PREDICTING SOLAR RADIATION FROM CLOUD COVER FOR SNOWMELT MODELING

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Introduction

In Arizona, efficient use of water is of concern because of its short supply. Much of this water originates as snowmelt runoff. Improvement of techniques to predict the amount and timing of snwomelt runoff may increase the efficiency by which this water can be used.

To improve prediction techniques, efforts have been made to model snowmelt processes through computer simulation (Leaf and Brink 1973, Solomon et al. 1976, Leavesley and Striffler 1979). Most snowmelt models require measurements of solar radiation, a primary source of energy for snowmelt. Unfortunately, direct measurements of solar radiation are not obtained routinely. Therefore, a means of estimating this parameter from readily available information would be useful.

Solomon et al. (1976) used average daily proportion of cloud-to-clear sky to estimate solar radiation in program SNOWMELT, a modified version of the snowmelt model MELTMOD (Leaf and Brink 1973), when solar radiation measurements were not available. Lacis and Hansen (1974) and Twomey (1976) have shown that cloud types vary in transmission and diffusion characteristics. Therefore, a better prediction of solar radiation may be achieved by relating solar radiation to clouds with similar diffusion characteristics.

As part of a study to relate solar radiation to cloud cover in ponderosa pine forests (McAda 1978), empirical equations relating solar radiation to opaque and transparent clouds were developed for incorporation into a computer subroutine for predicting solar radiation in program SNOWMELT. Development of these equations is described here.

Study Areas

Two study areas, Schnebley Hill and Alpine, were chosen to sample the range of spatial variability of ponderosa pine forests in Arizona, were chosen to monitor solar radiation and cloud cover. Schnebley Hill, 32 km south of Flagstaff, is at a latitude of 34 degrees 55 minutes North and a longitude of 111 degrees 40 minutes West, with an elevation of 2,100 m. Alpine, located in east-central Arizona, is at a latitude of 33 degrees 51 minutes North and a longitude of 109 degrees 8 minutes West, with an elevation of 2,400 m.

Methods

Global solar radiation was divided into its two components: direct and diffuse solar radiation. Therefore, two radiometers were utilized at each study area, one to measure global solar radiation and the other, fitted with a shadow band of the design used by Horowitz (1969), to obtain diffuse solar radiation. Direct solar radiation was calculated by subtraction.

At Schnebley Hill, global solar radiation was measured with a Kipp and Zonen solarimeter and diffuse solar radiation was measured with an Eppley (180 degree pyrheliometer) pyranometer under a shadow band. Two Lintronic dome solarimeters were used at Alpine, one to measure global solar radiation and the other to measure diffuse solar radiation under a shadow band. Differences in instrumentation, due to availability, were reconciled through calibration against each other.

Measurements of cloud cover used in this study were proportions of sky cover by opaque and transparent clouds. A cloud was defined as opaque if it obscured the portion of the sky it covered or transparent if it did not. The measurements of cloud cover were obtained from interpretations of 8-mm time-lapse imagery taken with cameras designed by Patton et al. (1972). The cameras, vertically oriented to photograph approximately 10 percent of the hemisphere, exposed a frame every 3 minutes during the daylight hours. Although only 10 percent of the hemisphere was sampled, it was assumed that the average cloud cover of that portion of the sky would adequately represent the average daily cloud cover of the entire sky. Interpretation of cloud cover was made by projecting each image onto a screen.

Emphasis in this study was placed on developing empirical equations to be used during the snowmelt season. Therefore, source data were collected over two snowmelt seasons, 1976-77 and 1977-78.

Results and Discussion

A preliminary analysis indicated no differences (at the 5 percent level of significance) in the coefficients of equations representing the two study areas. Therefore, the source data were combined for subsequent analysis.

Empirical Equations

Equations developed to predict direct and diffuse solar radiation utilized potential daily solar radiation (Frank and Lee 1966), solar elevation at solar noon (Sellers 1965), and opaque and transparent cloud cover as independent variables. Time of year and latitude were reflected in the solar elevation variable. Solar elevation at solar noon was calculated from knowledge of latitude and solar declination (Sellers 1965).

Given proportions of sky covered by opaque and transparent clouds, equations to predict daily direct and diffuse solar radiation are presented below.

$$R_{dir} = R_d\ (0.274 + 0.00546(S) - 0.971(O) + 0.516(O)^2 - 0.340(T)) \quad (1)$$

$r = 0.79$

$n = 124$

$$R_{dif} = R_d\ (-0.00422 + 0.00132(S) + 0.489(O) - 0.277(O)^2 + 0.259(T)) \quad (2)$$

$r = 0.76$

$n = 147$

where:

R_{dir} = daily direct solar radiation in langleys

R_{dif} = daily diffuse solar radiation in langleys

R_d = potential daily solar radiation in langleys

S = solar elevation at solar noon in degrees

O = average daily proportion of sky covered by opaque clouds

T = average daily proportion of sky covered by transparent clouds

r = correlation coefficient

n = sample size

To provide information about the conditions under which the above equations were developed, the means and standard deviations of all variables, both dependent and independent, are shown in table 1.

Subroutine Description

Subroutine RADAY, structured from the above empirical equations, can be used as an alternative to subroutines SOLAR and CLOUD in program SNOWMELT (Solomon et al. 1976). RADAY calculates times of sunrise and sunset on a horizontal and, if required, sloping surface. From these times, potential daily solar radiation at the top of the atmosphere is calculated for horizontal and sloping surfaces. As in SOLAR, the values of potential daily solar radiation are calculated for every fifth day, due to their relatively small change over that time period. Finally, daily direct and diffuse solar radiation is predicted from the empirical equations. The direct and diffuse solar radiation values are added to obtain the daily global solar radiation (figure 1).

If a user desired to use RADAY in program SNOWMELT, the only modification needed in the existing program is to call RADAY instead of SOLAR in subroutine RADBAL. A listing of subroutine RADAY can be obtained from the authors.

Table 1. — Means and Standard Deviations of Variables

Variable	Unit of Measure	Mean	Standard Deviation
Equation No. 1			
Dependent variable			
R_{dir}	langleys	323	190
Independent variables			
R_d	langleys	749	140
S	degrees	56.3	11.9
O	average daily proportion of sky covered	0.168	0.253
T	average daily proportion of sky covered	0.137	0.219
Equation No. 2			
Dependent variable			
R_{dif}	langleys	129	101
Independent variables			
R_d	langleys	731	140
S	degrees	55.0	11.6
O	average daily proportion of sky covered	0.218	0.321
T	average daily proportion of sky covered	0.137	0.237

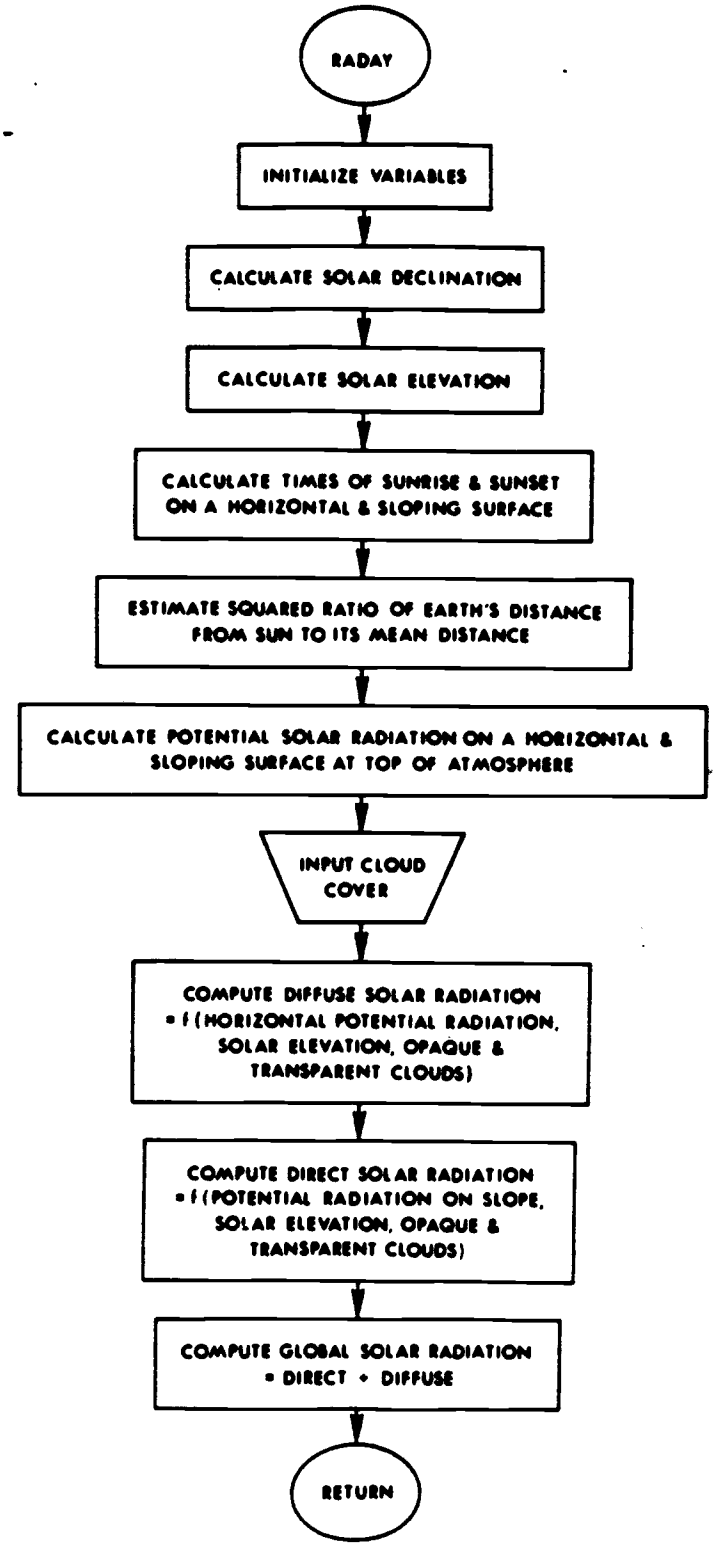

Figure 1. — Flowchart of Subroutine RADAY.

Conclusions

Through use of solar radiation-cloud cover equations such as those developed in this study and utilized in subroutine RADAY, a watershed manager can apply snowmelt simulation models to areas without direct measurements of solar radiation by using average daily cloud cover information obtained through on-site observations. The number of on-site observations required for an acceptable estimate of average cloud cover depends upon the accuracy desired and observer availability.

Importantly, extrapolation of solutions of the empirical equations presented beyond the range of latitudes sampled must be undertaken with caution.

References Cited

Frank, E. C., and R. Lee. 1966. Potential solar beam irradiation on slopes: Tables for 30 to 50 degrees latitude. USDA Forest Service, Research Paper RM-18, 116 p.

Horowitz, J. L. 1969. An easily constructed shadow-band for separating direct and diffuse solar radiation. Solar Energy 12:543-545.

Lacis, A. A., and J. E. Hansen. 1974. A parameterization for the absorption of solar radiation in the earth's atmosphere. Journal of Atmospheric Sciences 31:118-133.

Leaf, C. F., and G. E. Brink. 1973. Computer simulation of snowmelt within a Colorado subalpine watershed. USDA Forest Service, Research Paper RM-99, 16 p.

Leavesley, G. H., and W. D. Striffler. 1979. A mountain watershed simulation model. In: Proceedings, Modeling of Snow Cover Runoff. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, pp. 379-386.

McAda, D. P. 1978. Indexing solar radiation by clouds for snowmelt modeling. Unpublished Master's Thesis, University of Arizona, Tucson, Arizona, 54 p.

Patton, D. R., V. E. Scott, and E. L. Boeker. 1972. Construction of an 8-mm time-lapse camera for biological research. USDA Forest Service, Research Paper RM-88, 8 p.

Sellers, W. D. 1965. Physical Climatology. University of Chicago Press, Chicago, Illinois, 272 p.

Solomon, R. M., P. F. Ffolliott, M. B. Baker, Jr., and J. R. Thompson. 1976. Computer simulation of snowmelt. USDA Forest Service, Research Paper RM-174, 8 p.

Twomey, S. 1976. Computations of the absorption of solar radiation by clouds. Journal of Atmospheric Sciences 33:1087-1091.