Snow Depth/Area Relationships for Various Landscape Units in Southwestern Ontario

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ABSTRACT

Extensive field measurements conducted over the last six years in in southwestern Ontario have characterized the distribution of snow cover within various landscape units (e.g., cropped fields, forests, fence-lines and roadway easements). These measurements show that patterns of areal distribution of snow have predictably similar features for a given type of ground cover.

In this paper, we present the results of a statistical comparison of the areal distribution of snow cover for similar landscape units in twelve different locations in southwestern Ontario. The pattern of upper-limit capacity of snow-depth versus area covered appears to be stable, for a given landscape unit, from one year to the next and for units located some distance from each other.

Models of snow accumulation that include estimates of the spatial distribution of snow cover after redistribution by wind require retention relationships for snow cover in different landscape units as part of their calculation procedures. The stability of the capacity depth/area relationships (ADC's) makes it possible to apply snow-accumulation models to watersheds where no observations of snow cover are available.

INTRODUCTION

Enhanced knowledge of the amount and distribution of snow in a watershed would improve decisions of resource managers in a wide variety of action situations in which snow plays a controlling role. These actions include prediction of runoff amounts and streamflow peaks, managing snow distributions to provide desired soil-temperature regimes, creating and protecting animal habitat, providing recreational activities, and overall watershed planning. For accurate quantification of snow-cover distributions, numerous researchers have found that the snow amounts in different land-cover units must be distinguished, (Kuz'min, 1960; McKay, 1970; Stepphun and Dyck, 1974; Granberg, 1975; Adams, 1976; Goodison et al., 1981). Snow-cover models such as the Areal Snow Accumulation-Ablation Model (ASAAM) (Schroeter and Whiteley, 1987a and b; Schroeter et al., 1991), simulate the spatial distribution of snow depth and equivalent water content for shallow snowpacks within a watershed for the complete winter season by separately accounting for the snow amounts in different land-cover units.

Models such as ASAAM that account for variations of snow depth within landscape units after redistribution by wind make use of detailed snow-cover distribution measurements. To make it feasible to apply such models to a watershed it is commonly necessary to use a "typical" areal distribution curve (ADC) for a cover type based on the observed pattern at one or more locations. The basis from which typical ADC's can be constructed is different for "linear" and for "block" landscape units.

For linear features such as fencelines and roadways the ADC can be based on observed dimensions of a cross-section. For block landscape units, such as fields, typical ADC's for each cover type are constructed as cumulative frequency distributions of depth versus area. For units subject to snow redistribution the pertinent ADC for the upper-limit holding capacity can be determined from observed patterns of snow depth/area on dates when holding capacity has been reached. This holding capacity is very important in estimating snow-pack redistribution between land-cover units. So far it has not been possible to estimate the holding capacity pattern for the various land-cover units from physical measurements although a promising beginning is reported by Donald et al. (1991) in this proceedings.

The purpose of this paper is to determine whether snow-retention-capacity-depth/area relationships appear to be stable, in terms of a given land-cover unit, from one year to the next, and for similar units located some distance from each other. This was done by means of a qualitative assessment of observed snow depth/area patterns, and a statistical comparison of snow-depth-distribution measurements for similar landscape units in southwestern Ontario. These results are assessed to determine their implications for effective operational estimates of snow cover amounts.

STUDY AREAS

The data base available for this study includes more than 16,000 depth samples and 800 density samples collected by the authors as part of their graduate-study research on 43 different dates from 12 different locations in southwestern Ontario over the last six years (Table 1). Several of the locations - Waldemar, Jessopville, Corbetton, Damascus, Spring Creek and Canagagigue Creek - are Grand River Conservation Authority snow courses where intensive measurements were taken along the snow course line and in the surrounding area within different cover types (Fig.1). Other snow sampling locations within the Grand River watershed include sites in Elmira, Laurel Creek, Hanlon Creek, and at the University of Guelph. Snow data from the Pittock area and near Kettle Creek were collected as part of the Soil Water Environment Enhancement Program (SWEEP).

In southwestern Ontario, where these snow course are located, the winter snow cover is intermittent. Rainfall, thawing, and refreezing create ice layers within the snow pack and often at the ground surface also. Difference in net radiation and other heat fluxes among forests, fields, and forest edges results in marked differences in snow ablation rates and hence in residual snow depths during periods of melt. The greater accumulation of snow in linear elements such as roads, ditches, fences, and edges of forests is a distinctive feature created during redistribution by drifting and enhanced by slower ablation rates in these locations of deeper snow than in the open fields surrounding them.

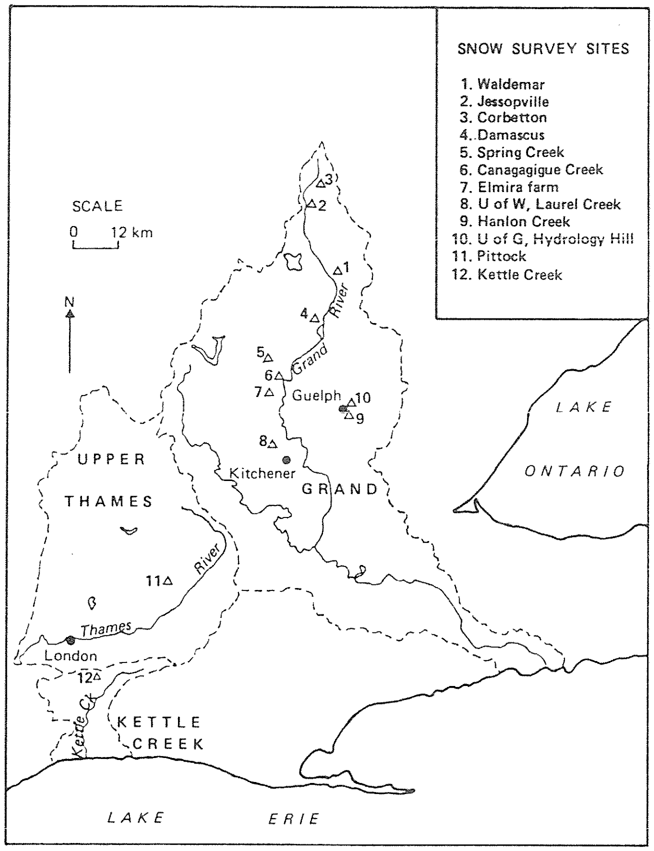

Figure 1: Locations of the snow survey sampling sites in southwestern Ontario.

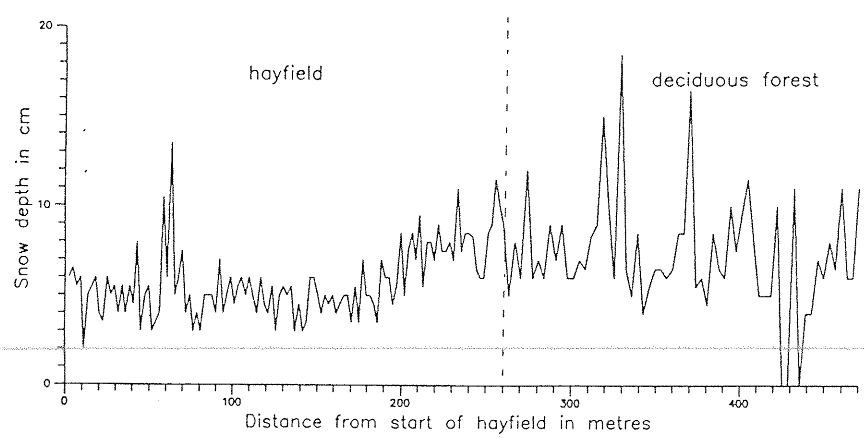

Figure 2: A sample survey line from the Elmira farm site (February 14, 1989) with snow depths plotted by distance.

Table 1: Summary of dates and cover types sampled at the snow survey locations.

SNOW SURVEY SITES	DATES	NO.	COVER TYPES SAMPLED
1. Waldemar	1986, 1987, 1989 1990, 1991	15	PF, CF, NG, SF
2. Jessopville	1986	7	CF, SF
3. Corbetton	1986	7	DF, NG
4. Damascus	1986, 1989	2	CF
5. Spring Creek	1989	1	DF, PF, CF
6. Canagagigue Creek	1989	1	PF, CF
7. Elmira (farm fields)	1989	4	DF, PF, NG, SF
8. U of W, Laurel Creek	1991	14	MF, PF, NG, SF
9. Hanlon Creek	1991	1	CF, NG, SF
10. U of G, Hydrology Hill	1985	1	DF, PF, SF
11. Pittock (2 sites)*	1990	4	DF, PF, SF
12. Kettle Creek (2 sites)*	1990	4	DF, PF, SF

Note:

CF - Coniferous forest
DF - Deciduous forest
MF - Mixed forest
PF - Plowed field
SF - Stubble fields (several types)
NG - Natural grass
* - SWEEP data

FIELD METHODS

Depths of snow were measured by inserting a wooden ruler or specially constructed steel probe through the snowpack to the ground surface. The distance-interval procedure used for measuring snow depth in edges differed from that in fields and forests. In the fields and forests snow depth samples were taken along linear snow courses at intervals of 4 to 6 walking paces (about 3 to 5 m). Sampling in tilled fields with distinct linear features was done along a zig-zag line to avoid biasing the sample. For road easements, fence lines, and forest edges, readings of snow depths were taken at intervals of one metre along a line perpendicular to the direction of the element. The distance of each of these readings from a reference point (e.g., centre of the road or of the fence) was determined using a 30-m tape measure. Figure 2 shows the variations in depth along a survey line.

OBSERVED SNOW DEPTH/AREA RELATIONSHIPS

In order to compare the snow depth profiles between cover types, locations, and dates, a characteristic structure for the snow cover pattern must be identified. Plots of snow depths with distance generally do not reveal quantifiable patterns (Fig. 2). Therefore, areal distribution curves (ADC's) were constructed by ordering the depths and calculating the cumulative percent of observations that equal or exceed each depth. The plotted cumulative frequencies show a clear pattern which can be compared with results from other studies (Dickinson and Whiteley, 1972; Schroeter and Whiteley, 1986; Schroeter, 1988) (See Figs. 3 to 7).

The comparison of ADC's for different cover types at times of highest snow accumulation indicates clear differences between cover types. This supports the conclusions from numerous previous studies (McKay, 1970; Goodison, 1981; Schroeter and Whiteley, 1986). Cover types with higher roughness elements, such as deciduous forests or natural grass (e.g., hayfields), tend to accumulate higher snow depths (Fig. 3). Cover types with more uniform roughness height across the terrain, such as a hayfield, have a lower range in measured snow depths than ploughed fields or forests where roughness height varies from place to place. Therefore, it can be assumed that snow-depth profiles for different cover types should be considered separately.

Exposed or wind-erodible cover types, such as ploughed fields, generally display a limited capacity to capture snow following a period when snow drifting occurs (Kuz'min, 1960; Schroeter and Whiteley, 1986; Schroeter, 1988). Once that capacity is reached any additional new snow deposited will be removed by subsequent drifting.Therefore the peak snow cover ADC's at the same location for different years should be similar if the cover type and its roughness are similar. Exceptions to capacity-limited behaviour can be created occasionally by sequences of wet snow events with little or no wind.

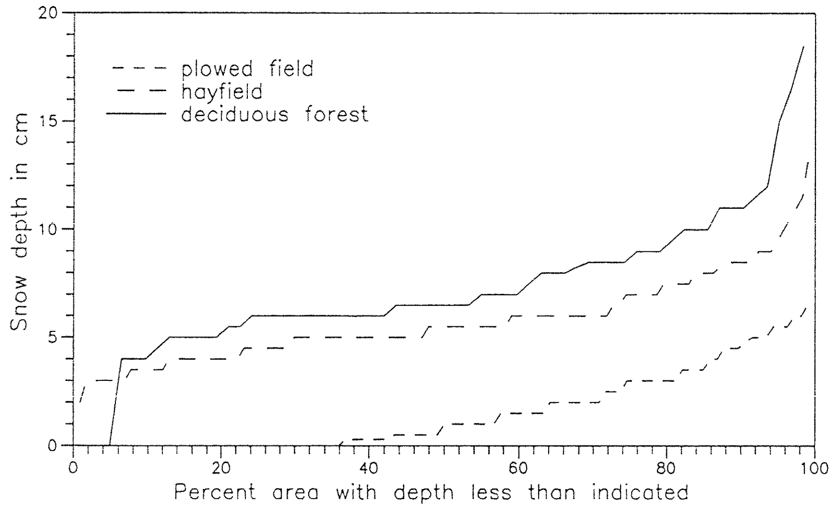

Figure 3: ADC plots of different land-cover types from the Elmira farm site on February 14, 1989.

Figure 4 shows that ADC's for the ploughed field at the Waldemar site on approximately the same date in February for five years. The date chosen is near the time of peak snow depth almost every year. The mean depths and shapes of the curves are similar except for 1987. In that year mean wind speed was below average, more total snow fell, many more events with an east wind occurred, and there were several events with wet snow. The result was an aberrant ADC with much higher mean and less concentration of snow in a few deeper drifts. Figure 5 shows the same similarity for the natural grassland site at Waldemar over five years. The curve for 1987 is again an outlier.

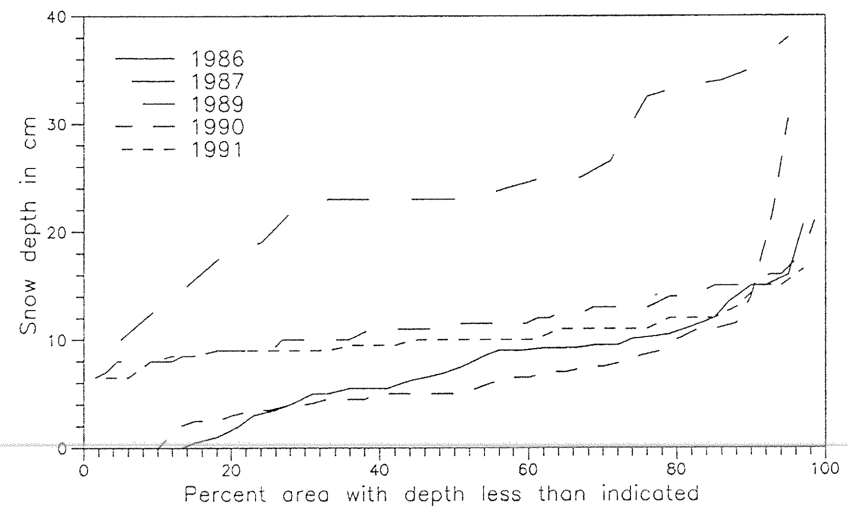

Figure 4: ADC plots of the same ploughed field at Waldemar between 1986 and 1991.

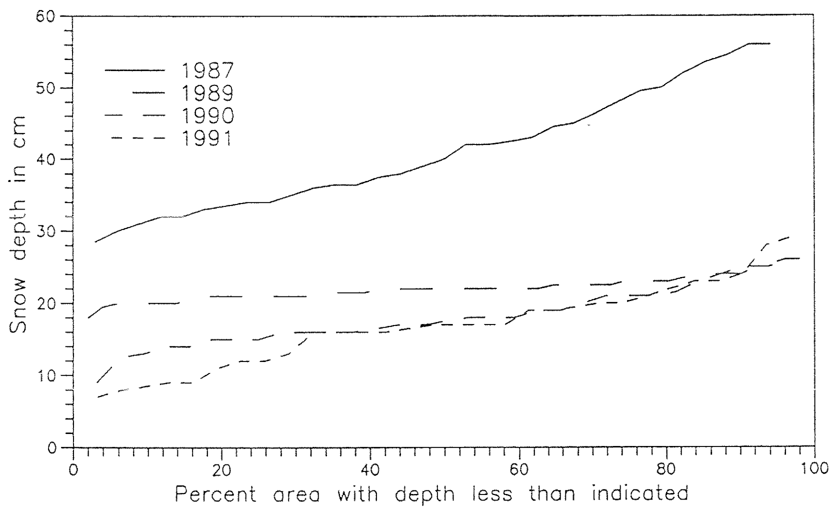

Figure 5: ADC plots of the same natural grassland at Waldemar between the years 1987 and 1991.

On February 27, 1989, several sites in widely spaced locations in the Grand River watershed were sampled on the same day. A qualitative comparison of snow surveys in different coniferous forest areas on that day shows that the general shapes of the ADCs are similar, even though each area received different amounts of snow inputs (Figure 6a). Moreover, a comparison of ploughed fields from varied locations also indicated that the shapes of the ADCs were similar (Figure 6b).

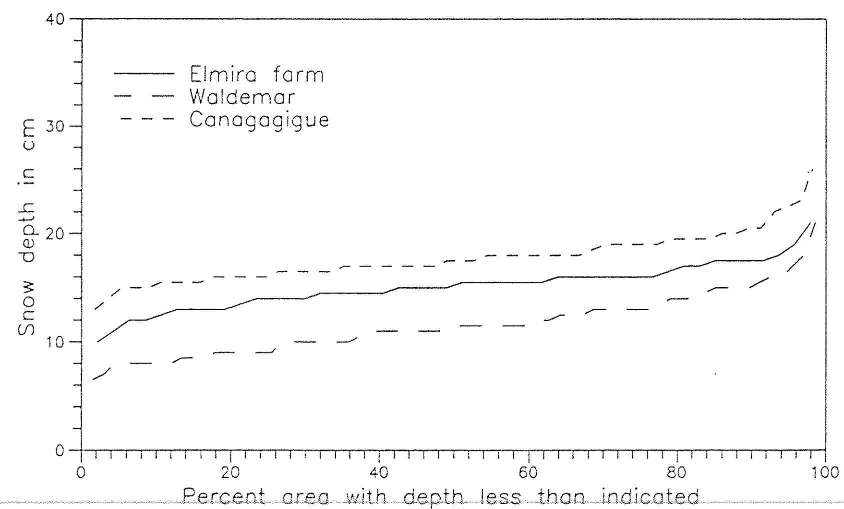

Figure 6a: ADC plots for ploughed fields in three different locations on the same date (February 27, 1989).

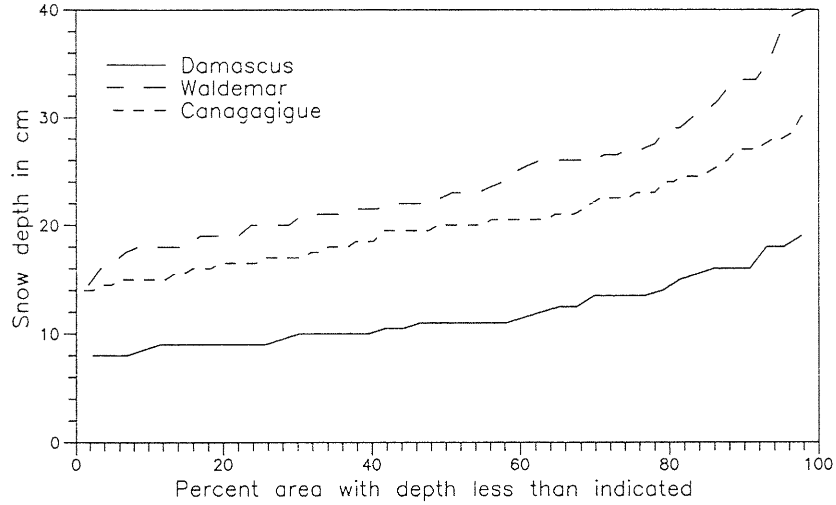

Figure 6b: ADC plots for coniferous forests in three different locations on the same date (February 27, 1989).

Although ADC's for a specific cover type are similar in shape throughout the winter, since the most important curve for erodible sites is the expected characteristic limiting-capacity curve, it is useful to compare snow surveys in different locations for dates when the snow cover is at or near its peak. Figure 7a shows that ADC's of forest sites (deciduous, coniferous, and mixed) from selected locations in southwestern Ontario for dates near maximum accumulation are alike in shape and appearance. Ploughed field ADC's from various locations also have similar ADC's (Figure 7b). Natural grassland, hayfields, and fields with residual crop stubble are compared in Figure 7c, and their ADC's too appear to be of similar shape although varying roughness height among them creates some change in mean depth. Therefore, the ADC's resulting from snow depth sampling of analogous land-cover types are visually similar.

ANALYSIS

From an extensive qualitative inspection of the many ADC's, one is left with the impression that differences between dissimilar cover types are visible between Figures 4 and 5. The same type of land-cover unit measured at different locations produced very similar curves (Figures 6 and 7). However, a more quantitative assessment of which ADC's are similar and which are different was sought.

The coefficient of variation (CV) has been used in studies to statistically characterize the distribution of snow (Stepphun and Dyck, 1974; Adams, 1976; Fitzgibbon, 1976; Stepphun, 1976; Fitzgibbon and Dunn, 1979). Therefore the CV was used as a surrogate value to represent the shape of the ADC's. Figure 8 demonstrates how variations in the CV produce changes in the shape of the cumulative frequency pattern. The calculations for this figure use a normal distribution, with a mean depth of 25 cm illustrated.

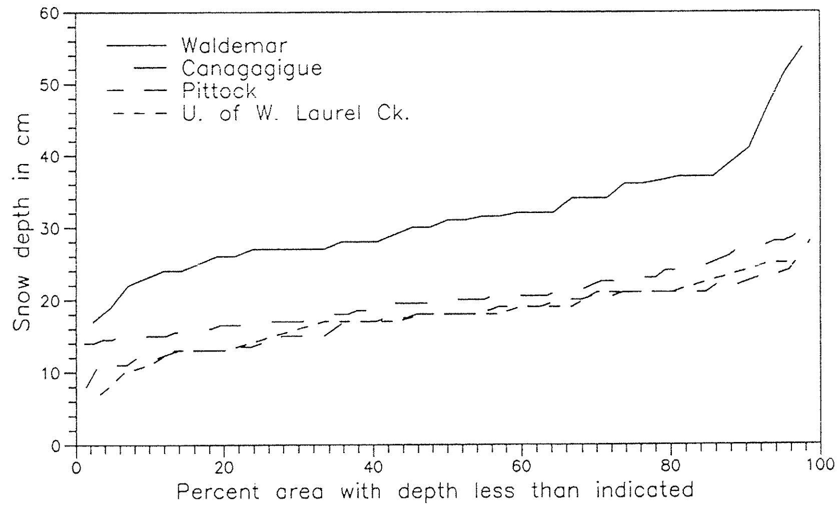

Figure 7a: ADC plots for coniferous forests at Waldemar and Canagagigue, a deciduous forest at Pittock, and a mixed forest at the U. of W. campus near Laurel Creek.

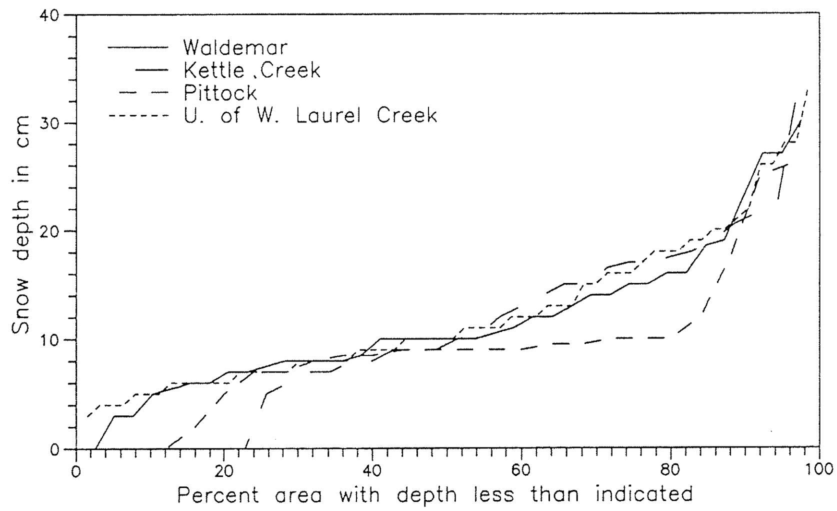

Figure 7b: ADC plots for ploughed fields at Waldemar, Kettle Creek, Pittock, and the U. of W. campus near Laurel Creek.

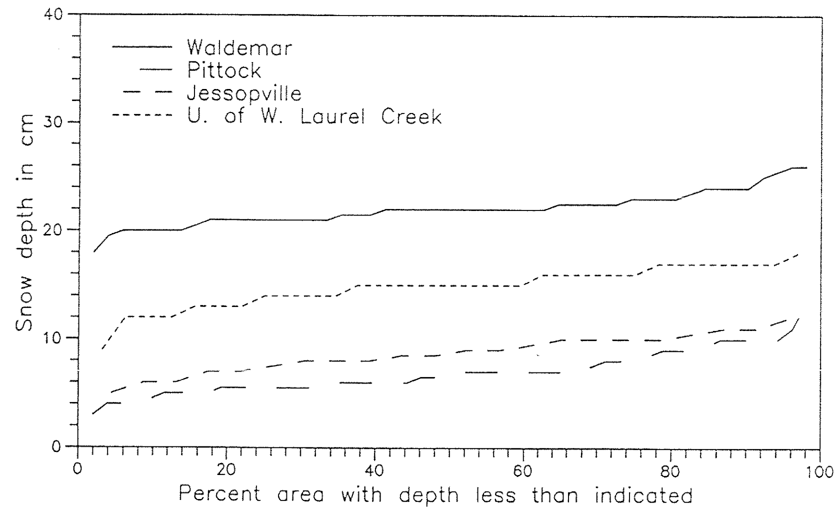

Figure 7c: ADC plots for a natural grassland at Waldemar, a no-fall-till bean field at Pittock, a stubble cornfield at Jessopville, and a grassy field at the U. of W. campus near Laurel Creek.

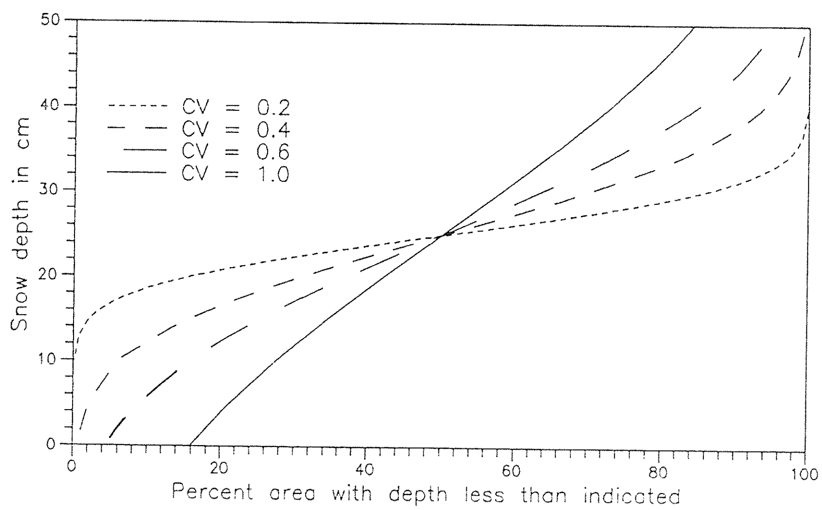

Figure 8: ADC plots of Coefficients of Variance derived from a normal distribution with mean depth 25 cm.

Standard analyses of variance presume the data points in samples are independent. To test for independence the depth data from the observation lines were subjected to the Spearman Rank Order Statistic and the Autocorrelation Function up to lag 20 (Kite, 1977; Viessman et al., 1977; Chatfield, 1984). Both tests indicated that the data points were random and independent. We were thus able to use standard analyses of variance to check for significance of differences. At each location, the CV's were computed for each distinct cover type and were compared with other cover types and between different dates using a two-way analysis of variance test (Spiegel, 1975; Freund, 1988).

Snow survey data were available for several dates at the following three sites: Waldemar (1986/87/89/90/91), U. of W. Laurel Creek (1991), and Jessopville (1986). A two-way analysis of variance was used to test the null hypothesis that there was no difference between the coefficient of variation of the snow depths between dissimilar cover types and the null hypothesis that there was no difference between CV's from snow surveys done at the same location on different dates (Table 2). At the Waldemar site, there was a significant difference between the CV's of coniferous forest, natural grassland, and a ploughed field at the 95% confidence level. This verifies the differences observed in the ADC's for each of the same cover types discussed in the previous section. There was no significant difference between the CV's derived from snow courses sampled at different dates between the years of 1986 and 1991. This indicates that the shape of the ADC's essentially remain similar for a number of different years.

At the U. of W. site in the Laurel Creek watershed, significant differences were found between the CV's derived from snow depths sampled in a mixed forest, a stubble hayfield, and a ploughed field. The site was sampled on 14 dates between January 1 and March 1, 1991, and there was no significant difference at the 95% confidence level between the CV's derived for different survey dates. Again, this suggests that the shapes of the ADC's for different cover types at the same location remain similar throughout the winter, a conclusion supported by the previous results for the Waldemar site.

In addition, there was also no significant difference between the CV's from snow surveys of different dates in 1986 at the Jessopville site. Unlike the other sites, there was no significant difference between the CV's of the coniferous forest and the wheat stubble field. The coniferous forest at this site was recently planted and had open grassy spaces and therefore was subjected to some wind. Thus, the results indicate that these two cover types would have similarly-shaped ADC's.

The second part of the analysis was to use a one-way analysis of variance test (Freund, 1988) to determine whether the CV's of similar cover types at different locations in southwestern Ontario on various dates representing peak snow covers are significantly different. The various cover types sampled were divided into three characteristic cover types as follows: forest (deciduous, coniferous, and mixed), ploughed fields, and stubble fields (natural grassland, hay stubble, corn stubble, and alfalfa). The coefficients of variation from several locations with the same cover type were analysed for significant differences using the one-way analysis of variance test (Table 3). In all cases the null hypothesis of no difference could not be rejected at the 95% confidence level. Therefore, the shapes of the ADC's for each main cover type are not significantly different at the 95% confidence level regardless of location in southwestern Ontario.

CONCLUSIONS: IMPLICATIONS FOR MODELLING OF SNOW COVER

Several conclusions based on the results reported in this paper are summarized briefly below. A few remarks about the implications of these findings for effective snow cover modelling are given as well, together with some suggestions for setting up a model of snow cover.

1. Areal distribution curves (ADC's) for a particular cover type measured at a specific site have similar shapes throughout a given winter, and for other winters. Moreover, limiting-capacity ADC's for the same cover type measured at several different locations scattered about southwestern Ontario are similar. This finding means that models of snow cover which use ADC's as a direct input to the snow distribution calculations, can be set up directly for operational snow cover estimation work in any watershed within the same geographical area using detailed snow survey measurements from a few sites.

2. For accurate modelling of snow cover distribution, a minimum of three different "areal" cover types must be represented in the model set-up. These can be grouped according to representative vegetative cover heights such as: low (e.g., ploughed fields), medium (e.g., grass or stubble fields), and high (e.g., forests).

Table 2: Summary of Two-Way Analysis of Variance Tests at Waldemar, U. of W. (Laurel Creekl), and Jessopville snow survey sites.

LOCATION	COVER TYPES	NO. [1]	COVER[2]	DATE[3]
WALDEMAR	CF, PF, NG	15	Reject	Accept
U of W, Laurel Ck	MF, PF, SF	14	Reject	Accept
Jessopville	CF, SF	7	Accept	Accept

CF - Coniferous forest MF - Mixed forest NG - Natural grassland
PF - Ploughed field SF - Stubble field

1 Number of dates sampled

2 Accept/reject the null hypothesis of no difference between coefficients of variance of various cover types (95% confidence level)

3 Accept/reject the null hypothesis of no difference between coefficients of variance from different dates (95% confidence level)

Table 3: Summary of the One-Way Analysis of Variance Test on Coefficients of Variance of the Same Cover Type at Different Locations.

COVER TYPE	FOREST[1]	PLOUGHED	STUBBLE[2]
LOCATIONS COMPARED	Waldemar U of W Kettle Creek Pittock Canagagigue Damascus Elmira Farm	Waldemar U of W Kettle Creek Pittock	Waldemar U of W Kettle Creek Pittock
HYPOTHESIS TEST[3]	Accept Null	Accept Null	Accept Null

1 FOREST includes coniferous, deciduous and mixed forests.

2 STUBBLE includes natural grassland, hay stuibble, corn stubble and alfalfa.

3 NULL HYPOTHESIS is that there is no difference between the coefficients of variance derived from snow depths from different locations in southwestern Ontario (95% confidence level).

CONCLUSIONS (continued)

3. For setting up a model of snow cover in a geographical location not covered by available sample data we suggest that the measurements of the distribution of snow cover be collected for the three major cover types using the following criteria to decide when to collect samples.

    a) Sample the distribution of snow depths in the various cover types near the time of peak accumulation, or after a period of about 25 to 40 days of continuous snow cover.

    b) For erodible cover types (e.g., ploughed and cropped fields), the measurements should be carried out after a period when significant snow drifting has occurred so that the cover type will have a chance to attain its limiting snow-holding capacity.

    c) In at least one winter, sample the snow cover on a least five dates during the period leading up to peak snow accumulation (that is about once a week for five weeks). This will ensure that the limiting-holding-capacity ADC will be identified for erodible blocks. Sampling on a single date in any given winter could lead to a biased estimate of the holding-capacity ADC if the accumulation period leading up to the sampling date is characterized by snowfall deposition without the normal associated wind drifting.

d) Measurements of the distribution of snow depths for several cover types can be collected rapidly in one field day by a single snow surveyor operating alone with a ruler and a tape recorder.
e) Sampling lines of snow depths should encounter some of the edge effect areas allowing the transition between a cover type and edge area to be clearly delineated.

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