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SOME THOUGHTS ON EVALUATING THE DISTRIBUTION OF POTENTIAL EVAPOTRANSPIRATION

by

B. J. GARNIER *

Evapotranspiration is now a well established term in climatological literature. It refers to the return of moisture to the atmosphere from a land surface through the combined processes of evaporation and transpiration. A distinction is commonly made between actual evapotranspiration, which refers to the evapotranspiration taking place under the specific conditions of a given place at a given time, and potential evapotranspiration, which refers - at least loosely speaking - to the evapotranspiration which occurs under the particular condition of water being a non-limiting factor in the process.

When the idea of evapotranspiration is applied to problems of agriculture, water resource, and the like, a water balance approach is often adopted. This involves comparing actual and potential evapotranspiration in some way or other. This in turn involves spatial comparisons, whether by making maps or by making evaluations over a given locality from point data derived from some place in the locality itself or from a more distant source. Clearly, therefore, a rational procedure for evaluating potential evapotranspiration spatially, either in a chorographic sense or in terms of the value at a point which is distant from a given point of observation, is as important as is its calculation or measurement at points of observation or the evaluation

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of its variation in time.

The evapotranspiration which actually occurs from the earth's surface at a given place is a function of five major factors. The relationship can be expressed in the following way:

$$E_v = f(R_e, A_t, S_r, o, m) \qquad (1)$$

where R_e, roughly speaking the net radiation, is the energy available at the spot, A_t is the ease with which water is carried away from the surface through atmospheric turbulence, S_r is the surface resistance due to the stomatal characteristics of the plant leaves, o is the so-called "oasis effect" which may add an energy source or drier air, and m is the moisture situation expressed particularly in the water supply. The last two of these factors, namely o and m, are modifying influences which become constants so far as potential evapotranspiration is concerned. Accordingly for potential evapotranspiration to occur, water must be non-limiting and the oasis effect absent. We thus have,

$$E_p = f(R_e, A_t, S_r)\ o, m \qquad (2)$$

as an equation to express the nature of potential evapotranspiration.

This concept, which is probably how Thornthwaite (Thornthwaite, 1948) originally thought of potential evapotranspiration although he does not seem to have expressed it in this way, is in many ways theoretical and does not conform to some current definitions of the term. In particular, the idea of E_p is often related to a particular plant covering usually short grass freely transpiring (Penman, 1948). Under such conditions the factor S_r must be taken out of the bracket in equation (2), which could then be written for, say, grass in the form

$$E_{pg} = f(R_e, A_t)_{S_{rg},} \quad o,m. \tag{3}$$

and in similar form for forest, or corn or mangrove swamp.

For universal applicability, however, the form as in equation (2) is to be preferred to equation (3). The former concept means that the variables involved in potential evapotranspiration become manageable in terms of surface, radiation and weather characteristics. This not only provides a sound physical basis for evaluating the variation of potential evapotranspiration from place to place but also offers a rational procedure for calculating the value of the term itself. Most formulae for calculating potential evapotranspiration include temperature and humidity conditions in some way or other. However, since these temperature/humidity conditions are a result and not a cause of evapotranspiration, such elements can only be used to calculate potential evapotranspiration if based on measurements where potential evapotranspiration is, in fact, taking place. Hence, the necessity for empirical adjustments in E_p formulae using "commonly available meteorological data".

It is not, however, the purpose of this disucssion to consider critically methods of evaluating potential evapotranspiration. The aim is to examine the concept expressed in equation (2) to see if this offers a rational approach to evaluating the distribution of potential evapotranspiration. Present methods for doing this seem to need re-examining. They are largely based on interpolating from the calculations of E_p at different points and, therefore, in the absence of an unrealistically dense net work of observation points, necessarily ignore the important variations due to nature's topographic variety. The latter can, however, be readily observed from maps and air photographs, and once this is made clear provides a more or less permanent foundation on which to work. Can we, then, use this foundation to indicate directions in which research might go to achieve the goal of a rational method for evaluating the distribution of potential evapotranspiration?

In equation (2), the energy factor can be expressed as

$$R_e = R_n - G$$

where R_n is net radiation and G is the heat flux into (or out of) the ground. The latter is usually small over time periods of a day or longer and, in the present context, becomes even more manageable since we are dealing with a fully moist condition. Thus, the large variable in this term is R_n.

Recent work at McGill University has shown how topographic variations in net short-wave radiation income can be evaluated from the observation of a single, representative site (Garnier and Ohmura, 1968, 1970). An essential requirement for this is to have observations of global and sky diffuse radiation which can then be fed into a basic formulae explained elsewhere (Garnier and Ohmura, 1970). This formula is used in conjunction with a map grid, made sufficiently fine for the area being studied, which gives the gradient, azimuth, and albedo at each intersection of the grid. Testing shows the resulting map of topographic variation in net short-wave radiation income to be accurate to $\pm 5\%$ in most circumstances, with an extreme accuracy limit of about $\pm 15\%$. The next step in the present context is to see if such a map can be used as a basis for evaluating R_n.

Work already done by John Davies (Davies, 1967), has pointed the way to how this might be achieved. He has shown that a good statistical relationship over periods of ten days or more exists between short-wave radiation and the daytime net radiation balance, which is the important element in evapotranspiration. It is now a question of examining this relationship more closely and seeing how it operates in respect to sloping surfaces. If reliability in this can be achieved, then the R_e term necessary to solving equation (2) presents no major problem.

The two terms A_t and S_r should also be capable of evaluation from basic principles in much the same way as R_e. The aim would be to calculate turbulence, A_t, as a product of surface character and wind speed, and surface resistance, S_r, in terms of plant covering.

Under neutral conditions and with a constant Z_o, A_t is already known as a linear function of wind speed (Sziecz, Emdrodi, and Tajchman, 1969). It is to be hoped that the vigourous work now proceeding in the aerodynamic field will provide a basis for a sufficiently accurate evaluation of A_t for different plant coverings and air flows, for this term to be given a meaning which can then be included in equation (2) for a particular surface by using the wind speed information available from standard weather maps. Similarly, since we are dealing always with a fully transpiring surface, it ought to be possible to interpret S_r as a factor which is related solely to the nature of the plant covering.

If the objectives outlined can be achieved in this way, a powerful tool of applied meteorology will have been discovered. The concept of potential evapotranspiration as expressed in equation (2) provides a base from which to work in many water resource and utilization problems. Ways already exist of evaluating actual evapotranspiration by reference to E_p and rainfall or in a more accurate way if necessary by reference to a combination formula such as suggested by Tanner and Fuchs (1968). Much of the weakness in the work to date lies in the unreliable nature of the spatial distribution evaluation for E_p. However accurate the calculation or measurement of this at a point may be, the resulting interpolation over area is only as accurate as the basis of the interpolation. Usually this basis is weak since it neglects the intervening surface variation. The approach suggested here is a way to help rectify this.

To achieve it will require a good deal of research. In particular, it will be necessary to examine carefully how E_p behaves in relation to the variables of equation (2) as well as to investigate fully the basis for evaluating these variables. One should, however, always be conscious of the accuracies and time scales needed in water resource work. These are not necessarily as fine as in the physics laboratory or as in the study of the development of thermals due to ground heating. Time periods of a few days or longer are used for irrigation and an accuracy sufficient to maintain water availability to the plant is all that is required. Even cruder estimates will probably do for many hydrological investigations.

Given this context, the approach suggested here could well operate with the required accuracy on a coarser network of stations than is at present required for work using temperature and humidity as the basis of evaluation. Moreover, the radiation/weather/surface approach is also physically sounder than many methods at present used. Research, too, can be concentrated in limited localities, with the obvious advantage of thus being able to operate sophisticated equipment with highly trained people, instead of spreading the resources thinly over many places. If the results are then incorporated into procedures which fundamentally use only radiation, surface character, and the weather to evaluate potential evapotranspiration, the applications could be both widespread and fruitful.

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A COMPUTER PROGRAMME FOR DETERMINING DIRECT SHORT-WAVE RADIATION INCOME ON SLOPES

by

R. F. FUGGLE *

Computer programmes for determining direct short-wave radiation income on slopes have been presented by Ohmura (1969), and by Garnier and Ohmura (1969). Recent applications of these programmes have revealed minor errors, as well as several inconveniences to users. The programmes accompanying this note attempt to rectify these points while adhering closely to the original versions. The programmes are written in Fortran IV.

The most significant change from the previously published programmes is in the determination of the optical air mass when the sun is within twenty degrees of the horizon. As originally written the programmes inadvertently maintained a value of 2.90 for the optical air mass throughout this range. As a result there was overestimation of radiation totals at low sun altitudes, particularly with a high atmospheric transmission coefficient. In the tropics steep (30° or more) east and west-facing slopes were in error by as much as 20 $lys.day^{-1}$ with an atmospheric transmission coefficient of 0.70. At 85° latitude an overestimation of up to 10 langleys per day occurred at the summer solstice for an atmospheric transmission of 0.60. By allowing the air mass value to vary between 2.90 (at 70°) and 30.0 (at 90°) the present programmes remove the overestimation of direct solar radiation

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that was occurring at low sun elevations.

Two further corrections were found to be necessary. Firstly, the specification of the initial hour angle and the increments of azimuth, gradient and hour angle in the original programmes were not sufficiently precise to avoid small but cumulative rounding errors. This source of error has been removed by a more exact presentation of the variables concerned. Secondly, a small error resulting from a change in the value of the sun's hour angle between two parts of the same calculation has been removed.

In an attempt to improve user convenience the following changes have been implemented:

a) The appropriate value of the intensity of extra-terrestrial radiation is now selected by the programme, thus eliminating the need to refer to a solar ephemeris. For this purpose a mean value of 2.00 $cal.cm.^{-2}mi.^{-1}$ for the solar constant is accepted, and the variation produced by changes in the Earth's radius vector thus lies between 1.94 and 2.07 $cal.cm.^{-2}min.^{-1}$

b) The programmes now require a selection card to be read for each table of values printed. Any number of selection cards may be used. This procedure allows the user to obtain results for a single situation, or for as many situations as required; unwanted results are no longer automatically produced.

c) As most persons are more familiar with latitude and solar declination expressed in degrees as opposed to radians, input may now be given in degrees, and decimal part thereof. e.g. $23^{o}30' = 23.5^{o}$. Experience has indicated that latitude and solar declination need only be expressed to the first decimal place in order to avoid errors exceeding 0.5 langleys per day. Atmospheric transmissivity, however, must be accurately specified to at least two decimal places as an error in the second decimal will give errors up to 5 langleys per day. The accuracy of the results obtained from the programmes presented is, therefore, strongly dependent on the accuracy of the coefficient of atmospheric transmissivity.

The two programmes illustrated here, and placed at the end of this article for convenient reference, are basically similar. The first produces a table of daily totals of direct solar radiation on slopes with gradients between 0 and 90^{o} and with azimuths between 0^{o}(North) and 180^{o}(South).

Azimuth values between 180^{o} and 360^{o} are not required when dealing with daily totals as the values are symmetrical to those between 180^{o} and 0^{o}. The second programme produces an hour by hour listing of the direct solar radiation on a slope of given gradient and azimuth.

PROGRAMME DESCRIPTIONS

The programmes listed are self-contained main programmes and require no subroutines.

Input. One card is read by the programme per selection and the programme terminates when selection cards are exhausted. There is no limit to the number of selection cards that may be used. The selection card is required in order to specify the latitude, solar declination and atmospheric transmissivity to be used in the computation; in the second programme, the actual gradient and azimuth of the slope under consideration must also be supplied.

Columns	Contents	Example
1 - 6	Latitude. Latitudes south of the equator are denoted by a negative value. The keypunched value should have a decimal point.	- 23.50
7 - 12	Solar declination. Declinations south of the equator are denoted by a negative value. The key-punched value should have a decimal point.	023.50
13 - 16	Atmospheric transmissivity. A decimal point should be punched.	0.75
For programme two only.		
17 - 21	Slope Azimuth. Values between 0 and 360^{o} are permissible. 0=N, 90=E, 180=S, 270=W, 360=N. A decimal point should be punched.	090.0
22 - 26	Slope Gradients. Values between 0 and 90^{o} are permissible. A decimal point should be punched.	030.0

Data Cards: No data cards are required.

Deck Setup: Selection cards are placed immediately following the main programme.

Output: Programme 1: Output listing includes latitude, solar declination, and atmospheric transmissivity, as read from the selection card. This is followed by a table giving the daily total of direct solar radiation for values of slope azimuth (0 to 180^o) and slope gradient (0 to 90^o) at ten degree intervals.

Programme 2: The values read from the selection card are listed. A three column tabulation follows, giving the solar time, direct solar radiation falling on the slope during the proceeding hour, and the total direct solar radiation received.

Programme Modification: A different format may be employed for the selection cards by altering the format statement concerned.

Should integration for periods other than twenty minute intervals be desired adjustments must be made to the statement in which the hour angle is incremented, and to the constant in the statement determining the radiation value (20.0 in the present programmes). It should be stressed that a twenty minute increment has been utilised as this reduces the execution time of the programme to one tenth of the time required by one minute integration without sacrificing accuracy.

Under present constraints the programmes perform integration over a sixteen hour period. In instances where the sun is above the horizon for more than sixteen hours per day modification of three statements is required: the initial setting of the hour angle, and the two checks that terminate looping of the programme. In the listed programmes the initial hour angle is set at 0340 hours, causing the first calculation to be performed at 0400 hours (i.e. 0340 + 20 mins.)

Looping is terminated when the hour angle exceeds 2000 hours.

Error Messages

Should solar declination inadvertently be given a value exceeding 23.5^{o} the selection will be skipped and the following message will be printed: "Selection skipped because of unallowable declination".

Operating Instructions

No special instructions are required for use of the programmes on an IBM 360 system. Data set 5 is used for input and data set 6 for output. No scratch tapes are required.

Timing

Execution time for programme 1 using one selection card is 36 secs. employing an IBM 360 model 75 with an IBM 2501 card reader as input, and an IBM 1403 as output. Execution time for programme 2, with one selection card, is 30 secs., using the same equipment as for programme 1.

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Programme One

```
C THIS PROGRAM WILL CALCULATE THE DAILY TOTAL OF DIRECT SOLAR RADIATION
C.............................................................................
C PARAMETERS:
C           F  : LATITUDE, IN DEGREES. SOUTH NEGATIVE.
C           FO : ANGLE OF DECLINATION OF THE SUN IN DEGREES. SOUTH NEGATIVE.
C           G  : ATMOSPHERIC TRANSMISIVITY, GIVEN AS A DECIMAL.
C
C REMARKS:  1) THIS PROGRAM PRINTS A TABLE OF VALUES WITH SLOPE AND AZIMUTH
C              IN TEN DEGREE INCREMENTS.
C           2) VALUES FOR THE SOLAR CONSTANT ARE SELECTED BY THE PROGRAM.
C
C USAGE:       THIS IS A MAIN PROGRAM AND REQUIRES NO SUBROUTINES.
C
C METHOD:      DESCRIBED IN GARNIER,B.J. AND A. OHMURA,"A METHOD OF CALCULATING
C              THE DIRECT SHORTWAVE RADIATION INCOME OF SLOPES", JOURNAL OF
C              APPLIED METEOROLOGY, VOL. 11, 1968.
C.............................................................................
C
      DIMENSION Q(19), IQ(19)
C READ SPECIFICATION CARD (ANGLES IN DEGREES). FORMAT IS (2F6.0,F4.0)
   99 READ(5,100,END=7)F,FO,G
C HEAD PRINT OUT TABLE
      WRITE(6,101) F,FO,G,(I,I=10,180,10)
C CONVERT DEGREES TO RADIANS FOR CALCULATION
      F=F*1745.3E-5
      FO=FO*1745.3E-5
C ESTABLISH SINES
      SF=SIN(F)
      SFO=SIN(FO)
C ESTABLISH COSINES
      CF=COS(F)
      CFO=COS(FO)
C SELECTION OF SOLAR CONSTANT.
      IF(FO.GT.0.411 ) GO TO 6
      IF(FO.LE.0.411 ) SOL=1.94
      IF(FO.LT.0.341 ) SOL=1.97
      IF(FO.LT.0.205 ) SOL=1.99
      IF(FO.LT.0.068 ) SOL=2.02
      IF(FO.LT.-0.068) SOL=2.04
      IF(FO.LT.-0.205) SOL=2.06
      IF(FO.LT.-0.341) SOL=2.07
      IF(FO.LT.-0.411) GO TO 6
C INITIATE VALUES.
      IB=0
      B=0.0
    1 A=0.0
      DO 4 I=1,19
      Q(I)=0.0
      X=-COS(A)*SIN(B)
      Y=SIN(B)*SIN(A)
      Z=COS(B)
      T1=(X*SF+Z*CF)*CFO
      T2=(-X*CF+Z*SF)*SFO
C SET HOUR ANGLE TO 0340 HOURS.
      W=-2181.67E-3
C INCREMENT HOUR ANGLE BY 20 MINUTES
    2 W=W+8726.5E-5
C CHECK WHETHER HOUR ANGLE EXCEEDS 2000 HOURS.
      IF(W.GT.2.1) GO TO 4
C DETERMINE COSINE OF SUNS ZENITH ANGLE.
      QO=CFO*CF*COS(W)+SFO*SF
C DETERMINE COSINE OF ANGLE BETWEEN SOLAR BEAM AND NORMAL TO THE SLOPE.
      Q2=-Y*SIN(W)*CFO+T1*COS(W)
      QT=Q2+T2
C CHECK WHETHER SUN IS ABOVE HORIZON
      IF(QO.LE.0.0) GO TO 2
C CHECK WHETHER SLOPE IS IN SHADOW
      IF(QT.LE.0.0) GO TO 2
```

```
C DETERMINE OPTICAL AIR MASS, SECANT APROXIMATION (0 TO 70 DEGREES)
      Q1=1.0/CO
      IF(Q1.LT.2.9) GO TO 3
C..............................................................................
C DETERMINE OPTICAL AIR MASS FOR 70 TO 90 DEGREES. (SMITHSONIAN TABLES).
      IF(Q1.GE.114.6) QQ=30.00
      IF(Q1.LT.114.6) QQ=26.96
      IF(Q1.LT.38.20) QQ=19.79
      IF(Q1.LT.22.93) QQ=15.36
      IF(Q1.LT.16.38) QQ=12.44
      IF(Q1.LT.12.74) QQ=10.39
      IF(Q1.LT.10.43) QQ= 8.90
      IF(Q1.LT. 8.84) QQ= 7.77
      IF(Q1.LT. 7.66) QQ= 6.88
      IF(Q1.LT. 6.76) QQ= 6.18
      IF(Q1.LT. 6.06) QQ= 5.60
      IF(Q1.LT. 5.49) QQ= 5.12
      IF(Q1.LT. 5.02) QQ= 4.72
      IF(Q1.LT. 4.62) QQ= 4.37
      IF(Q1.LT. 4.28) QQ= 4.07
      IF(Q1.LT. 3.99) QQ= 3.82
      IF(Q1.LT. 3.74) QQ= 3.59
      IF(Q1.LT. 3.52) QQ= 3.39
      IF(Q1.LT. 3.33) QQ= 3.21
      IF(Q1.LT. 3.15) QQ= 3.05
      IF(Q1.LT. 2.99) QQ= 2.90
      Q1=QQ
C..............................................................................
C COMPUTE TWENTY MINUTE RADIATION VALUES AND ADD TO TOTAL.
    3 Q(I)=Q(I)+20.0*SOL*(G**Q1)*CT
C CHECK WHETHER HOUR ANGLE HAS REACHED 2000 HOURS.
      IF(W.LT.2.1) GO TO 2
C INCREMENT AZIMUTH BY 10 DEGREES, CONVERT TO RADIANS.
    4 A=A+1745.3E-4
C ROUND OFF TOTAL RADIATION TO NEAREST WHOLE NUMBER, AND PRINT RESULT.
      DO 5 M=1,19
    5 IQ(M)=Q(M)+0.5
      WRITE(6,102)IB,IQ
C INCREMENT SLOPE ANGLE BY 10 DEGREES, CONVERT TO RADIANS.
      IB=IB+10
      B=B+1745.3E-4
C CHECK SLOPE ANGLE DOES NOT EXCEED 90 DEGREES.
      IF(B.LT.1.6) GO TO 1
      GO TO 99
    6 WRITE(6,104)
      GO TO 99
    7 WRITE(6,103)
      STOP
C..............................................................................
  100 FORMAT(2F6.0,F4.0)
  101 FORMAT(1H1/50X,'TABLE OF DIRECT RADIATION ON SLOPES'//21X,
     1'LATITUDE',F9.2,20X,'DECLINATION',F9.2,20X,'TRANSMISIVITY',F7.2///
     29H ANGLE OF50X,'AZIMUTH OF SLOPE',/12H SLOPE      018I6/)
  102 FORMAT(1H ,I5,19I6)
  103 FORMAT(1H1)
  104 FORMAT(55H0SELECTION SKIPPED BECAUSE OF UNALLOWABLE DECLINATION  )
C..............................................................................
      END
```

Programme Two

```
C THIS PROGRAM WILL CALCULATE AND PRINT THE HOUR BY HOUR CONTRIBUTION
C OF DIRECT SOLAR RADIATION ON A SLOPE. A RUNNING TOTAL IS MAINTAINED.
C.............................................................................
C PARAMETERS:
C              F  : LATITUDE, IN DEGREES. SOUTH NEGATIVE.
C              FO : ANGLE OF DECLINATION OF THE SUN IN DEGREES. SOUTH NEGATIVE.
C              G  : ATMOSPHERIC TRANSMISIVITY, GIVEN AS A DECIMAL.
C              A  : AZIMUTH OF SLOPE, 0 TO 360 DEGREES. 0=N,90=E,180=S,270=W.
C              B  : GRADIENT OF SLOPE, 0 TO 90 DEGREES.
C
C USAGE:     THIS IS A MAIN PROGRAM AND REQUIRES NO SUBROUTINES.
C
C METHOD:        DESCRIBED IN GARNIER,B.J. AND A. OHMURA,"A METHOD OF CALCULATING
C                THE DIRECT SHORTWAVE RADIATION INCOME OF SLOPES", JOURNAL OF
C                APPLIED METEOROLOGY, VOL. 11, 1968.
C.............................................................................
C
C READ SPECIFICATION CARD (ANGLES IN DEGREES). FORMAT IS (2F6.0,F4.0,2F5.0)
   99 READ(5,100,END=5)F,FO,G,A,B
C HEAD PRINT OUT TABLE
      WRITE(6,101)F,FO,G,A,B
C CONVERT DEGREES TO RADIANS FOR CALCULATION
      F=F*1745.3E-5
      FO=FO*1745.3E-5
      A=A*1745.3E-5
      B=B*1745.3E-5
C ESTABLISH SINES
      SF=SIN(F)
      SFO=SIN(FO)
C ESTABLISH COSINES
      CF=COS(F)
      CFO=COS(FO)
C SELECTION OF SOLAR CONSTANT.
      IF(FO.GT.0.411 ) GO TO 4
      IF(FO.LE.0.411 ) SOL=1.94
      IF(FO.LT.0.341 ) SOL=1.97
      IF(FO.LT.0.205 ) SOL=1.99
      IF(FO.LT.0.068 ) SOL=2.02
      IF(FO.LT.-0.068) SOL=2.04
      IF(FO.LT.-0.205) SOL=2.06
      IF(FO.LT.-0.341) SOL=2.07
      IF(FO.LT.-0.411) GO TO 4
C INITIATE VALUES
      Q=0.0
      SQ=0.0
      ICOUNT=0
      X=-COS(A)*SIN(B)
      Y=SIN(B)*SIN(A)
      Z=COS(B)
      T1=(X*SF+Z*CF)*CFO
      T2=(-X*CF+Z*SF)*SFO
C SET HOUR ANGLE TO 0340 HOURS.
      W=-2181.67E-3
C SET HOUR ANGLE AT WHICH FIRST VALUE WILL BE PRINTED.
      ITIME =0500
C INCREMENT HOUR ANGLE BY 20 MINUTES
    1 W=W+8726.5E-5
      ICOUNT=ICOUNT+1
C DETERMINE COSINE OF SUNS ZENITH ANGLE AND TEST WHETHER SUN IS ABOVE HORIZON.
      QD=CFO*CF*COS(W)+SFO*SF
      IF(QD.LE.0.0) GO TO 3
C DETERMINE COSINE OF ANGLE BETWEEN THE SOLAR BEAM AND THE NORMAL TO THE SLOPE.
      Q2=-Y*SIN(W)*CFO+T1*COS(W)
      QT=Q2+T2
```

```
C CHECK THAT SLOPE IS NOT IN SHADOW.
      IF(QT.LE.0.0) GO TO 3
C DETERMINE OPTICAL AIR MASS, SECANT APROXIMATION (0 TO 70 DEGREES)
      Q1=ABS(1.0/(QD+1.0E-12))
      IF(Q1.LT.2.9) GO TO 2
C.....................................................................................
C DETERMINE OPTICAL AIR MASS FOR 70 TO 90 DEGREES. (SMITHSONIAN TABLES).
      IF(Q1.GE.114.6) QQ=30.00
      IF(Q1.LT.114.6) QQ=26.96
      IF(Q1.LT.38.20) QQ=19.79
      IF(Q1.LT.22.93) QQ=15.36
      IF(Q1.LT.16.38) QQ=12.44
      IF(Q1.LT.12.74) QQ=10.39
      IF(Q1.LT.10.43) QQ= 8.90
      IF(Q1.LT. 8.84) QQ= 7.77
      IF(Q1.LT. 7.66) QQ= 6.88
      IF(Q1.LT. 6.76) QQ= 6.18
      IF(Q1.LT. 6.06) QQ= 5.60
      IF(Q1.LT. 5.49) QQ= 5.12
      IF(Q1.LT. 5.02) QQ= 4.72
      IF(Q1.LT. 4.62) QQ= 4.37
      IF(Q1.LT. 4.28) QQ= 4.07
      IF(Q1.LT. 3.99) QQ= 3.82
      IF(Q1.LT. 3.74) QQ= 3.59
      IF(Q1.LT. 3.52) QQ= 3.39
      IF(Q1.LT. 3.33) QQ= 3.21
      IF(Q1.LT. 3.15) QQ= 3.05
      IF(Q1.LT. 2.99) QQ= 2.90
      Q1=QQ
C.....................................................................................
C
C DETERMINE TWENTY MINUTE VALUE AND ADD TO TOTAL.
    2 Q=Q+20.0*SOL*(G**Q1)*QT
C SET NEGATIVE VALUES EQUAL TO ZERO
      IF(Q.LT.0.0) Q=0.0
C PRINT VALUES EVERY HOUR.
    3 IF(ICOUNT.NE.3) GO TO 1
      SQ=SQ+Q
      WRITE(6,102) ITIME,Q,SQ
      Q=0.0
      ICOUNT=0
      ITIME=ITIME+100
      IF(ITIME.LE.2000) GO TO 1
      GO TO 99
    4 WRITE(6,104)
      GO TO 99
    5 WRITE(6,103)
      STOP
C.....................................................................................
  100 FORMAT(2F6.0,F4.0,2F5.0)
  101 FORMAT(1H1/45X,'HOURLY CONTRIBUTION OF SOLAR RADIATION ON SLOPES'/
     11/10X,'LATITUDE',F7.2,10X,'DECLINATION',F7.2,10X,'TRANSMISIVITY',
     2F6.2,10X,'AZIMUTH',F7.2,10X,'ANGLE',F6.2///35X,'HOUR',25X,'VALUE',
     325X,'TOTAL'/)
  102 FORMAT(1H ,34X,I4,24X,F6.1,24X,F6.1)
  103 FORMAT(1H1)
  104 FORMAT(55H0SELECTION SKIPPED BECAUSE OF UNALLOWABLE DECLINATION
C.....................................................................................
      END
```

NOTE: Card decks for each of these programmes may be obtained for $5 each programme or $8 the pair. Please send orders to Department of Geography (Climatology), McGill University, Montreal 110, P.Q., Canada.

THE INFLUENCE OF THE SKY-LINE ON THE INCIDENCE OF DIRECT SHORT-WAVE RADIATION

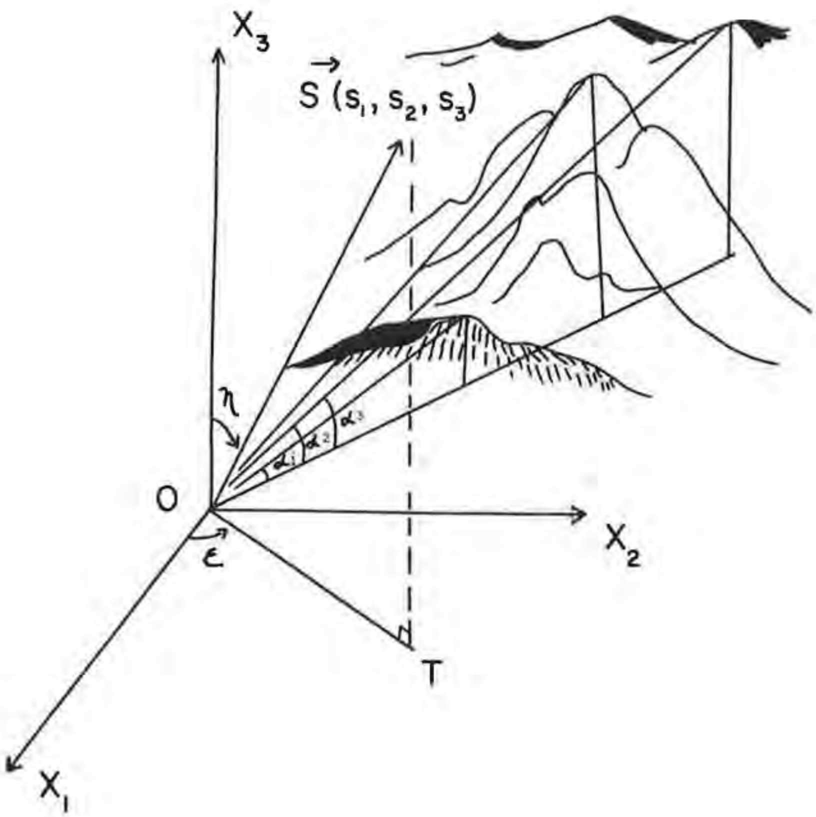
BY

ATSUMU OHMURA

When the sun is at a low altitude, it is evident that high obstacles such as mountains and buildings will cast shadows, causing a decrease in the incidence of direct short-wave radiation. Such obstructions are called "sky-line disturbances". The effect of a sky-line disturbance is related to the position of the sun, the angular height of the sky-line measured from the site and the three-dimensional orientation of the slope at the site. This effect is extremely small in lower latitudes and is also negligible in middle latitudes in summer. However, in mid-latitude winters and in high latitudes (over 60^{o}) at all seasons, sky-line disturbances may appreciably influence the amount of direct short-wave radiation falling on a slope, and their effect needs to be taken into account in many calculations (Garnier and Ohmura, 1968).

Previous attempts to devise methods to allow for the influence of sky-line disturbance include those of Garnett (1935), Asai (1951) and Ozawa (1962). Garnett tried to solve the problem by drawing many cross-sections on topographic maps, along which the solar beam would pass. This solution was restricted to a few individual cases by the great labour involved. Asai attempted to map the distribution of direct radiation by making a model of the topography with no vertical exaggeration of the relief, while Ozawa devised an instrument with which he measured the times of local sunrise and sunset in the field.

In the present article a method is proposed which describes the relations between local time, azimuth and the altitude of the sun, and then




```
          SINSIG=SCRT(1.0-GC**2)
          DUMO=CGS(FO)*SIN(F)*COS(W)-SIN(FO)*COS(F)
          AZI=DUMC/SINSIG
          SIMO=AZI*DUMO
          IF(SIMO) 801, 802, 802
      801 AZI=-1.0*AZI
      802 K=1
          IF(AZI.GT.-0.70) K=2
          IF(AZI.GT.-0.57) K=3
          IF(AZI.GT.-0.42) K=4
          IF(AZI.GT.-0.26) K=5
          IF(AZI.GT.-0.08) K=6
          IF(AZI.GT. 0.08) K=7
          IF(AZI.GT. 0.26) K=9
          IF(AZI.GT. 0.57) K=10
          IF(AZI.GT. 0.70) K=11
          IF(AZI.GT. 0.82) K=12
          IF(AZI.GT. 0.85) K=13
          IF(AZI.GT. 0.96) K=14
          IF(AZI.GT. 0.99) K=15
          IF(W) 10C,100,101
      101 K=30-K
      100 IF(QD.LT.H(1,J,K)) GC TC 6
```

Fig. 1. A Diagram Illustrating the Calculation of the Sky-line, with an extract from the relevant computer programme.

using an electronic computer, compares the altitude of the sun in a particular azimuth with the altitude of a local horizon. If the sun is higher than the horizon, the computation of direct short-wave radiation is executed; if not, the computation routine skips to the next time interval.

The height of the sky-line in any given direction can be obtained from a topographic map, and expressed in terms of the elevation angle of the highest obstruction, as shown in Fig. 1. Since the tangent of the elevation angle is the easiest to derive from a map, the diagrams given in Fig. 2 have been prepared to readily derive the tangent of the sky-line elevation along each required azimuth. Fig. 2(a) is a diagram which when drawn on transparent paper, can be laid over a map so that the horizontal distance from a point to a possible sky-line obstruction along each required azimuth can be measured. The elevation angle of these possible obstacles can be obtained by reference to the values of horizontal distance and difference of elevation shown on the graph given in Fig. 2(b). The largest value of elevation in each azimuth is the angular height of the sky-line for that azimuth.*

If the azimuth of the sun is measured clockwise from the south, the relationship between the azimuth of the sun (ε) and the three-dimensional direction of the sun can be expressed in the local co-ordinate system as shown in Fig. 3(a). If a unit vector S in the global system Fig. 3(b) is transferred into the local system:

$$S = (s_1, S_2, S_3) = \begin{matrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{matrix} \quad (0,\ \cos\delta, \sin\delta) \qquad (1)$$

* If extreme accuracy is not required, this procedure can easily be programmed by adding the data-set made of the altitude of each point to the azimuth and maximum gradient.

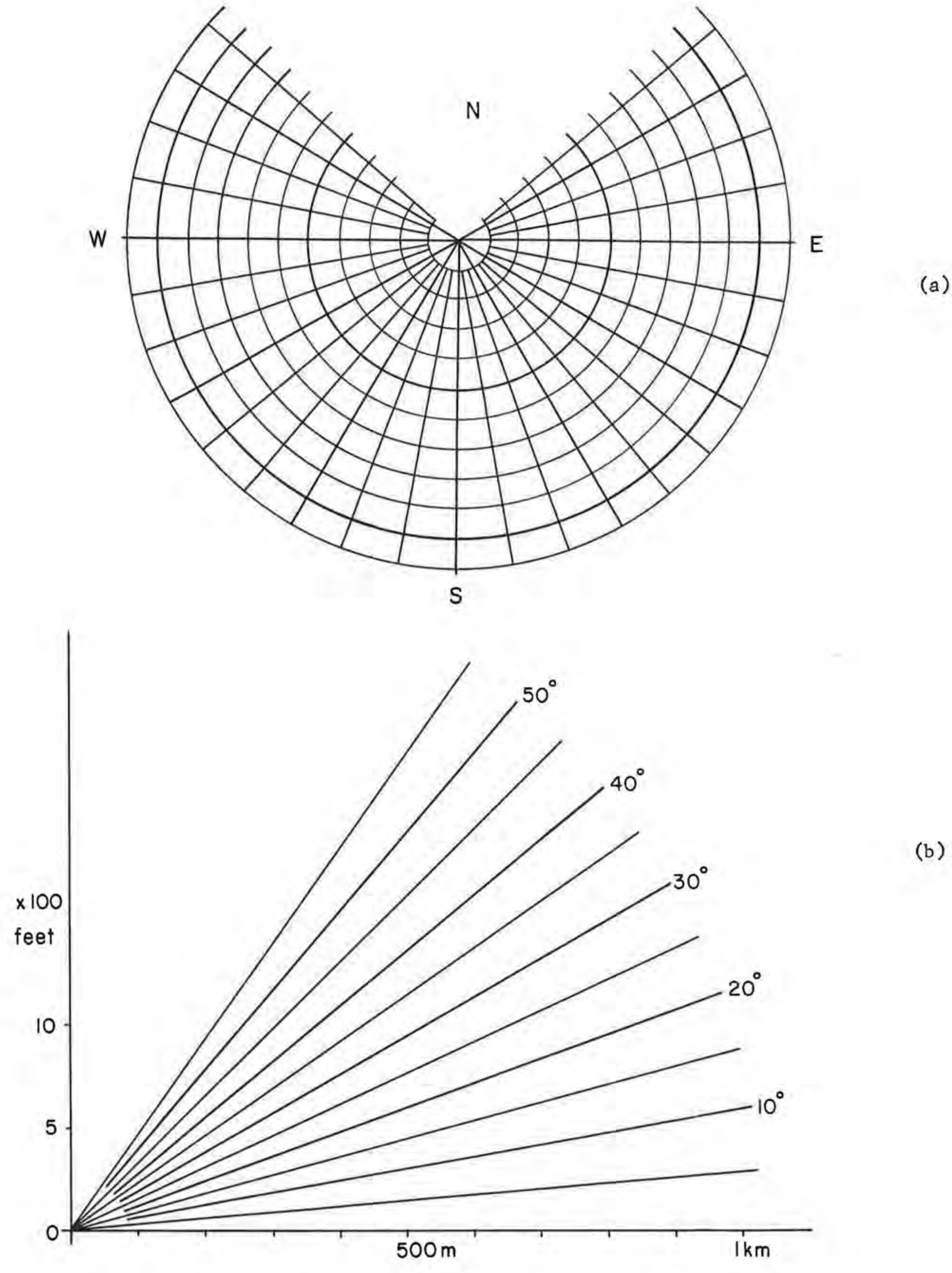


Fig. 2. Diagrams for Calculating the Height of the Sky-line along Different Azimuths.

where δ is the declination of the sun (positive in the northern hemisphere) and t_{ij} are the direction cosines of the local coordinate axes with respect to the global coordinate system, and are expressed as:

$t_{12} = \cos\zeta\cos H \qquad t_{22} = -\sin H \qquad t_{32} = \cos\zeta\cos H$

$t_{13} = -\cos\zeta \qquad t_{23} = 0 \qquad t_{33} = \sin\zeta$

where ζ is the latitude and H is the hour angle measured from solar noon, positively towards west and negatively towards east.

Therefore

$$S_1 = t_{11}\cdot 0 + t_{12}\cos\delta + t_{13}\sin\delta$$

or
$$S_1 = \cos\delta\ \sin\zeta\ \cos H - \sin\delta\ \cos\zeta \qquad (2)$$

On the other hand, from Fig. 3(a):

$$\cos\varepsilon = \frac{S_1}{\sin\eta} \qquad (3)$$

where η is the zenith angle of the sun.

Combining (2) and (3):

$$\cos\varepsilon = \frac{\cos\delta\ \sin\zeta\ \cos H - \sin\delta\ \cos\zeta}{\sin\eta} \qquad (4)$$

Another relation between η and δ, ζ, and H will be given by a well-known equation for the zenith angle of the sun:

$$\cos\eta = \cos\zeta\ \cos\delta\ \cos H + \sin\zeta\ \sin\delta \qquad (5)$$

Removing η by means of equations (4) and (5):

$$\sin^2\eta + \cos^2\eta = \left(\frac{\sin\zeta\cos\ \cos H - \cos\zeta\sin\delta}{\cos\varepsilon}\right)^2 + (\cos\zeta\cos\delta\cos H + \sin\zeta\sin\delta)^2 \qquad (6)$$

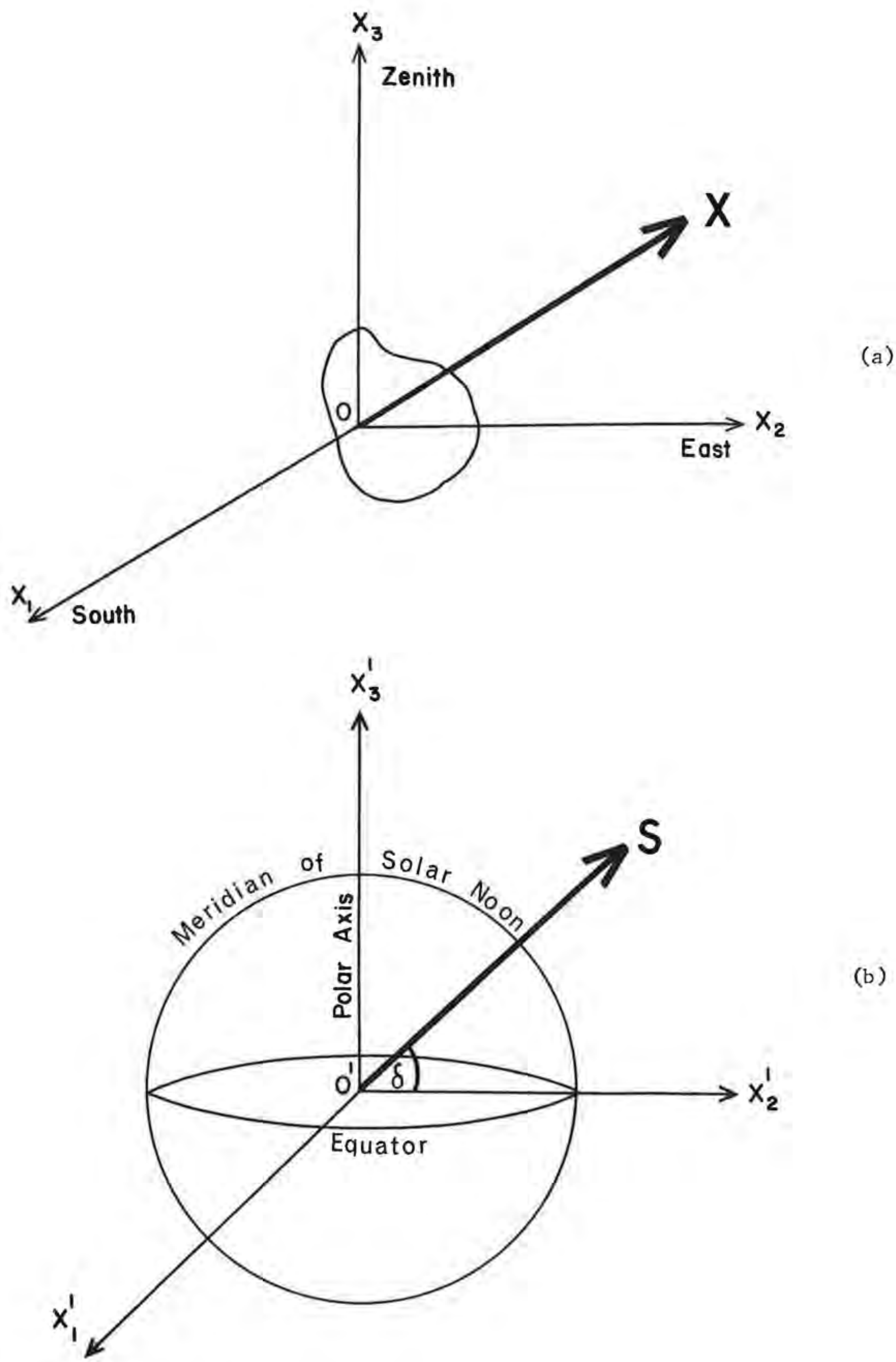


Fig. 3. Local and Global Co-ordinate vector systems for calculating Surface Radiation Values.

and rearranging equation (6) for ε :

$$\cos^2\varepsilon = \frac{(\sin\zeta\cos\delta\cos H - \cos\zeta\sin\delta)^2}{1 - (\cos\zeta\cos\delta\cos H + \sin\zeta\sin\delta)^2}$$

Since the denominator of equation (7) is never less than zero, it follows

that if $\cos\varepsilon(\sin\zeta\cos\delta\cos H - \cos\zeta\sin\delta) \geqslant 0$

$$\cos\varepsilon = \frac{\sin\zeta\cos\delta\cos H - \cos\zeta\sin\delta}{\sqrt{1 - (\cos\zeta\cos\delta\cos H + \sin\zeta\sin\delta)^2}} \tag{8}$$

and if

$\cos\varepsilon\ (\sin\zeta\cos\delta\cos H - \cos\zeta\sin\delta) < 0$

then

$$\cos\varepsilon = -\frac{\sin\zeta\cos\delta\cos H - \cos\zeta\sin\delta}{\sqrt{1 - (\cos\zeta\cos\delta\cos H + \sin\zeta\sin\delta)^2}} \tag{9}$$

The use of one of the last two equations will enable one to obtain the azimuth of the sun ε , which will then pick up the corresponding height of the local sky-line that was previously stored in the computer programme, as shown in the programme extract included in Fig. 1. Then the necessary comparison between the altitudes of the sun and the obstacle can be made.

A pilot study using this method was carried out on Lac Hertel, a small lake surrounded by the steep walls of an extince volcano, Mont St.Hilaire (lat.45°N). The surface of Lac Hertel was described by a coordinate system using a rectangular grid with fifty yard intervals. The altitude of the sky-line for each grid intersection was measured in the way previously explained, from an azimuth of 040° through south to 320°, for each ten degrees of azimuth. The 29 azimuths were numbered and stored as subscripted variables in the computer programme together with the other subscripted variables indicating the two-dimensional location of each point on the lake. The calculated values of cos ε in equations (8) and (9) were then related to the subscripts for the sky-line. The subsequent process is the same as the method previously described by Ohmura (1968) and Garnier and Ohmura (1968). The results of this computation showed that, at this latitude, even such a rugged topography as that of Mont St.Hilaire with its 20-25° slopes has a negligibly small influence for most of the year. However, when the sun's declination is less than -20° sky-line effects should be taken into account.

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Atsumu Ohmura is a graduate in Climatology of McGill University, and a Research Assistant to the McGill Axel Heiberg Island Expedition.

THE SPATIAL DISTRIBUTION OF SOLAR RADIATION IN SOUTHERN QUEBEC

A PROGRESS REPORT

by

R. D. PETERSON *

This study involves the measurement and analysis of the effect of different weather situations on the spatial distribution of shortwave solar radiation in Southern Quebec. The investigation was initiated in order to find out the size of the area for which solar radiation measurements from a single base station would enable one to make accurate maps of the topographic variation of radiation. The maps will be produced by using the methods and computer programmes developed by Atsumu Ohmura (Ohmura, 1969; Garnier and Ohmura, 1968; Ohmura,1968).

In other words, the area of validity of the single base station's measurements has to be determined. For this purpose the area of validity has been defined as the area in which the daily total of shortwave global radiation at any point is within 20% of the daily total of radiation measured at the base station. The measurements which will be analysed in this article were made during August, 1969.

The base station was the McGill Climatological Station at Mont St. Hilaire, which is located 26 miles east of downtown Montreal.

* R.D. Peterson is a graduate of McGill University and a Research Assistant in Climatology in the Department of Geography.

The station is in an apple orchard, 700 feet above sea level and 500 feet above the St. Lawrence lowland which surrounds it. The equipment used at Mont St. Hilaire consisted of a Kipp and Zonen pyranometer to measure global radiation and a Lintronic dome solarimeter with a shade ring for the determination of sky-diffuse radiation. The outputs of these sensors were recorded on a Leeds and Northrup Speedomax H Multipoint recorder. Daily totals of radiation were found by integrating the strip-chart records with a planimeter.

Two actinographs, measuring global and diffuse short-wave radiation respectively, were also located at Mont St. Hilaire. The actinographs are operated all year-round whereas the other instruments were in operation from August 2nd to September 8th, 1969. We are particularly interested in the actinograph records covering the period May 1st to September 30th, 1969 in order to make maps of radiation which existed during the growing season.

Portable equipment in use consisted of two Lintronic solarimeters each connected to separate battery-operated Rustrak strip-chart recorder-amplifier systems. The solarimeters were mounted on a cross-shaped wooden base which provided slopes of 20^{o} in four directions. Only global radiation was detected by this equipment.

The portable equipment was first located at Rougemont which is 8 miles from Mont St. Hilaire on a bearing of 130^{o}. Near the end of August the equipment was located at Yamaska which is 17 miles from Mont St. Hilaire on a bearing of 120^{o}.

Scattergrams were drawn to display actinograph daily totals versus the Kipp and Zonen and Lintronic daily totals of global, diffuse, and direct radiation at Mont St. Hilaire. The data used covered the period August 2nd to August 13th.

Equations of the best fitting lines were as follows:

GLOBAL: $y = 0.79x + 21$

DIFFUSE: $y = 1.12x - 154$

DIRECT: $y = 0.92x + 78$

where y = actinograph totals (ly/day)

x = solarimeter totals (ly/day)

It was found that the data from August 20-24 which was examined later, also fits these equations.

From the diffuse equation it can be seen that the diffuse actinograph should read negative for radiation totals less than 137 ly/day. An examination of the scattergrams suggests that an accuracy better than 10% is unlikely to be achieved for daily totals using actinographs. However, weekly totals should be accurate within 10%. These figures may be slightly revised after more data is analysed.

TABLE ONE

COMPARATIVE RADIATION VALUE AT MONT ST.HILAIRE AND ROUGEMONT

1969 Date	ST.HILAIRE			ROUGEMONT SLOPE		Rougemont Measured Global (ly/day)	Rougemont Predicted Global	Rougemont Global Predicted / Measured
	Global	Diffuse	Direct	Azimuth	Elevation			
Aug.5	446	231	215	East	18°	500	425	0.85
Aug.6	423	218	205	East	18°	418	403	0.96
Aug.7	342	261	81	East	18°	306	329	1.08
Aug.13	469	253	216	North West	20.5°	396	421	1.06
Aug.14	313	216	97	North West	20.5°	255	289	1.13
Aug.20	601	77	524	North East	20°	610	507	0.83
Aug.21	597	101	496	North East	20°	518	508	0.98
Aug.22	390	169	221	North East	20°	322	344	1.07
Aug.23	489	109	380	North East	20°	478	400	0.84
Aug.24	499	127	372	North East	20°	588	411	0.70

Table One displays the daily totals of global, diffuse and direct radiation as measured by the Kipp and Zonen and the Lintronic sensors mounted horizontally at Mont St. Hilaire; the daily totals of global radiation on various slopes measured by the portable equipment at Rougemont; the predicted daily totals of global radiation on the Rougemont slopes; and the ratio of predicted to measured values of the Rougemont global radiation figures.

The predicted Rougemont global totals were calculated from the Mont St.Hilaire direct and diffuse daily totals with the aid of the tables for daily total direct short-wave radiation on slopes available in Ohmura (1969) and the use of Kondrat'yev's equation for sky-diffuse radiation received by slopes:

$$D_\theta = D_h \cos^2 \frac{\theta}{2}$$

where D_θ = daily total of sky-diffuse radiation on a slope of gradient θ and D_h = daily total of sky-diffuse radiation on a horizontal surface.

No strong correlation between the various weather situations and the Rougemont predicted to measured ratio has been found yet. The weather factors which were used to define each day's weather situation were the type of pressure system dominating the area as shown on 7 a.m. surface weather maps; the amount of cloud cover, taken as the average of the 8 a.m. and 6 p.m. observations at Mont St. Hilaire; the visibility, taken as the average of the 8 a.m. and 6 p.m. Mont St.Hilaire observations; and the partial pressure of water vapour at the surface calculated from the 8 a.m. and 6 p.m. screen level wet and dry bulb temperature at Mont St.Hilaire.

It can be seen from Table One that the largest deviations from unity of the Rougemont global predicted to measured ratio are in the < 1 direction, i.e. the measured value is often less than the predicted value. This implies that the amount of radiation received at Mont St. Hilaire, upon which the predictions are based, may often be less than the amount received at Rougemont. This effect might be due to the fact that Mont St. Hilaire is closer to the Montreal air pollution sources than is Rougemont. Alternatively, a local pollution source from a nearby industrial plant near the mountain may be influential.

If this explanation is correct, then the Yamaska site should tend to receive even more global radiation than Rougemont, as it is further away from both pollution sources. Thus one would expect to encounter even smaller predicted to measured ratios in the Yamaska data. The Yamaska data will be analysed in the near future to check out this hypothesis.

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RESEARCH REPORT

The urban climate and micro-scale advection studies under the direction of Dr. T.R. Oke (see BULLETIN No. 5 pp. 1-20 and No. 6 pp. 26-43 respectively) are all in the stage of analysis, and final results are anticipated during the summer months.

Richard Fuggle, who is studying infra-red flux divergence and other characteristics of the urban atmosphere at night, has completed sufficient observations to conduct an interim analysis before deciding areas of special emphasis. The results of his study will be very helpful to David Yap who is formulating a Ph.D. research proposal to study the urban eddy fluxes. Brett Maxwell in studying the Montreal urban heat island is analysing his present results to investigate possible differences in urban, suburban and rural cooling rates.

Scott Munro is well advanced with his study of the aerodynamic characteristics of wheat, and the modification of the wind and temperature profiles downwind of a smooth-rough boundary, from results gathered during the 1968 McGill-Master experiment at Simcoe, Ontario. Brian Banks is similarly working on the results of the 1969 advection experiment where the transition was essentially from dry to wet instead of smooth to rough. The flux estimates from the latter study and those of the McMaster group will be used as a calibration standard against which to compare the performance of a modified eddy correlation instrument (see BULLETIN No. 6 p. 61) operated by Dr. Oke.

The principal research activity at Mont St. Hilaire since the end of last July has been to test the representativeness of the site as a radiation station for providing basic data for studies in the topographic variation of short-wave radiation over this part of southern Quebec. This testing was carried out by establishing field stations at Rougemont and Yamaska, both to the east of Mont St. Hilaire, the former is approximately eight miles away and the latter seventeen. The equipment used at the field stations consisted of Lintronic dome solarimeters, calibrated by the manufacturers before shipment. They were further tested against the Kipp and Zonen pyranometers at Mont St. Hilaire and against each other as a further calibration check. From this it was apparent that one could expect approximately 10% accuracy from daily figures of global radiation with these instruments, the greatest error being during the middle of the day. Thus, they appear to function about as well as a bi-metallic actinograph which has been found to have a very similar relationship when tested against Kipp and Zonen pyranometers both at Mont St. Hilaire and in Barbados.

The siting of the instruments at both Rougemont and Yamaska was similar. Through the courtesy of M. Charron at Rougemont and Mr. George Reeves at Yamaska it was possible to use the flat-topped roof of a building, with an unobstructed skyline in both cases. Battery-operated Rustrak recorders were used to record the data. The latter proved satisfactory most of the time, but their operation is sensitive to high humidities. It was found at Rougemont and Yamaska that on some warm, humid days, with a vapour pressure 20 mb. or greater, the instrument did not return to electrical zero. Thus it proved necessary to follow the technique which has been used in Barbados with similar recorders: dry them out at a high temperature in a drying room or oven, and then enclose them in watertight plastic bags for field use. This procedure in Barbados allows the instruments to be used for about two weeks, before they have to be "re-baked".

The experimental techniques at Rougemont and Yamaska were essentially the same. The dome solarimeters were mounted either horizontally or at an angle on a simple wooden stand made of cross-pieces, angled at about 20° to the horizontal. Thus measurements in up to four slope directions could be made at one time. The measurements recorded in different directions over selected periods were then compared either directly with corresponding measurements being made at Mont St. Hilaire, or with the values of global radiation calculated from the Mont St. Hilaire data. A preliminary report on some of the results will be found on pp. 25-29 of this BULLETIN.

During the winter the greater part of the time devoted to the Mont St. Hilaire research programme has been taken up with data analysis. This is prooving to be a somewhat formidable task since the data accumulation over the past eighteen months seems to have out run the capacity to maintain a corresponding analysis rate. Most of the chart data from the summer of 1968 and 1969 has now, however, been reduced and a start has been made on the preparation of maps of the topographic variation in southern Quebec for selected periods.

In Barbados the field work in connection with the energy budget programme was completed last December. Since the end of last July, the work has been in four phases: (1) as a follow-up to the remote sensing experiment reported in BULLETIN No. 6, pp. 61-62, a land use survey was made of the areas which had been traversed, and the different types of surface were sampled for albedo by means of a portable field measuring system using up and down facing Kipp and Zonen pyranometers; (2) a series of comparative radiation and energy-budget measurements were made, similar to those reported in BULLETIN No. 5, pp. 62-64, in co-operation with the Florida State University Barbados Experiment; (3) a series of special radiation and energy budget measurements were made on the east coast of the island from mid-September to the end of October; and (4) a second remote sensing experiment (see BULLETIN No. 6, pp. 61-62) was made during the first week of December.

<u>The East Coast Experiment</u> represented a concentration of observations at a site on eastward facing slopes. Short-wave radiation analyses have already shown the importance to the diurnal variations in the radiation pattern of the radiation intensity on the east facing slopes during the first three or four hours after sunrise. It seemed, therefore, desirable to study the possible effects of this on energy budget conditions.

The site chosen for this study was on open ground, with a grass covering interspersed with bare patches of stoney soil, sloping at an angle of 10° - 12° towards the east. The observation station was half a mile from the sea at an altitude of approximately 300 ft. The land behind sloped upwards to a height of 1000 ft. with an irregular relief due to soil erosion in the area.

Since this experiment was the only one possible at the site, all available instruments (other than those necessary to maintain the base observations at Waterford) were transferred to the site. Thus a full range of energy budget measurements, recording mainly on Rustrak portable recorders and/or Thornthwaite portable systems, was made.

The Remote Sensing experiment took place during the first week of December. It represents a follow-up and continuation of the experiment undertaken at the end of June within the framework of BOMEX. That experiment comprised several traverses across the island from east to west along the same track, and included some work to sample (a) the influence of atmospheric attentuation on the performance of a standard PRT-5 recording in the 8 μ - 14 μ wave-band and (b) the radiative temperatures over a tropical city (Brigetown).

Preliminary results of the June atmospheric attentuation experiments were sufficiently interesting and potentially so significant from the instrument performance viewpoint, that for the December experiment the Barnes Engineering Company kindly made available a second PRT-5 with a filter limiting the wave-length sensitivity to 10 μ- 12 μ , in the centre of the "atmospheric window". This second instrument was mounted on one side of the aircraft and standard PRT-5, sensing at 8 μ - 14 μ , was mounted on the other. Both instruments recorded on ¼ inch magnetic tape on a Metrodata System portable recorder installed in the aircraft. Ground truth measurements were maintained at Waterford and, for one day, at the East Coast site used in October.

The obsevational procedures in December were essentially the same as those for June, but the results are potentially more valuable in view of the use of two PRT-5s on the aircraft (a Cessna 150) operating at diffent spectral bands. The flying was carried out by Mr. Derek Leggatt, made available to the experiment through the courtesy of Barclays Bank Ltd., with the help of Mr. Bob Peterson, and the aircraft was supplied and maintained by aero Services (Barbados) Ltd., under the direction of Mr. Andy Stewart. Mr. Morris Weiss, Chief engineer of the Barnes Engineering Co., supervised the operation of the PRT-5s in the air and on the ground.

A total of 12 hours of observation was undertaken, beginning on Wednesday, December 3 and finishing on Sunday December 7. These observations consisted of:

(1) A series of traverses following the route taken in June. These sampled conditions at each of the times covered in June, and also included a traverse covering the 1½ hours around sunrise.

(2) Observations on the influence of atmospheric attentuation undertaken over the sea and the land. One series sampled the sea to east of the island and the land in short runs centred on Ragged point,

and a second series sampled the sea to the west of the island and over the land, centred on Waterford. In each case the aircraft flew for approximately one minute at each of the following levels above mean sea level: 8000 ft., 7000 ft., 6000 ft., 5000 ft., 4500 ft., 4000 ft., 3500 ft., 3000 ft., 2500 ft., 2000 ft., 1200 ft., and 900 ft. Over the sea only additional measurements at 600 ft., 300 ft., and 100 ft were made.

(3) A systematic series of traverses at 1500 ft above mean sea level was made covering the entire urban area of Bridgetown.

(4) Short traverses from the sea and inland for one mile across the East Coast site at 1500 Ft. were made at the following times on one day (Thursday, December 4): 0630-0730 hours; 0900-1000 hours; 1600-1500 hours; 1800-1900 hours. On these days hourly traverses on the ground using a portable PRT-5 were made from 0700 to 1900 hours inclusive from the beach inland to the observation station sampling the sandy beach, coastal vegetation, the coast road, and the different grass and bare soil surfaces of the area.

(5) A final systematic survey of the whole island was undertaken. This was made by east/west and north/south traverses along lines approximately one mile apart in each direction.

B. J. Garnier
Professor of Climatology
McGill University

NEWS AND COMMENTS

Dr. T. R. Oke is being sponsored by theCanada Department of Transport (Meteorological Branch) and the Canadian Meteorological Society to conduct a cross-Canada lecture tour on the topic "Urban Climate and Air Pollution". The tour includes visits to Vancouver, Edmonton, Regina, Winnipeg, Ottawa, Toronto, Montreal, Québec, Fredericton and Halifax. In addition to lecturing to each of the Canadian Meteorological Society centres the tour includes consultation with the meteorologists, municipal and procincial officials, urban planners and health officials and seminars at most universities.

Dr. Oke has accepted a position in the Department of Geography at the University of British Columbia, effective July 1st 1970, where he will continue teaching and research in microclimatology, especially urban climate.

Professor B. J. Garnier represented McGill University at the Ninth Meeting of the Caribbean Meteorological Council, held in Trinidad from January 14-17.

C. Kagenda-Atwoki has been awarded the M.Sc. degree in Geography (Climatology). His thesis was entitled "Weather Conditions and the Climate of the Rupununi".

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