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Characteristics of subarctic snowcover

J. E. FITZGIBBON Department of Geography,
University of Saskatchewan, Saskatoon, Canada S7N 0W0
T. DUNNE Department of Geological Sciences,
University of Washington, Seattle, Washington, USA

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Abstract. The areal and temporal characteristics of the snowpack in a small subarctic drainage basin at Schefferville, Quebec, were analysed prior to and during the snowmelt in 1972 and 1973. The data showed that vegetation cover is of prime importance in determining the areal distribution of snowpack properties. The areal distribution of snow water equivalent could be characterized by a normal distribution in each of four vegetation cover types. It was found that the mean and standard deviation of snow water equivalent are closely related to vegetation cover. Also, mean snow water equivalent varies from year to year but standard deviation shows no significant variation. This suggests that mean accumulation is the result of annual snowfall amounts, while the variability is due to the effects of vegetation cover and accumulation processes. The data also showed that during the snowmelt, the variability of snowcover properties shows no significant change. Using the normal distributions of the peak accumulation snow water equivalents, and observed and calculated melt rates, the areal extent of snowcover was determined.

Les caractéristiques de la couverture de neige presque arctique

Résumé. Les caractéristiques changeantes des entassements de neige en lieux divers et á périodes variées dans un petit bassin hydrographique presque arctique á Schefferville, Québec, furent analysées antérieurement à et pendant la fonte de neige de 1972 et 1973. La donnée a révélé que le couvert végétal est de la plus haute importance pour déterminer la distribution en lieux divers des propriétés des entassements de neige. La distribution en lieux divers de l'équivalent d'eau de neige peut être caractérisée par une distribution normale dans chacun de quatre types de couverts vegétaux. On a découvert que les déviations moyennes et normales de l'équivalent d'eau de neige ont un rapport étroit avec le couvert végétal. En outre, l'équivalent moyen d'eau de neige se modifie chaque année mais la déviation normale ne montre aucun changement important. Ce fait suggère que l'entassement moyen est conséquent des montants annuels des chutes de neige, tandis que la variabilité provient des effets du couvert végétal et des procédés d'entassement. La donnée a aussi révélé que pendant toute la durée de la fonte de neige, l'entassement moyen diminue, tandis que la variabilité des propriétés du couvert de neige ne manifeste aucun changement d'importance. En employant les distributions normales de la pointe d'entassement des équivalents d'eau de neige et les trains de fonte, observés et calculés, l'étendue de surface couverte de neige fut déterminée.

INTRODUCTION

Assessment of the nature and extent of snowcover both before and during the melt season represents a major part of many hydrological and environmental studies (Formozov, 1966). This is particularly true in the Subarctic and Arctic where snowcover exists for much of the year and where snowmelt provides the main source

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of runoff. An accurate estimate of show accumulation is especially important in assessing the water storage in a basin for such purposes as the generation of hydroelectric power, for provision of flood forecasts and water forecasts and water supply for urban and agricultural use.

Snowcover is a highly variable spatial phenomenon which is not easily characterized by point observations. The variability arises from climatic gradients in accumulation and ablation, as well as smaller scale interactions of meteorological and terrain features.

The area over which peak snowpack properties are uniform depends on the steepness of climatic gradients. In mountainous areas large scale topographic effects produce sharp climatic gradients. Thus average snowpack characteristics change within short distances. In lowland areas, however, average snowpack conditions may remain uniform over appreciable distances. Kuz'min (1960) suggests that within areas of 50–100 km in radius snowfall does not vary significantly. Stepphun & Dyck (1974) suggest that this may be true for even larger areas. Thus within many small to medium size drainage basins in lowland areas, average snowpack characteristics are uniform and are a product of the regional climate.

Variation of snowcover properties within this type of basin is due to small scale interactions of the terrain and the processes of snowcover formation. The two terrain features of concern are local topography and vegetation cover. They influence patterns of air movement over the surface and thus can affect initial patterns of snow deposition as well as subsequent redistribution through drifting. Further, they create local differences in snowmelt thereby contributing to local variation in snowcover properties.

Assessment of snowcover patterns for an area may be approached in two ways: through modelling the processes of snowcover formation, or through statistical analysis of snowcover properties and their relation to terrain and meteorological phenomena (Kuz'min, 1960). Physical modelling of the formation of snowcover is difficult due to the complexity of the processes. Thus for routine determination of areal snowcover characteristics the statistical approach is more practical.

The descriptive statistical approach to snowcover analysis requires that a theoretical frequency distribution be fitted to the observed peak accumulation data (snowpack depth, density, and water equivalent). Some appropriate distributions have been identified; e.g. for a whole drainage basin the Pearson type 3 or gamma distribution (Kuz'min, 1960), and for individual vegetation cover types the normal or Gaussian distribution (Stepphun & Dyck, 1974). The statistical parameters of these distributions have been related to factors governing the formation of the snowpack (Kuz'min, 1960; Stepphun & Dyck, 1974; Granberg, 1975). Thus when snowcover is described by frequency distributions the problem of estimating areal patterns of the peak snowcover is reduced to definition of the parameters of the characteristic distribution.

Because of irregular changes caused by snowmelt, the assessment of the areal distribution of snowcover during the snowmelt is an even more difficult problem than determination of the peak accumulation. For many purposes it is even more important that the extent and nature of the snowcover during the snowmelt be known since the extent of snowcover partially determines the production of meltwater and reserves of water held in the pack. Snow depths and densities are important in determining the effects of the snowcover on cross-country trafficability during the snowmelt.

Relatively little is known of the nature of snowcover throughout the snowmelt, largely because of the difficulty of obtaining widespread measurements during the melt. Most methods of determining the areal extent of snowcover during the melt involve remote observation, using aerial photos (Nicholson, 1975), satellite imagery (Haworth & Woo, 1975), or a ground level vantage point (US Army Corps of Engineers, 1956). The resulting data are then frequently used to construct areal depletion curves for estimation of the areal extent of snowcover (US Army Corps of Engineers, 1956). Reserves of water equivalent can be estimated by subtracting the accumulated runoff from the peak accumulated water reserve. Snow depths and densities remain largely unknown except from limited surveys and some empirical relationships.

This paper reports the results of a study of both the peak snow accumulation and the changes in snowcover through the melt in a small, lowland subarctic drainage basin. It demonstrates that snowcover properties in such a region may be characterized according to vegetation cover as it controls snow redistribution through drifting. Topographical influences are important only in open areas of sparse vegetation. Further, this paper assesses the statistical properties of the snowcover patterns in each of the vegetation types. It also tests a method that uses peak accumulation distributions to estimate the extent of snowcover throughout the snowmelt season.

THE STUDY

The fieldwork was carried out in the experimental drainage basin of the McGill Subarctic Research Laboratory located at Schefferville, Quebec. The physical environment of the study area is typical of the lowland tree line area of subarctic Canada. Topography is gently rolling with local relief of 160 m. The vegetation consists mainly of lichen woodland typical of the Subarctic. In addition much of the area has been burned by forest fires in the recent past and is in some stage of regeneration. Four major classes of vegetation were defined for this study. They are:

TABLE 1. *Average tree height, percentage cover, and crown radius of vegetation in each class*

Vegetation class	Tree height (m)	Crown radius (m)	Percentage 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

closed lichen woodland, open lichen woodland, regenerating burn, and burn. The 'closed lichen woodland' is open structured forest with an average distance between trees of 3–4 m. The trees are evenly distributed and form a relatively uniform canopy. 'Open lichen woodland' is a more variable forest cover with the trees growing in clumps. Open spaces between clumbs are as much as 7 m in diameter. The 'regenerating burn' consists of low regrowth of spruce, tamarack, and shrubs with a few isolated trees which have survived burning. The 'burn' areas are devoid of tree growth other than shrubs. Table 1 summarizes some properties of each of the vegetation classes.

The average maximum accumulation of snow has a water equivalent of 330 mm. On average 40 days of drifting snow occur per year. Winters are generally cold with no periods of melt during the accumulation season. Snowmelt begins in early to late May and snowcover is absent from mid June until late September.

DATA COLLECTION

Snowcover data were collected at both peak accumulation and throughout the melt seasons of 1972 and 1973. Samples were taken using a 'Greens' Adirondack' sampler. Additional data were obtained from published survey analysis carried out by other researchers in the study area (Adams *et al.*, 1965; Rogerson, 1967; Granberg, 1975). The peak accumulation surveys were carried out along transects

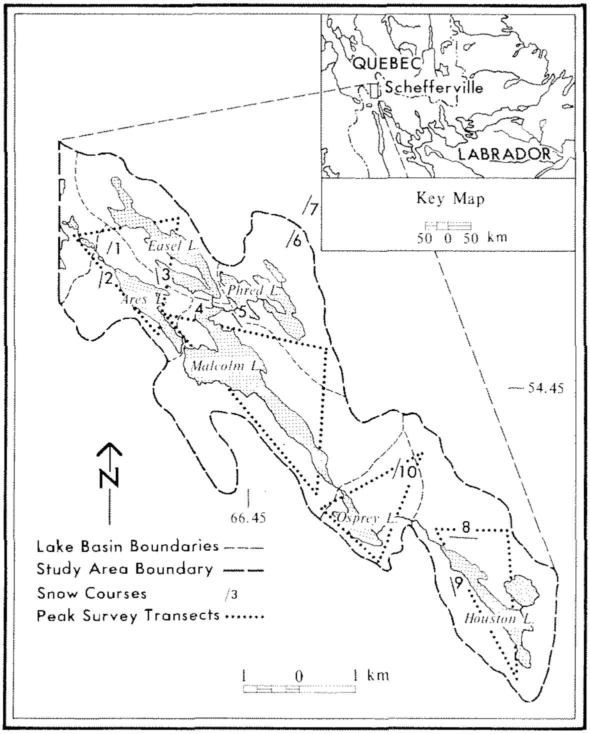

FIG. 1. The study area.

across the study basin. Snow depth, density, and water equivalent were recorded for each sample, as was the vegetation cover and topographic location of each sample site. Ten snow courses, each consisting of ten snow stakes, were used to monitor snowcover during the melt. These courses were sampled every 3 days during the melt season in 1972 and 1973. Snow depth, density, and water equivalent were measured at each stake. Location of the study area and sites of the transects are shown in Fig. 1.

RESULTS

Peak snow accumulation patterns

The data obtained from the peak accumulation surveys were examined for relationships between snowpack characteristics and topographic location and vegetation cover. No topographic effects were discernible from the snowcover data. Average snowpack characteristics as well as the variability of these characteristics are related mainly to vegetation cover. The data were divided into subsets based on vegetation cover of the sampling site. The resulting groups of data were used to construct cumulative frequency curves of the peak water equivalent which could all be fitted closely by normal distributions (Fig. 2).

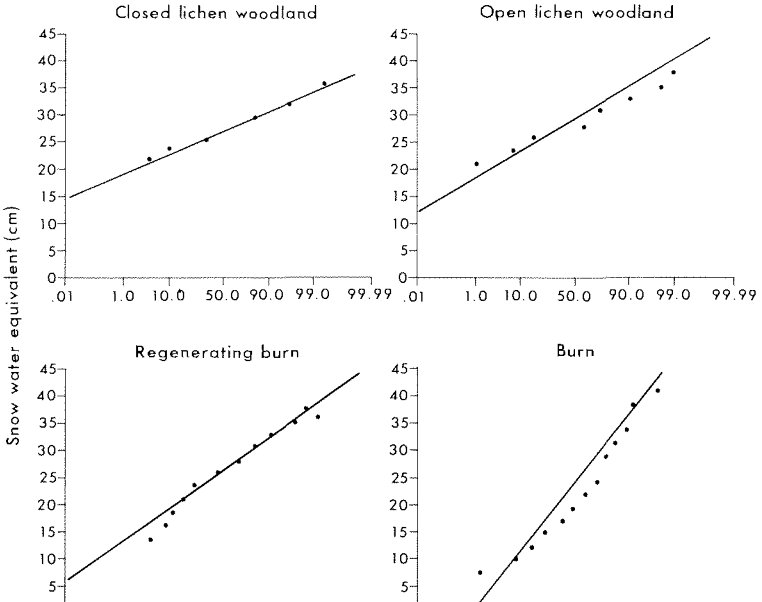

FIG. 2. Cumulative frequency curves of the peak water equivalent fitted by normal distributions.

Mean water equivalent varies from one year to the next as a result of differences in the amount of precipitation. Table 2, however, shows that the average accumulation varies with the vegetation cover. In both 1972 and 1973 average peak accumulation was greatest in open lichen woodland. Closed lichen woodland accumulated less and accumulation decreased even further in burn. A similar pattern has been found in the surveys conducted by other workers in the study area (see Table 3). Statistical tests of the differences indicate that accumulation in the open lichen woodland is significantly different (at 0.05 level of significance) from that in all other vegetation classes. The pack under the closed lichen woodland is significantly less than that under the open lichen woodland, and greater than that in the burned areas, but differences from regenerating burn may be due to sampling alone. The contrasts between burned areas and regenerating burns are not statistically significant although they agree in sign with the trends discussed here. Mean snow densities also show a strong relationship to vegetation cover. There is a progressive decrease in snow density with increasing vegetation cover (i.e. from burn to closed lichen woodland).

The variability of the snowcover as determined by the standard deviations of the distributions can also be related to vegetation cover. The magnitude of the standard deviation of water equivalents in each vegetation class shows remarkable consistency from 1972 to 1973. Water equivalent variability is least in the closed lichen woodland and increases with decreasing vegetation cover. Snow densities also show an increase in variability with decreasing vegetation cover.

Peak accumulation patterns

In as much as snowmelt rarely occurs during the accumulation season, differences in mean accumulation between vegetation classes must reflect the effects of snow drifting. Kungurtsev (1956) suggests that snow may be transported by wind on average 9.3 to 0.5 km and under extreme conditions as much as 2.0 km. Over greater distances an equilibrium between erosion and deposition of snow is achieved. Thus drifting would not produce differences in mean accumulation between large areas of uniform vegetation. In the study area the vegetation cover is segregated into small patches averaging 0.4 km in diameter. Thus snow transport between vegetation

TABLE 2. Peak snow accumulation data

	Water equivalent		Depth		Density	
Vegetation class	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
1972						
Burn	23.2	12.6	77.6	32.3	0.29	0.05
Regenerating burn	29.9	5.3	109.0	18.7	0.28	0.06
Open lichen woodland	34.3	4.6	128.8	17.5	0.23	0.05
Closed lichen woodland	29.5	3.4	116.8	14.1	0.24	0.02
1973						
Burn	25.7	10.26	95.4	35.6	0.29	0.04
Regenerating burn	28.4	5.8	112.4	17.0	0.25	0.03
Open lichen woodland	30.9	4.8	125.7	8.3	0.24	0.02
Closed lichen woodland	29.0	3.03	122.6	9.1	0.24	0.02

TABLE 3. Peak accumulation data collected by other researchers

Vegetation class	Water equivalent		Depth		Density	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Adams et al. (1965)						
Open (burn + regenerating burn)	31.2	13.7	110.5	37.6	0.28	—
Open lichen woodland	38.6	5.5	144.3	34.8	0.27	—
Closed lichen woodland	28.9	3.0	137.4	21.6	0.21	—
Rogerson (1967)						
Open (burn + regenerating burn)	33.0	12.1	105.2	33.8	0.31	—
Open lichen woodland	39.4	3.2	129.0	19.3	0.31	—
Closed lichen woodland	38.1	3.4	127.0	14.2	0.30	—
Granberg (1975)						
Open (burn + regenerating burn)	39.9	11.4	118.4	—	0.34	—
Open lichen woodland	40.4	5.4	127.0	—	0.32	—
Closed lichen woodland	39.7	2.9	131.3	—	0.31	—

classes occurs and is effective in creating different levels of mean accumulation for each vegetation class.

In general snow is transported from the open areas to forested sites. In the burn areas there is little vegetation cover to catch snow so drifting takes place throughout the winter. In the regenerating burn, snow is initially caught in the low shrubby regrowth. Once accumulation has covered most of the low trees, however, snow can be transported out of this vegetation class. Within the forested areas drifting is limited. The low density of the open lichen woodland allows snow to be transported into the forest from more open areas. In the case of closed lichen woodland which has a more uniform closed canopy, falling snow can be transported over the canopy thus reducing the total accumulation, and a small amount may be intercepted by the canopy and returned to the atmosphere.

Differences in mean snow density in the different vegetation classes are probably due to the packing of snow by wind drifting, since melting is very rare during the accumulation season. Densities are greatest in the burn where drifting occurs frequently, and least in closed lichen woodland where drifting is negligible.

Variability of the peak snow accumulation can also be directly related to snow redistribution. In the closed lichen woodland our measurements show that wind speeds average only 10–30 per cent of those recorded in open areas. Redistribution, however, is accomplished as snow is intercepted by the forest canopy and subsequently dumped into the spaces between trees. In open lichen woodland the open spaces between trees are relatively large and snow is caught preferentially. Also wind speeds within this forest average about 65 per cent of those recorded in open areas. This is sufficient to allow some limited drifting of snow within the forest. In regenerating burn, drifting becomes significant after the low shrubby vegetation is buried. Snow is eroded from places in which vegetation is absent and is caught by the occasional mature tree which survived burning or in topographically sheltered sites. In the burn, snow is eroded from the exposed sites and is deposited in the more sheltered locations. For example, snow is eroded from the crests of slopes and deposited on leesward slopes and in gullies.

The variations in density show similar patterns to those of water equivalent, that is, greatest variability in the more open areas and least in the forested sites. These patterns can similarly be attributed to the effects of snow drifting.

Snowcover during the snowmelt

Snow water equivalents, depths, and densities as measured throughout the snowmelt season in 1973 are shown in Fig. 3. Mean snow water equivalent and depth

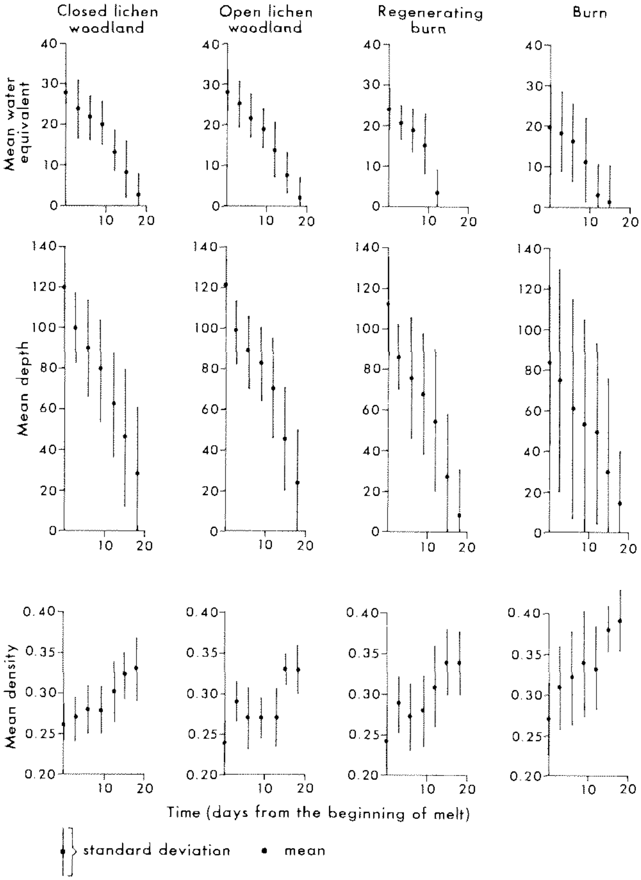

FIG. 3. Mean snowpack characteristics for the 1973 melt season.

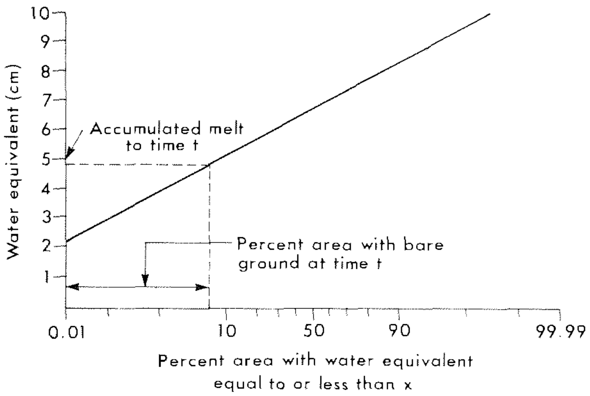

FIG. 4. Diagram for the calculation of the areal extent of snow cover.

TABLE 4. Percentage area of snowcover during the 1972 melt season estimated using snow courses, air photos, and peak accumulation distribution prediction method in conjunction with melt rates predicted from the US Army Corps of Engineers basin melt equations

Days from beginning of melt	Snow courses	Air photos (data from Granberg, 1975)	Peak accumulation distribution method	
			Plus observed melt	Plus predicted melt
Closed lichen woodland				
19	100	100	100	99.9
22	95	41	99.8	96.0
25	55	na	91.0	94.0
28	40	na	38.0	42.0
Open lichen woodland				
19	96	100	99.6	99.5
22	92	80	89.0	89.0
25	48	na	44.0	56.0
Regenerating burn				
14	93		99.9	99.9
16	93		99.5	99.5
19	93	93	78.0	87.0
22	33	77	20.0	44.0
25	13	na	4.0	9.0
Burn				
5	90		90.5	96.0
8	88		89.9	96.0
11	80		89.9	92.0
14	80		82.0	79.0
17	62		76.0	60.0
19		77	68.0	50.0
20	35	na	62.0	43.0
22	na	54	48.0	26.0

TABLE 5. Percentage area of snowcover during the 1973 melt season estimated using snow courses, air photos, and peak accumulation distribution prediction method in conjunction with observed melt rates and also in conjunction with melt rates predicted from the US Army Corps of Engineers basin melt equations

Days from beginning of melt	Snow courses	Air photos	Peak accumulation distribution method	
			Plus observed melt	Plus predicted melt
Closed lichen woodland				
12	100	na	100	100
15	80	na	99.4	99.9
18	40	37	67.0	72.0
21	15	na	9.0	40.0
Open lichen woodland				
15	100	na	99.9	99.5
18	80	40	86.0	99.0
21	16	na	16.0	7.0
Regenerating burn				
9	100	na	99.0	99.0
12	93	na	96.0	80.0
15	40	na	72.0	62.0
18	13	27	34.0	24.0
21	13	na	9.0	6.0
Burn				
7	97	na	94.5	96.0
10	90	na	85.0	85.0
13	62	na	60.0	65.0
16	23	na	38.0	48.0
19	13	7.5	16.0	22.0
22	8	na	7.0	11.0

generally declined during the melt season while snow density increased. With respect to vegetation class, melt rates were greatest in open areas and least in forested sites.

The standard deviations of the water equivalent, depth, and density measurements did not vary significantly from the beginning to the end of the melt. This was verified by calculating the *F* ratio between the standard deviations for each sampling during the snowmelt (for the 95 per cent confidence level). This suggests that the processes of melt may not increase the variability of the snowcover.

Prediction of the extent of snowcover

During the melt season trafficability in the field is difficult, if not impossible. As a result it is preferable to develop some indirect method of assessing and perhaps predicting the extent and nature of the snowpack. Martinec (1973) and Granberg

(1975) have suggested such a technique. In this method the percentage of the snow course sample with water equivalent equal to, or less than, a given amount is taken as the percentage of the area with water equivalent equal to, or less than, that value at any time during the melt season. Thus the areal extent of snow cover may be found by determining the percentage of the snow course samples with a peak water equivalent equal to, or greater than, the total snowmelt up to that time. This may be done graphically as shown in Fig. 4. The method assumes that snowmelt occurs uniformly over the surface of the snowpack. The validity of this assumption has not been tested, however. In this study this assumption is verified. Analysis of the distributions of snowcover as measured throughout the snowmelt showed that while the mean snow water equivalent declined during the melt there was no significant change in the variability of the snowcover distribution. Thus use of a mean melt rate for estimation of the areal extent of the snowpack is appropriate.

Testing of the prediction method

Tables 4 and 5 show the area of snowcover throughout the melt as estimated for each vegetation class using a number of different predictive techniques. Comparison of the snowcover estimates obtained from aerial photographs, snow course observations, and peak distribution with observed and predicted melt rates shows that all three methods agree during the early part of the melt. Later in the melt the photographic estimates as well as the others differ significantly from each other, suggesting that all the methods are subject to error late in the melt. The data suggested that the peak accumulation distribution method can give a useful estimate of the extent of snowcover where remote sensing or snow course observations throughout the melt season are not possible.

CONCLUDING REMARKS

In lowland subarctic regions where the vegetation is segregated into small areal units, drifting is the major determinant of snow accumulation levels and snow cover variability. The nature and extent of snow redistribution through drifting is controlled mainly by the vegetation cover.

Differences in mean accumulation result mainly from snow transport between vegetation classes. Variation of snowcover within a vegetation class is related to the structure and form of the vegetation as it controls snow deposition and drifting.

Peak snow accumulation within a vegetation class can be characterized by a normal distribution. Snowmelt, while reducing snow cover, does not create any increase in the variability of snowpack properties. These facts suggest the applicability of the peak accumulation distribution method for estimating the areal extent of snowcover during the melt.

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