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ESTIMATION OF SOLAR RADIATION RECEIVED ON SLOPES IN TASMANIA

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(with four text-figures)

ABSTRACT

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A solar radiation model has been used to calculate direct and diffuse solar radiation received on a surface. A series of diagrams are presented which enable the quick calculation of the daily total insolation received by a surface of known orientation.

INTRODUCTION

Solar radiation forms an important parameter in many ecological and botanical studies. In Tasmania many of these studies are conducted in complex topographic terrain which is characterized by highly variable solar energy microclimates. Solar radiation data of this nature cannot be obtained from the available climatological literature, and it is to this problem that this paper is addressed.

Pyranometers are used throughout Australia by the Bureau of Meteorology to collect global and diffuse solar radiation on a unit horizontal surface. However data collected from this network of stations is commonly of little value to Tasmanian researchers who often require to know the mean solar energy incident on a surface with a given slope and aspect. One option is to measure the solar energy directly using a pyranometer tilted at a given slope and azimuth. Whilst this is a perfectly valid technique, the equipment and manpower requirements are usually in excess of the resources available.

At present, theoretical models seem to be the most satisfactory way of calculating the solar energy received on slopes. Studies such as Garnier & Ohmura (1968), Holland & Steyn (1975), and Revfiem (1976) consider only direct radiation incident in sloping terrain. Diffuse radiation has also been incorporated by Rouse & Wilson (1969), Schulze (1975) and Bugler (1975) using empirical techniques.

A more generally applicable model was developed by Nunez (1980) who used cloud cover data to derive direct and diffuse solar radiation incident on a tilted surface of any orientation and limited by sky view factor and shadow effects.

Initially the model was applied as a case study to a mesoscale hilly environment at Risdon, Tasmania. In the present paper the model is used to derive three diagrams which relate solar energy to the slope and aspect of the receiving surface. The diagrams provide a reference base from which the solar radiation incident on slopes of any orientation can be readily estimated.

THE MODEL

The global solar radiation on a horizontal surface (G_C) can be described (Nunez, 1980) as

$$G_C = I_o \tau \cos Z + D \qquad (1)$$

where I_o = solar constant = 1353 Wm^{-2}
τ = transmission of the atmosphere to direct radiation
D = diffuse radiation incident on a horizontal surface (Wm^{-2})
Z = solar zenith angle.

The term τ is a function of Rayleigh scatter, precipitable water vapour and cloud cover at three levels. D is also calculated in terms of Rayleigh scattering and cloud cover. In this paper only the broad outlines of the model are described. The interested reader is referred to the above reference for further details.

In the case of a sloping surface both the angle of incidence of direct radiation and the diffuse component D change from the horizontal case, so that the incoming solar radiation ($K_C\downarrow$) is:

$$K_C\downarrow = \underbrace{I_o\,\tau\cos\gamma}_{\text{term 1}} + \underbrace{D\,VF}_{2} + \underbrace{G_C\,\alpha(1-VF)}_{3} \tag{2}$$

VF = sky view factor
α = albedo of surface
γ = angle of incidence of direct radiation

Term 1 denotes the direct radiation received by the surface. Diffuse radiation is represented by terms 2 and 3, term 2 denoting radiation from the sky incident on the surface and term 3 representing diffuse radiation that originates from reflection of global radiation by the ground. the angle of incidence of direct radiation with the inclined surface can be given as:

$$\cos\gamma = \sin Z.\cos\phi.\sin X.\cos Y + \sin Z.\sin\phi.\sin X.\sin Y + \cos Z.\cos X \tag{3}$$

and Z,ϕ = zenith and azimuth angles for direct solar radiation
X,Y = zenith and azimuth angles for the normal to the surface (see fig. 1).

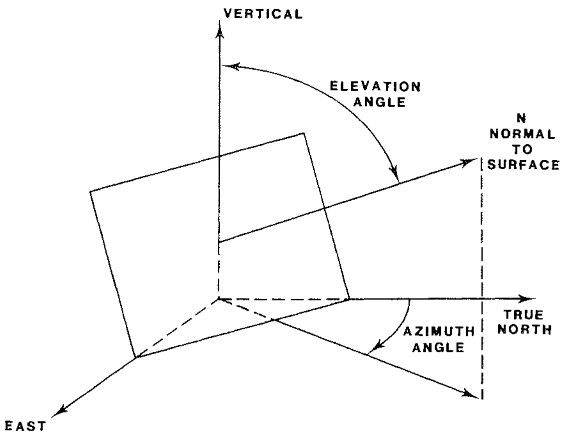

FIG. 1 - Geometry used for estimating insolation on slopes. The vertical intersects the square surface at the midpoint of the diagonals.

VF, the sky view factor varies from 1.0 for a horizontal surface to 0.5 for a vertical surface. Methods for obtaining VF can be obtained readily in the literature (Paltridge 1976, Nunez 1980). Note that the relationship described in equation 3 does not take into account shadow effects. That is, the tilted surface is considered exposed to solar radiation except for limitations imposed by its own elevation and azimuth orientations. This has been done purposely to make the relations as general and widely applicable as possible.

Testing $K_C\downarrow$ in equation 2 is not possible at present since there is no experimental data to compare it with. However Nunez (1980) has shown that estimates of G_C (equation 1) agree to within 5% of the mean monthly value (1971-75) of the daily total of solar radiation for Hobart airport.

In this paper $K_C\downarrow$ is used to derive a series of insolation diagrams for various elevation and azimuth orientations. In deriving this term a value of surface albedo (α) of 0.20

is used representing a mean value between eucalyptus forests and dry grasslands (Paltridge 1975). Cloud data at three levels (low, medium and high) are needed to obtain τ and D. These were obtained as monthly averages of six observations (06, 09, 12, 15 and 18 hours EST) taken from Hobart airport for a five-year period (1971-1975). These were interpolated to give half-hourly values. Monthly precipitable water vapour and cloud base albedo are also needed in τ and D. Monthly mean estimates of precipitable water vapour for Hobart airport were taken from Pierrehumbert (1972). Following Hay (1976) a cloud base albedo of 0.6 was used.

The following procedure was used in deriving the insolation diagrams. A given surface was considered to tilt in 15 degree steps from a horizontal to a vertical position. At each tilt position the surface was rotated through 360 degrees in the azimuth using 15 degree steps. Thus, a total of 85 different azimuth and elevation combinations are considered here. At each of these positions $K_C\downarrow$ was solved for every half hour using the cloud data, solar elevation and azimuth typical of the month. Summing the half-hourly values gave a daily total figure for each position. Solar elevation and azimuth were calculated at the fifteenth day of each month, and it was assumed that they represented mean conditions for that month.

RESULTS

Figure 2 shows the results for December when solar radiation is at a maximum. A highest value of 22.0 $MJm^{-2}day^{-1}$ is estimated along the horizontal This result is somewhat unexpected since direct radiation receipt is at a maximum in north facing slopes of 15 degree elevation. Equation shows why this apparent anomaly occurs. As the surface tilts northwards there is an increase in the direct radiation, plus diffuse radiation originating from surface reflection (terms 1 and 3). However the increase in these two terms is not enough to offset the decrease in diffuse sky radiation (term 2).

In general the trend in figure 2 is one of decreasing solar radiation with increasing elevation. The curves show a lesser dependence on azimuth orientation, and only so at greater elevations ($>40°$) and in south-facing slopes. A lowest value of just under 9.0 $MJm^{-2}day^{-1}$ was obtained for a vertical south-facing surface.

By contrast the June diagram (figure 3) shows a marked dependence on azimuth orientation. Solar elevations are much lower and this makes the azimuth orientation much more critical in determining the angle of incidence of direct radiation. Thus, a maximum radiation of 9.0 $MJm^{-2}day^{-1}$ is obtained in north-facing slopes of 65 degrees elevation. By contrast the south-facing slopes of the same elevation have an insolation of 2.3 $MJm^{-2}day^{-1}$. A lowest value of 1.9 $MJm^{-2}day^{-1}$ is obtained for a vertical south-facing surface.

On a yearly basis both the azimuth and elevation dependence are represented (figure 4). A maximum value of 5.3×10^3 $MJm^{-2}day^{-1}$ occurs on north-facing slopes at elevations of 30 degrees. This value is only slightly higher than the horizontal case (4.8×10^3 MJm^{-2} day^{-1}). However a south-facing slope of 30 degrees elevation only receives 3.6×10^3 MJm^{-2} day^{-1} of insolation.

DISCUSSION AND CONCLUSION

The representativeness of the results for other areas in Tasmania must now be considered. Three level cloud data are only available for Hobart airport, so that the model is not easily transposed to other areas. However models using sunshine duration data show that on a *climatological time scale* radiation data vary by at most 10-15% over large areas in central and eastern Tasmania (Hounam 1963, Nunez 1978). It is likely then that the results presented here are applicable over these areas to within 10-15%.

In some cases local topography may block the direct radiation and therefore special models need to be constructed (Nunez 1980). Trees also present a problem is solar radiation data are required at ground level on a forested slope and a model of tree transmission is currently being developed.

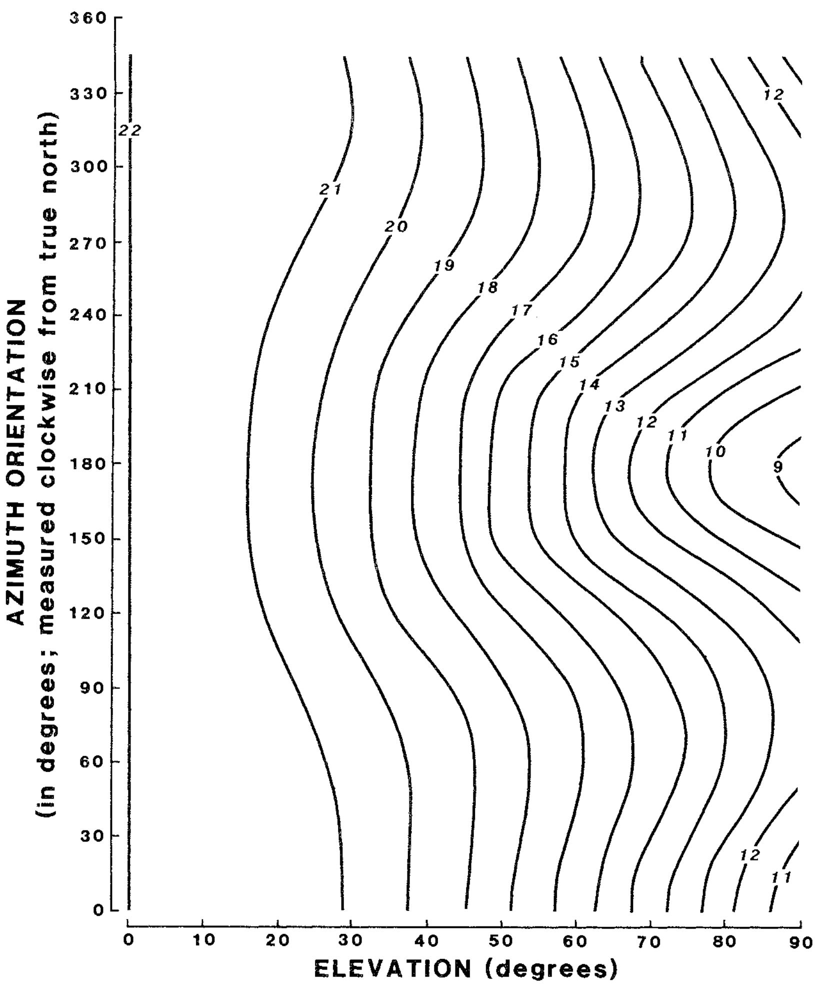

FIG. 2 - Mean daily solar radiation received on a slope ($MJm^{-2}day^{-1}$), December. (Total received on a horizontal surface = 22.0 $MJm^{-2}day^{-1}$.)

Overall, to compensate for the absence of experimental information, these results provide estimates of solar radiation for sloping terrain. Local cloud and precipitable water data are used in a model of atmospheric opacity. The model compares well with measured values of solar radiation on a horizontal surface.

It should be emphasized that monthly climatological data have been used both in cloud cover and precipitable water vapour. These diagrams cannot represent short-term fluctuations, and therefore their use will depend on the objectives of the researcher. Direct measurements are necessary if a research problem involves a definite event of short-term duration. On the other hand, many processes in ecology and botany respond to climatological averages, and in this case the use of these diagrams is justified.

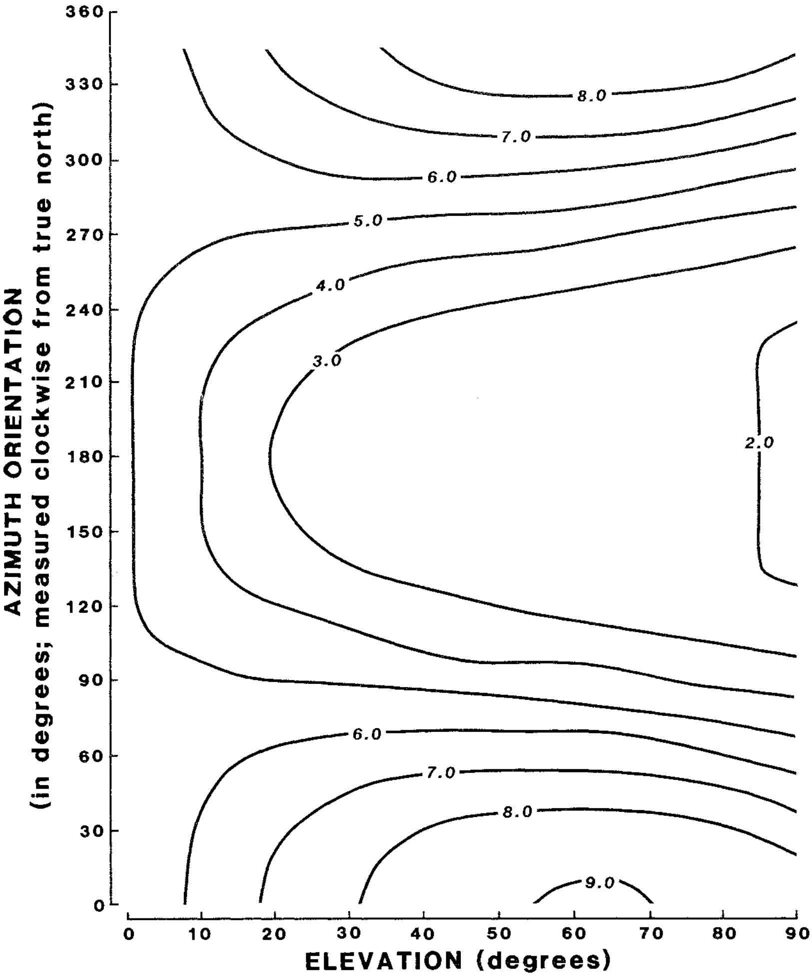

FIG. 3 - Mean daily solar radiation received on a slope ($MJm^{-2}day^{-1}$), June. (Total received on a horizontal surface = 5.1 $MJm^{-2}day^{-1}$.)

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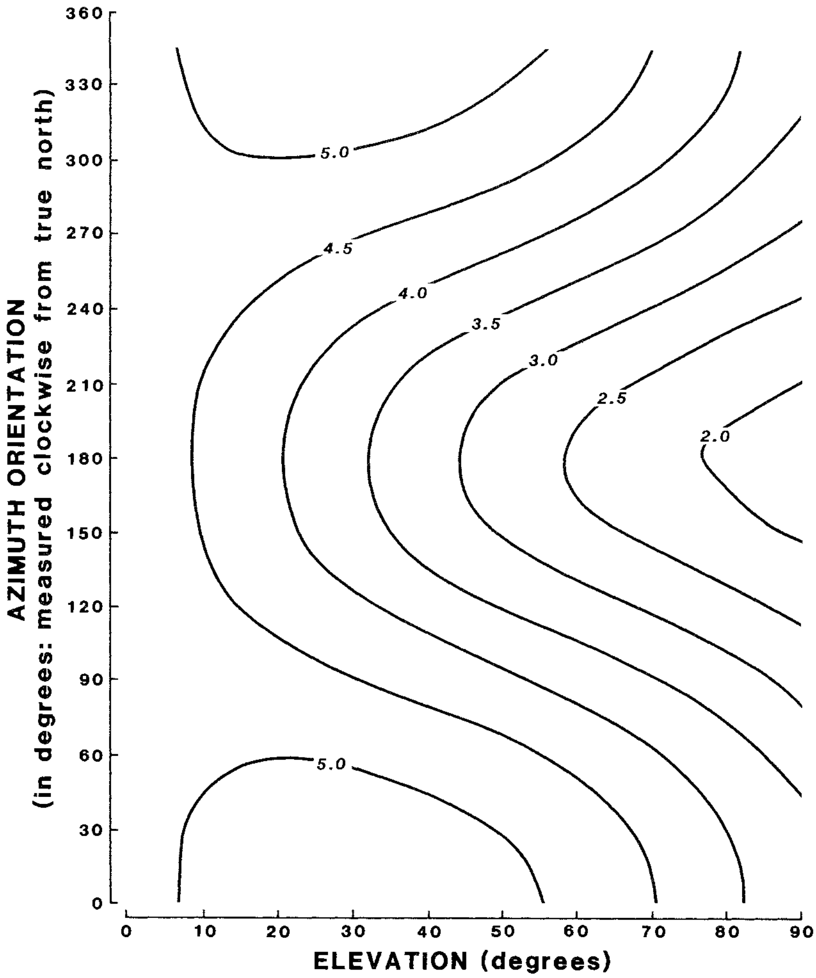

FIG. 4 - Yearly total solar radiation received on a slope ($MJm^{-2} \times 10^3$).
(Total received on a horizontal surface = 4.8×10^3 MJm^{-2}.)

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