INFLUENCE OF SUBARCTIC VEGETATION COVER ON SNOWMELT

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Abstract: An examination of the three major components of the energy balance has shown that subarctic vegetation cover markedly alters the relative importance of these components for the snowmelt. It has been found that the contribution of net radiation decreases as forest cover decreases while sensible and latent heat contributions to the snowmelt increase with decreasing forest cover. The decrease in the importance of net radiation with decreasing forest cover is due to the effect of the forest cover on albedo and the effects of the forest cover on the long-wave radiation component of the radiation balance. This situation seems to be typical for open canopy forests. The increase in importance of sensible and latent heat in the open is due to the increase in wind speed from the forest to open sites.

INTRODUCTION

Development of the subarctic for its forest, mineral, and energy resources is resulting in significant changes in vegetation cover over large areas. Such changes might be expected to produce significant alteration in the patterns of snowmelt and runoff production. A knowledge of the relationship between gross types of subarctic vegetation and snowmelt would allow assessment of changes in the snowmelt which will be caused by development and also allow for planning in advance of such changes.

Research into prediction of snowmelt has been dominantly aimed at developing a suitable expression for a snowmelt energy balance (U.S.A.C.E., 1956, 1960; Anderson, 1968, 1976; Hendrick et al., 1971). Energy balance models have been developed for prediction of snowmelt in the midlatitudes and are constantly being refined. Extensive testing of these models has not been carried out in other regions. However, FitzGibbon and Dunne (1980) and Price and Dunne (1976) have shown that the energy balance can be successfully applied to predict snowmelt in the subarctic. One advantage of the energy balance approach is that it identifies equations which calculate the heat available for snowmelt from each of the mechanisms contributing heat to the snowmelt including:

radiant heat,
sensible heat,
latent heat,
stored heat,
geothermal heat,
heat in percipitation.

As a result, this approach provides a unique opportunity for assessment of the relative importance of each heat source for snowmelt and the opportunity to determine

Physical Geography, 1983, 4, 1, pp. 61-70.

Table 1. Vegetation Cover Characteristics

Vegetation class	Tree height (m)	Crown radius (m)	Percent cover (%)
Closed lichen woodland (4 sample plots)	7.54	1.17	25.8-51.0
Open lichen woodland (4 sample plots)	6.85	1.17	16.6-23.0
Regenerating burn (3 sample plots)	2.07	0.58	10.5
Burn (5 sample plots)	0.68	1.00	6.2

the effect of vegetation cover on the snowmelt. Snow course melt measurements and more generalized index models do not provide this opportunity and only allow calculation of gross melt rates without explanation.

THE PRESENT STUDY

This study examines the effect of four different types of subarctic vegetation cover on the snowmelt at Schefferville, Quebec (54°45'N, 66°45'W). It also considers the relative importance of the various heat transfer mechanisms for snowmelt in each vegetation type. In particular, radiative heat, sensible heat, and latent heat are considered. In areas of cold climate where snow packs store little heat and the soils remain frozen through the melt season, the other main components of the energy balance, stored and geothermal heat, are negligible.

The four vegetation types studied are closed lichen woodland, open lichen woodland, regenerating burn, and recent burn areas. Table 1 provides summary statistics of the vegetation types. The lichen woodland consists of spruce forest with an understory of shrubs (mainly *betula gladulosa*) and herbs (*ledum groenlandicum*) with a thick lichen mat (mainly, *cladonia*). The trees tend to occur in clumps rather than as individuals. This creates a noncontinuous forest canopy.

Burning has altered much of the forest cover in the study area (approximately 59% of the area has been burned in the last 35 years). Regeneration is slow and may take from 50 to 100 years to reestablish the forest cover. In exposed areas, i.e., on ridge tops, forest cover tends not to regenerate and a tundra type (here termed burn) of vegetation cover, consisting of low shrubs, herbs, mosses, and lichens, becomes established. As a result, large portions of the study area are either burn or regenerating burn. The regenerating burn vegetation class consists of small trees (to 2 m height) and shrubs with a moss and lichen ground cover.

A variety of data was required to calculate the energy available for snowmelt in each vegetation class. The data collection network consisted of six stations. Two stations were standard open meteorologic sites (sites 1 and 21) (see Fig. 1). The remaining stations were located in each of the four vegetation cover types (sites 2, 3, 4, and 19). Details of the data collection are given in Table 2.

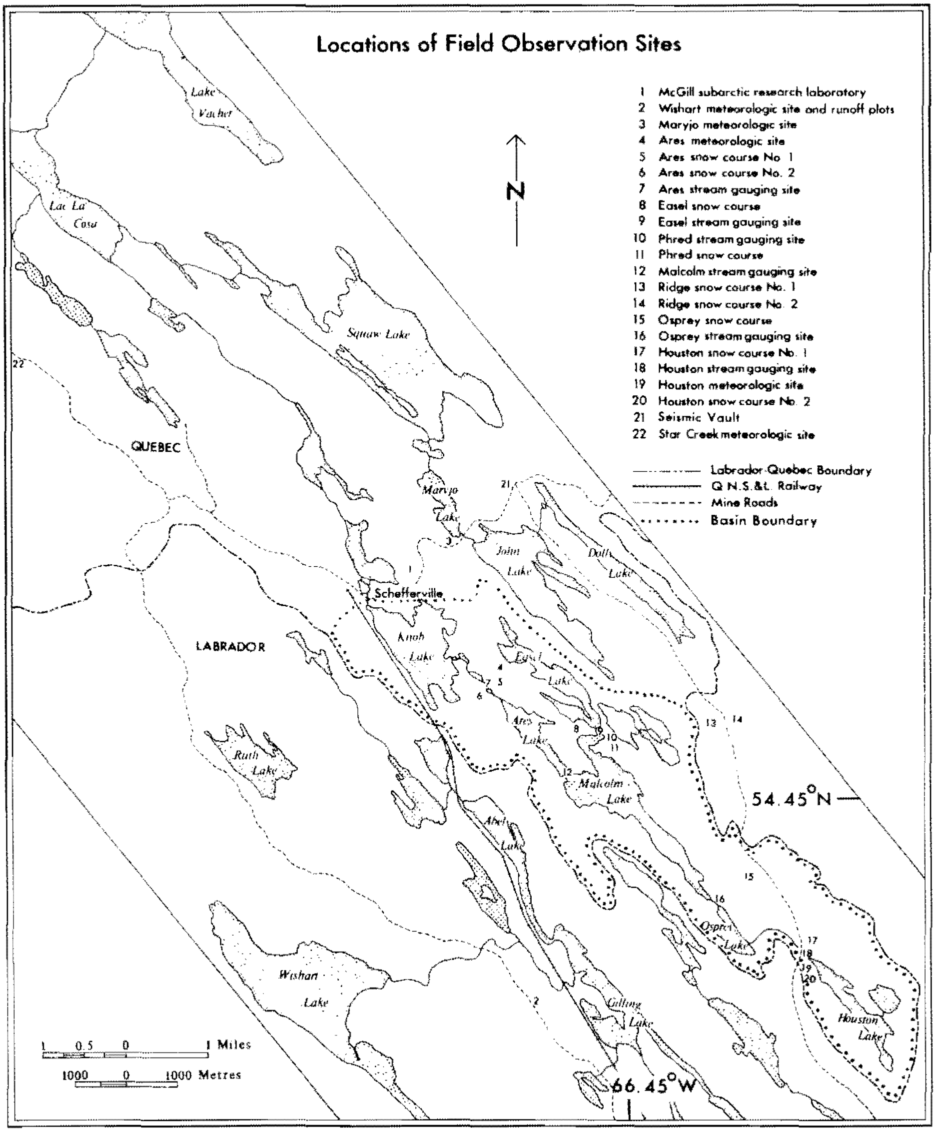

Fig. 1. The study area.

The energy available for snowmelt from net radiation and sensible and latent heat was estimated for each vegetation type using the equations listed in Table 3. These formulations include a number of approximations. (For a detailed discussion of the model application and testing, see FitzGibbon and Dunne, 1980.)

The physical energy balance models have not been widely used to predict snowmelt in forested environments. This is due to problems of modeling the effects of a forest canopy on the various components of the energy balance.

Table 2. Data Measured

Data	Site		Vegetation cover
Net radiation*	1	At 2m	open
	2	"	OLW
	3	"	CLW
Global radiation**	1	At 2m	open
	21	"	"
	4	"	CLW
	19	"	Burn
	2	"	OLW
Wind speed***	1	At 10m	open
	2	At 5, 1 and 2m	OLW
	4	At 2m	CLW
	22	At 2m	R Burn
	19	At 2m	Burn
	3	At 1, 2 and 3m	CLW
Temperature and vapour pressure	1	At 2m	open
	2	"	OLW
	4	"	CLW[e]
	19	"	Burn[e]
	22	"	R Burn[e]
Precipitation[!]	1	Read 6 hourly	open
	2	Read daily	OLW
	4	Read daily	CLW
	22	Read daily	R Burn
	19	Read every 3 days	Burn

*Funk type net radiometers.
**Eppley pyronometers and Belfort pyrheliometers.
***Cassella annomometers and Thornthait annomometers.
[e]Recording hygrothermographs and Assman psychrometer.
[!]Standard 5" rain guages.

The amount of radiative heat available for snowmelt is a function of the balance of incoming and outgoing short- and long-wave radiation. The effect of forest cover on the radiative heat exchange has been extensively studied (Reifsnyder and Lull, 1965; Petzold, 1981; Wilson, 1973; Thom, 1971; Moore, 1976; and many others). Net radiation was determined for this study using empirical equations defined by Petzold (1974) which relate net radiation in a vegetated site to global solar radiation at an open site.

The amount of sensible and latent heat available for snowmelt is a function of the gradients of atmospheric heat, moisture, and momentum (as measured by temperature, water vapor and wind speed). Forest cover tends to complicate the gradient profile by introducing irregular changes in the gradient slope, making it different from the logarithmic profile found over smooth surfaces. A number of models have been suggested for the forest profile (Sellers, 1965; Cionco, 1965). The most widely

Table 3. The Energy Balance Formulation

$$\frac{Hm}{L} = Hr + Hc + He \text{ (cm/day)}$$

where

Hm = the heat available for snow melt ($cal/cm^2/day$)

L = the latent heat of fusion of snow ($cal/cm^3/day$)

Hr = heat from net radiation ($cal/cm^2/day$)

Hr = a + b (Qs + qs)

where

a and b are obtained by linear regression (from Petzold, 1974)

Qs + qs = global solar radiation

Hc = heat from the sensible heat flux ($cal/cm^2/day$)

$$Hc = \frac{k^2 \, U_a}{\ln \left[\frac{z_a}{z_o}\right]^2} P_a \, c_a \, (Ta - Ts) \, S$$

He = heat from the latent flux ($cal/cm^2/day$)

$$He = 0.622 \, \frac{k^2 \, u_a}{\ln \left[\frac{z_a}{z_o}\right]^2} P_a \cdot w \, (c_a - c_s) \, S$$

where

k = Von Karman's constant (0.4)

u_a = wind speed at height z_a (cm/day)

P_a = density of air g/cm^3

w = latent heat of vaporization of water cal/g

c_a = specific heat of air ($cal/g/^\circ C$)

Ta = air temperature at height 2_a ($^\circ C$)

Ts = surface temperature ($^\circ C$)

z_a = height of measurement of c_a, Ta, and u_a (cm)

z_o = roughness length of the surface (cm)

e_a = air vapor pressure (mb)

e_s = surface vapor pressure (mb)

P = atmospheric pressure (mb)

S = atmospheric stability correction

where for stable conditions

S = (1 - 10 Ri)

and for unstable conditions

S = 1/(1 + 10 Ri)

where

Ri = the bulk Richardson number

$$Ri = \frac{g \cdot T \;\; Z}{Tak \;\; (\Delta u)^2}$$

where

g = acceleration due to gravity (cm/day^2)

T = temperature difference ($^\circ K$) over height difference Z

u = wind speed difference (cm/day) over height difference Z

Z = height difference (cm) over which Ri is calculated

Tak = air temperature ($^\circ K$)

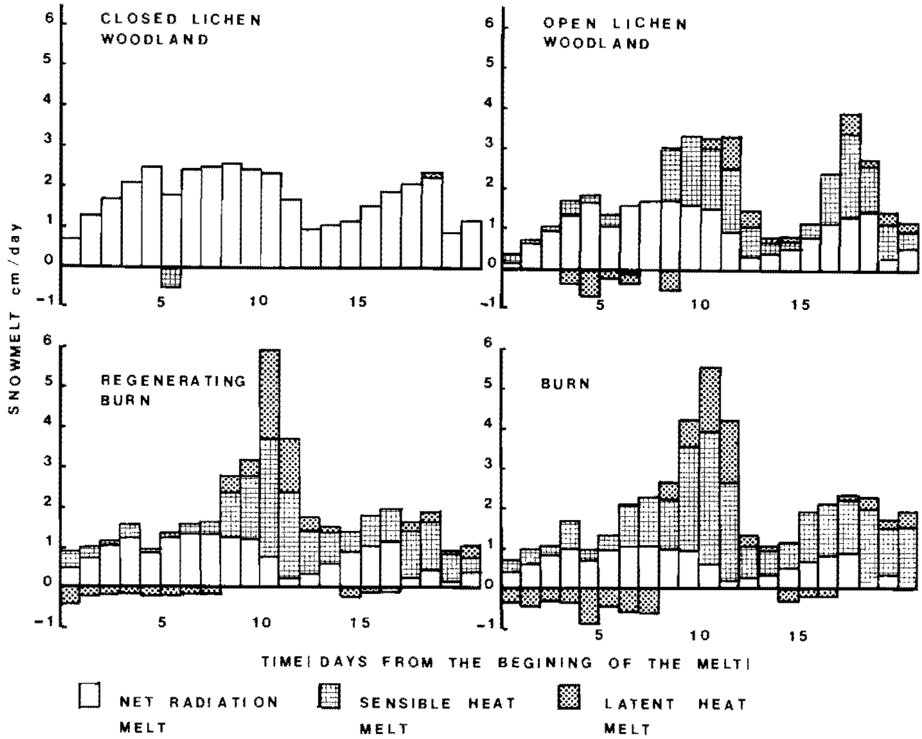

Fig. 2. Components of the snowmelt.

used is a modified logarithmic profile with a zero plane displacement. In most cases, the forest cover being dealt with forms a complete canopy, which allows the definition of a zero plane displacement based on tree height.

However, the open structured forest of the subarctic is such that definition of a crown controlled zero plane displacement is not possible. Thus the sensible and latent heat fluxes were modelled using a roughness length defined by the morphology of the snow surface (Lettau, 1969) and use of a simple logarithmic wind profile. Although the applicability of the logarithmic profile in forests has been questioned, it was observed that over a long period (i.e., an entire snowmelt season) average conditions could be approximated by a logarithmic profile (Price, 1975). The roughness length used was taken to be the form roughness of the snow surface. This was estimated from wind profile data and confirmed by the formula proposed by Lettau (1969). This may introduce some error, especially late in the melt when shrubs extend through the thin snow cover.

RESULTS

Calculated daily melt rates for each vegetation class through one melt season are shown graphically in Figure 2 and are summarized for the entire melt season in Table 4. It can be seen that in the closed lichen woodland, the bulk of the snowmelt is attributable to net radiation; latent and sensible heat play almost no part

Table 4. Snowmelt Due to Net Radiation and Sensible and Latent Heat for Each Vegetation Type

Heat transfer mechanism	Melt rate (cm/day)			Average seasonal contribution (% of total melt)
	Maximum	Minimum	Average	
Burn				
Net radiation melt	1.10	0.10	0.65	37.0
Sensible heat melt	2.88	0.23	1.05	60.0
Latent heat melt	2.11	-0.86	0.05	3.0
Regenerating burn				
Net radiation melt	1.34	0.11	0.78	39.0
Sensible heat melt	2.94	0.00	1.09	54.0
Latent heat melt	2.21	-0.38	0.15	7.0
Open lichen woodland				
Net radiation melt	1.71	0.11	1.02	60.0
Sensible heat melt	2.90	-0.10	0.63	36.0
Latent heat melt	0.80	-0.52	0.07	4.0
Closed lichen woodland				
Net radiation melt	2.46	0.68	1.72	+90.0
Sensible heat melt	0.18	-0.51	0.00	—
Latent heat melt	0.06	-0.06	0.00	—

in the melt in this environment. Daily melt in the closed lichen woodland has a smaller range than that in the other vegetation cover types.

The melt in the open lichen woodland is less the result of radiant heat with a larger proportion due to sensible heat. Periods of rapid melt coincide with times when sensible and latent heat transfers are large. The pattern of radiation melt through the season is similar to that of the closed lichen woodland but reduced in magnitude.

The pattern of melt in the regenerating burn shows a further reduction in the contribution from net radiation. Periods of extreme melt coincide with the occurrence of large contributions from sensible and latent heat, as in the period from 8 to 12 days after the beginning of the melt. Melt in the burn-tundra areas shows a similar pattern to that in the regenerating burn. Heat losses are primarily due to negative fluxes of latent heat. This component of the energy balance is most significant in the burn-tundra and regenerating burn environments.

DISCUSSION

A pattern of greater net radiation has been observed for open pine forests (canopy cover 0.1-0.3) as compared to grasslands (without snow cover) by Moore (1976) in Australia. He suggests that this is due to the effects of lower forest albedos and differences in net long-wave radiation associated with differing surface temperatures for the two vegetation types. Estimates of albedo (at the beginning of the snowmelt season) are 25 to 32% for closed lichen woodland, 36%, for open lichen woodland, 40% for regenerating burn, and 43 to 60% for burn (figures are based on measurements by Davies, 1962; Petzold, 1974; calculated by FitzGibbon, 1977). Thus more radiation would be absorbed by the forested surfaces. Solar radiation incident upon the subarctic forest canopy is in part absorbed and reradiated as long-wave radiation to the snow surface, in part reflected to the snow surface from the trees, and in part lost to the atmosphere. Snow has a high albedo for short-wave radiation; however, it is a near perfect absorber of long-wave radiation (Reifsnyder and Lull, 1965). Thus a goodly proportion of the higher net radiation in the subarctic forest during the snowmelt would seem to be due to the absorption of long-wave energy by the snow surface. In the burn and regenerating burn, more solar radiation would be reflected back to the sky due to higher albedos and the lack of a canopy to absorb the reflected solar radiation and reradiate it as long-wave energy back to the snow surface. The forests observed in this study, and by Moore, have a relatively open canopy. This suggests that higher net radiation in forests as compared to open areas may be generally typical of open canopy forest.

Sensible heat melt shows a general decline in importance from the burn areas through regenerating burn and open lichen woodland to closed lichen woodland. The reason for this general decline is probably the reduction of wind speed by forest cover. Szeicz, Petzold, and Wilson (1979) have shown that wind speed in closed lichen woodland is reduced by 70 to 80% when compared with wind speed in the open. Reductions of 40 to 60% were recorded by the author in open lichen woodland, while only 10% reduction was recorded for regenerating burn. The massive reduction in wind speed by the forest cover would reduce the efficiency of the turbulent exchanges. Although higher air temperatures were recorded in the forest, these were not sufficient to produce unstable conditions which could compensate for lower wind speeds. Thus, sensible heat transfers in the forest are reduced. In contrast, in the burn and regenerating burn, the higher wind speeds and the presence of turbulent air movement over the snow surface would allow heat from the atmosphere to be freely moved over the snow surface, thus increasing sensible heat melt.

Table 4 shows that the seasonal average contribution of latent heat to the snowmelt for all vegetation types is a very small quantity. This is probably due to low atmospheric vapor pressure which is related to the low atmospheric temperatures that generally prevailed during the melt. There were, however, occasions (1- or 2-day periods) when latent heat contributed significantly to the melt. These occasions generally coincided with the presence of maritime air masses in the study area (maritime low pressure air masses) which contained large quantities of advected sensible and latent heat. On such occasions, the latent heat melt was greatest in the burn and regenerating burn and decreased significantly with increasing forest cover. This pattern reflects the relationship of vegetation cover to wind speed, as discussed above.

Differences in the amount of melt in any given day are substantial, both in amount and source of heat. This is due to both micro climatic conditions caused by the surface environments and the atmospheric conditions.

The closed forest produces a steady melt which would result in the production of a smooth attenuated snowmelt flood hydrograph. The more open areas produce a more variable melt pattern which would cause sharper flood peaks. The extreme melt periods coincide with periods of substantial sensible and latent heat melt.

CONCLUSIONS

In the subarctic, the nature of the vegetation cover is significant in determining the relative importance of net radiation and sensible and latent heat for snowmelt.

Lower forest albedos and absorption by the snow of long-wave radiation from the forest canopy seem to be important contributors to higher net radiation melt in the forest. The subarctic forest also decreases the significance of sensible and latent heat through reduced forest wind speeds. In burn and regenerating burn, higher albedos reduce the importance of net radiation, while the turbulent heat fluxes account for a large proportion of the snowmelt (due to the higher wind speeds).

The differences in the importance of the melt mechanisms result in differences in daily rates of snowmelt. A relatively uniform steady melt production is generated in the forest while greater fluctuation in melt rates is experienced in the open areas. Vegetation cover in the subarctic produces local variation in mechanisms of melt and melt rates. Thus the development of more generalized models (index models) for the subarctic will have to include these factors.

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