ESTIMATING DAILY NET RADIATION OVER A SNOWPACK

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Introduction

Estimates of net (allwave) radiation over a snowpack are required for computations of snowmelt and for understanding the energy-balance climatology of cold regions. Few stations in the snow belt measure net radiation, and at these stations records are too short for reliable statistical analysis of extreme melt conditions. It would be useful, therefore, to have a method of extrapolating over time and space from the records of net radiation at the few available stations.

In this paper, we attempt to show that net allwave radiation over a snowpack can be estimated reliably for periods of a day from records of global radiation.

In computing the energy-balance of snowpacks in Vermont and subarctic Labrador, we found it necessary to estimate net radiation for periods during which instrumental observations of this parameter were not available. We used the Brunt equation with a variety of coefficients (U.S. Geological Survey, 1954) to calculate net longwave radiation. The predicted values were extremely unreliable and unstable, and often underestimated measured values (for days when instrumental observations were available) by more than 100 percent. Such errors in the estimation of daily net longwave radiation are extremely damaging to energy-balance computations, because the net longwave component is a large value in the radiation balance equation.

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Shaw (1956), Davies (1966), and others have shown that for daytime totals over vegetated surfaces, it is possible to define a linear relationship between incoming shortwave radiation and net radiation as:

$$R_n = a + b\,R_s$$

where R_n is the net radiation (langleys/day), R_s is global radiation (langleys/day), and a and b represent regression parameters. A discussion of the form of this approximation of the radiation balance has been given by Monteith and Szeicz (1961), and will not be repeated here.

Petzold (1974) has demonstrated that daily totals of solar and net radiation over a snowpack are correlated. The work reported in this paper was carried out parallel with the Petzold study, and benefitted from the advice of D.E. Petzold and Dr. R.G. Wilson.

The Study

We obtained daily totals of global radiation and daily and daytime totals of net radiation for one site in northern Vermont, and from two sites in sub-arctic Canada. The Vermont site is located at the National Oceanographic and Atmospheric Administration - Agricultural Research Service Cooperative Snow Research Station on the Sleepers River Experimental Watershed of the Agricultural Research Service, near Danville, Vermont. The site lies at an elevation of 540 m. in latitude 44°25'N and 72°00'W. The data from this site were kindly made available by E.R. Anderson of N.O.A.A. The Canadian stations were located at Goose Bay, Newfoundland (sea level; lat. 53°18'N; long. 60°27'W) and Knob Lake, Quebec (540 m; lat. 54°52'N, long. 67°01'W). Data from these stations are published in the Monthly Radiation Summary of the Canadian Atmospheric Environment Service.

Results

In Figure 1 are presented correlations of daily total net radiation and daily total global radiation during each month for the Vermont station. For the critical month of March when the snowpack is ripening or melting, we have arbitrarily divided the data into two 15-day periods. The diagram shows an inverse linear correlation between net and global radiation for the colder months. The slope of the regression line

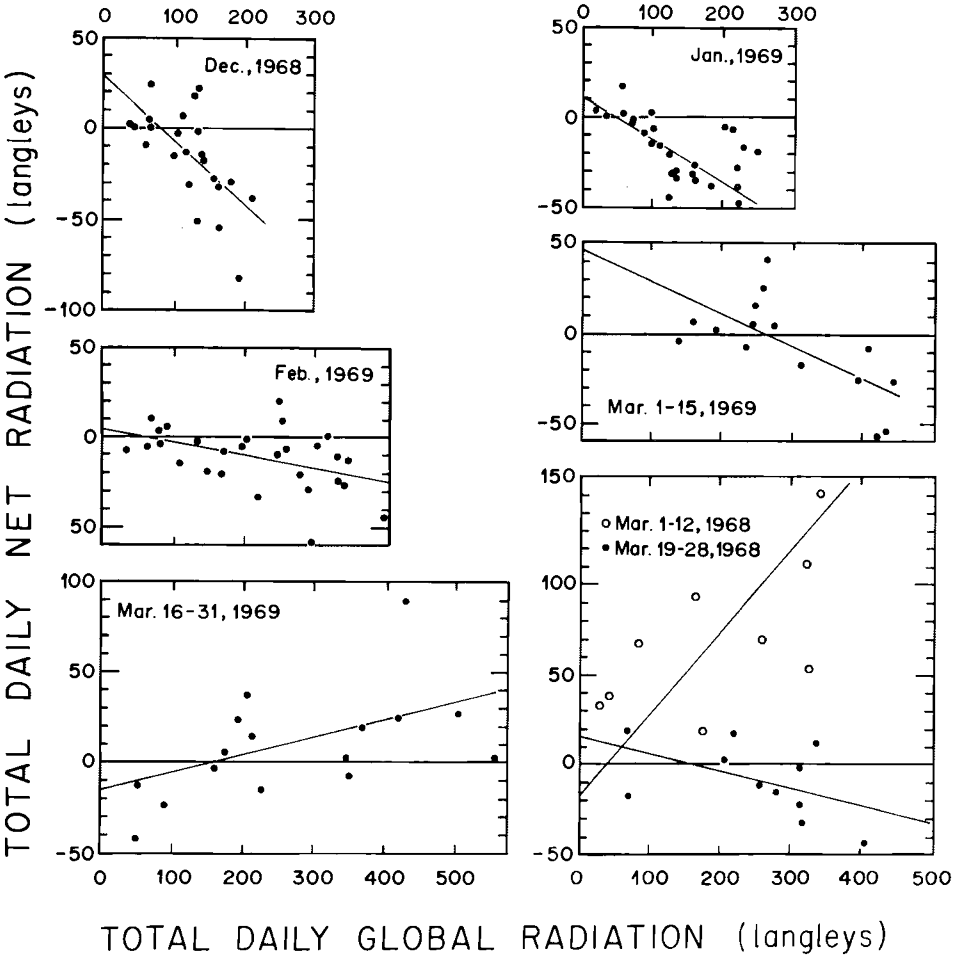

Fig. 1. Relation of daily net radiation to daily global radiation for various months at Danville, Vermont.

increases with the mean monthly temperature, and eventually becomes positive in mid-March, as air temperatures rise, and as snowpack albedos decrease during the period of ripening. The data relevant to Figure 1 are presented in Table One. They indicate that although the correlations are significant at the .05 level, the standard errors of estimate range from 15 to 27 langleys per day. This indicates an average error of estimate of approximately 10 to 18 langleys per day, which is much better than we obtained by using the Brunt equations.

Figure 2, shows similar linear regressions for Goose Bay and Knob Lake for various months of the year. The same pattern emerges. During the coldest months, net radiation losses are relatively small on cloudy days with low insolation, while on days with high insolation the net radiation loss is extreme. The slopes of the regression lines become less negative as air temperatures rise, and the slopes become positive during the early snowmelt period at each location. Regression data for Figure 2 are given in Table One. At Knob Lake, the meteorological station lies within the town of Schefferville, Dust from the town lowers the albedo of the snowpack to 0.40 - 0.50 within a few days after every snow storm. For this reason, the slope of the regression lines for Knob Lake in Figure 2 becomes positive more than one month before that for Goose Bay, which lies at approximately the same latitude, and at an elevation 540 meters below the former site. The Knob Lake data are included in this report, not because they are appropriate to large areas of the subarctic, but to show that the same general relationship exists between net and global radiation over dirty snow in urban areas. Snowmelt in urban disposal areas is beginning to receive the attention of hydrologists in several large cities across Canada and the northern United States.

Figure 1 suggests that the regression parameters in the relation between global and net radiation depend largely upon air temperature. Atmospheric vapour pressure and cloud cover, type and elevation must also influence net radiation, but it is interesting that air temperature exerts such a dominant effect. In Figure 3 we have shown the relationship between mean monthly air temperature and the monthly regression parameters for the Vermont station. The most obvious effect is that the slope of the regression line increases with air temperatures, while the intercept decreases. The slope becomes positive in the early part of the snowmelt season at each of the stations discussed in this paper.

In winter, when air temperatures are very low, days of high insolation in the snow belt are anticyclonic, cloudless days and therefore periods of high net longwave loss. This loss is not compensated by the high insolation because of the high albedo of the snow surface. Cloudy days in winter are periods of low global radiation but relatively high net radiation because the net longwave loss is reduced by the cloud cover. During the coldest months this negative relationship is strongest because the longwave loss is inversely related to air temperature. The negative relationship is particularly strong in December, when the albedo of the snow is high (averaging 0.86 at Danville), rather than in January (albedo at Danville was 0.81) which is often equally cold or even colder.

As air temperatures rise, and average albedos decline through the winter and early spring, the amount of net radiation absorbed by the snow-

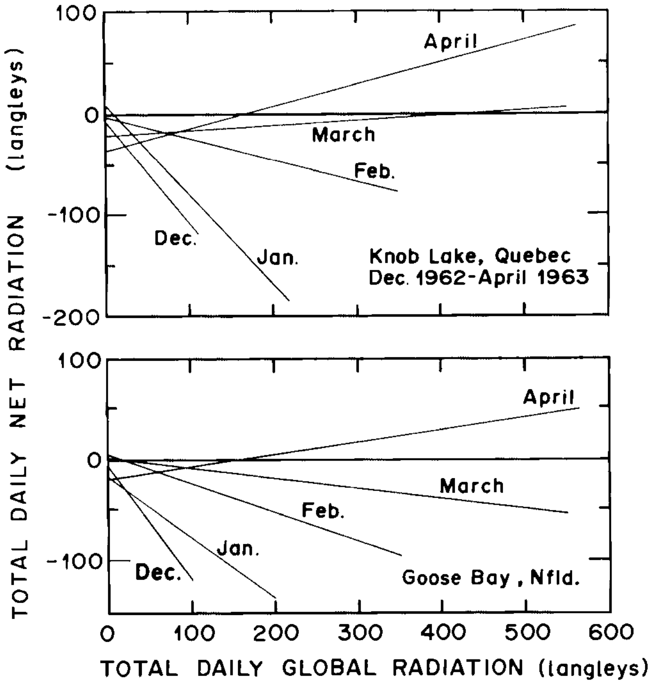

Fig. 2. Relation of daily net radiation on daily global radiation at Knob Lake, Quebec and Goose Bay, Newfoundland.

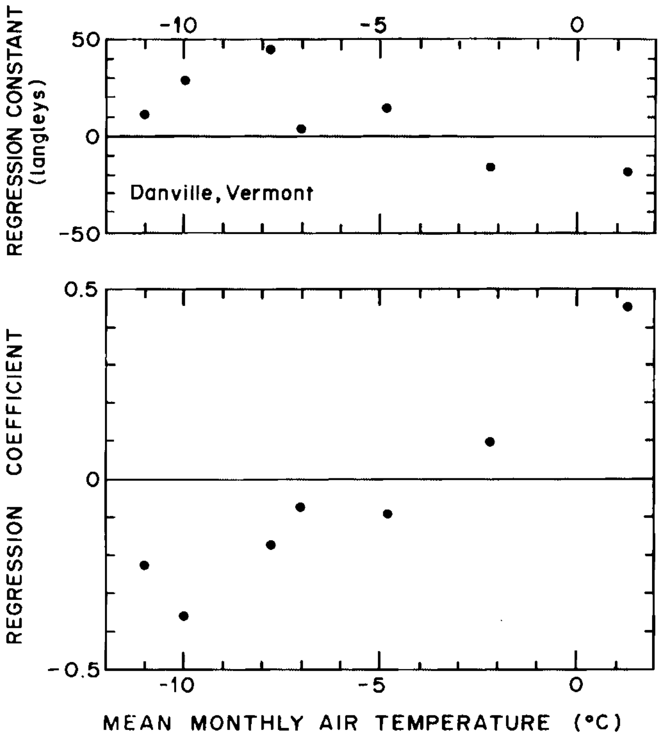

Fig. 3. Relation of monthly regression parameters for each month at Danville to the mean monthly air temperature.

pack for a given amount of global radiation increases. At the beginning of the snowmelt period in each area, the slope of the relationship is approximently zero, but increases quickly as albedos rise sharply during the melt. During the main part of the melt period in each area, the relationship becomes strongly positive. Sunny days are then also days of high net radiation because the lower albedo increases the amount of absorbed solar radiation, and the warmer air temperatures reduce the loss of longwave radiation.

If values of net radiation are needed only for the period of daylight, it is also possible to obtain linear regression relationships between total daily global radiation and daytime net radiation. A summary of data for the stations analyzed is presented in Table Two. Again the slope of the regression lines increases with mean monthly daytime air temperature through the winter and spring.

Summary

We have demonstrated that the kind of relationships developed by Shaw, Davies, and others for estimating daytime net radiation over vegetated surfaces on clear days can be extended to both daily and daytime values over snowpacks on both clear and cloudy days. The relationship is not constant throughout the snow season, however, but varies from month to month. The variation depends upon monthly difference of air-mass climatology and (during the melt period) of surface albedo, but these differences can be represented to a reasonable degree of accuracy by the mean month air temperature which is correlated with the regression parameters relating net and global radiation.

The regression predictions are not extremely precise because of the other factors that can affect net radiation besides incoming solar radiation and air temperature. These include vapour pressure, cloud characteristics, the structure of the atmosphere, and changes in the albedo of the snowpack. Even computations of net longwave radiation of the Brunt-type, which include some of these parameters, can give erratic results over a period of a day. Uncertainties over cloud characteristics, the structure of the atmosphere, or the correct empirical parameters to be used in these equations produce major errors in the computation of net radiation. Lack of widespread information on snowpack albedo adds other difficulties. Given these problems, even the rather imprecise relations of the type introduced above can be used in many studies of climatology, large-scale snowmelt hydrology, or permafrost, where a rapid estimate of total daily

TABLE ONE

Summary Table for Regression and Correlation of Total Daily Net Allwave Radiation (Rn) on Total Daily Global Radiation (Rs) for Stations Referred to in the Text

Station	Date	Regression Coefficients (Rn = a + b Rs)		Correlation Coefficients	Standard Error of Estimate	Degrees of Freedom*	Mean Air Temp. °C
		Intercept	Slope				
Danville, Vermont	March 1-12, 1968	45.65	-0.178	-0.670	20.82	9	-4.8
	March 19-28, 1968	-18.30	0.452	0.925	17.75	7	1.3
	December, 1968	28.76	-0.362	-0.650	20.40	21	-10.0
	January, 1969	6.42	-0.175	-0.640	14.20	26	-11.0
	February, 1969	3.90	-0.074	-0.460	15.20	26	-7.0
	March 1-15, 1969	45.96	-0.177	-0.670	20.70	13	-7.8
	March 16-31, 1969	-16.37	0.098	0.530	25.67	14	-2.2
Knob Lake, P.Q.	December, 1962	-9.80	-1.040	-0.720	23.20	29	
	January, 1963	6.90	-0.860	-0.820	21.70	29	
	February, 1963	-4.80	-0.210	-0.580	18.80	26	
	March, 1963	-23.00	0.050	0.190	21.80	29**	
	April, 1963	-38.20	0.220	0.550	34.40	22	
Goose Bay, Nfld.	December, 1962	-4.80	-1.160	-0.840	26.20	29	
	January, 1963	-16.70	-0.580	-0.770	21.20	28	
	February, 1963	5.10	-0.280	-0.770	20.70	26	
	March, 1963	2.10	-0.100	-0.470	25.50	29	
	April, 1963	-18.60	0.120	0.710	20.70	26	

* Instrument malfunction reduced the number of days of available data.
** Not significant at the .05 level.

TABLE TWO

Summary Table for Regression of Total Daytime Allwave Radiation (Rn) on Total Daily Global Radiation (Rs)

Station	Date	Regression Coefficients (Rn = a + b Rs)		Correlation Coefficients	Standard Error of Estimate	Degrees of Freedom*	Mean Day-time Air Temp. °C
		Intercept	Slope				
Danville, Vermont	March 1-12, 1968	18.8	0.013	0.10	14.56	9**	-3.4
	March 19-28, 1968	-47.2	0.591	0.57	31.03	7**	3.0
	December, 1968	21.1	-0.174	-0.59	11.34	21	-8.8
	January, 1969	11.4	-0.092	-0.54	9.61	26	-8.3
	February 1-15, 1969	6.2	0.020	0.26	8.23	26**	-5.4
	March 1-15, 1969	31.0	-0.030	-0.29	10.50	13**	-6.2
	March 16-31, 1969	-11.2	0.160	0.77	21.39	14	-0.7
Knob Lake, P.Q.	December, 1962	5.3	-0.318	-0.64	9.00	29	
	January, 1963	7.6	-0.260	-0.71	9.20	29	
	February, 1963	-3.7	0.045	0.26	10.80	26**	
	March, 1963	-16.8	0.172	0.77	12.60	29	
	April, 1963	-46.4	0.310	0.68	35.20	22	
Goose Bay, Nfld.	December, 1962	3.8	-0.350	-0.78	7.80	29	
	January, 1963	1.4	-0.260	-0.80	8.50	28	
	February, 1963	6.8	-0.100	-0.68	9.70	26	
	March, 1963	-0.4	0.010	0.09	16.10	29**	
	April, 1963	-23.7	0.210	0.88	21.10	28	

* Instrument malfunction reduced the number of days of available data.
** Not significant at the 0.5 level.

net radiation is required for various months of the year. The relationships that we have presented here are meant to be suggestive. Perhaps they could be defined more precisely by other workers with access to larger amounts of data.

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