGIN COMPUTATION FOR INCLINED SURFACES
1  859      160      A = (COS(SLOPE/2.0))**2 * DIFUSE
1  860      B = (SIN(SLOPE/2.0))**2 * ALBEDO * (DIRECT + DIFUSE)
1  861      DIFUSE = A + B
1  862 C
1  863 C      CALCULATE DAILY TOTALS OF DIFFUSE RADIATION
1  864      DLGTH = TINC * 3600.0
1  865      DAREA = DLGTH * ((DIFUSE + DIFP) / 2.0)
1  866      DTOT = DAREA + DTOT
1  867      DIFP = DIFUSE
1  868 C
1  869 C      DETERMINE AZIMUTHAL DIFFERENCES
1  870      AZDIF = AZSUN - AZIMTH
1  871 C
1  872 C      COMPUTATIONS FOR DIRECT BEAM ON INCLINED PLANE
1  873 C      GENERATE COTANGENT FUNCTION (1.0 / TAN(X))
1  874      COTAN = 1.0 / TAN(BETA)
1  875      IF (COTAN.GT. 9.0) COTAN = 9.0
1  876      SHAPE = COS(SLOPE) - SIN (SLOPE) * COTAN * COS (AZDIF)
1  877 C
1  878      DIRECT = DIRECT * SHAPE
1  879      IF (DIRECT.GT.KEXINS) DIRECT = KEXINS
1  880      IF (DIRECT.LT.0.0) DIRECT = 0.0
1  881 C      DAILY TOTALS OF DIRECT
1  882      SLGTH = TINC * 3600.0
1  883      SAREA = SLGTH * ((DIRECT + DIRP) / 2.0)
1  884      STOT = SAREA + STOT
1  885      DIRP = DIRECT
1  886 C
1  887 C      DAILY TOTALS OF GLOBAL RADIATION
1  888      GLOBAL = DIRECT + DIFUSE
1  889      GLGTH = TINC * 3600.0
1  890      GAREA = GLGTH * ((GLOBAL + GLOBP) / 2.0)
1  891      GTOT = GAREA + GTOT
1  892      GLOBP = GLOBAL
1  893 C
1  894 C      COMPUTE DAILY TOTALS OF NET RADIATION
1  895      NET = GLOBAL * (1.0 - ALBEDO)
1  896      NLGTH = TINC * 3600.0

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
1  897      NAREA = NLGTH * ((NET + NETP) / 2.0)
1  898      NETOT = NAREA + NETOT
1  899      NETP = NET
1  900 C
1  901 C      COMPUTE REFLECTED RADIATION AND DAILY TOTALS
1  902      REF = GLOBAL * ALBEDO
1  903      RLGTH = TINC * 3600.0
1  904      RAREA = RLGTH * ((REF + REFP) / 2.0)
1  905      REFTOT = RAREA + REFTOT
1  906      REFP = REF
1  907      GO TO 170
1  908 C
1  909      900 DIRECT = 0.0
1  910      DIFUSE = 0.0
1  911      GLOBAL = 0.0
1  912      KEXINS = 0.0
1  913      REF = 0.0
1  914      NET = 0.0
1  915 C
1  916 C      PRINT OUT INSTANTANEOUS VALUES
1  917      170 WRITE (*,70) TIME,DIRECT,DIFUSE,GLOBAL,REF, NET,KEXINS
1  918      70 FORMAT( 5X,F5.2,3X,F7.2,4X,F7.2,3X,F7.2,4X,F7.2,4X,F7.2,4X,F7.2)
1  919 C
1  920      AB = TIME
1  921      888 CONTINUE
1  922 C
1  923 C      CONVERT DAILY TOTALS TO MEGAJOULES
1  924      DTOT = DTOT / 1000000.0
1  925      STOT = STOT / 1000000.0
1  926      GTOT = GTOT / 1000000.0
1  927      REFTOT= REFTOT/1000000.0
1  928      NETOT = NETOT/ 1000000.0
1  929      KEX = KEX / 1000000.0
1  930 C
1  931 C      WRITE OUT DAILY TOTALS
1  932      WRITE(*,71) DTOT,STOT,GTOT,REFTOT,NETOT,KEX
1  933      71 FORMAT('0',18X,'DAILY TOTAL OF DIFFUSE RADIATION -- = ',F6.2,
1  934      *' MJ/m**2'/
1  935      *19X,'DAILY TOTAL OF DIRECT RADIATION --- = ',F6.2,' MJ/m**2'/
1  936      *19X,'DAILY TOTAL OF GLOBAL RADIATION --- = ',F6.2,' MJ/m**2'/
1  937      *19X,'DAILY TOTAL OF REFLECTED RADIATION = ',F6.2,' MJ/m**2'/
1  938      *19X,'DAILY TOTAL OF NET SHORTWAVE RAD.-- = ',F6.2,' MJ/m**2'/
1  939      *19X,'DAILY TOTAL OF EXTRATERRESTRIAL RAD.= ',F6.2,
1  940      *' MJ/m**2'//)
1  941 C
1  942 C      SET ALL ELEMENTS OF THE INTEGRATED DAILY TOTALS TO ZERO
1  943      DTOT = 0.0
1  944      STOT = 0.0
1  945      GTOT = 0.0
1  946      REFTOT = 0.0
1  947      NETOT = 0.0
1  948      KEX = 0.0
1  949      KEXP = 0.0
1  950      DIFP = 0.0
1  951      DIRP = 0.0
1  952      GLOBP = 0.0

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
 953          NETP = 0.0
 954          REFP = 0.0
 955 C
 956 C      BEGIN ROUTINE FOR SOLAR PATH CALCULATIONS
 957 C      IF(ISOL.EQ.0) GO TO 200
 958 C
 959 C      444 WRITE(*,300)
 960 C      300 FORMAT('1',28X,'SOLAR PATH CALCULATIONS'/
 961 C      *29X,23('-'))
 962 C      WRITE(*,301) PHI
 963 C      301 FORMAT(' ',23X,'Site latitude ----- = ',F6.2,1X,'Deg')
 964 C      WRITE(*,302) DEC
 965 C      302 FORMAT(' ',23X,'Site declination ----- = ',F6.2,1X,'Deg')
 966 C
 967 C      CONVERT NECESSARY VARIABLES (DECLINATION AND LATITUDE)
 968 C      PHIR = PHI * RAD
 969 C      DECR = DEC * RAD
 970 C      IF(PHIR.GT.1.57079) PHIR = 1.57079
 971 C      IF(PHIR.LT.-1.57079) PHIR = -1.57079
 972 C      CALCULATE TIMES OF SUNRISE AND SUNSET
 973 C      AC = - TAN (PHIR) * TAN (DECR)
 974 C      IF(AC.LE.-1.0) GO TO 350
 975 C      IF(AC.GE. 1.0) GO TO 350
 976 C      AC = ACOS(AC)
 977 C      SR = 12.0 - ((AC * APID)/ 15.0)
 978 C      SS = 12.0 + (( AC * APID) / 15.0)
 979 C      AZ = ACOS(SIN(DECR)/COS(PHIR))
 980 C      AZSR = AZ * APID
 981 C      AZSS = 360.0 - (AZ * APID)
 982 C      GO TO 360
 983 C      350 SR = 0.0
 984 C      SS = 0.0
 985 C      AZSR = 0.0
 986 C      AZSS = 0.0
 987 C      360 CONTINUE
 988 C      WRITE(*,303) AZSR
 989 C      303 FORMAT(' ',23X,'Azimuth of sunrise --- = ',F6.2,1X,'Deg')
 990 C      WRITE(*,304) AZSS
 991 C      304 FORMAT(' ',23X,'Azimuth of sunset ---- = ',F6.2,1X,'Deg')
 992 C      WRITE(*,305) SR
 993 C      305 FORMAT(' ',23X,'Time of sunrise ----- = ',F6.2,' Hrs')
 994 C      WRITE(*,306) SS
 995 C      306 FORMAT(' ',23X,'Time of sunset ----- = ',F6.2,' Hrs')
 996 C
 997 C      WRITE OUT HEADINGS
 998 C      WRITE(*,307)
 999 C      307 FORMAT('0',22X,'TIME',5X,'SOLAR AZIMUTH',4X,'SOLAR ALTITUDE'/
1000 C      *23X,4('-'),5X,13('-'),4X,14('-'))
1001 C      INITIALIZE ITERATION INTERVAL
1002 C      SR = IFIX(SR)
1003 C      DAYLTH = (12 - SR) * 2
1004 C      ITER = (DAYLTH * (60 / ISOLT)) + 1
1005 C      AA = FLOAT (ISOLT)
1006 C      SOLT = AA/ 60.0
1007 C      AB = SR - SOLT
1008 C      BEGIN LOOP

```



```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
 1009      DO 666 I = 1, ITER
1 1010      TIME = AB + SOLT
1 1011      H = ((12.0 - TIME) * 15.0 ) * RAD
1 1012      XCOS =(SIN(PHIR)*SIN(DECR))+(COS(PHIR)*COS(DECR)*COS(H))
1 1013      IF(XCOS.LE.0.0) GO TO 365
1 1014      IF(XCOS.GT.1.0) XCOS = 1.0
1 1015      Z = ACOS(XCOS)
1 1016      SOLALT = 90.0 - (Z*APID)
1 1017      AZUM = (SIN(DECR)*COS(PHIR))-(COS(DECR)*SIN(PHIR)*COS(H))
1 1018      IF(Z.EQ.0.0) GO TO 370
1 1019      AZUM = AZUM/ SIN(Z)
1 1020      IF(AZUM.GT.1.0) AZUM = 1.0
1 1021      IF(AZUM.LT.-1.0) AZUM = -1.0
1 1022      AZUM = ACOS(AZUM)
1 1023      GO TO 380
1 1024      370 CONTINUE
1 1025      AZUM = 0.0
1 1026      380 SOLAZ = AZUM * APID
1 1027      IF(SOLAZ.GT.0.0.AND.SOLAZ.LT.0.9) SOLAZ= 0.0
1 1028      IF(SOLAZ.GT.179.5.AND.SOLAZ.LT.180.5) SOLAZ=180.0
1 1029      IF(TIME.GT.12.0) SOLAZ = 360.0 - SOLAZ
1 1030      GO TO 390
1 1031      365 CONTINUE
1 1032      SOLALT = 0.0
1 1033      SOLAZ = 0.0
1 1034      390 WRITE(*,308) TIME,SOLAZ, SOLALT
1 1035      308 FORMAT(22X,F5.2,8X,F6.2,10X,F7.2)
1 1036      AB = TIME
1 1037      666 CONTINUE
1038      HELP = 0
1039 C      END OF SOLAR PATH CALCULATIONS
1040 C
1041      200 CONTINUE
1042 C
1043      WRITE(*,400)
1044      400 FORMAT('0',17X,'DO YOU REQUIRE CHANGES IN ANY OF THE INPUT'/
1045      *14X,'PARAMETERS? NO=0; YES=1. IF ANS=NO YOU WILL EXIT THE'/
1046      *28X,'PROGRAM TO SYSTEM PROMPT: B>.')
1047      WRITE(*,399)
1048      399 FORMAT('0',14X,'_',/1X,'ENTER NUMBER..'')
1049      READ(*,401) ICH
1050      401 FORMAT(I1)
1051      IF(ICH.EQ.0) GO TO 999
1052      333 IF(HELP.EQ.1) GO TO 650
1053      WRITE(*,402)
1054      402 FORMAT('0',18X,'TO ALTER THE VALUE OF ANY INPUT OPTION ENTER'/
1055      *17X,'THE CORRESPONDING NUMBER AS GIVEN (I.E. FORMAT I2)')
1056      GO TO 651
1057      650 WRITE(*,652)
1058      652 FORMAT('0',18X,'YOU HAVE REQUESTED ADDITIONAL INFORMATION FOR'/
1059      *16X,'THE INPUT OPTIONS. AGAIN, SIMPLY ENTER THE CORRESPONDING'/
1060      *1X,'HELP MODE',16X,'NUMBER AS GIVEN (I.E. FORMAT I2)')
1061      651 WRITE(*,403)
1062      403 FORMAT('0',22X,'LATITUDE OF SITE ----- 01'/
1063      *23X,'DECLINATION ----- 02'/
1064      *23X,'EARTH/SUN CORRECTION ----- 03'/

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
1065      *23X,'TIME INCREMENT ----- 04'/
1066      *23X,'ATMOSPHERIC TRANSMISSION ----- 05'/
1067      *23X,'PRECIPITABLE WATER ----- 06'/
1068      *23X,'ATMOSPHERIC PRESSURE ----- 07'/
1069      *23X,'ELEVATION OF SITE ----- 08')
1070      WRITE(*,404)
1071      404 FORMAT(23X,'INCLINATION OF SITE ----- 09'/
1072      *23X,'AZIMUTH OF SITE ----- 10'/
1073      *23X,'ALBEDO OF SITE ----- 11'/
1074      *23X,'ELEVATION OF SKYLINE FOR SUNRISE -- 12'/
1075      *23X,'ELEVATION OF SKYLINE FOR SUNSET --- 13'/
1076      *23X,'ATMOSPHERIC REFRACTION (KASTEN) --- 14'/
1077      *23X,'BACKSCATTERED RADIATION ----- 15')
1078      if(help.eq.1) go to 385
1079      WRITE(*,620)
1080      620 FORMAT(23X,'SOLAR AZIMUTHS AND ELEVATIONS ----- 16'/
1081      *23X,'HELP ***** 17'/
1082      *23X,'OPTION PREVIEW ***** 18'/)
1083      nohelp = 0
1084      go to 386
1085 C
1086      385 write(*,387)
1087      387 FORMAT(23X,'SOLAR AZIMUTHS AND ELEVATIONS ----- 16'/
1088      *21X,'* EXIT HELP ***** 17'/
1089      *23X,'OPTION PREVIEW ***** 18')
1090      NOHELP = 1
1091      386 WRITE(*,405)
1092      405 FORMAT (' ',14X,'__'/1X,'ENTER NUMBER..')
1093      READ(*,406) IX
1094      406 FORMAT (I2)
1095 C
1096 C      TEST FOR INPUT OPTION
1097 C
1098      IF(IX.EQ.17.AND.NOHELP.EQ.0) HELP = 1
1099      IF(IX.EQ.17.AND.NOHELP.EQ.0) GO TO 650
1100      IF(IX.EQ.17.AND.NOHELP.EQ.1) HELP = 0
1101      IF(IX.EQ.18) GO TO 555
1102 C
1103      IF(IX.EQ.01.AND.HELP.EQ.0) GO TO 501
1104      IF(IX.EQ.01.AND.HELP.EQ.1) GO TO 701
1105      IF(IX.EQ.02.AND.HELP.EQ.0) GO TO 502
1106      IF(IX.EQ.02.AND.HELP.EQ.1) GO TO 809
1107      IF(IX.EQ.03.AND.HELP.EQ.0) GO TO 504
1108      IF(IX.EQ.03.AND.HELP.EQ.1) GO TO 815
1109      IF(IX.EQ.04.AND.HELP.EQ.0) GO TO 503
1110      IF(IX.EQ.04.AND.HELP.EQ.1) GO TO 817
1111      IF(IX.EQ.05.AND.HELP.EQ.0) GO TO 505
1112      IF(IX.EQ.05.AND.HELP.EQ.1) GO TO 990
1113      IF(IX.EQ.06.AND.HELP.EQ.0) GO TO 506
1114      IF(IX.EQ.06.AND.HELP.EQ.1) GO TO 835
1115      IF(IX.EQ.07.AND.HELP.EQ.0) GO TO 507
1116      IF(IX.EQ.07.AND.HELP.EQ.1) GO TO 842
1117      IF(IX.EQ.08.AND.HELP.EQ.0) GO TO 508
1118      IF(IX.EQ.08.AND.HELP.EQ.1) GO TO 842
1119      IF(IX.EQ.09.AND.HELP.EQ.0) GO TO 509
1120      IF(IX.EQ.09.AND.HELP.EQ.1) GO TO 861

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.30 March 1985
1121      IF(IX.EQ.10.AND.HELP.EQ.0) GO TO 510
1122      IF(IX.EQ.10.AND.HELP.EQ.1) GO TO 867
1123      IF(IX.EQ.11.AND.HELP.EQ.0) GO TO 511
1124      IF(IX.EQ.11.AND.HELP.EQ.1) GO TO 875
1125      IF(IX.EQ.12.AND.HELP.EQ.0) GO TO 512
1126      IF(IX.EQ.12.AND.HELP.EQ.1) GO TO 337
1127      IF(IX.EQ.13.AND.HELP.EQ.0) GO TO 513
1128      IF(IX.EQ.13.AND.HELP.EQ.1) GO TO 897
1129      IF(IX.EQ.14.AND.HELP.EQ.0) GO TO 514
1130      IF(IX.EQ.14.AND.HELP.EQ.1) GO TO 916
1131      IF(IX.EQ.15.AND.HELP.EQ.0) GO TO 515
1132      IF(IX.EQ.15.AND.HELP.EQ.1) GO TO 227
1133      IF(IX.EQ.16.AND.HELP.EQ.0) GO TO 516
1134      IF(IX.EQ.16.AND.HELP.EQ.1) GO TO 925
1135 C
1136      222 WRITE(*,522)
1137      522 FORMAT('0',2X,'OTHER CHANGES? NO=0; YES=1'/15X,'_')/
1138      *1X,'ENTER NUMBER..' \)
1139      READ(*,523) IZ
1140      523 FORMAT(I1)
1141      IRUN = 0
1142      IF(IZ.EQ.0) IX = 0
1143      IF(IZ.EQ.1) GO TO 333
1144      IF(IP.EQ.1) GO TO 444
1145      IF(IZ.EQ.0.AND.HELP.EQ.0) GO TO 555
1146      IF(IZ.EQ.0.AND.HELP.EQ.1) GO TO 933
1147 C
1148 C
1149      501 WRITE(*,520) PHI
1150      520 FORMAT('0',2X,'ENTER SITE LATITUDE (F6.2). NOW SET = ',F6.2,1X,
1151      *'Deg.'/12X,'___.'/1X,'NEW VALUE =',\ )
1152      READ(*,521) PHI
1153      521 FORMAT(F6.2)
1154      GO TO 222
1155      502 WRITE(*,524) DEC
1156      524 FORMAT('0',2X,'SITE DECLINATION (F5.1). NOW SET = ',F5.1,' Deg.'/
1157      *12X,'___.'/1X,'NEW VALUE =',\ )
1158      READ(*,525) DEC
1159      525 FORMAT(F5.1)
1160      GO TO 222
1161      503 WRITE(*,526) ATINC
1162      526 FORMAT('0',2X,'TIME INCREMENT (I2). CURRENT VALUE = ',I2,' Min.'/
1163      *12X,'__' /1X,'NEW VALUE =',\ )
1164      READ(*,527) ATINC
1165      527 FORMAT (I2)
1166      GO TO 222
1167      504 WRITE(*,528) EDIST
1168      528 FORMAT('0',2X,'EARTH/SUN CORRECTION (F8.6). NOW SET = ',F8.6/
1169      *12X,'_.'/1X,'NEW VALUE =',\ )
1170      READ(*,529) EDIST
1171      529 FORMAT(F8.6)
1172      GO TO 222
1173      505 WRITE(*,530) K
1174      530 FORMAT('0',2X,'ATMOSPHERIC TRANSMISSION (F4.2). NOW SET = ',F4.2/
1175      *12X,'_.'/1X,'NEW VALUE =',\ )
1176      READ(*,531) K

```

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```

1177 531 FORMAT(F4.2)
1178 GO TO 222
1179 506 WRITE(*,532) W
1180 532 FORMAT('0',2X,'PRECIPITABLE WATER (F4.2). CURRENT VALUE = ',F4.2,
1181 *' Cm.'/12X,'_._.'/1X,'NEW VALUE =',\ )
1182 READ(*,533) W
1183 533 FORMAT(F4.2)
1184 GO TO 222
1185 507 IF(IOPT.EQ.1) GO TO 661
1186 WRITE(*,534) PRES
1187 534 FORMAT('0',2X,'ATMOSPHERIC PRESSURE (F7.2). NOW SET = ',F7.2,
1188 *' Mb.'/12X,'_._.'/1X,'NEW VALUE =',\ )
1189 READ(*,535) PRES
1190 535 FORMAT(F7.2)
1191 C
1192 661 WRITE(*,662) PRES
1193 662 FORMAT('0',2X,'ESTIMATED ATMOSPHERIC PRESSURE IS ',F8.2,' Mb.'//
1194 *9X,'Do you wish to enter a new value? 0=NO; 1=YES. Note that'/
1195 *9X,'if ANS=YES then elevation will become the estimated value.'/
1196 *15X,'_'/1X,'ENTER NUMBER..' \ )
1197 READ(*,663) OPT

```

Variable alteration routines

```

1289 READ (*,558) IP
1290 558 FORMAT(I1)
1291 GO TO 222
1292 C
1293 C END OF INPUT OPTIONS
1294 999 CONTINUE
1295 END

```

END OF SECTION 7.

SECTION 8.

INITIALIZING THE SOLAR RADIATION PROGRAM AND DATA ENTRY PROCEDURES.

This section outlines the sequence and procedures necessary to execute the solar radiation program. The on-screen display generated during data entry, program execution and subsequent user options are explicitly documented. Only the operation of the already created executable file (SOLAR.EXE) is discussed. If the program is to be altered in any form the modified file will require re-editing, compiling and linking under the DOS EDLIN and Microsoft FORTRAN codes. The user should consult the technical information provided on page 107 for additional information.

There are four FORTRAN files provided on the enclosed diskette. These are identified as SOLAR.FOR, SOLAR.BAK, SOLAR.EXE and SOLAR.OBJ.

8A. SWITCHING THE COMPUTER ON AND POSITIONING FILES.

To activate the computer system:

1. With the computer switched OFF place the MS-DOS diskette in DRIVE A.
2. Switch the computer ON.
3. Enter the DATE and TIME as requested and the SYSTEM PROMPT, A>, will appear on the left side of the screen.
4. If only one disk drive is available remove the DOS diskette and replace it with the disk containing the FORTRAN files. Go to point 6.
5. If two disk drives are available place the disk containing the FORTRAN files in Drive B. Transfer the system drive from A to B. With the system prompt appearing as A> type

b: and press the ENTER key ↵ .

System prompt will now appear as B>.

6. To ensure that the required file exists on the program disk type

dir (for directory) and press ↵ .

The existing files on the disk will appear on the screen. The four FORTRAN files should be listed.

8B. OVERVIEW OF DATA ENTRY AND PROGRAM OPERATION.

The following listing is intended to serve only as a quick reference and guide to entering the solar radiation program, system responses and user options. Sections 8C through 8K explicitly document the operations of the program and the user is encouraged to work through these sections.

1. Place the solar radiation program in current (logged) disk drive. Enter the program code, solar.

B>solar and press the enter (↵) key.

2. System prompt - Input route?

A: without HELP routines (Entry =#1).

B: with HELP routines (Entry =#2).

3. Enter responses to 16 user options.

4. Last data entry - Solar azimuths and elevations.

If: Answer = NO - program execution.

Answer = YES - enter time increment.
Program execution.

5. Data Generation on screen.

6. System prompt - Run model again?

If: Answer = NO - Exit program to B>.

Answer = YES - Option alteration menu.

7. System prompt - Variable change?

1. With HELP routines. Information displayed.

2. Without HELP routines. Data entry only.

8. System prompt - Other variable changes?

If: Answer = YES - Option alteration menu.

Answer = NO - Program execution.

8C. ENTERING THE SOLAR RADIATION PROGRAM.

With the sequence outlined in 8A completed and the system prompt displayed on the screen (A> for single disk drive; B> for dual disk drive). Type the word Solar, i.e:


B>Solar

and press the enter () key.

First, the program title will be displayed on the screen followed by the first user entry option. This will appear as:

There are two ways to enter this program:

1. If you are familiar with the data entry sequence and the nature of the variables then just ENTER the NUMBER 1.
2. If you would like additional information on the variables and how to enter your choice ENTER the NUMBER 2.

ENTRY NUMBER =  (Cursor will be flashing in this position)

Thus, there exists two ways in which data can be entered into the program (see the flow chart provided on page 32). The first option (NUMBER 1) will only identify each of the 16 variables with no explanatory information. While this is the most efficient way to enter the program it is not recommended for the first-time user.

Option 2 results in the user being provided with descriptive information on the variables, how to enter choices and other useful information that can greatly facilitate the data entry procedures. The information and format displayed in this entry sequence will be referred to as the HELP routines. This option is recommended until the user is familiar with the model operation.

8C. DATA ENTRY WITHOUT HELP ROUTINES (Option NUMBER 1).

The data entry sequence involves providing answers to 16 variables or options. The variables will be systematically identified and the cursor will be positioned below lines that appear as "_____" which indicate the size of the variable input and the location of the decimal point (where necessary). This format must be explicitly followed as the entered data must be of the correct field type and length and is right justified (consult page 33 for the input sequence, field type and length). If at some point in the data entry sequence a mistake is made then compiler error may occur. If so, consult page 53 (8H) for error messages and program reentry procedures. The entry selection used in the following example results in the data base generated and applied in Example 1 on page 65. Note that in the following information the comments in parenthesis will not appear

on the screen but have been included to assist the user.

ENTRY NUMBER = 1 ← (From previous choice.
Press the ENTER key (↵).)

Enter site latitude (F6.2). ← (System response)

ENTRY = 42.12 ← (User input. Press the ENTER key (↵).)

Enter declination (F5.1).

ENTRY = 11.0

Enter the earth/sun correction factor (F8.6).

ENTRY = 0.989354

Enter the time increment for calculations in mins. (I2).

ENTRY = 30

Enter atmospheric transmission factor (F4.2).

ENTRY = 0.89

Enter precipitable water in centimeters (F4.2).

ENTRY = 2.00

Do you wish to enter site elevation or pressure?

For ELEVATION enter the number 1.

For PRESSURE enter the number 2.

ENTRY = 1

Enter atmospheric pressure in millibars (F7.2).

ENTRY = 1013.25

Enter slope of site in deg. (F4.1).

ENTRY = 00.0

Enter site azimuth in deg. (F5.1).

ENTRY = 000.0

Enter albedo of site in 10ths (F4.2).

ENTRY = 0.25

Elevation of horizon at sunrise in deg. (F4.1).

ENTRY = 00.0

Example cont'd.

Elevation of horizon at sunset in deg. (F4.1).

ENTRY =00.0

Backscattered radiation (I1)? 0=NO; 1=YES.

ENTRY =0

Atmospheric refraction (Kasten 1966)? 0=NO; 1=YES.

ENTRY =0

Do you require SOLAR AZIMUTHS and ELEVATIONS?

These calculations will also provide times and azimuths of sunrise and sunset. You will need to enter a time increment for calculations; 30 or 60 minutes are recommended. NO=0; YES=1.

ENTRY =1 ← (If ANS=0 program will execute)

Enter time increment for solar path calculations (I2).

ENTRY =60 ← (Final data entry. Model will now execute and generated data will be displayed on the screen)

8E. DATA ENTRY WITH HELP ROUTINES.

If, upon entering the program, option 2 is selected (see 8C) the following information will be written on the computer screen.

WELCOME TO THE SOLAR RADIATION PROGRAM.

From this point on you will be prompted for answers to 16 questions (or options). You should be somewhat familiar with the order of input and the nature of the variable. If in doubt consult Sections 3 and 8 of the User's Manual.

For each data entry you will be guided by lines above the location where your value will be entered. These lines will appear as "___." and indicate the size of the data input and the location of the decimal point.

READ YOUR ANSWER BEFORE YOU PRESS THE ENTER KEY.

If you realize that you have entered the wrong number then press the backspace key. This will erase your answer and you can enter a new value.

TO BEGIN JUST PRESS THE ENTER KEY.

Upon pressing the enter key the first input option will appear

with the following information:

OPTION 1 - SITE LATITUDE.

The latitude is the position of the site NORTH or SOUTH of the equator. For all SOUTH latitudes the value should be preceded by a NEGATIVE sign. For example, suppose you require calculations for a site at 52.5 degrees south then your input would appear as -52.50.

For all NORTH latitudes the positive sign need not be entered (the computer assumes it to be positive if a negative sign is not supplied). Thus 52.5 degrees north would be entered as 52.50.

The limits of latitude are +90.0 and -90.0 degrees for the North and South Poles respectively; the equator is given as 0.0 degrees of latitude. Enter your choice and simply press the enter key.

ENTRY = (The cursor will be flashing in this position).

Thus, for each input option a basic body of information is provided to assist the user. Upon entry of an appropriate answer the next option will appear. If at some point in the entry sequence an incorrect response is entered, compiler error may occur. This will result in error messages be displayed and the user should consult page 53 (8H) for error codes and program reentry procedures.

Due to the total amount of information provided for each variable by selecting this data entry route only the first input option has been presented. All other options present pertinent information with the same format. The input sequence is as follows:

1. Latitude
2. Declination
3. Earth/sun correction factor
4. Time increment for calculations
5. Atmospheric transmission factor
6. Precipitable water
7. Site elevation or pressure
8. Inclination or slope of site
9. Site azimuth
10. Albedo of site
11. Elevation of horizon at sunrise
12. Elevation of horizon at sunset
13. Backscattered radiation
14. Atmospheric refraction
15. Calculations for solar elevations and azimuths
16. Time increment for solar elevations/azimuths.

Upon data entry for the last option the following will be displayed on the screen.

You have now entered all the necessary data and the model is ready to execute.

OPTIONS:

1. To run the model simply PRESS the ENTER KEY.
2. If you would like to PREVIEW your inputs ENTER the number 1.

To PRINT the data:

Press the CONTROL (CTRL) key and, while holding it down, press the PRINT SCREEN (PRTSC) key. Release both keys and press the ENTER key. Make sure the printer is switched ON.

To STOP PRINTING repeat the above sequence.

ENTRY..

If option 1 is selected calculations will begin and the generated data user options will appear on the screen (consult Example 1 on page 65 for output format). Option 2, however, allows the input options to be written on the screen along with the entered values. Thus, if an incorrect choice has been entered it can be changed before any computations are undertaken.

8F. PRINTING RESULTS.

If data entry using the help routines (option 2) is chosen the option preview and print information will always be displayed prior to any calculations being performed by the computer. The user need only follow the directions displayed on the screen.

However, for the more direct entry path (Option 1), at the last data entry the solar radiation program will execute and the generated data will automatically appear on the screen. There are two positions in the data entry sequence at which the model will execute. If the user does not require calculations for the solar elevations and azimuths (i.e. a 0 be entered) the request for a time increment will not be displayed and the model will run (see output format on page 65). The last possible entry is the time increment for the solar azimuths and elevations and the model will execute upon pressing the enter key.

Cont'd.

If a PRINTOUT of the data is required:

Prior to pressing the ENTER key at the last data entry point, depress the CONTROL (CTRL) key and simultaneously press the PRINT SCREEN (PRTSC) key. The ENTER key should then be pressed. The print option is suppressed by repeating the above sequence.

BG. HALTING SCREEN DISPLAY.

In most instances the size of the generated data base will be too large to be contained within the viewing panel of the video screen. This does not represent a problem if the output is being printed but printing does slow down the execution time and a complete data listing is not always required.

To HALT the screen display and to temporarily suspend the program execution:

press the CONTROL (CTRL) key and simultaneously press the NUMLOCK key. To continue press the ENTER key.

BH. DATA ENTRY ERROR.

If, at some point in the data entry sequence, an incorrect value is entered compiler (system) error can occur and an error message will be displayed on the screen. The executable file (SOLAR.EXE) has been created under Version 3.30 of the Microsoft FORTRAN series and error messages can take two basic forms.

1. Incorrect input at time of data entry.

Enter site latitude (F6.2)

ENTRY = .
 44.12

Enter declination (F5.1)

ENTRY = .
 45.0

← (The letter "O" has been entered in place of a "0".)

The following message will appear on the screen

```
? Error: Data format error in file USER
Error Code 1236, Status 000E
PC = 0102: 88B8; SS = 1343, FP = 000C, SP = 886B
```

Cont'd.

At this point simply press the ENTER (↵) key and the system prompt B> will appear. You will now need to reenter the program. As before, just type the program code Solar.

B>Solar

and press the ENTER (↵) key.

2. Errors generated during program execution.

For Version 3.30 the input error may not be immediately detected by the FORTRAN compiler. For example, a latitude, declination or slope may be entered that is not within the specified range. In this instance it is possible that the input will be accepted by the system and the next user option will appear on the screen. Usually, however, such input will generate compiler error during program execution and an error message will be displayed on the screen. At this point the system prompt, B>, will appear and the data entry sequence will need to be repeated. Again, the user should consult page 33 to ensure the correct field type and length for each variable has been used. If uncertainty exists the OPTION PREVIEW facility should be used (see page 56) to ensure that the data entry is correct.

8I. INPUT CHANGES.

After the results are generated using the initial inputs selected by the user, the following question will be displayed on the screen.

DO YOU REQUIRE CHANGES IN ANY OF THE INPUT
PARAMETERS ? NO=0; YES=1. IF ANS=NO YOU WILL EXIT THE
PROGRAM TO SYSTEM PROMPT B>.

ENTER NUMBER..

If the option NO is selected the SYSTEM prompt, B>, will appear on the screen. As previously shown, to reenter the program the code, SOLAR, needs to be typed and the enter key pressed. None of the previous entries are stored by the program and the complete entry sequence will need to be repeated. Such an option may prove to be more efficient if it is necessary to alter most of the program variables. If YES is selected the following sequence will be written on the screen:

Example cont'd

ENTER NUMBER..1 ← (Input from previous option.)
 (Screen display - Option alteration Menu.)

TO ALTER ANY PARAMETER ENTER THE CORRESPONDING NUMBER AS GIVEN (I.E. FORMAT=I2)

- LATITUDE OF SITE ----- 01
- DECLINATION ----- 02
- EARTH/SUN CORRECTION ----- 03
- TIME INCREMENT ----- 04
- ATMOSPHERIC TRANSMISSION ----- 05
- PRECIPITABLE WATER ----- 06
- ELEVATION OF SITE ----- 07
- ATMOSPHERIC PRESSURE ----- 08
- INCLINATION OF SITE ----- 09
- AZIMUTH OF SITE ----- 10
- ALBEDO OF SITE ----- 11
- ELEVATION OF SKYLINE FOR SUNRISE -- 12
- ELEVATION OF SKYLINE FOR SUNSET --- 13
- ATMOSPHERIC REFRACTION (KASTEN)---- 14
- BACKSCATTERED RADIATION ----- 15
- SOLAR AZIMUTHS AND ELEVATIONS ----- 16
- HELP ***** 17
- OPTION PREVIEW ***** 18

ENTER NUMBER..

By selecting any one of the above input numbers (01-16) the corresponding user option will appear on the screen. The current value of the variable will be displayed and a new entry will be requested. For example:

ENTER NUMBER..01 ← (From previous choice.)

(Display)

ENTER SITE LATITUDE (F6.2). NOW SET = 42.12 Deg.

NEW VALUE = 55.00

(New value entered)

OTHER CHANGES? 0=NO; 1=YES

(System request and response)

ENTER NUMBER..1

Example cont'd.

TO ALTER ANY PARAMETER ENTER THE CORRESPONDING
NUMBER AS GIVEN (I.E FORMAT I2)

```
.  
.  
.  
ATMOSPHERIC TRANSMISSION ----- 05  
PRECIPITABLE WATER ----- 06  
ELEVATION OF SITE ----- 07  
.  
.  
.  
HELP ***** 17  
OPTION PREVIEW ***** 18
```

ENTER NUMBER..06

PRECIPITABLE WATER (F4.2). CURRENT VALUE = 2.00

NEW VALUE =1.25

OTHER CHANGES? 0=NO; 1=YES

ENTER NUMBER..0

(Program will now execute.)

Thus, for the above example two variables were altered: the latitude (01) and the precipitable water (06).

Option 18, OPTION PREVIEW, allows for all the variables and their current values to be displayed on the screen prior to any calculations being undertaken by the computer. Thus:

```
.  
.  
.  
BACKSCATTERED RADIATION ----- 15  
SOLAR AZUMUTHS AND ELEVATIONS ----- 16  
HELP ***** 17  
OPTION PREVIEW ***** 18
```

ENTER NUMBER..18 (Response)

(Screen display on
following page.)

USER SUPPLIED OPTIONS

Latitude of site ----- = 44.12 Deg.
Declination of site ----- = 11.00 Deg.
Time increment for calculations = 30 Mins.
Earth/sun correction factor ---- = .989354
Atmospheric transmission ----- = .89 10ths.
Precipitable water ----- = 1.25 Cm.
Atmospheric pressure ----- = 1013.25 Mb.
Estimated elevation ----- = .0 Meters.
Inclination of slope ----- = .0 Deg.
Azimuth of slope ----- = .0 Deg.
Albedo of site ----- = 0.25 10ths.
Elevation of skyline for sunrise = .0 Deg.
Elevation of skyline for sunset = .0 Deg.
Atmospheric refraction ----- = 0
Backscattered radiation ----- = 0
Time of SUNRISE ----- = 5.28 Hrs.
Time of SUNSET ----- = 18.72 Hrs.

OTHER CHANGES? NO=0; YES=1.

ENTER NUMBER..

Contingent upon the choice entered the model will either execute (ANS=0) or the option alteration menu will be written on to the screen (ANS=YES).

8J. OPTION ALTERATION WITH THE HELP ROUTINES.

From the initial option alteration display (see 8I page 54) the HELP code is specified as number 17.

.
.
.
SOLAR AZIMUTHS AND ELEVATIONS ----- 16
HELP ***** 17
OPTION PREVIEW ***** 18

ENTER NUMBER..17 ← (Entry choice)

Upon pressing the ENTER key the following menu will be displayed:

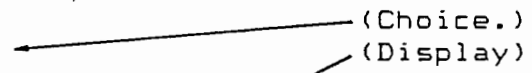
YOU HAVE REQUESTED ADDITIONAL INFORMATION FOR THE INPUT OPTIONS. AGAIN, SIMPLY ENTER THE CORRESPONDING NUMBER AS GIVEN (I.E. FORMAT I2).

HELP MODE

LATITUDE OF SITE -----	01
DECLINATION OF SITE -----	02
EARTH/SUN CORRECTION FACTOR -----	03
TIME INCREMENT -----	04
ATMOSPHERIC TRANSMISSION -----	05
PRECIPITABLE WATER -----	06
ATMOSPHERIC PRESSURE -----	07
ELEVATION OF SITE -----	08
INCLINATION OF SITE -----	09
AZIMUTH OF SITE -----	10
ALBEDO OF SITE -----	11
ELEVATION OF SKYLINE FOR SUNRISE --	12
ELEVATION OF SKYLINE FOR SUNSET ---	13
ATMOSPHERIC REFRACTION (KASTEN) ---	14
BACKSCATTERED RADIATION -----	15
SOLAR AZIMUTHS AND ELEVATIONS ----	16
* EXIT HELP *****	17
OPTION PREVIEW *****	18

ENTER NUMBER..--

At this point any number that is entered will result in pertinent information about the variable being displayed on the screen. For example:

ENTER NUMBER..11 

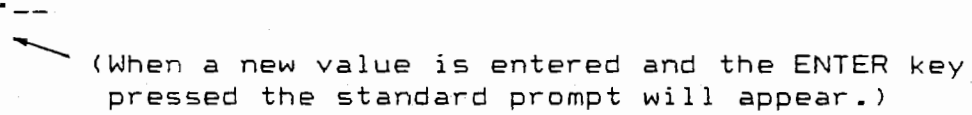
OPTION 11 - SITE ALBEDO

The albedo is simply a measure of the capacity of a given surface to reflect incoming solar radiation and is sometimes referred to as the surface reflection coefficient. For each surface type, therefore, a different albedo can be expected.

While this quantity is usually expressed as a percentage the value is entered into the program in 10ths. Thus, for a surface that has the capacity to reflect 34% of the incoming solar radiation enter the number 0.34.

A complete listing of surface types and albedos has been provided on page 103 of the User's Manual.

ENTER SITE ALBEDO IN 10THS (F4.2). NOW = .25

NEW VALUE = 

Example cont'd

OTHER CHANGES? NO=0; YES=1.

ENTER NUMBER..

Depending upon entry selection, the option alteration menu or the model RUN, PRINT and PREVIEW help codes will appear. If other changes are required (ANS=1) the menu will still be in HELP mode. To exit the HELP routines, simply enter the number 17 when the option appears on the screen.

8K. INTERNAL PROGRAM OPTIONS.

There exists two basic user options contained within the program that are not immediately apparent from the output or the user options considered to this point. These are the pressure and elevation relationships and the solar azimuth/elevation calculations.

1.Pressure/Elevation Relationships.

As pressure and elevation are directly related it is possible for the user to enter either of these two options into the program. The computer will, in turn, compute the elevation or pressure depending upon the the initial choice. Thus, if pressure is selected as input the computer will calculate elevation the value of which will appear as ESTIMATED ELEVATION on the output of user options (see page 65); should elevation be entered the atmospheric pressure will become the estimated value.

This user option can be changed from the input alteration menu (see page 55). For example:

```

.
.
ATMOSPHERIC PRESSURE ----- 07
ELEVATION OF SITE ----- 08
.
.
HELP ***** 17
OPTION PREVIEW ***** 18

```

ENTER NUMBER..07

(Variable selected for change)

 (System response from Example 3B - Elevation was the initial entry)

ESTIMATED ATMOSPHERIC PRESSURE IS 700.09 Mb.

Do you wish to enter a new value? 0=NO; 1=YES. Note that if ANS=YES then elevation will become the estimated value.

ENTER NUMBER..1

Example cont'd

ENTER ATMOSPHERIC PRESSURE IN MB (F7.2).

NEW VALUE = 650.00 (New value entered)
(System response)

OTHER CHANGES? NO=0; YES=1.

ENTER NUMBER.. 1 (Model will either execute or return to option alteration menu.)

The HELP routines have a similar response. However, regardless of the selection of either pressure or elevation from the menu (07 or 08) the system will respond with a body of information and then specifically request either pressure or elevation.

2. Solar Azimuths and Elevations.

The program provides the user with a choice of eliminating the solar path calculations from the generated results, or in turn, computing only these values (refer to the generalized flow chart on page 32). To use this option:

When the variable alteration listing is displayed select option 16. Should the solar path data be required (i.e. ANS=YES) the following sequence will appear.

SOLAR AZIMUTHS AND ELEVATIONS ----- 16
HELP ***** 17
OPTION PREVIEW ***** 18

ENTER NUMBER.. 16 (Choice.)
(System response.)

SOLAR AZIMUTHS/ELEVATIONS NO=0; YES=1. NOW = 1

ENTER NUMBER.. 1 (Choice.)
(System response.)

TIME INCREMENT FOR SOLAR AZ/ELEV (I2). NOW = 60

NEW VALUE = 30

SOLAR PATH CALCULATIONS ONLY? NO=0; YES=1. NOW = 0

ENTER NUMBER.. 1

OTHER CHANGES? 0=NO; 1=YES

Example cont'd

ENTER NUMBER..0

(program will now execute.)

Thus, for the above entry only the solar path data will be generated (determined by the third question). Note also, that if the answer to the first question was NO, then the following two questions would not appear on the screen. If variable alteration is in HELP mode, the input and output format is similar to the above.

END OF SECTION 8.

SECTION 9.

APPLICATIONS OF MODEL OUTPUT.

The following examples and their graphical representation have been included to indicate the variety of climatological problems to which the model can be applied. These examples are by no means the only possibilities but hopefully reveal a diversity of applications beyond the straightforward generation of radiative curves for a specific location. No attempt is made to interpret the generated results as the emphasis is directed toward model use, data presentation and the necessary graphics commands for the LOTUS 1-2-3 data base management system.

As suggested earlier, the graphics capacity of LOTUS 1-2-3 offers considerable ease in the presentation of the FORTRAN generated data. Once the data has been manually entered into the LOTUS spreadsheet the elementary commands necessary to generate the graph makes LOTUS 1-2-3 a particularly powerful system. This is not necessarily meant to endorse this product as other equally appropriate data base management software exists (i.e. SuperCalc 3). However, such software are generally conceptually similar and it is the intention to illustrate the manner in which these types of software packages can be directly applied to problems such as those encompassed by this FORTRAN routine. It should also be noted that the format as presented in these examples are not the only options contained within LOTUS 1-2-3 graphics routines. However, these simple procedures enable the user to obtain maximum benefit from the results of the computer output without spending considerable time in understanding the specifics of LOTUS 1-2-3 graphics commands. For additional information, the user should consult either the LOTUS 1-2-3 manual or refer to Chapters 8, 9 and 10 of Le Bond and Cobb (1983) for details of the commands required for these examples. Hopefully, the solutions and documentation presented in this section will provide the user with adequate information to directly manipulate the data without detailed reference consultation.

For the examples presented, it is important to note that the graphics capacity of LOTUS 1-2-3 does not allow the addition of text within the "window" as created by the graph axis. Thus, all the labels, areas of shade, etc., on the following graphs have been applied after printout. The data base for Examples 1,2,3,6 and 7 along with their corresponding graphs, 1,2,3A,6B and 7B have been included on the program diskette. To access these files - Upon initial display of the LOTUS spreadsheet type:

/ F R (i.e. Slash (/) & for File Retrieve)

The data base will now be displayed on the screen.
To display the provided graph (assuming graphics capability) type:

/ G V (for Graph View)

and the corresponding graph will be displayed.

EXAMPLE 1.

Shortwave Radiative Balance, Ashland, Oregon.

This example perhaps represents the simplest application of the radiation model. The surface is horizontal, no obstruction of the solar disk due to surrounding terrain, surface albedo is equivalent to a short grass surface (consult listing in the Appendix) and all other variables considered to be representative of the "average" state of the atmosphere. The user options and computer output are provided on page 65. The data as entered into the LOTUS 1-2-3 data base system (including printout under PRINT commands), the commands for the generation of Graph 1 and a solar path diagram are all presented below.

Entering Data into LOTUS 1-2-3.

1. Place LOTUS Systems disk in drive A.
2. Place data disk in drive B.
3. With system prompt specified as drive A> type:
LOTUS then press the ENTER key (↵).

With the initial display of the spreadsheet the cursor will be represented by a solid block, the location of which is controlled by the positioning keys (→ ← ↑ ↓) usually located on the right hand side of the computer keyboard. The data columns are identified alphabetically and the rows numerically. The default value of available space for each data entry is 9 positions (i.e. a maximum number of 9 digits or a word of 9 characters). Thus, each data entry occupies a position on the spreadsheet defined by a specific column and row number. In the example below the first two rows are occupied by headings that identify the data. The remaining rows, 3 through 20, contain the data as taken directly from the results of the program output (page 65). Once the data is entered, the file will need to be identified and saved.

4. Press the / (slash) key and type FS (for File Save).
5. Select a filename and type "filename". Press ↵.

To print out the data under system default (i.e. no manual changes to LOTUS commands):

6. Press the / key to bring up Lotus user options
7. Move cursor to PRINT option (or simply press P).
8. With cursor on PRINTER. ↵
9. With cursor on RANGE. ↵
10. On command: ENTER PRINT RANGE: A1..G31 ↵ *
11. Move cursor to GO ↵
12. Upon completion of printout move cursor to QUIT ↵

* The range A1..G31 encompasses all cells within the data base matrix. As for all graphics commands, the range delimiters must be separated by two period symbols.

The output as controlled by the above commands for the Ashland data is presented in Table 1. The column and row labels are not printed under these commands but have been added to indicate what is observed on the screen.

	A	B	C	D	E	F
1	ASHLAND	OREGON	LAT=42.12N		DEC=11.00	
2	TIME	DIRECT	DIFFUSE	GLOBAL	REFLECTED	NET
3	5	0	0	0	0	0
4	5.5	3.47	8.25	11.72	2.93	6.79
5	6	22.31	33.63	55.94	13.98	41.95
6	6.5	86.75	54.48	141.22	35.31	105.92
7	7	169.5	67.83	237.33	59.33	177.99
8	7.5	258.68	77.19	335.87	83.97	251.9
9	8	348.21	84.12	432.34	108.08	324.25
10	8.5	434.14	89.46	523.6	130.9	392.7
11	9	513.59	93.63	607.22	151.81	455.42
12	9.5	584.33	96.91	681.24	170.31	510.93
13	10	644.56	99.45	744.01	186	558.01
14	10.5	692.86	101.35	794.21	198.55	595.65
15	11	728.13	102.67	830.8	207.7	623.1
16	11.5	749.6	103.45	853.05	213.26	639.79
17	12	756.81	103.71	860.52	215.13	645.39
18	12.5	749.6	103.45	853.05	213.79	639.79
19	13	728.13	102.67	830.8	207.7	623.1
20	13.5	692.86	101.35	794.21	198.55	595.65
21	14	644.56	99.45	744.01	186	558.01
22	14.5	584.33	96.91	681.24	170.31	510.93
23	15	513.59	93.63	607.23	151.81	455.42
24	15.5	434.14	89.46	523.6	130.9	392.7
25	16	348.21	84.12	432.34	108.08	324.25
26	16.5	258.68	77.19	335.87	83.97	251.9
27	17	169.5	67.83	237.33	59.33	177.99
28	17.5	86.75	54.48	141.22	35.31	105.92
29	18	22.31	33.63	55.94	13.98	41.95
30	18.5	3.47	8.25	11.72	2.93	8.79
31	19	0	0	0	0	0

TABLE 1.

Graphics Commands.

The following commands are necessary to generate Graph 1 (page 69). The ranges are directly interpretable from the data as entered into the LOTUS 1-2-3 spreadsheet and printed in Table 1.

Example Cont'd on Page 68.

USER SUPPLIED OPTIONS

Latitude of site ----- = 42.12 Deg
 Declination of site ----- = 11.00 Deg.
 Time increment for calculations = 30 Mins.
 Earth/sun correction factor ---- = .989354
 Atmospheric transmission ----- = .89 10ths
 Precipitable water ----- = 2.00 Cm.
 Atmospheric pressure ----- = 1013.25 Mb.
 Estimated elevation ----- = .0 Meters
 Inclination of slope ----- = .0 Deg.
 Azimuth of slope ----- = .0 Deg.
 Albedo of site ----- = .25 10ths
 Elevation of skyline for sunrise = .0 Deg.
 Elevation of skyline for sunset = .0 Deg.
 Atmospheric refraction ----- = 0
 Backscattered radiation ----- = 0
 Time of SUNRISE ----- = 5.33 Hrs
 Time of SUNSET ----- = 18.67 Hrs

TIME	DIRECT	DIFFUSE	GLOBAL	REFLECTED	NET	EX.TERR.
----	-----	-----	-----	-----	-----	-----
5.00	.00	.00	.00	.00	.00	.00
5.50	3.47	8.25	11.72	2.93	8.79	44.09
6.00	22.31	33.63	55.94	13.98	41.95	171.30
6.50	86.75	54.48	141.22	35.31	105.92	298.52
7.00	169.50	67.83	237.33	59.33	177.99	423.56
7.50	258.69	77.19	335.87	83.97	251.90	544.29
8.00	348.21	84.12	432.34	108.08	324.25	658.63
8.50	434.14	89.46	523.60	130.90	392.70	764.63
9.00	513.59	93.63	607.23	151.81	455.42	860.49
9.50	584.33	96.91	681.24	170.31	510.93	944.55
10.00	644.56	99.45	744.01	186.00	558.01	1015.38
10.50	692.86	101.35	794.21	198.55	595.65	1071.76
11.00	728.13	102.67	830.80	207.70	623.10	1112.74
11.50	749.60	103.45	853.05	213.26	639.79	1137.62
12.00	756.81	103.71	860.52	215.13	645.39	1145.95
12.50	749.60	103.45	853.05	213.26	639.79	1137.62
13.00	728.13	102.67	830.80	207.70	623.10	1112.74
13.50	692.86	101.35	794.21	198.55	595.65	1071.76
14.00	644.56	99.45	744.01	186.00	558.01	1015.38
14.50	584.33	96.91	681.24	170.31	510.93	944.55
15.00	513.59	93.63	607.23	151.81	455.42	860.49
15.50	434.14	89.46	523.60	130.90	392.70	764.63
16.00	348.21	84.12	432.34	108.08	324.25	658.63
16.50	258.69	77.19	335.87	83.97	251.90	544.29
17.00	169.50	67.83	237.33	59.33	177.99	423.56
17.50	86.75	54.48	141.22	35.31	105.92	298.52
18.00	22.31	33.63	55.94	13.98	41.95	171.30
18.50	3.47	8.25	11.72	2.93	8.79	44.09
19.00	.00	.00	.00	.00	.00	.00

DAILY TOTAL OF DIFFUSE RADIATION -- = 3.82 MJ/m**2
 DAILY TOTAL OF DIRECT RADIATION --- = 20.21 MJ/m**2
 DAILY TOTAL OF GLOBAL RADIATION --- = 24.03 MJ/m**2
 DAILY TOTAL OF REFLECTED RADIATION = 6.01 MJ/m**2
 DAILY TOTAL OF NET SHORTWAVE RAD.-- = 18.02 MJ/m**2
 DAILY TOTAL OF EXTRATERRESTRIAL RAD.= 34.59 MJ/m**2

SOLAR PATH CALCULATIONS

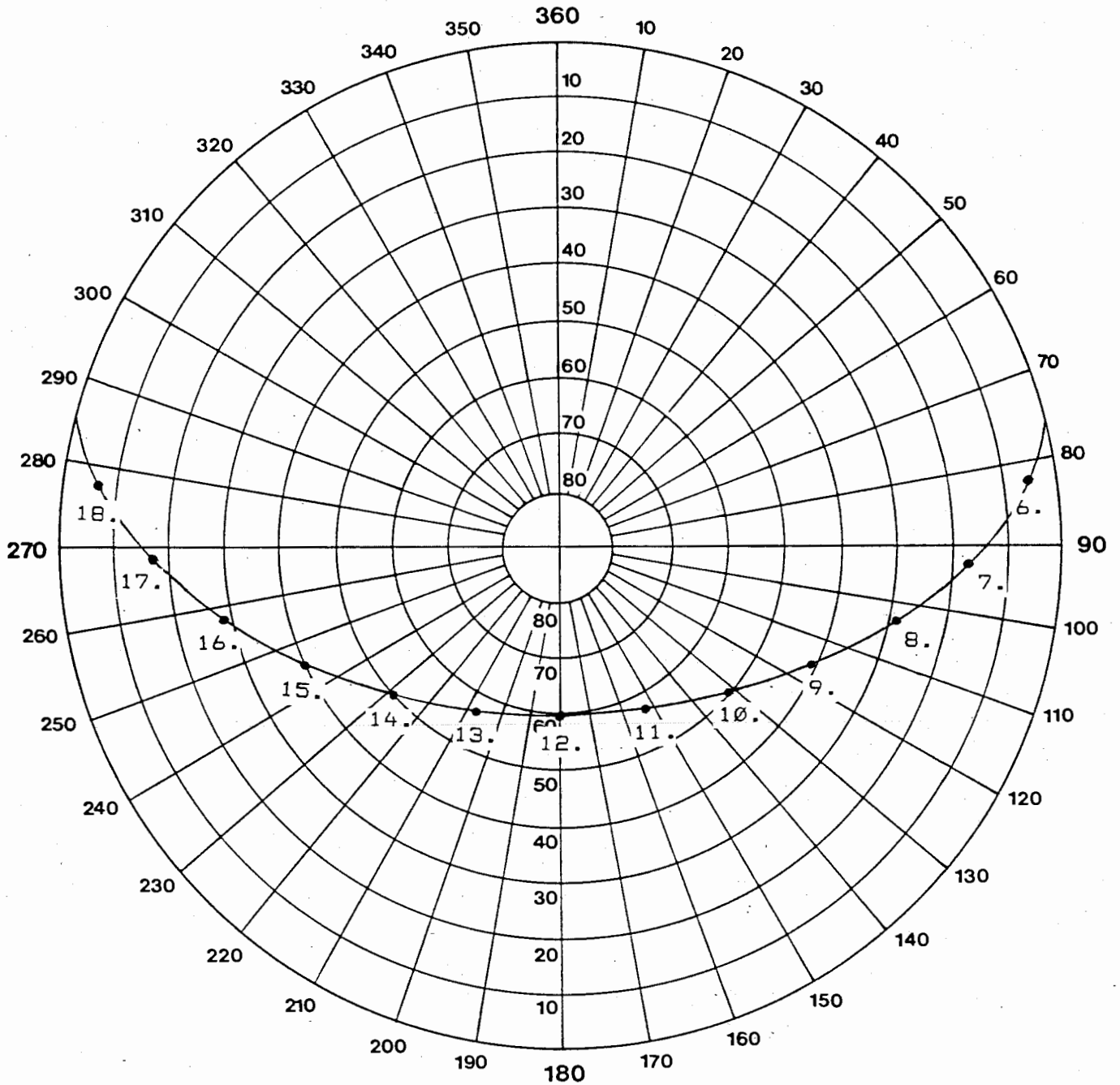
 Site latitude ----- = 42.12 Deg
 Site declination ----- = 11.00 Deg
 Azimuth of sunrise --- = 75.09 Deg
 Azimuth of sunset ---- = 284.91 Deg
 Time of sunrise ----- = 5.33 Hrs
 Time of sunset ----- = 18.67 Hrs

TIME	SOLAR AZIMUTH	SOLAR ALTITUDE
----	-----	-----
5.00	.00	.00
5.50	76.84	1.89
6.00	81.80	7.35
6.50	86.73	12.89
7.00	91.74	18.45
7.50	96.94	23.99
8.00	102.45	29.47
8.50	108.41	34.84
9.00	115.02	40.00
9.50	122.51	44.88
10.00	131.13	49.34
10.50	141.17	53.19
11.00	152.80	56.23
11.50	165.93	58.20
12.00	180.00	58.88
12.50	194.07	58.20
13.00	207.20	56.23
13.50	218.83	53.19
14.00	228.87	49.34
14.50	237.49	44.88
15.00	244.98	40.00
15.50	251.59	34.84
16.00	257.55	29.47
16.50	263.06	23.99
17.00	268.26	18.45
17.50	273.27	12.89
18.00	278.20	7.35
18.50	283.16	1.89
19.00	.00	.00

DO YOU REQUIRE CHANGES IN ANY OF THE INPUT
 PARAMETERS? NO=0; YES=1. IF ANS=NO YOU WILL EXIT THE
 PROGRAM TO SYSTEM PROMPT: B>.

ENTER NUMBER..

SOLAR PATH DIAGRAM



LOCATION ASHLAND, OREGON. LAT.= 42.12° N; DEC.= 11.0°

After the data as been entered and the file saved, move the cursor to the GRAPH option (or enter the letter G), press the ENTER key and proceed according to the following (Note that the comments do not appear on the screen but are included for user convenience):

<u>LOTUS TEXT.</u>	<u>COMMENTS</u>
Type = XY ↓	(Rows 1 & 2 used for headings)
X = A3..A31 ↓	(X axis - TIME)
A = B3..B31 ↓	(1st data range - DIRECT)
B = C3..C31 ↓	(2nd data range - DIFFUSE)
C = D3..D31 ↓	(3rd data range - GLOBAL)
D = E3..E31 ↓	(4th data range - REFLECTED)
E = F3..F31 ↓	(5th data range - NET)
F = G3..G31 ↓	(6th data range - KEX)

Options ↓ , Titles ↓ ,

First ↓ = SHORTWAVE RADIATIVE BALANCE
 Second ↓ = ASHLAND OREGON: LAT=42.12; DEC=11.0
 X axis ↓ = TIME (L.A.T)
 Y axis ↓ = IRRADIANCE (Wm**-2)

If on-screen display is possible, move the cursor to VIEW and press the ENTER key. The graph and titles will appear on the screen. To return to LOTUS commands, simply press the ENTER key.

To save the graph:

Save ↓ = "Filename" ↓ .

Note: to avoid confusion the graph "Filename" should not be the same as the data "Filename".

Printgraph ↓ .

(Place LOTUS PRINTGRAPH in drive A and press ENTER)

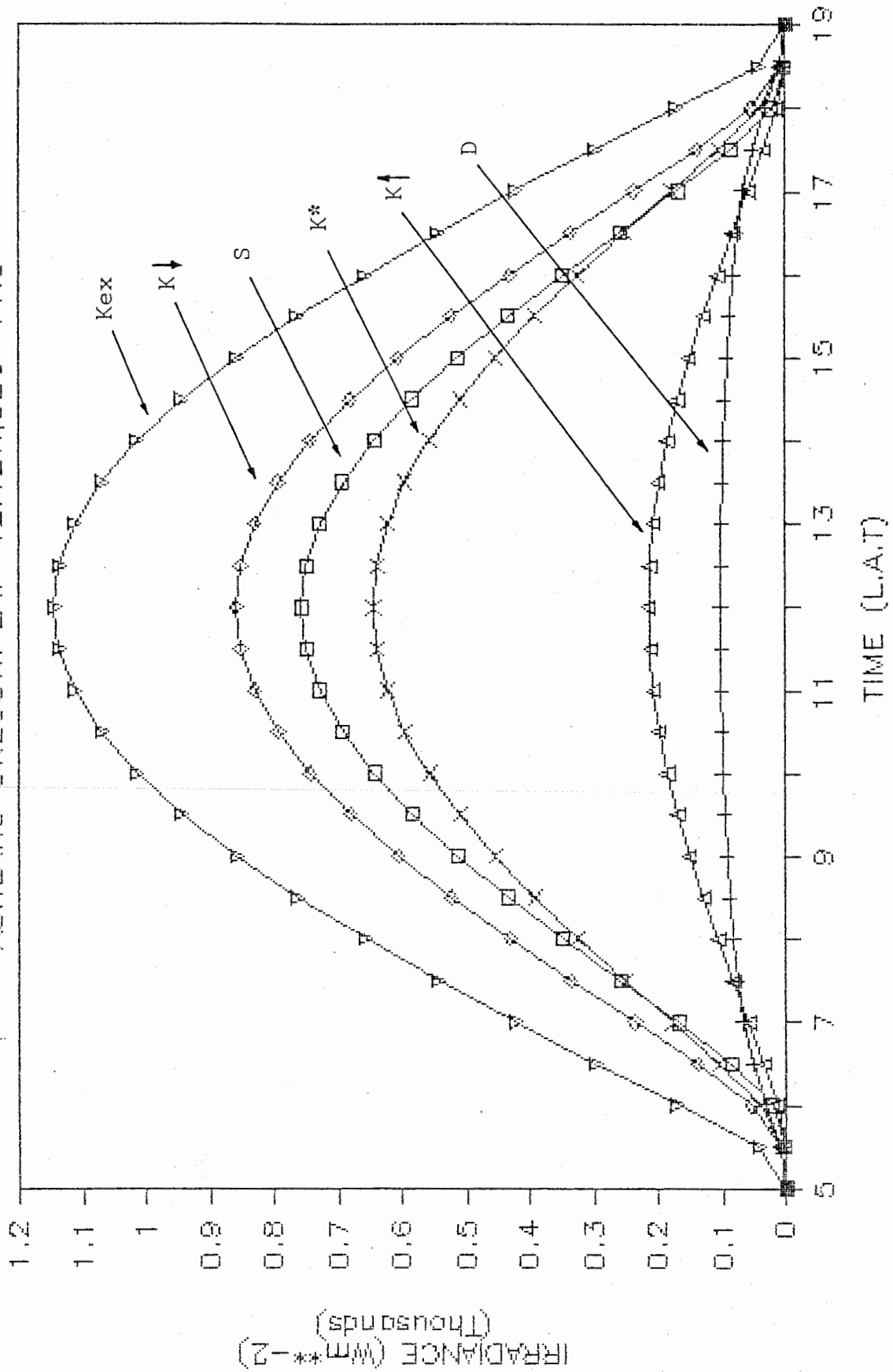
Select ↓ = "Filename" ↓ *
 Options ↓
 Size ↓ = Full ↓
 Quit ↓
 Quit ↓
 Go ↓

The graph will now be printed.

* To select the graph move the cursor to "Filename" and press the keyboard spacebar. The # symbol will appear in front of the file name. Press the ENTER key and continue.

SHORTWAVE RADIATIVE BALANCE

ASHLAND OREGON: LAT=42.12N;DEC=11.0



GRAPH 1.

EXAMPLE 2.

Radiative Receipt on a Three Dimensional Structure.

Direct radiative loading on a building located in Columbus, Ohio (40 Deg. N) during the June solstice (declination = +23.5). The building facets are vertical (inclination of 90 deg.) and face directly north, south, east and west; the structure roof is considered horizontal requiring both the site azimuth and inclination to be set equal to zero. Thus, the data base for this graph requires five executions of the model, altering only the site azimuth for the walls and the azimuth and inclination for the roof. In this example only the direct beam (S or DIRECT) from each program run has been entered into the Lotus spreadsheet and plotted. The FORTRAN generated data for all building aspects is provided on the following page (71) and the user supplied options (in this case the west wall) have been included below.

USER SUPPLIED OPTIONS

Latitude of site -----	=	40.00 Deg.
Declination of site -----	=	23.50 Deg.
Time increment for calculations	=	30 Mins.
Earth/sun correction factor ----	=	.983777
Atmospheric transmission -----	=	.90 10ths
Precipitable water -----	=	1.50 Cm.
Atmospheric pressure -----	=	1000.00 Mb.
Estimated elevation -----	=	112.4 M.
Inclination of slope -----	=	90.0 Deg.
Azimuth of slope -----	=	270.0 Deg.
Albedo of site -----	=	.20 10ths.
Elevation of skyline for sunrise	=	.0 Deg.
Elevation of skyline for sunset	=	.0 Deg.
Atmospheric refraction -----	=	0
Backscattered radiation -----	=	0
Time of SUNRISE -----	=	4.57 Hrs
Time of SUNSET -----	=	19.43 Hrs

Graphics Commands. *

* For the remaining examples the ENTER symbol (↵) will be deleted from the text. If in doubt consult Example 1.

		COMMENTS
Type =	XY	(Rows 1 & 2 for headings)
X =	A5..A36	(TIME)
A =	B5..B36	(North Wall)
B =	C5..C36	(East Wall)
C =	D5..D36	(South Wall)
D =	E5..E36	(West Wall)
E =	F5..F36	(Roof - horizontal)

Options, Titles,

First = DIRECT RAD. ON BUILDING AT 40 N.
 Second = COLUMBUS, OHIO; DEC=23.5 D; WALLS=90 D.
 X axis = TIME (L.A.T)
 Y axis = IRRADIANCE (Wm**-2)
 View
 Save = "Filename"

Printgraph,

Select = "Filename"
 Options
 Size = Full
 Quit
 Quit
 Go

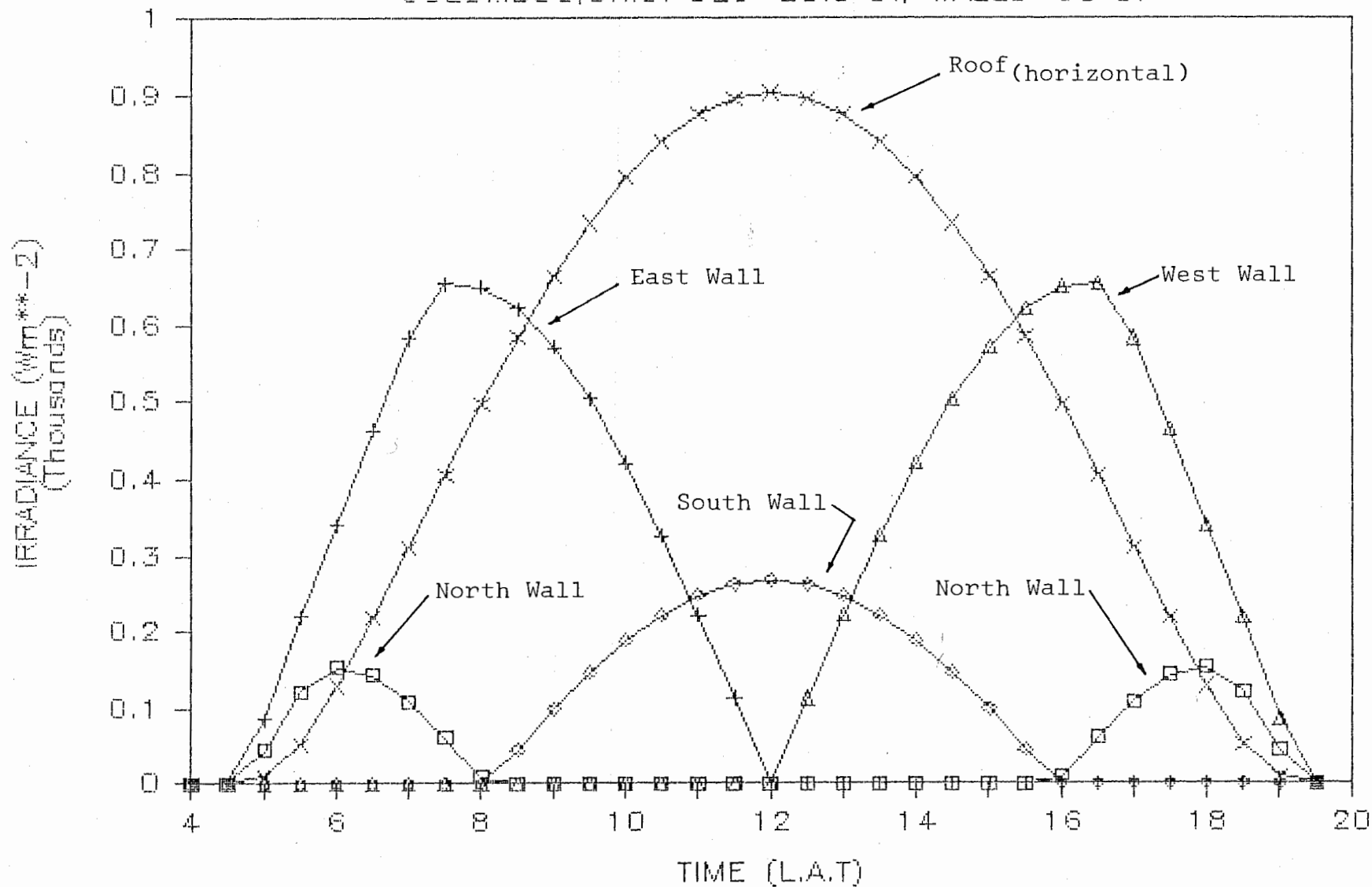
	A	B	C	D	E	F
1	DIRECT RADIATION			ON BUILDING		
2	LOCATION 40.0 D.N DEC=23.5					
3	WALLS =VERTICAL			ROOF =HORIZONTAL		
4	TIME	NORTH	EAST	SOUTH	WEST	ROOF
5	4	0	0	0	0	0
6	4.5	0	0	0	0	0
7	5	44.27	85.62	0	0	10.71
8	5.5	121.96	219.11	0	0	52.5
9	6	153.29	341.16	0	0	128.63
10	6.5	142.71	463.21	0	0	217.33
11	7	108.58	583.18	0	0	311.16
12	7.5	61.69	654.4	0	0	405.61
13	8	8.78	650.25	0	0	497.45
14	8.5	0	621.29	45.59	0	584.08
15	9	0	571.22	98.1	0	663.37
16	9.5	0	503.28	146.22	0	733.5
17	10	0	420.49	188.03	0	792.97
18	10.5	0	325.81	222.02	0	840.52
19	11	0	222.19	247.07	0	875.18
20	11.5	0	112.59	262.41	0	896.26
21	12	0	0	267.58	0	903.33
22	12.5	0	0	262.41	112.59	896.26
23	13	0	0	247.07	222.19	875.18
24	13.5	0	0	222.02	325.81	840.52
25	14	0	0	188.03	420.49	792.97
26	14.5	0	0	146.22	503.28	733.5
27	15	0	0	98.1	571.22	663.37
28	15.5	0	0	45.59	621.29	584.08
29	16	8.78	0	0	650.25	497.45
30	16.5	61.7	0	0	654.4	405.61
31	17	108.58	0	0	583.18	311.16
32	17.5	142.71	0	0	463.21	217.33
33	18	153.29	0	0	341.16	128.63
34	18.5	121.96	0	0	219.11	52.5
35	19	44.27	0	0	85.62	10.71
36	19.5	0	0	0	0	0

TABLE 2.

Data base for Graph 2
 as entered into the
 spread-sheet and
 printed under LOTUS
 1-2-3 commands.

DIRECT RAD.ON BUILDING AT 40.0N

COLUMBUS, OHIO: DEC=23.5 D.; WALLS=90 D.



72.

GRAPH 2.

EXAMPLE 3.

Radiative balance of a High Elevation Alpine Glacier.

Glaciar Yanamarey is a small deeply entrenched alpine glacier located in the southern portion of the Cordillera Blanca, Peru (Latitude = 9.6 Deg. S.). The main body of the glacier is inclined to the southwest with an average surface slope of 12 degrees. The elevation of the ablation zone approaches 3000 meters which can be translated into the 700 millibar level by use of the U.S. Standard Atmosphere Tables (see page 105). Examples 3A and 3B have been developed using known information about this particular glacier.

The skyline of the surrounding terrain as surveyed from the center of the ablation zone is plotted on the solar path diagram on page 74. The shaded area, therefore, represents that region of the sky hemisphere obscured by the surrounding mountains, and combined with the plot of the solar trajectories, provides an indication of the extent to which the solar disk is not visible from this site over the period from astronomical sunrise to sunset (i.e. the solar disk lies below the visible horizon). Solar paths have been included for both the June and December solstices (declination of +23.5 and -23.5 degrees respectively). Thus, the region bounded by these two curves represents that region of the sky hemisphere traversed by the sun throughout the year. For both of the following examples, the solar path for the declination of +20.6 (July 20th) is used as model input.

EXAMPLE 3A.

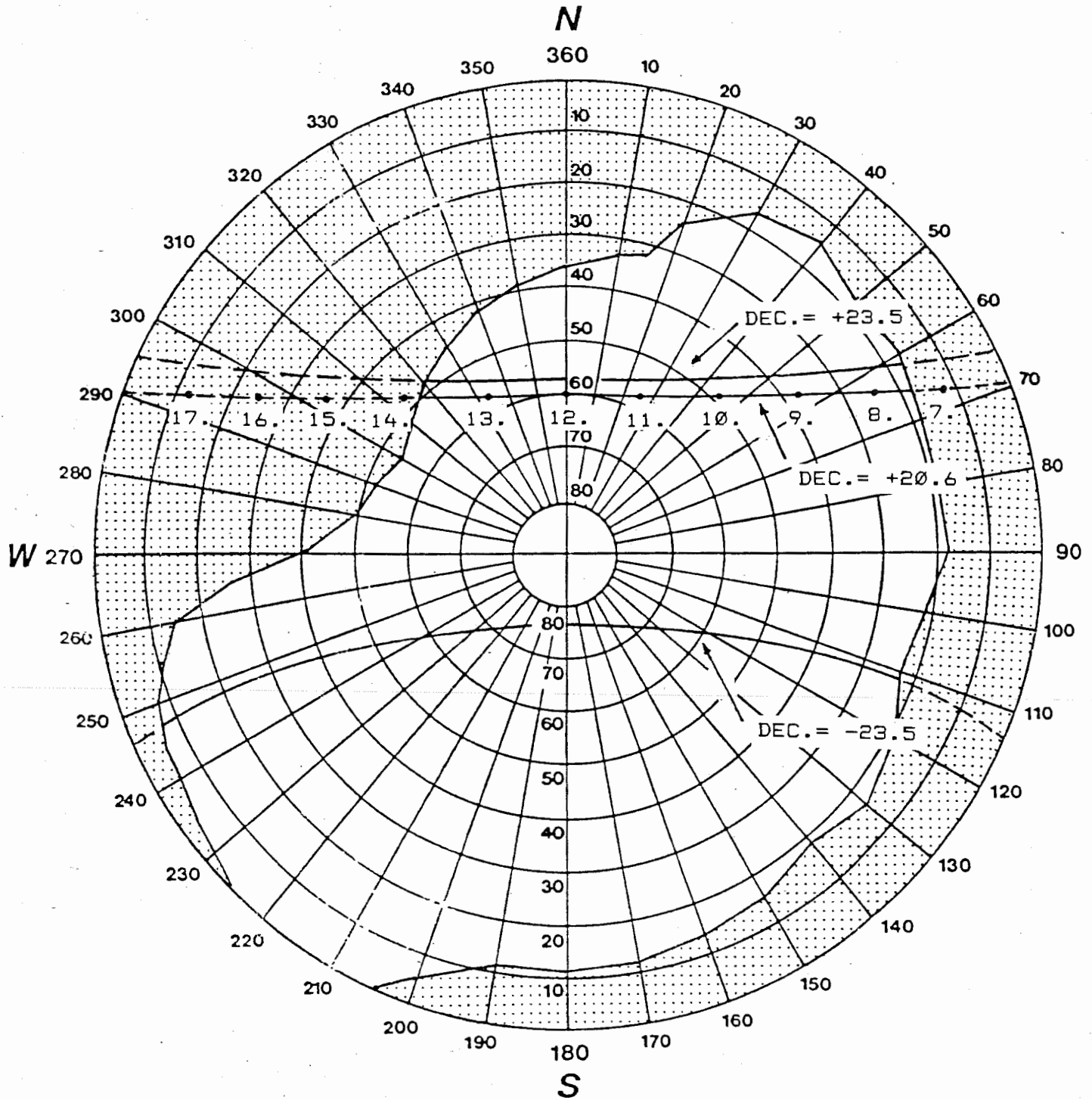
Graph 3A (page 77) is the result of 4 runs of the computer model the primary intention of which is to determine the effects of surface inclination, azimuth and topographic control on the direct beam radiative receipt over the ablation zone of Glaciar Yanamarey. The user options as listed by the program (for Run #4) are provided below.

USER SUPPLIED OPTIONS

Latitude of site -----	=	-9.60 Deg.
Declination of site -----	=	20.60 Deg.
Time increment for calculations	=	30 Mins
Earth/sun correction factor -----	=	.984155
Atmospheric transmission -----	=	.90 10ths
Precipitable water -----	=	1.30 Cm.
Site Elevation -----	=	3000.0 M.
Estimated atmospheric pressure --	=	700.90 Mb.
Inclination of slope -----	=	12.0 Deg.
Azimuth of slope -----	=	225.0 Deg.
Albedo of site -----	=	.20 10ths
Elevation of skyline for sunrise	=	17.5 Deg.
Elevation of skyline for sunset	=	47.0 Deg.

Example cont'd

SOLAR PATH DIAGRAM



LOCATION: GLACIAR YANAMAREY, PERU. LAT=9.6° S.

Atmospheric refraction ----- = 0
 Backscattered radiation ----- = 1
 Time of SUNRISE ----- = 6.24 Hrs
 Time of SUNSET ----- = 17.76 Hrs

For each model execution the variable alterations become :

	HORIZONTAL		INCLINED	
	Run #1	Run #2	Run #3	Run #4
Site Azimuth	0.0	0.0	225.0	225.0
Site Inclination	0.0	0.0	12.0	12.0
Skyline Elev. Sunrise	0.0	17.5	0.0	17.5
Skyline Elev. Sunset	0.0	47.0	0.0	47.0

The output for the direct beam (S) from each of these runs is graphed in 3A. The shaded region (hand drawn) represents the area under the curve removed when the shading effects of the surrounding terrain are included. The extraterrestrial radiation has been included for comparative purposes only. Apart from the inferences that can be drawn from the trends exhibited by the computed curves and, perhaps, a quantitative evaluation of the instantaneous results, it is also possible to use the integrated daily totals to considerable advantage. For example:

	HORIZONTAL SURFACE	INCLINED SURFACE
Excluding Topography	21.33 *	18.48
Including Topography	16.59	13.98
Difference	4.74	4.50
Percent Difference	22.2%	24.4%
Excluding Topography	21.33	18.48
Percent Difference	13.3%	
Including Topography	16.59	13.98
Percent Difference	15.7%	

* All radiation values in megajoules per square meter per day.

In addition, if the surface were horizontal and excluding the effects of the surrounding terrain, it can be determined that the 69.9% of the daily energy available at the edge of the atmosphere is transmitted to the surface as direct beam radiation. For the inclined surface, this value is reduced to 60.6%.

Thus, the model run with the inclusion and exclusion of known site characteristics makes possible quantitative evaluation of relative effects of these characteristics upon the radiative receipt. Such flexibility in the radiation model offers the capacity to isolate those components that are of importance in

determining the specifics of the radiative balance at a particular location.

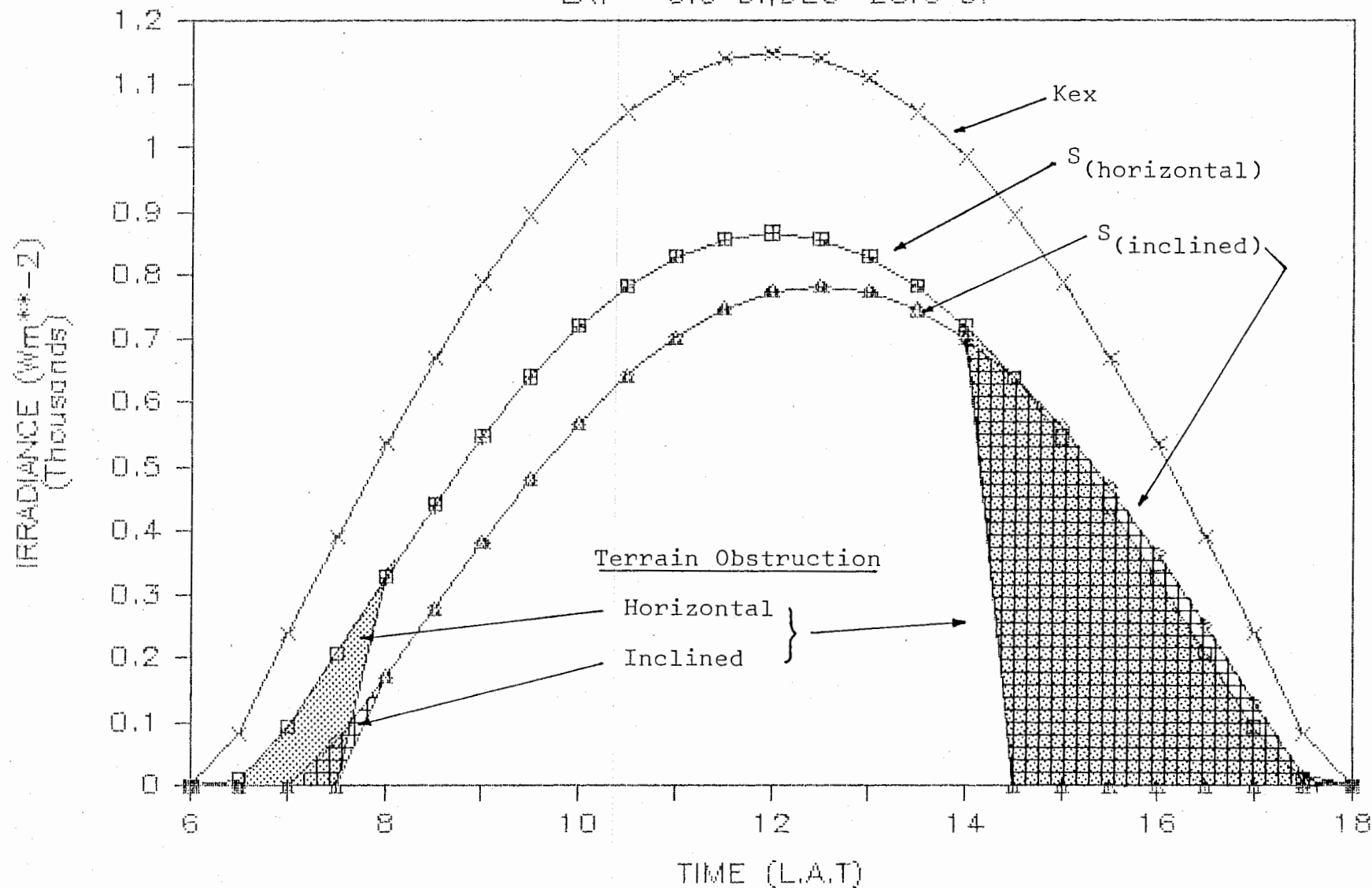
Graphics Commands.

Once the data from the four model runs has been entered into the spreadsheet, the required graphics commands are identical to those presented in Example 2.

Graph 3A following page.

GLACIAR YANAMAREY, PERU.

LAT=-9.6 D.; DEC=20.6 D.



GRAPH 3A.

77.

EXAMPLE 3B.

Comparison of Computed to Measured Data.

The user selected time increment (TINC or t) ranges from a minimum of 1 to a maximum of 60 minutes and, for most purposes, an interval of 30 to 60 minutes is adequate. However, if the model performance is to be tested against field measured data it is advantageous to be able to compare the computed to the measured value at exactly the same point in time. It is, however, not always possible to obtain field measured data at regular time intervals unless the measured data is placed on a continuously recording system (i.e. strip chart or magnetic tape). Thus, for example, if the model was run using a time interval of 30 minutes it would not be possible to directly compare results if the data was measured at 04.47 hrs. (this point would lie between the closest computed times of 04.50 and 05.00 hrs.).

If the model output is to be compared with field measurements made randomly throughout the day, the program can be run at 1 minute intervals and the data for the exact time of measurement isolated from the output. Contingent upon the day length, however, the printout time required for one model run could be substantial with much of the generated data not required. For example, a daylength of 14.5 hours would require 870 iterations for a time increment of one minute. In this instance it becomes far more efficient for the user to avoid data printout and let the results be displayed only on the video screen. When the required time appears on the screen, program execution can be halted by pressing down the CONTROL key and simultaneously pressing the NUM LOCK key. Once the operator has recorded the data point, program continuation is achieved simply by pressing the ENTER key (refer to 86 page 53 HALTING SCREEN DISPLAY).

Graph 3B compares computed to instantaneous values as measured over Glaciar Yanamarey on July 20th, 1983 (declination of 20.6 deg.). The topographic effects incorporated into the FORTRAN model become critical in the duplication of the curve described by the measured data. Thus, used in conjunction with the information available from the solar path diagram, this particular application of the computer model results in an extremely powerful diagnostic tool. Note also, that the graphing of this data by the LOTUS procedures absolutely necessitates the use of the XY graph type as the data intervals are not uniformly distributed on the X axis (abscissa).

The data for Graph 3A as entered into the LOTUS systems disk is provided in Table 2. The value entered into column E represents a false or a bogus data point that allows the user to expand the axis of the graph and make the output more visually satisfying. The use of this point is explained in the comments section of the graphics commands.

	A	B	C	D
1	GLACIAR YANAMAREY LAT=9.65 DEC=20.6			
2	DIRECT		BEAM	
3	TIME	COMPUTED	MEASURED	YAXIS
4	6	0	0	950
5	6.24	0	0	
6	6.5	15.1	0	
7	7.1	42.7	50.9	
8	7.5	51.4	60.5	
9	8.1	250.9	160	
10	9	463.1	440.7	
11	10	657.9	590.3	
12	11.15	810.4	780.1	
13	12	871.3	853.9	
14	12.5	879.8	820.7	
15	13	869.5	840.1	
16	13.45	840	807	
17	14	791.6	740.1	
18	14.2	760.2	762.9	
19	14.5	69.8	79.9	
20	15.5	63.2	79	
21	17.1	34.6	39.3	
22	17.5	16.3	9.3	
23	17.76	0	0	

TABLE 3.

Graphics Commands

Graph,	COMMENTS
Type = XY	(Rows 1 & 2 used for headings)
X = A4..A23	(X axis - TIME)
A = B4..B23	(1st data range - computed)
B = C4..C23	(2nd data range - measured)
C = D4..D4 *	(3rd data range - Bogus point)

* The graph axis are automatically determined by the upper and lower values of the entered data. In certain instances, particularly if the data is random over a certain time interval, the result does not always visually satisfy the needs of the user. By specifying the data limits, it is possible to control the scale of the axis (both X and Y). There are two ways that this can be done. If the user is familiar with the LOTUS package the Worksheet/Graph/Options/Scale commands can be used. A more direct approach is simply to enter a false or bogus data point and specifying the plot ranges to encompass only that cell. In example 3B the Y axis is expanded by the value of the third data range (950) and specified as having a range equal to D4..D4. This results in a single symbol plotted at the position equal to the value on the axis and, therefore, does not interfere with the curves generated for the other data.

Example Cont'd

Options, Titles

First = GLACIAR YANAMAREY, PERU
Second = SLOPE=12.0; AZIMUTH=225
X Axis = TIME (L.A.T)
Y Axis = IRRADIANCE (Wm**-2)
Save = "Filename"

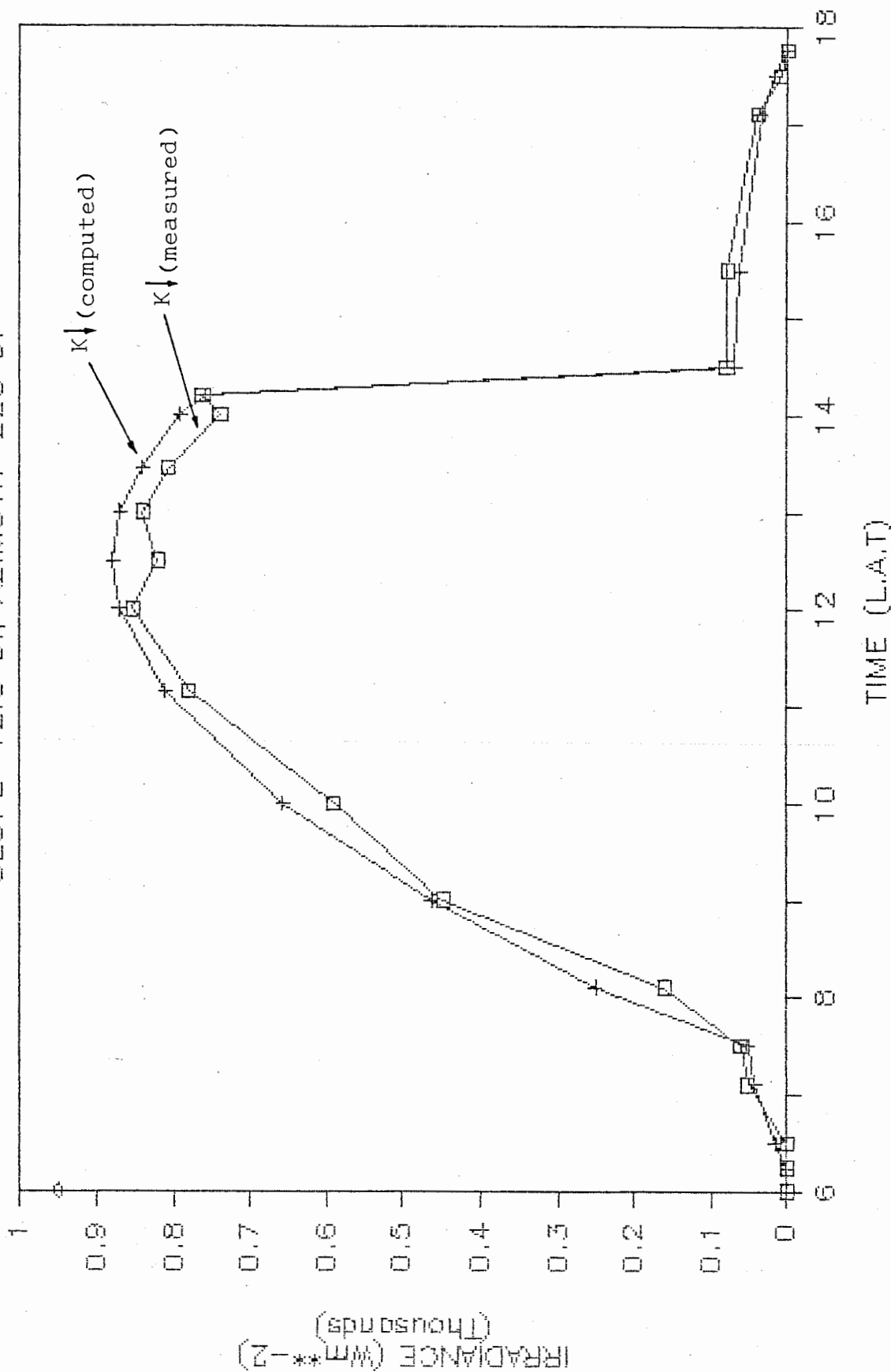
Printgraph,

Select = "filename"
Options
size = Full
Quit
Quit
Go

Graph 3B following page

GLACIAR YANAMAREY, PERU

SLOPE=12.0 D.; AZIMUTH=225 D.



GRAPH 3B.

EXAMPLE 4.

Daily Radiative Loading on a Slope varying from 0 to 90 Degrees.

Allied with appropriate program design the flexibility of interactive computer systems becomes apparent when it is necessary to test the influence of a singular variable over a specified range. This enables the user to operate the system efficiently in terms of both time required at the terminal and time for system output.

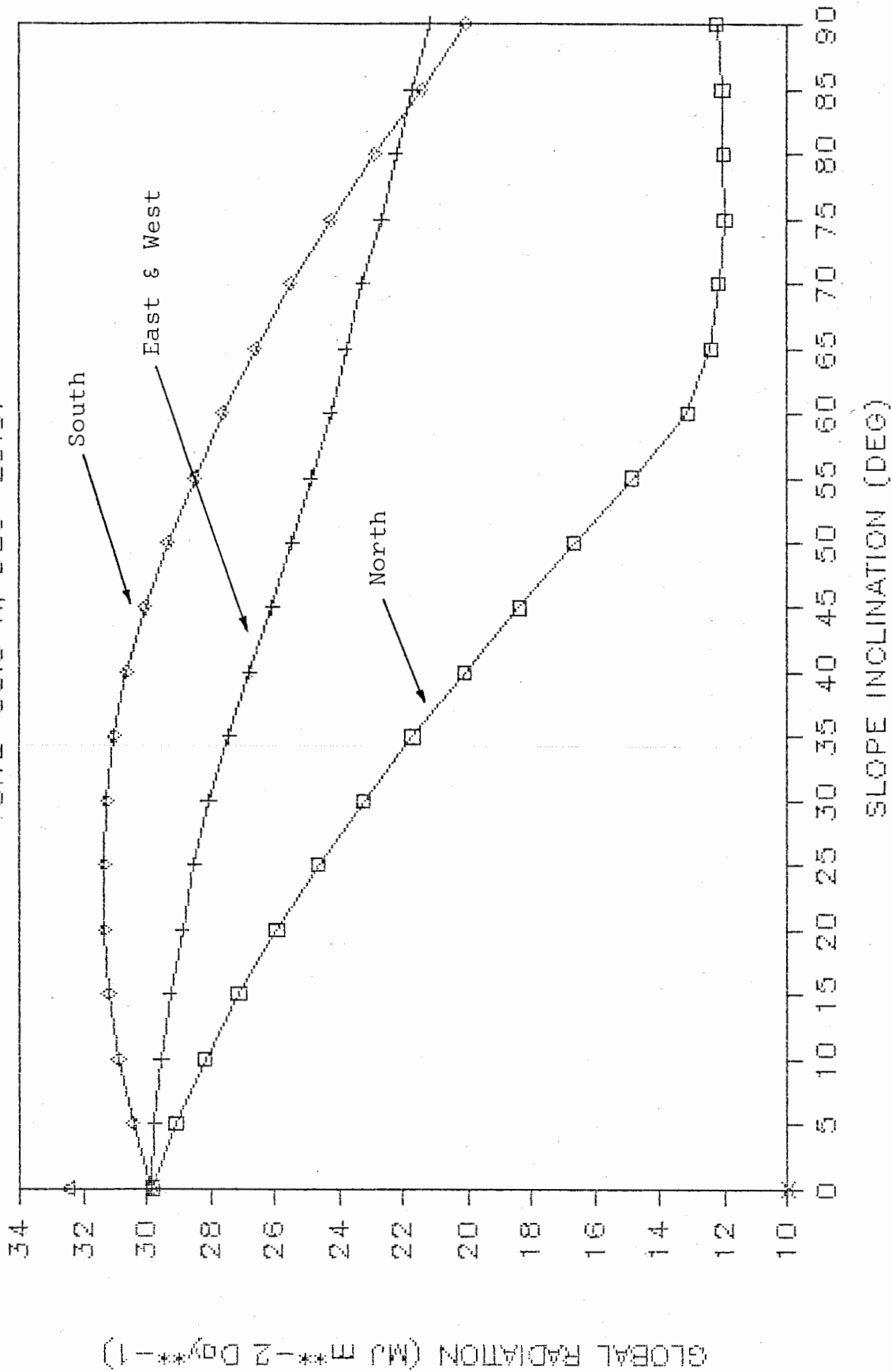
For this example the slope of the site (55 N. at the June solstice) was allowed to vary from the horizontal to the vertical (0 to 90 Deg.) at five degree increments and repeated for four azimuths (N,S,E and W). Thus, the data base necessitated 57 executions of the program from which only the integrated daily total of the global radiation (K_d) was of interest. The total amount of operator time required to obtain the data was approximately 90 minutes as no printout was necessary and the values manually recorded. The results are presented in Graph 4. Note that only three curves are plotted due to the symmetry in the radiative receipt for the east and west azimuths.

Graphics Commands.

Apart from the data ranges and headings, the syntax required for Graph 4. is basically identical to Examples 1 & 2. The Y axis, however, has been expanded by the addition a false data point equal to 35 megajoules, the symbol of which is plotted on this axis in the upper left corner. The user should consult the discussion that accompanies the syntax for Graph 3b. to understand the purpose of this additional data point.

DAILY TOT. K↓ FOR SLOPES=0/90 Deg.

SITE=55.0 N; DEC=23.5;



GRAPH 4.

EXAMPLE 5.

Meridional Distribution of Global and Net Shortwave Radiation for 100 Deg. West Longitude.

As the radiation model will function over all latitudes and declinations it becomes possible to consider the global distribution of radiative phenomena. Graphs 5a and 5b are the result of iterating the model over all latitudes at 10 degree increments to estimate the meridional distribution of surface global and net radiation. The albedo for each increment of latitude was taken directly from a map of the average planetary albedo which can be found in almost any standard physical geography or general climatology text, i.e. Neiburger, Edinger and Bonner (1982;76-77); Strahler and Strahler (1978;54-55).

Thus, for each program execution, the latitude and site albedo are the only variables that require alteration. The information required from each program run is the instantaneous values of the global and net radiation for solar noon and their integrated daily totals. For graphs 5a and 5b, the surface albedo was interpreted at 10 degree increments along the 100° W. meridian following Neiburger et.al (1982; 77).

Graphics Commands.

For Example 5 only the commands for Graph 5a are documented. With the exceptions of the headings and the A and B data ranges the same commands will generate 5b.

Graph,	COMMENTS
Type = BAR	(Rows 1&2 data headings)
X = A3..A19	(Latitude - 60 N to 90 S)
A = B3..B19	(Net shortwave - K*)
B = C3..C19	(Global radiation - K↓)

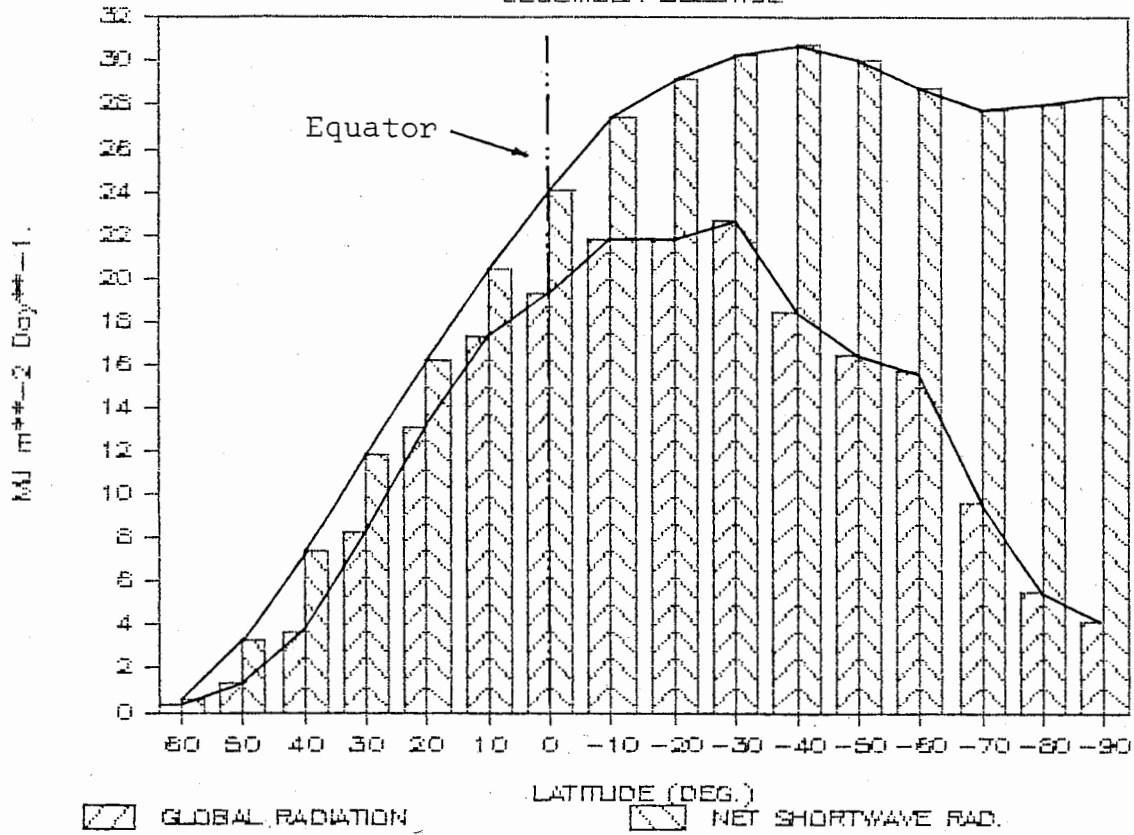
Options, Titles,
First = DAILY TOTALS OF RADIATION
Second = DECEMBER SOLSTICE
X Axis = LATITUDE (DEG.)
Y Axis = MJ m**-2 Day**-1

Options, Legend,
1st data range = NET SHORTWAVE
2nd data range = GLOBAL RADIATION
VIEW
Save = "Filename"

Printgraph,
Select = "Filename"
Options
Size = HALF
Quit
Quit
Go

DAILY TOTALS OF RADIATION

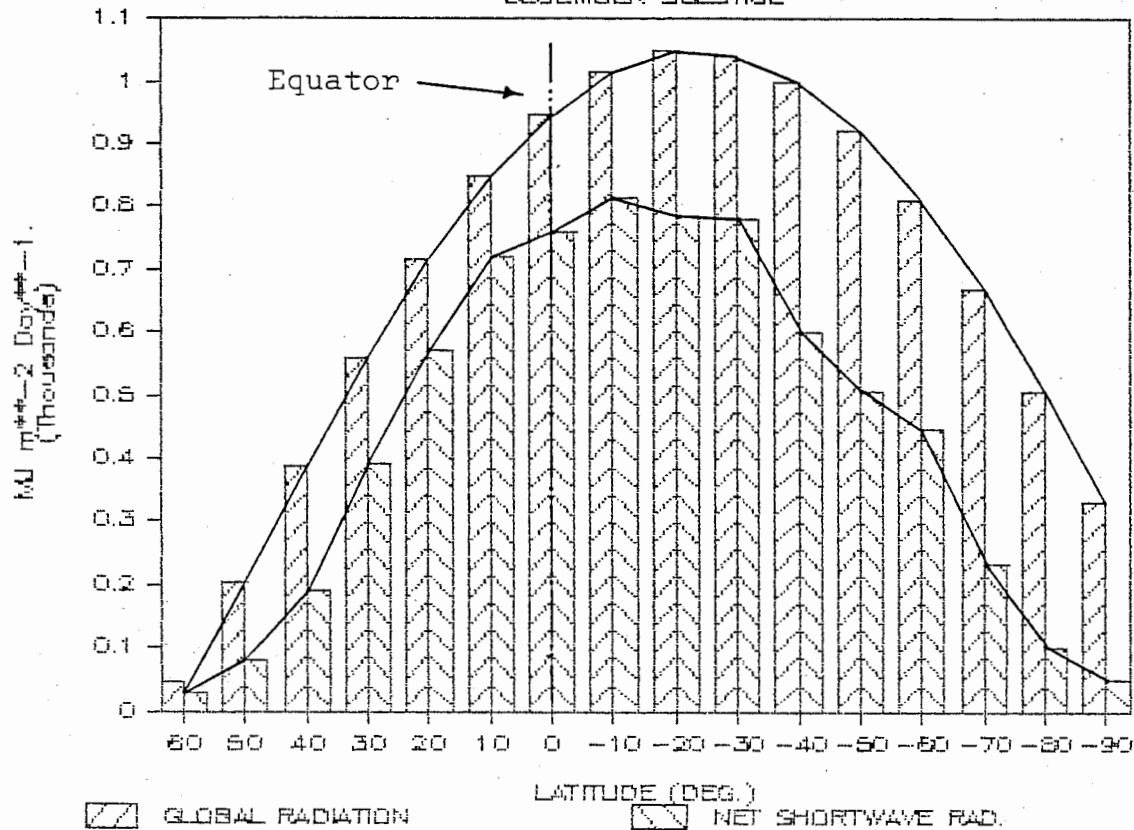
DECEMBER SOLSTICE



GRAPH 5A.

RADIATIVE BALANCE AT SOLAR NOON

DECEMBER SOLSTICE



GRAPH 5B.

EXAMPLE 6.

Seasonal Distribution of Radiation on a Specified Slope.

It is possible to use the information generated by the model to obtain the data base for a three variable graph. Although this particular application may require a considerable amount of time at the computer terminal, once complete and entered into the Lotus spreadsheet, the additional information that can be derived from the results makes this an extremely instructive and useful application of the model. In addition, such a format begins to capitalize on the flexibility and power of the graphics capacity inherent in Lotus 1-2-3.

Graph 6A is an isoline diagram interpolated directly from the data base presented in Table 4. The information was obtained by running the radiation model 12 times the intention of which is to determine the seasonal trends of the direct beam radiation intercepted on a slope inclined at 50 degrees, facing to the west and located at 60 degrees north latitude. The first day of each month was selected as the primary seasonal reference and the declination and earth/sun correction factor entered into the model for each of these twelve days. Graph 6A represents the isoline diagram as interpreted directly from the data as entered into the spreadsheet and printed out under the Lotus PRINT routines (Table 4). Sellers (1981, 36) presents a variety of similar diagrams generated for direct beam receipt but using as the graph axis slope and time of the day. Thus, for the Sellers examples, the time of the year is taken as constant rather than, as for Example 6, the site slope.

Once the data has been entered into the spreadsheet, graphs can be generated using either the columns or rows as the graph axis. Thus, it becomes possible to plot the more standard two variable graphs from both horizontal and vertical transects through the data base matrix. Graphs 6b and 6c have been created from the data base capitalizing upon this capacity. The data ranges for these graphs can be interpreted directly from Table 4.

Graphics Commands.

Graph 6B.

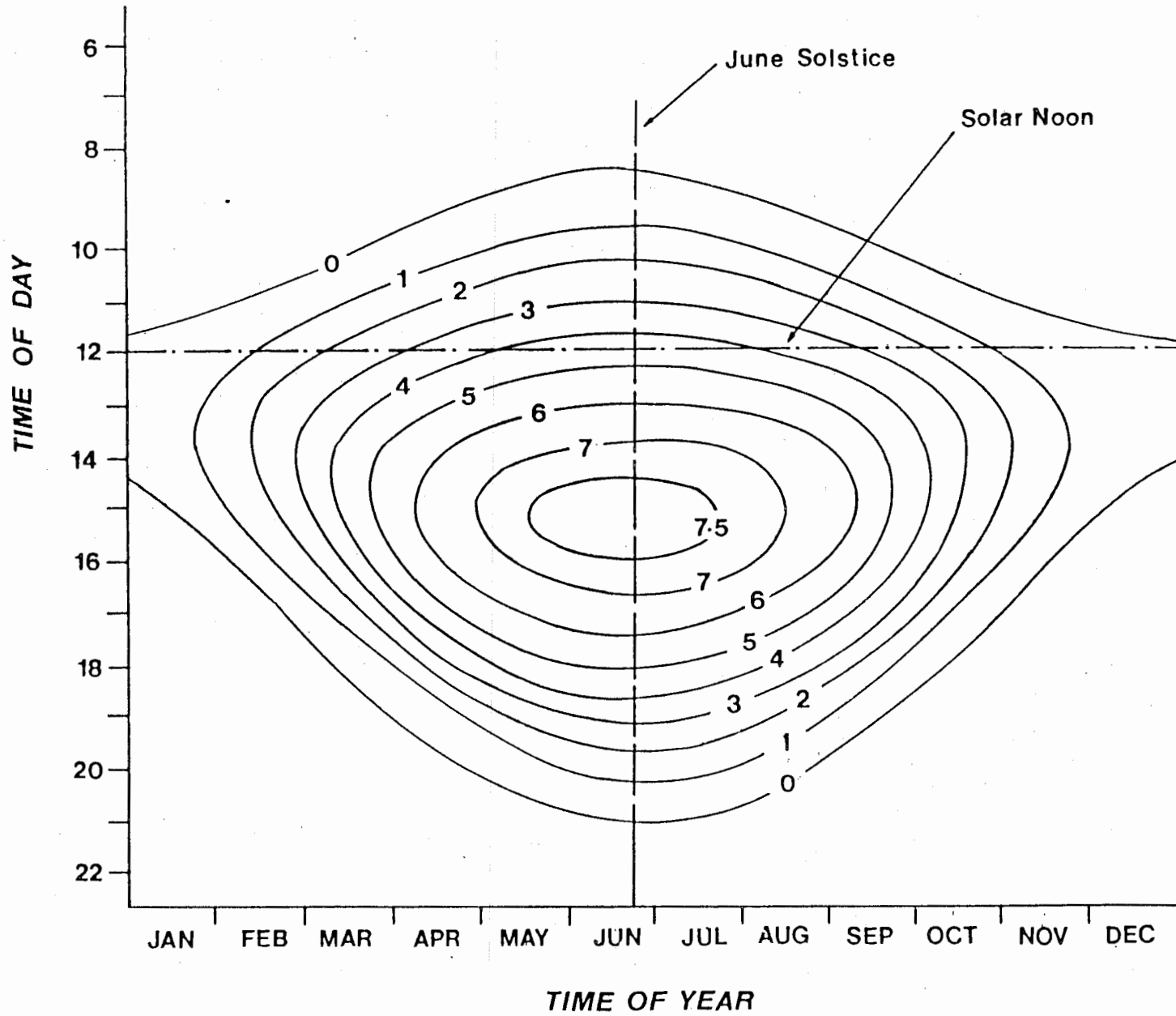
Graph ,	COMMENTS
Type = XY	
X = A2..A33	(X Axis - TIME)
A = C2..C33	(1st data range - FEB)
B = D2..D33	(2nd data range - MAR)
C = E2..E33	(3rd data range - APR)
D = F2..F33	(4th data range - MAY)
E = H2..H33	(5th data range - JUL)

Example cont'd on Page 89.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2	6.5	0	0	0	0	0	0	0	0	0	0	0	0
3	7	0	0	0	0	0	0	0	0	0	0	0	0
4	7.5	0	0	0	0	0	0	0	0	0	0	0	0
5	8	0	0	0	0	0	0	0	0	0	0	0	0
6	8.5	0	0	0	0	0	0	0	0	0	0	0	0
7	9	0	0	0	0	0	0	0	0	0	0	0	0
8	9.5	0	0	0	0	0	0	21	0	0	0	0	0
9	10	0	0	0	0	34	94	105	62	0	0	0	0
10	10.5	0	0	0	34	121	182	193	149	69	0	0	0
11	11	0	0	22	118	210	271	281	239	155	59	0	0
12	11.5	0	18	95	216	320	400	400	490	134	134	0	0
13	12	14	39	156	283	384	462	470	411	324	207	89	23
14	12.5	28	95	216	358	462	520	529	490	401	275	134	42
15	13	33	122	267	423	533	590	598	599	469	333	172	55
16	13.5	32	134	304	478	592	650	658	620	526	379	192	50
17	14	28	127	325	517	639	699	707	667	568	409	197	40
18	14.5	14	94	320	541	671	733	742	700	596	421	174	27
19	15	0	52	300	543	687	753	762	718	606	411	127	6
20	15.5	0	23	243	526	685	755	767	720	596	373	60	0
21	16	0	0	151	481	664	745	755	703	564	305	25	0
22	16.5	0	0	61	411	622	714	727	667	507	201	0	0
23	17	0	0	0	304	558	667	681	612	423	77	0	0
24	17.5	0	0	0	169	471	601	619	537	309	20	0	0
25	18	0	0	0	58	360	517	538	441	167	0	0	0
26	18.5	0	0	0	0	227	417	444	325	57	0	0	0
27	19	0	0	0	0	82	302	334	194	2	0	0	0
28	19.5	0	0	0	0	30	170	216	71	0	0	0	0
29	20	0	0	0	0	0	67	102	25	0	0	0	0
30	20.5	0	0	0	0	0	28	42	0	0	0	0	0
31	21	0	0	0	0	0	0	10	0	0	0	0	0
32	21.5	0	0	0	0	0	0	0	0	0	0	0	0
33	22	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.

Data base for Graph 6A as printed under the Lotus
PRINT routines



GRAPH 6A.

Seasonal Distribution of Direct Beam Radiation on a 50 Deg. West Facing Slope at 50 Deg. North Latitude. All Values are in Megajoules per Square Meter per Day.

```
Options, Titles,  
  First = DIRECT BEAM RADIATION  
  Second = SITE=60 N; SLOPE=50; AZIM.=270  
  X Axis = TIME (L.A.T)  
  Y Axis = IRRADIANCE (Wm**-2)  
  VIEW  
  Save = "Filename"
```

```
Printgraph,  
  Select = "Filename"  
  Options  
  Size = HALF  
  Quit  
  Quit  
  Go
```

Graph 6C.

COMMENTS

```
Graph ,  
  Type = LINE      (must be LINE format)  
  X = B1..M1      (X Axis - TIME OF YEAR)  
  A = B13..M13    (1st data range - 1200 or Solar Noon)  
  B = B17..M17    (2nd data range - 1400 Hrs)  
  C = B20..M20    (3rd data range - 1550 Hrs)  
  D = B25..M25    (4th data range - 1800 Hrs)  
  E = B28..M28    (5th data range - 1950 Hrs)
```

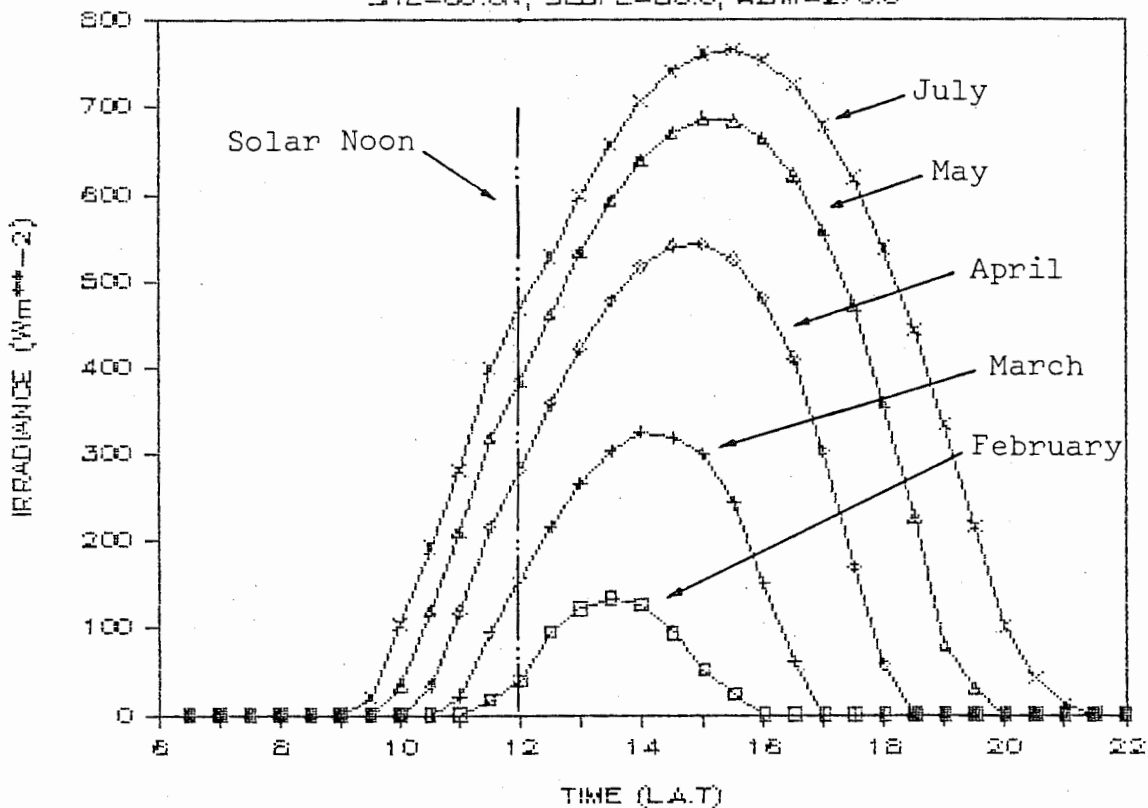
```
Options, Titles,  
  First = DIRECT BEAM RADIATION (S)  
  Second = SITE=60 N; SLOPE=50; AZIM.=270  
  X Axis = TIME OF YEAR  
  Y Axis = IRRADIANCE (Wm**-2)  
  VIEW  
  Save = "Filename"
```

```
Printgraph,  
  Select = "Filename"  
  Options  
  Size = HALF  
  Quit  
  Quit  
  Go
```

As the above graphs are printed under the HALF command it is possible to print them both at the same time and on one page. The procedure for this option is explained in Example 7 (page 94).

DIRECT BEAM RADIATION (S)

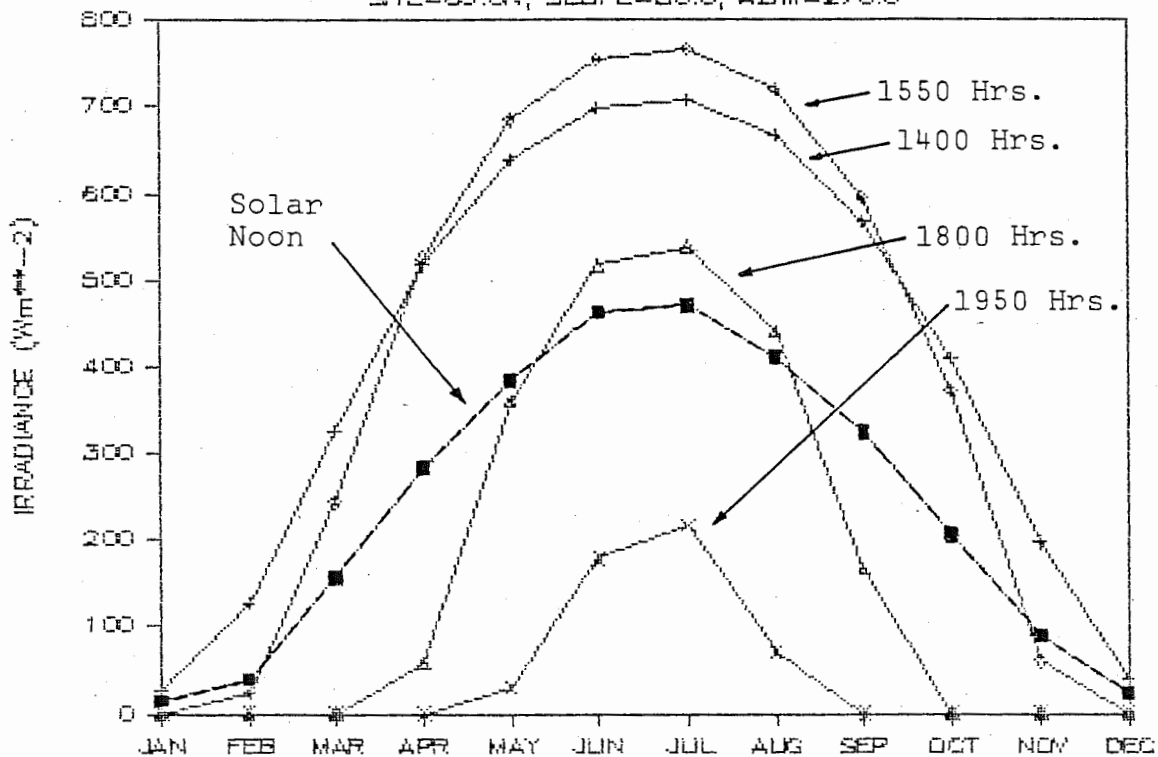
SITE=50.0N; SLOPE=50.0; AZM=270.0



GRAPH 6B.

DIRECT BEAM RADIATION (S)

SITE=50.0N; SLOPE=50.0; AZM=270.0



GRAPH 6C.

EXAMPLE 7.

The Distribution of Solar Radiation over the Earth's Surface.

The distribution of global radiation received over the surface of the earth is conventionally presented on an isoline diagram as a function of time of the year and latitude. Usually, two such diagrams are provided: one for the distribution of global radiation received on a horizontal surface at the edge of the atmosphere, and the other, for the horizontal at the earth's surface (see Sellers, 1971, 18; Neiburger, et.al., 1982; Strahler & Strahler, 1978, 49).

By running the FORTRAN model, varying the latitude, declination, the earth/sun correction factor and isolating the integrated daily totals of global radiation from the computed results, it is possible to generate a data base matrix such as that presented in table 5 (columns A-M). The 17th day of each month was selected as the seasonal reference and the declination and earth/sun correction entered into the user options for these times. The latitude was then iterated at 5 degree intervals with the other variables held constant. A sample of the the inputs is provided below.

USER SUPPLIED OPTIONS

Latitude of site -----	=	30.00 Deg.
Declination of site -----	=	-1.50 Deg.
Time increment for calculations	=	60 Mins.
Earth/sun correction factor ----	=	1.003420
Atmospheric transmission -----	=	.91 10ths
Precipitable water -----	=	2.00 Cm.
Atmospheric pressure -----	=	1000.00 Mb.
Estimated elevation -----	=	112.40 M.
Inclination of slope -----	=	.0 Deg.
Azimuth of slope -----	=	.0 Deg.
Albedo of site -----	=	.20 10ths
Elevation of skyline for sunrise	=	.0 Deg.
Elevation of skyline for sunset	=	.0 Deg.
Atmospheric refraction -----	=	0
Backscattered radiation -----	=	0
Time of SUNRISE -----	=	6.36 Hrs
Time of SUNSET -----	=	17.65 Hrs

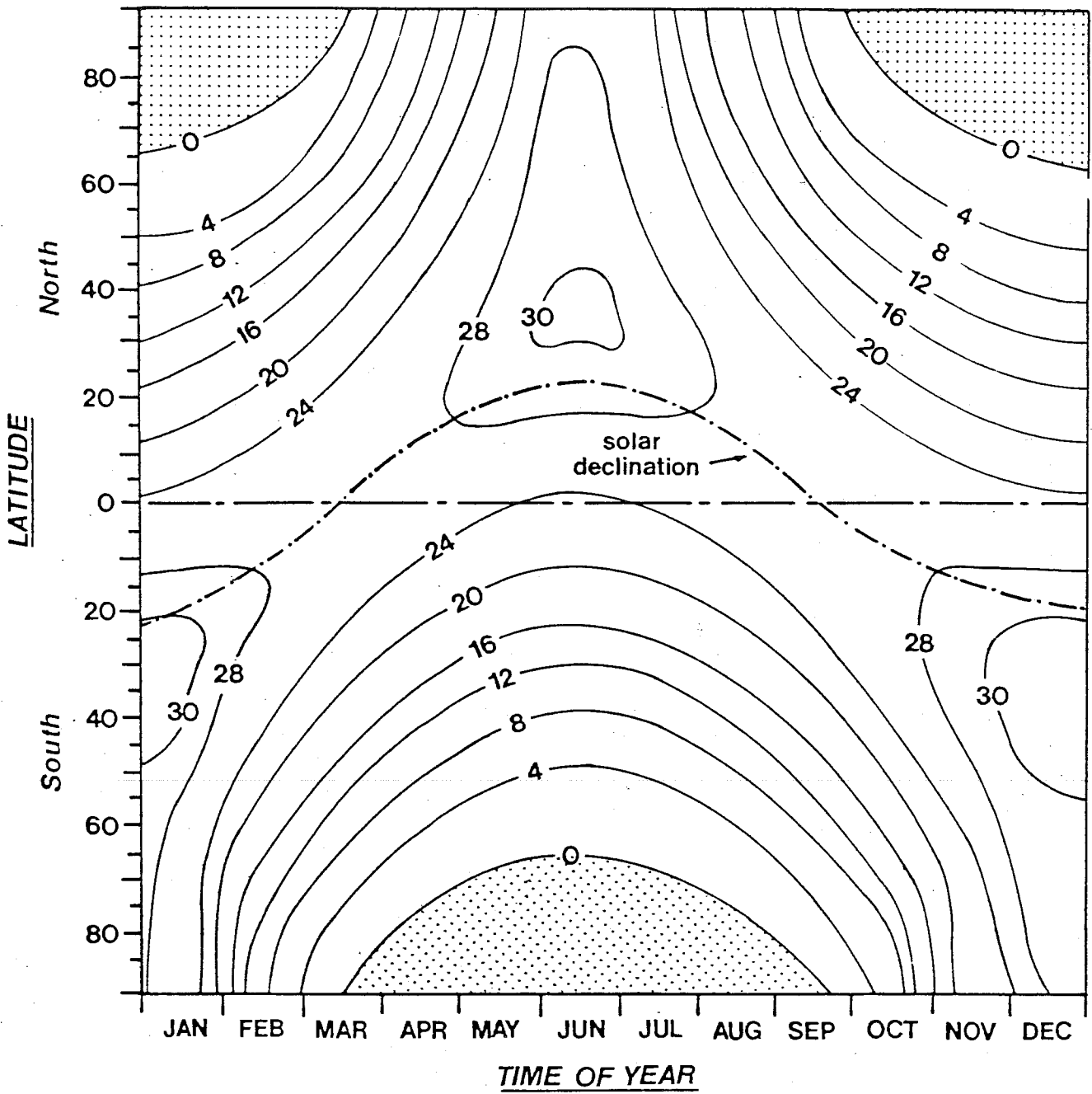
The data base as presented in Table 5. requires a considerable amount of time to compile. However, once generated and entered into the spreadsheet, the ease to which this data can be manipulated makes this a particularly instructive exercise and, similar to Example 6, begins to capitalize upon model design and the flexibility of LOTUS 1-2-3 graphics routines.

COL.#	A	B	C	D	E	F	G	H	I	J	K	L	M	FALSE X AXIS
ROW.#1	LATITUDE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
2	90	0	0	0	8.3	21.6	27.9	24.7	13.1	1.2	0	0	0	9
3	85	0	0	0.5	8.9	21.6	28.2	24.6	13.6	1.2	0	0	0	8
4	80	0	0	1.2	10.1	21.6	28.1	24.5	14.2	3.7	0	0	0	8
5	75	0	0	3.4	11.9	21.8	27.6	24.4	15.3	5.9	0.6	0	0	7
6	70	0	0.9	5.6	13.9	22.5	27.4	24.8	16.9	8.2	1.2	0	0	7
7	65	0.3	2.4	7.8	16.1	23.7	27.6	25.6	18.8	10.5	3.8	0.5	0	6
8	60	1.1	2.2	10.1	18.1	25	28.3	26.5	20.5	12.7	5.8	1.6	0.5	6
9	55	2.6	6.3	12.4	19.8	25.9	28.9	27.2	22.1	14.9	8.1	2.4	1.2	
10	50	4.5	8.5	14.6	21.6	27	29.5	28.2	23.6	16.9	10.4	5.4	3.4	5
11	45	6.6	11	16.7	23.1	27.8	29.8	28.8	24.7	18.9	12.6	7.6	5.5	
12	40	8.8	13.1	18.7	24.4	28.6	30.2	29.3	25.9	20.6	14.7	9.6	7.7	4
13	35	11	15.3	20.5	25.5	28.8	30.2	29.6	26.7	22.2	16.8	12.1	9.7	
14	30	13.6	17.4	22.1	26.4	28.9	29.7	29.3	27.3	23.5	18.8	14.4	12.2	3
15	25	15.7	19.3	23.5	27	28.8	29.5	29.1	27.6	24.7	20.5	16.5	14.5	
16	20	17.8	21.1	24.7	27.4	28.5	28.8	28.6	27.7	25.6	22.2	18.6	16.8	2
17	15	19.9	22.8	25.6	27.5	27.9	27.9	27.8	27.6	26.2	23.6	20.6	19	
18	10	21.8	24.3	26.3	27.4	27.1	26.8	26.9	27.3	26.7	24.9	22.5	21	1
19	5	23.6	25.5	26.8	26.9	26.4	25.5	25.9	26.6	27.2	25.9	24.1	23	
20	0	25.2	26.5	26.7	26	24.5	23.6	24.3	25.4	26.8	26.6	25.7	24.4	0
21	-5	26.9	27.6	27.1	25.5	23.4	22.3	22.7	24.7	26.5	27.5	26.8	26.3	
22	-10	27.8	27.8	26.8	24.5	21.7	20.4	20.9	23.4	25.9	27.5	27.8	27.7	1
23	-15	28.7	28.1	26.3	23.2	19.9	18.4	19.1	21.9	25.1	27.5	28.6	28.7	
24	-20	29.5	28.2	25.6	21.7	17.9	16.3	17.1	20.2	24.1	27.3	29.2	29.7	2
25	-25	30	27.9	24.6	19.9	15.9	14.1	14.9	18.4	22.8	26.8	29.5	30.5	
26	-30	30.2	27.5	23.4	18.1	13.8	11.8	12.8	16.4	21.4	26.1	29.6	30.6	3
27	-35	30.3	26.8	21.9	16.1	11.7	9.4	10.4	14.3	19.7	25.1	29.2	31.1	
28	-40	30	25.8	20.3	14	9.3	7.4	8.3	12.1	17.9	23.9	28.9	31.1	4
29	-45	29.5	24.7	18.5	11.9	7.1	5.3	6.1	9.9	15.9	22.6	28.3	30.8	
30	-50	28.8	23.4	16.5	9.6	5.1	3.2	4.2	7.6	13.8	20.9	27.5	30.4	5
31	-55	28	21.7	14.4	7.3	3.1	1.2	2.3	5.6	11.6	19.2	26.3	29.8	
32	-60	26.9	20	12.2	5.1	1.6	0.5	1	3.5	9.4	17.3	25.1	29.1	6
33	-65	25.9	18.1	9.9	3.3	0.4	0.1	0.2	1.8	7.1	15.2	23.8	28.4	
34	-70	25	16.2	7.5	1.5	0	0	0	0.6	4.9	13	22.7	28.2	7
35	-75	24.5	14.2	5.3	0.4	0	0	0	0.1	2.8	10.9	21.9	28.3	
36	-80	24.5	12.7	3.1	0	0	0	0	0	1.2	8.8	21.7	28.7	8
37	-85	24.6	11.7	1.4	0	0	0	0	0	0.3	7.3	21.7	28.9	
38	-90	24.7	11.5	1.1	0	0	0	0	0	0	6.7	21.7	28.3	9

TABLE 5.

The format of above table is simply the result of entering the data into the Lotus spreadsheet and printed using the PRINT commands discussed in Example 1. Even though the size of the data base is such that it is not possible to view the complete data set on the screen, the print default compresses the spreadsheet data allowing for a single page printout. For even larger data bases it is possible to control the Lotus print routines to achieve any desired print format. This option is particularly useful if an isoline diagram is to be constructed from the output, i.e. Graphs 6 and 7 (see Chapter 8 of Le Bond and Cobb (1983) or the Lotus manual under / Print Commands).

* This column is exclusively required for the X axis on Graph 7D and is not model generated data. Refer to page 95 for discussion.



GRAPH 7A.

Latitudinal and Seasonal Distribution of Global Radiation.

Graphs 7B and 7C represent just two possibilities directly derived from the data base. After creating the two graphs it is possible to print them on one page by using the HALF option in the printing routines. The following commands generate these two graphs:

```

                                COMMENTS
Graph, Type = Line
    X = B1..M1      (X axis - TIME OF YEAR)
    A = B2..M2      (1st data range - LAT.= 90)
    B = B9..M9      (2nd data range - LAT.= 55)
    C = B18..M18    (3rd data range - LAT.= 10)
    D = B20..M20    (4th data range - LAT.= 0 )

Options, Titles,
    First = SEASONAL DIST. OF GLOBAL RADIATION
    Second = SOUTHERN HEM; SEA LEVEL
    X Axis = TIME OF YEAR
    Y Axis = GLOBAL RADIATION (MJm***-2 Day**-1)
    View
    Save = "Filename" (7B)

```

As both these graphs are being constructed from the same data base and have identical axis it is not necessary to repeat the entire sequence outlined above to create the second graph (7C). All that will require modification are the 4 data ranges (A,B,C and D) and the second title command. All other entries will be repeated as they are carried over by the system from the previous graph entries. For Graph 7C:

Graph, and move cursor directly to the 1st data range,

```

    A = B20..M20    (1st data range - LAT.= 0 )
    B = B22..M22    (2nd data range - LAT.= -10)
    C = B31..M31    (3rd data range - LAT.= -55)
    D = B38..M38    (4th data range - LAT.= -90)

```

Options, Titles, (and go directly to the second title option)

```

    Second = SOUTHERN HEM; SEA LEVEL
    View
    Save = "Filename" (7C)

```

Printgraph (and enter PRINTGRAPH disk upon request)

```

    Select = "Filename" (7B) and "Filename" (7C) *

```

* Move cursor to "Filename" for the northern hemisphere graph and press the space bar. The # symbol will appear in front of the file name. Move the cursor to the southern hemisphere graph and, again, press the space bar to generate the # symbol. Then press the ENTER key.

Example cont'd.

Options, Size = HALF
Quit
Quit
Go

Both graphs will now be printed

From the data base presented in Table 5 it is possible to consider aspects of the meridional (longitudinal) distribution of the earth's radiative balance. Obviously, to achieve this all that is required is to use the latitude (+90 to -90) as the X axis and select the required months from the other data columns (Lotus allows a maximum of 6 columns to be plotted). However, as was alluded to earlier in this section, the standard commands do not always result in the generation of graphs that directly meet the needs of the user. Directly applying the data base generated for this example (columns A-M Table 5) to generate curves of the meridional distribution of radiation represents such a case. To overcome the complications an additional column has been created and is identified in Table 5 as a false X axis. The numbers represent the integer values of the latitude and no distinction has been made between north and south latitudes. The intermediate cells have been left vacant. To generate Graph 7D:

COMMENTS

Graph, Type	= Line	(must be Line format)
X	= A2..A38	(X axis using all latitude data)
A	= D2..D38	(March)
B	= B2..B38	(June)
C	= M2..M38	(December)

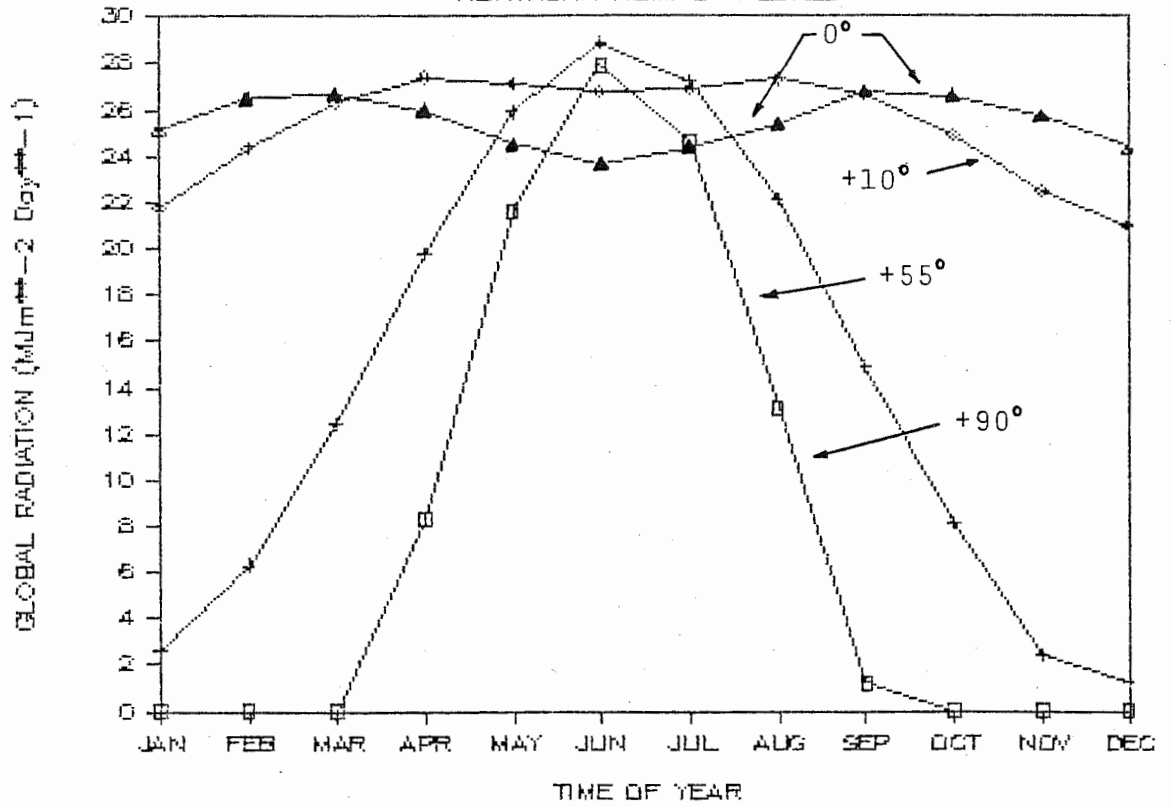
The actual plots of the data (A,B and C) will be satisfactory. However, the X axis, due to the amount of data points, will be subject to information conjection to point where numbers will be written over each other during graph printout. This results in the axis being uninterpretable. At times this problem can be overcome by selecting the XY graph option during compilation. Unfortunately, for this data base, the automatically interpreted axis will range from +100 to -100 which is beyond our data range and is, therefore, also unusable. To overcome this problem, once the graph has been created by the initial commands outlined above:

Return to the X axis, press the enter key and enter the new range N2..N38. Press the enter key and return to the graph menu. The data contained within this column is then substituted for the initial X axis under which the graph was created. Even though this column is incomplete and does not make any sense to the Lotus graphing routines, as the graph is already created and held by the system, it is possible to use this data to label the X axis. The plot is then able to be printed without any distortion of the information on this axis (see Graph 7D).

Continuing graph creation

SEASONAL DIST. GLOBAL RADIATION

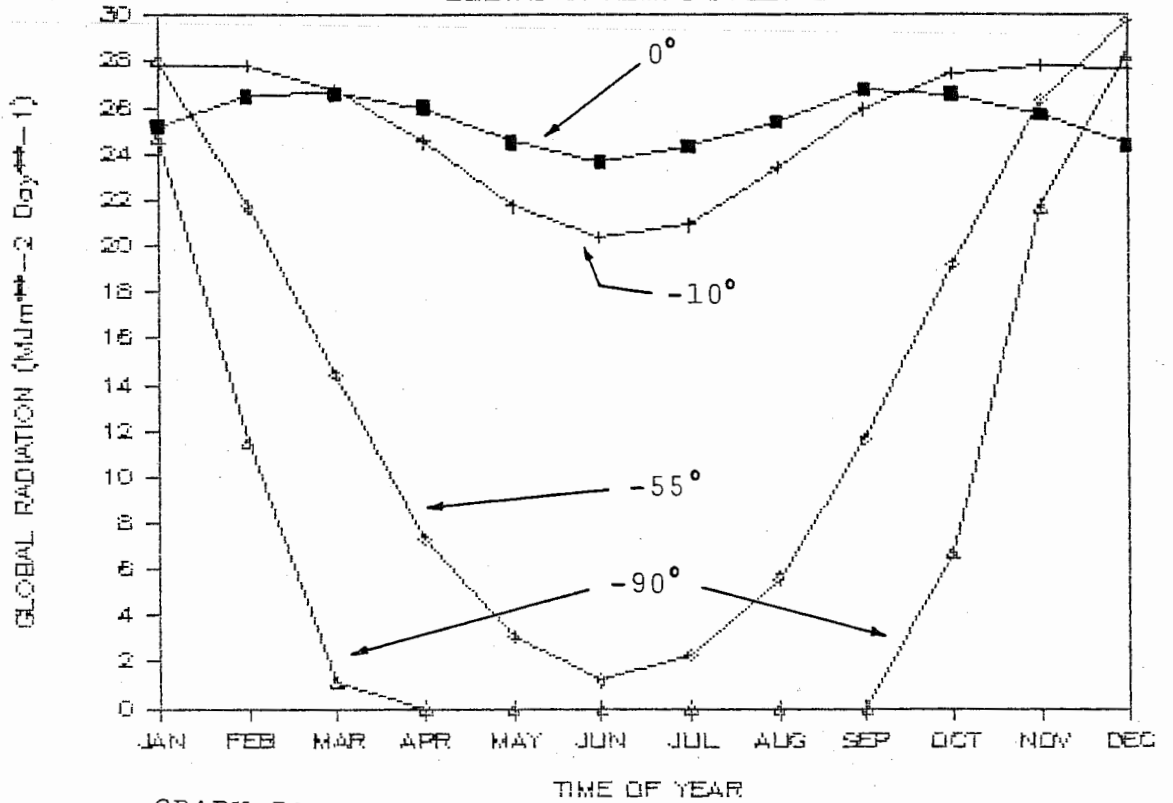
NORTHERN HEM: SEA LEVEL



GRAPH 7B.

SEASONAL DIST. GLOBAL RADIATION

SOUTHERN HEM: SEA LEVEL



GRAPH 7C.

Options, Titles

First = MERIDIONAL DISTRIBUTION OF K↓.

Second = JUNE & DEC.SOLSTICE; MARCH EQUINOX.

X Axis = NORTH bbbb LATITUDE (*10 D.) bbbbbb SOUTH *

Y Axis = GLOBAL RADIATION (MJm**-2 Day**-1)

View

Save = "Filename" (7D)

- * The position available within the system for axis labelling occupies only one line. It is, however, 35 characters in length and the information entered is centered along the abscissa. For this example three elements of information have been entered separated by blanks (identified as b and created by pressing the space bar). The information is then centered automatically and identifies the north and south latitudes which had not been conventionally presented through the use of the negative sign for southern hemisphere data. This further serves to reduce the amount of information that must be placed on the X axis during initial graph creation.

Printgraph (and enter PRINTGRAPH disk upon request)

Select = "Filename" (7D)

Options, Size = FULL

Quit

Quit

Go

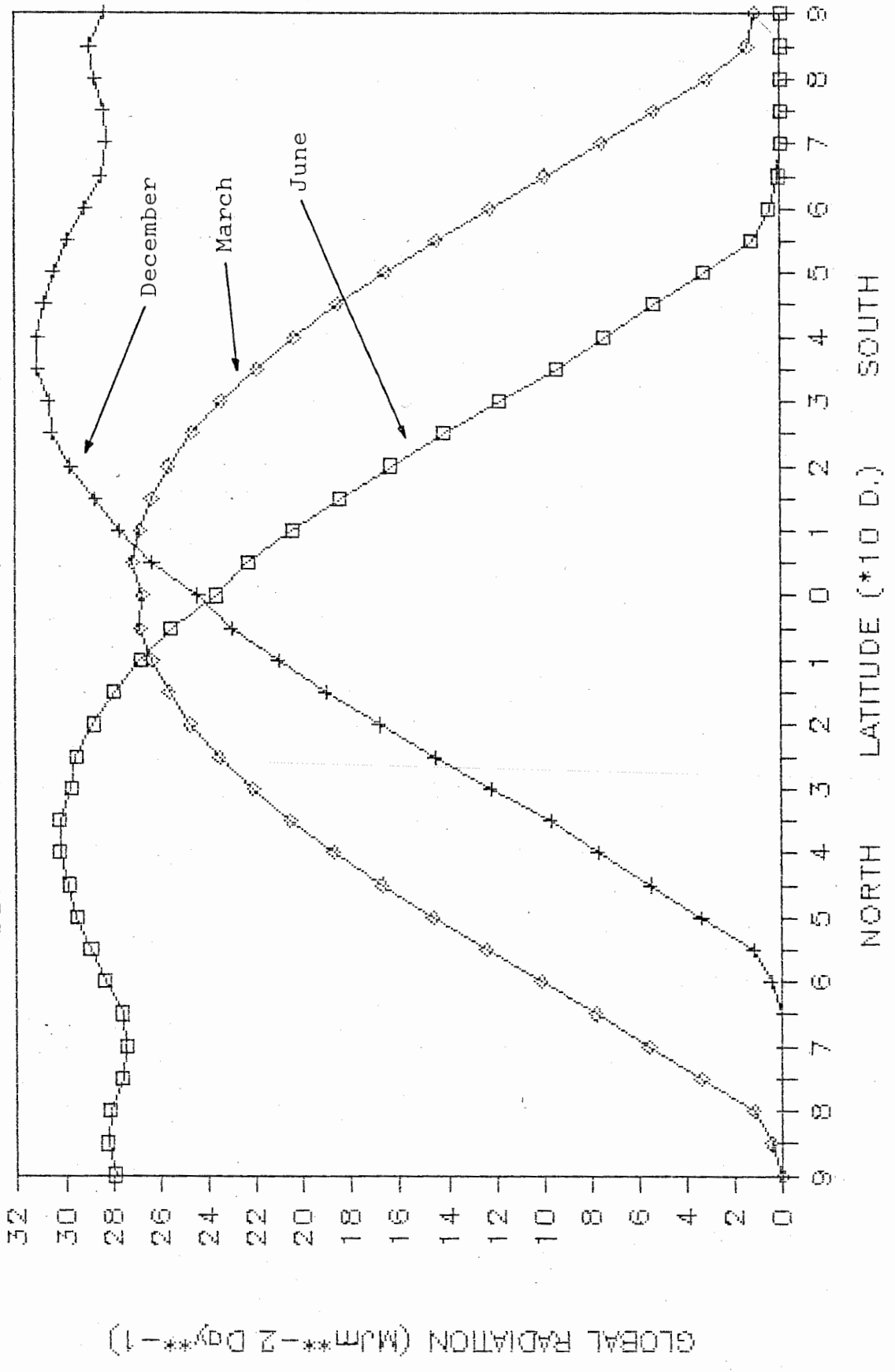
Graph 7D will now be printed.

Graph 7D following page

END OF SECTION 9

MERIDIONAL DISTRIBUTION OF K↓

JUNE & DEC. SOLSTICE; MARCH EQUINOX.



GRAPH 7D.

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APPENDIX

1. SYSTEME INTERNATIONAL UNITS OF MEASUREMENT AND THEIR EQUIVALENTS.

Quantity	SI	C.G.S	British
<u>Basic</u>			
Length	1 m	= 10^2 cm	= 3.281 ft
Mass	1 kg	= 10^3 gm	= 2.205 lb
Time	1 (min,h,day,yr)	= 1 s	= 2.778×10^{-4} h
Temperature	1 Kelvin (1°C)	= 1 K (1°C)	= 1.8°F
<u>Derived</u>			
Area	1m^2	= 10^4cm^2	= 10.76 ft^2
Volume	1m^3	= 10^6cm^3	= 35.31 ft^3
Density	1 kg m^{-3}	= 10^{-3}g cm^{-3}	= $6.243 \times 10^{-2}\text{lb ft}^{-3}$
Velocity	1 m s^{-1}	= 10^2cm s^{-1}	= 3.281 ft s^{-1}
Acceleration	1 m s^{-2}	= 10^2cm s^{-2}	= 3.281 ft s^{-2}
Force	1 kg m s^{-2} = 1 Newton	= 10^5g cm s^{-2} = 10^5 dynes	= 0.225 lbf
Pressure	$1\text{ kg m}^{-1}\text{s}^{-2}$ = 1 Pascal	= $10\text{ g cm}^{-1}\text{s}^{-2}$ = 10^{-2}mb	= 0.021 lbf ft^{-2}
Work,energy	$1\text{ kg m}^2\text{s}^{-2}$ = 1 Joule	= $10^7\text{g cm}^2\text{s}^{-2}$ = 10^7 ergs	= 0.738 ft lbf
Power	$1\text{ kg m}^2\text{s}^{-3}$ = 1 Watt	= $10^7\text{g cm}^2\text{s}^{-3}$ = 10^7 ergs s^{-1}	= 0.738 ft lb f s^{-1}
Heat,energy	1 J (Joule)	= 0.2388 cal	= 9.478×10^{-4} BTU
Heat flux	1 W (Watt)	= 0.2388 cal s^{-1}	= 3.412 BTU h^{-1}
Heat flux density	1 Wm^2	= $2.388 \times 10^{-5}\text{cal cm}^{-2}\text{s}^{-1}$	= 0.317 BTU $\text{ft}^{-2}\text{h}^{-1}$

Prior to the standardization of units, climatologists primarily used the Langley (ly) as a measure of the radiant flux density (irradiance).

$$1\text{ ly} = 1\text{ cal}^{-2}\text{cm}^{-1} = 697.3\text{ Wm}^{-2}$$

(after Oke, 1978, 337)

2. EPHEMERIS OF THE SUN TABLES (adapted from List, 1966)

The declination (γ) of the sun is its angular distance north (+) or south (-) of the equator.

The equation of time (e) (apparent - mean) is the correction to be applied to mean solar time in order to obtain local apparent (true) time (L.A.T.).

The radius vector of the earth is the distance from the center of the earth to the center of the sun expressed in terms of the length of the semimajor axis of the earth's orbit.

The earth/sun correction factor (d/d^2) is the inverse of the orbital radius vector

Date	Dec. o /	Equation of Time o /	Radius Vector	(d/d) ²	Date	Dec. o /	Equation of Time o /	Radius Vector	(d/d) ²
Jan. 1	-23 04	-03 14	0.98324	1.017044	Feb. 1	-17 19	-13 34	0.98533	1.014888
5	-22 42	-05 06	0.98324	1.017044	5	-16 10	-14 02	0.98593	1.014271
9	-22 13	-06 50	0.98333	1.016952	9	-14 55	-14 17	0.98662	1.013561
13	-21 37	-08 27	0.98352	1.016756	13	-13 37	-14 20	0.98738	1.012781
17	-20 54	-09 54	0.98378	1.016487	17	-12 15	-14 10	0.98819	1.011951
21	-20 05	-11 10	0.98410	1.016156	21	-10 50	-13 50	0.98903	1.011092
25	-19 09	-12 14	0.98448	1.015764	25	-09 23	-13 19	0.98991	1.010193
29	-18 08	-13 05	0.98493	1.015300					
Mar. 1	-07 53	-12 38	0.99084	1.009244	Apr. 1	+04 14	-04 12	0.99928	1.000720
5	-06 21	-11 48	0.99182	1.008247	5	+05 46	-03 01	1.00043	0.999570
9	-04 48	-10 51	0.99287	1.007181	9	+07 17	-01 52	1.00160	0.998403
13	-03 14	-09 49	0.99396	1.006076	13	+08 46	-00 47	1.00276	0.997248
17	-01 39	-08 42	0.99508	1.004944	17	+10 12	+00 13	1.00390	0.996115
21	-00 05	-07 32	0.99619	1.003824	21	+11 35	+01 06	1.00500	0.995025
25	+01 30	-06 20	0.99731	1.002697	25	+12 56	+01 53	1.00606	0.993977
29	+03 04	-05 07	0.99843	1.001572	29	+14 13	+02 33	1.00708	0.992970
May 1	+14 50	+02 50	1.00759	0.992467	June 1	+21 57	+02 27	1.01405	0.986145
5	+16 02	+03 17	1.00859	0.991483	5	+22 28	+01 49	1.01465	0.985561
9	+17 09	+03 35	1.00957	0.990520	9	+22 52	+01 06	1.01518	0.985047
13	+18 11	+03 44	1.01051	0.989599	13	+23 10	+00 18	1.01564	0.984601
17	+19 09	+03 44	1.01138	0.988748	17	+23 22	-00 33	1.01602	0.984233
21	+20 02	+03 34	1.01218	0.987967	21	+23 27	-01 25	1.01630	0.983961
25	+20 49	+03 16	1.01291	0.987254	25	+23 25	-02 17	1.01649	0.983778
29	+21 30	+02 51	1.01358	0.986602	29	+23 17	-03 07	1.01662	0.983652
Jul. 1	+23 10	-03 31	1.01667	0.983603	Aug. 1	+18 14	-06 17	1.01494	0.985280
5	+22 52	-04 16	1.01671	0.983564	5	+17 12	-05 59	1.01442	0.985785
9	+22 28	-04 56	1.01669	0.983583	9	+16 06	-05 33	1.01384	0.986349
13	+21 57	-05 30	1.01659	0.983680	13	+14 55	-04 57	1.01318	0.986991
17	+21 21	-05 57	1.01639	0.983874	17	+13 41	-04 12	1.01244	0.987713
21	+20 38	-06 15	1.01610	0.984155	21	+12 23	-03 19	1.01163	0.988503
25	+19 50	-06 24	1.01573	0.984513	25	+11 02	-02 18	1.01076	0.989355
29	+18 57	-06 23	1.01530	0.984930	29	+09 39	-01 10	1.00986	0.990236
Sept. 1	+08 35	-00 15	1.00917	0.990913	Oct. 1	-02 53	+10 01	1.00114	0.998861
5	+07 07	+01 02	1.00822	0.991847	5	-04 26	+11 17	1.00001	0.999999
9	+05 37	+02 22	1.00723	0.992821	9	-05 58	+12 27	0.99888	1.001121
13	+04 06	+03 45	1.00619	0.993848	13	-07 29	+13 30	0.99774	1.002265
17	+02 34	+05 10	1.00510	0.994926	17	-08 58	+14 25	0.99659	1.003422
21	+01 01	+06 35	1.00397	0.996046	21	-10 25	+15 10	0.99544	1.004581
25	-00 32	+08 00	1.00283	0.917178	25	-11 50	+15 46	0.99433	1.005702
29	-02 06	+09 22	1.00170	0.998303	29	-13 12	+16 10	0.99326	1.006785
Nov. 1	-14 11	+16 21	0.99249	1.007567	Dec. 1	-21 41	+11 16	0.98604	1.014158
5	-15 27	+16 23	0.99150	1.008573	5	-22 16	+09 43	0.98546	1.014754
9	-16 38	+16 12	0.99054	1.009550	9	-22 45	+08 01	0.98494	1.015290
13	-17 45	+15 47	0.98960	1.010509	13	-23 06	+06 12	0.98446	1.015785
17	-18 48	+15 10	0.98869	1.011439	17	-23 20	+04 17	0.98405	1.016208
21	-19 45	+14 18	0.98784	1.012310	21	-23 26	+02 19	0.98372	1.016549
25	-20 36	+13 15	0.98706	1.013109	25	-23 25	+00 20	0.98348	1.016797
29	-21 21	+11 59	0.98636	1.013829	29	-23 17	-01 39	0.89334	1.016942

3. ALBEDO OF VARIOUS SURFACES.

The following table has been compiled from a variety of sources: primarily List (1966, 442-443); Sellers (1972, 29); and Oke (1978, 15 and Appendix A2). For details concerning the nature of observation, the type of measurement system and the manner in which the surface albedo can be determined the user should consult these references. The albedo of snow and glacial surfaces has been derived primarily from the Author's field data.

SURFACE	ALBEDO %
Bay	3-4
Bay and river	6-10
Inland Waters	5-10
Ocean	3-7
" , deep	3-5
" , near shore, solar elevation 47 Deg.	4
" , " " , " " 43 "	6
" , " " , " " 20 "	14
" , " " , " " 12 "	30
" , " " , " " 5.5 "	46
Forest, deciduous, bare	15
" , " , leaved	20
" , coniferous	5-15
" , snow covered ground	10-25
Meadows, green	10-20
Chaparral	15-20
Tundra	18-25
Orchards	15-20
Fields, dry, plowed	20-25
" , green	10-15
" , most agricultural crops	15-25
Grass, dry	15-25
" , high (1.0 m.), dry	30-33
" , high (1.0 m.), green	16-26
Soil, dark, dry	5-15
" , light, dry	25-40
" , dark, wet	10-20
" , light, wet	15-30
Sand , light, dry	35-45
" , " , wet	20-30
Snow, fresh ,smooth, high zenith angle	90-95
" , " , " , low zenith angle	79-85
" , old, clean , smooth	60-70
" , " , rough	40-60

Cont'd

ALBEDO OF VARIOUS SURFACES Cont'd.

<u>SURFACE</u>	<u>ALBEDO %</u>
Glacial Ice, alpine, ablation zone, smooth	25-40
" " " " " " , rough	18-25
Glaciers, alpine, ablation zone, winter months	40-70
Glacial firn, alpine, accumulation zone, clean	60-70
" " " " " " , rough & dirty	40-60
Glaciers, alpine, accumulation zone, winter months ...	70-90
Large Ice Sheets (Greenland, Antarctica),	
Central regions	80-95
Superimposed ice zone	50-70
Outer margins	25-40
Glacial moraine and debris, dark	9-14
" " " " " " , light	12-18
Sea ice	30-40
Concrete, dry	17-27
Road top, black	5-10

4. ELEVATION AND PRESSURE RELATIONSHIPS FOR THE U.S. STANDARD ATMOSPHERE *

<u>ELEVATION</u>			<u>ELEVATION</u>		
<u>Meters</u>	<u>Feet</u>	<u>PRESSURE</u>	<u>Meters</u>	<u>Feet</u>	<u>PRESSURE</u>
0	0	1013.25	2600	8532.9	737.32
50	164.1	1007.30	2700	8861.2	728.08
100	328.2	1001.28	2800	9189.4	718.92
150	492.3	995.35	2900	9517.6	709.87
200	656.4	989.44	3000	9845.7	700.90
250	820.5	983.55	3100	10173.9	692.03
300	984.6	977.70	3200	10502.1	683.24
350	1148.7	971.87	3300	10830.3	674.55
400	1312.8	966.08	3400	11158.5	665.94
450	1476.9	960.31	3500	11486.7	657.44
500	1640.9	954.57	3600	11814.9	649.01
550	1805.1	948.86	3700	12143.1	640.67
600	1969.1	943.16	3800	12471.3	632.42
650	2133.2	937.51	3900	12799.4	624.23
700	2297.3	931.88	4000	13127.7	616.18
750	2461.4	926.28	4100	13455.8	608.19
800	2625.5	920.70	4200	13784.0	600.27
850	2789.6	915.15	4300	14112.2	592.45
900	2953.7	909.63	4400	14440.4	584.71
950	3117.8	904.13	4500	14768.6	577.05
1000	3281.9	898.66	4600	15096.8	569.47
1100	3610.1	887.82	4700	15425.0	561.97
1200	3938.3	877.07	4800	15753.2	554.55
1300	4266.4	866.42	4900	16081.4	547.21
1400	4594.7	855.87	5000	16409.6	539.95
1500	4922.9	845.45	5100	16737.8	532.79
1600	5251.1	835.12	5200	17065.9	525.66
1700	5579.3	824.89	5300	17394.2	518.64
1800	5907.4	814.77	5400	17722.3	511.69
1900	6235.6	804.74	5500	18050.5	504.81
2000	6563.8	794.82	5600	18378.7	498.00
2100	6892.0	784.98	5700	18706.9	491.28
2200	7220.2	775.26	5800	19035.1	484.63
2300	7548.4	765.63	5900	19363.3	478.05
2400	7876.6	756.09	6000	19691.5	471.54
2500	8204.8	746.66			

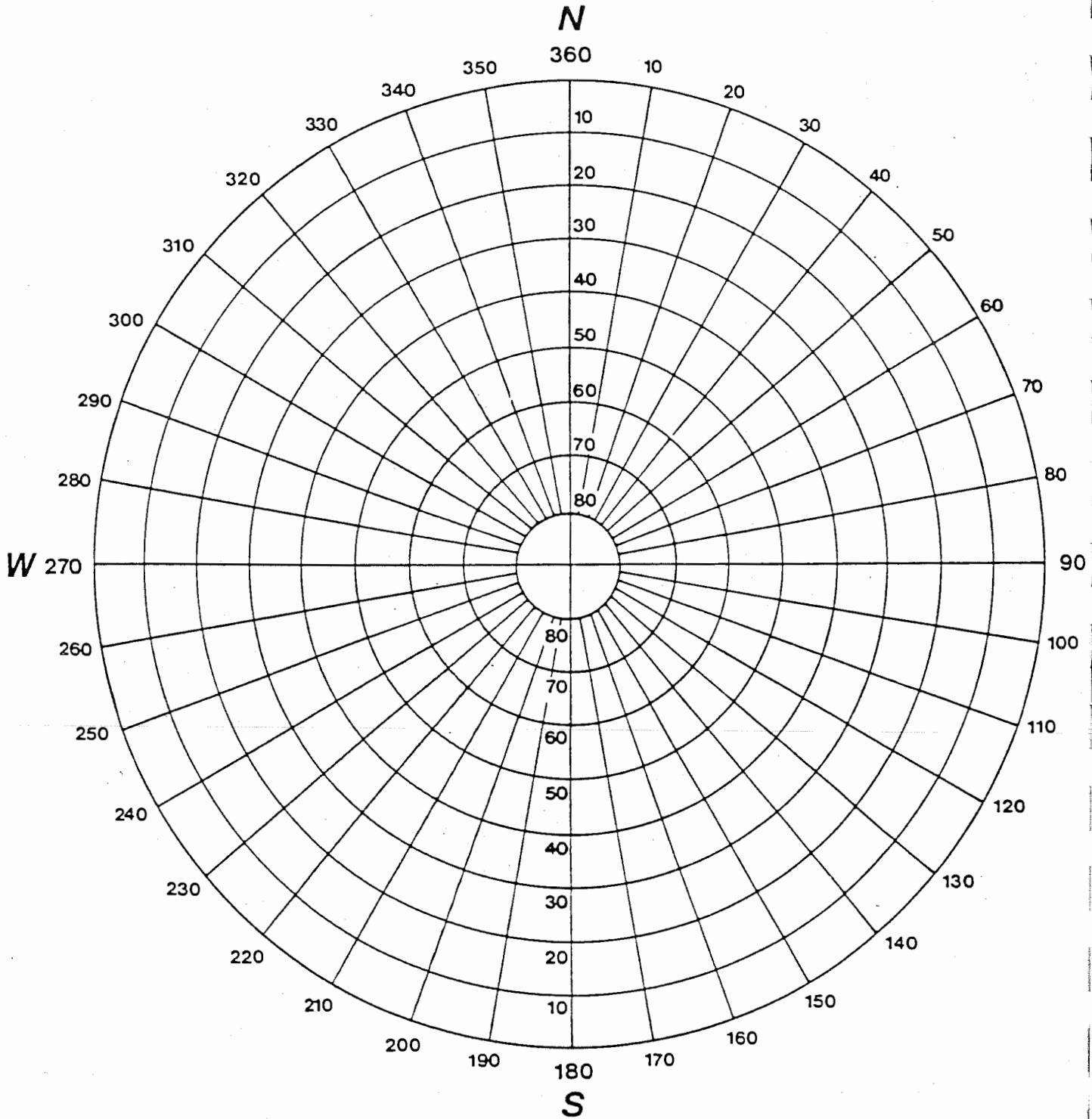
* Derived from Equation 6.3 Page 25.

Pressure Conversion:

Sea level pressure = 1013.25 mb. = 101325 Pa.
 = 76 cm Hg. = 760 mm Hg.
 = 29.92 in Hg.

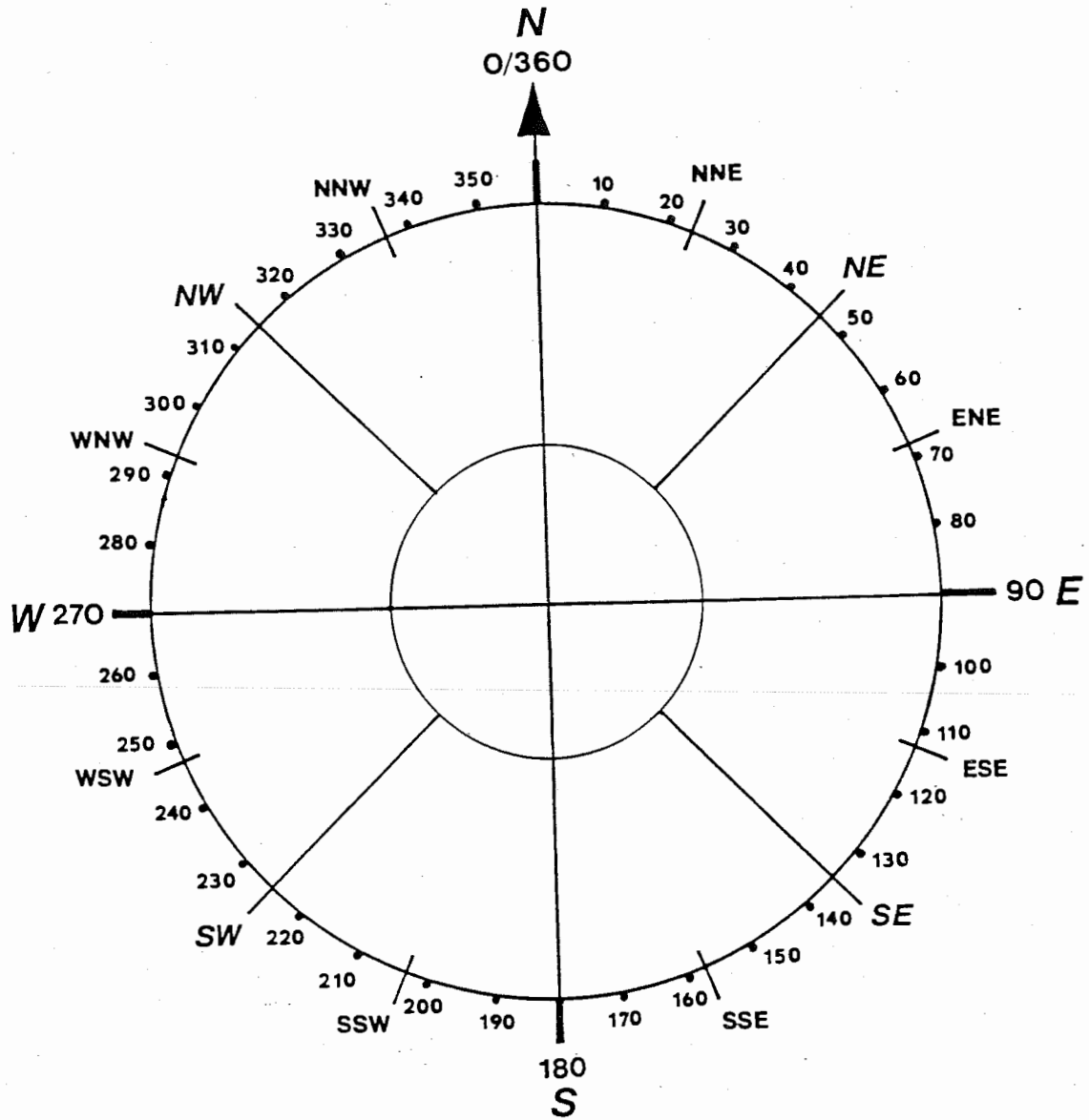
SOLAR PATH DIAGRAM

5.



LOCATION: _____

6. AZIMUTH/COMPASS DIAGRAM.



7. PROGRAM TECHNICAL INFORMATION.

1. The FORTRAN Files.

The solar radiation program has been created under the MS-DOS EDLIN commands and has been edited, compiled and linked using Version 3.30 of the Microsoft FORTRAN series. On the program diskette four files with the prefix SOLAR. can be identified. The basic solar radiation generator has the filename SOLAR.FOR while the others, SOLAR.EXE, SOLAR.OBJ and SOLAR.BAK are files created during the editing, linking and compiling sequence required by the FORTRAN package.

The file SOLAR.EXE is the executable file required to run the model using the commands outlined in Section 8 of this manual. Thus, upon the entry

```
B>Solar
```

it is this file that is activated. If the SOLAR.FOR program is to be modified then new executable and object files will need to be created. Note also, that for a system with 256 K of R.A.M the complete program cannot be accessed without applying the the MS-DOS EDLIN APPEND and WRITE commands. In addition, prior to the compiling process, it may be necessary to purge the disk of all files other than the SOLAR.FOR file to ensure that adequate space is available for the several intermediate files created during the first stage of FORTRAN editing (For1).

The following presents the basic commands required by the FORTRAN package to edit, compile and link the program. Several versions of Microsoft FORTRAN exist and, if the program is to be reedited, it may be necessary to alter some program statements in accordance with the specific requirements of the particular version. Depending upon the FORTRAN package available the following information may be subject to some variation. Generally, however, procedures necessary to initialize and execute this (or any other) program are generally conceptually identical. The fundamental commands necessary to initialize any fortran program can be found in the appropriate FORTRAN manual under the section dealing with the FORTRAN compiler.

Program Initialization.

Microsoft FORTRAN Version 3.30.

The following commands will edit, compile and link the radiation program. The FORTRAN operations as they appear on-screen have been included with appropriate comments and directions. Where the ENTER sign (↵) only appears, no data is required and the user should simply press the enter key. The direction arrows and the entry comments will not appear on the

screen but have been included to guide the user through the required sequence. Note that the following assumes the FORTRAN disk to be in drive A and the program diskette in drive B.

B> a:for1 ← At system prompt, B>, type a:for1 and ↵ .

Microsoft FORTRAN77 V3.30 March 1985
(C) Copyright Microsoft Corp. 1982,1983,1984,1985

Source filename [.FOR]: solar ← Type solar and ↵ .
Object filename [solar.OBJ]:
Source listing [NUL.LST]: ← If program printout is required type PRN and press ↵ .
Object listing [NUL.COD]:

Pass One No Errors Detected
1294 Source Lines

B>a:pas2 ← At system prompt place Pas2 disk in drive A and type a:pas2 For MS FORTRAN V1.1 type a:for2 and ↵ .

Code Area Size = #3B43 (15171)
Cons Area Size = #02C0 (704)
Data Area Size = #708C (28812)

Pass Two No Errors Detected

B>a:Pas3 ← This option can be deleted

B>a:link ← Place linker disk (with LIBRARY files) in drive A and type a:link and ↵ .

Microsoft 8086 Object Linker
Version 3.02 (C) Copyright Microsoft Corp 1983, 1984, 1985

Object Modules [.OBJ]: solar ← Type solar and ↵ .
Run File [SOLAR.EXE]:
List File [NUL.MAP]:
Libraries [.LIB]: a: ← Type a: and ↵ .

B>solar ← Without changing disks at system prompt type SOLAR and ↵ .

Data entry sequence will now begin (see Section 8).

2. The LOTUS 1-2-3- Files.

For Examples 1,2,3, 6 and 7 documented in Section 8 the data base and graphics as entered into and created by the LOTUS 1-2-3 package have been included on the program diskette. Thus there are 10 LOTUS files. In order of entry:

EXAMP1.WKS	GRAPH1.PIC
EXAMP2.WKS	GRAPH2.PIC
EXAMP3.WKS	GRAPH3A.PIC
EXAMP6.WKS	GRAPH6B.PIC
EXAMP7.WKS	GRAPH7B.PIC

The data base is identified by the extension .WKS (worksheet) and the corresponding graphs .PIC (picture). Note that it is necessary to have access to the LOTUS SYSTEMS and PRINTGRAPH routines to access these files.

The generated graphs can only be viewed on-screen if a graphics card exists in the computer and is correctly configured. The necessary procedure is to be found under the section on installing drivers in the LOTUS manual or on pages 34-35 of Le Bond and Cobb. However, if no graphics capacity exists for the system in use, the database for each of the files can be activated and the graphs can be passed directly to almost any dot matrix printer from the PRINTGRAPH stage of the LOTUS procedures. Of course, from the database additional graphs can be generated according to need and the fundamental commands necessary to construct graphs under LOTUS1-2-3- routines are documented in Section 10.

If on-screen viewing is possible then the graph corresponding to each of the data base is simply accessed from the GRAPH/VIEW stage of the LOTUS worksheet routines. The picture will automatically be drawn on the screen.

End of Section 9.

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