SNOW AND GROUND THERMAL REGIMES IN A SUBARCTIC WOODLAND

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ABSTRACT

The thermal regime of a snowpack and of ground material in an open woodland can exhibit great spatial and temporal variation during winter and spring months. Temperatures of near-surface layers of the ground, snowcover and snow-ground interface were intensively monitored between October 1986 and May 1987 at an open woodland site near Schefferville, northern Quebec.

Mean temperature profiles and interface measurements displayed great variability with changes in air temperature, snow depth, tree shadow, soil properties and different microtopographic and microclimatic parameters. Freezing and thawing depths are compared with the energy exchange near the surface layers of the ground and the snowcover, and changes in thermal regimes are evaluated. In addition, results of snow temperatures from intensive monitoring techniques are also compared with snow temperatures obtained by destructive sampling surveys near the site.

INTRODUCTION

The influence of seasonal snowcover on ground material has been widely reported in the literature (e.g. Atkinson and Bay, 1940; Berggren, 1940; Gold, 1963; Goodrich, 1982). Heat and mass transfer processes within the snow and ground mediums have been also well documented (e.g. de Quervain, 1972; Farouki, 1981; Palm and Tveitereid, 1979; Peck, 1974). However, the thermal variations of snowcover and ground material have not been fully investigated, **spatially or temporally**. The objective of this paper is to show spatial and temporal variations in thermal regimes within a snowpack, ground material and at the snow-ground interface in a subarctic woodland.

In a forest environment, the interception of snowfall by trees can most definitely cause spatial variations in snow depth and snow temperatures (Bates and O'Brien, 1985). The presence of cavities around tree branches near the ground may induce considerable localised cooling as a result of free convection and to some extent affect the temperature regime at or near the surface of the ground.

Study Area and Methods

The study was conducted in Schefferville near stake 10 of the McGill Subarctic Research Station (see Fig. 1 in Desrochers and Granberg, 1986a). Instrumentation at the 10 x 10 m site consisted of ground thermistor cables at depths of 0.5 to 100 cm, thermistors at the snow-ground interface at intervals of 100 cm along six transects, thermocouple sensors within the snowcover at levels varying from 0.5 to 90 cm above ground surface and a series of other micrometeorological measurements (see Fig. 3 in Desrochers and Granberg, 1986a). All sensors were monitored by a datalogging system. This paper will deal with the thermal regimes of the lower 5 m of the study array.

Snow Temperatures

Time-depth patterns of mean daily snow temperatures at four locations on the study array are shown in Figure 1. The snow temperature sensors measured snow-air interface temperatures when uncovered. However, when covered the sensors revealed the diurnal temperature regime that exists below the snow-air interface and the great insulating properties of the snowcover.

Diurnal temperature fluctuations occurred on both a short-term (i.e. a few hours to days) and long-term (i.e. several days to weeks) basis. Temperatures within the top 10 to 35 cm portion of the snowcover tended to respond to short-term variations in mean daily air temperature. On the other hand, temperatures below this portion responded to long-term variations in mean daily air temperature. In both cases, damping depths and warming/cooling effects were a function of snow depth, and isotherms had the tendency to slowly migrate upwards with increasing snow depth. A monthly total snowfall of 55 cm in February permitted snow temperature isotherms to migrate upwards by 10 to 35 cm and maintain their positions for about 30 days. A combination of fluctuating air temperatures, occasional snowfalls and onset of snowmelt thereafter allowed isotherms to slowly increase to isothermal conditions.

Three distinct thermal stages in the development of the snowpack were detected: (1) cold conditions (i.e. temperatures less than -1.5^{o}C); (2) isothermal and wet conditions (i.e. temperatures that ranged between -1.5 and 0^{o}C); and (3) no snow conditions. Cold snowpack conditions were observed between the end of October 1986 and mid-March 1987. Warming trends and isothermal conditions within the snowcover were initiated in early April and the entire snowcover was depleted by mid-May.

Diurnal snow temperature fluctuations at two locations on the study array are shown in Figure 2. Fluctuations tend to disappear below the top 10 cm of the snow surface and are in response to air temperatures and incoming solar radiation. Cold and dry snowpack conditions are depicted in Figures 2a and 2b and temperature profiles attaining isothermal and wet conditions are shown in Figures 2c and 2d. The range in temperature in the top portion of the snowpacks versus those slightly above the interface are very striking.

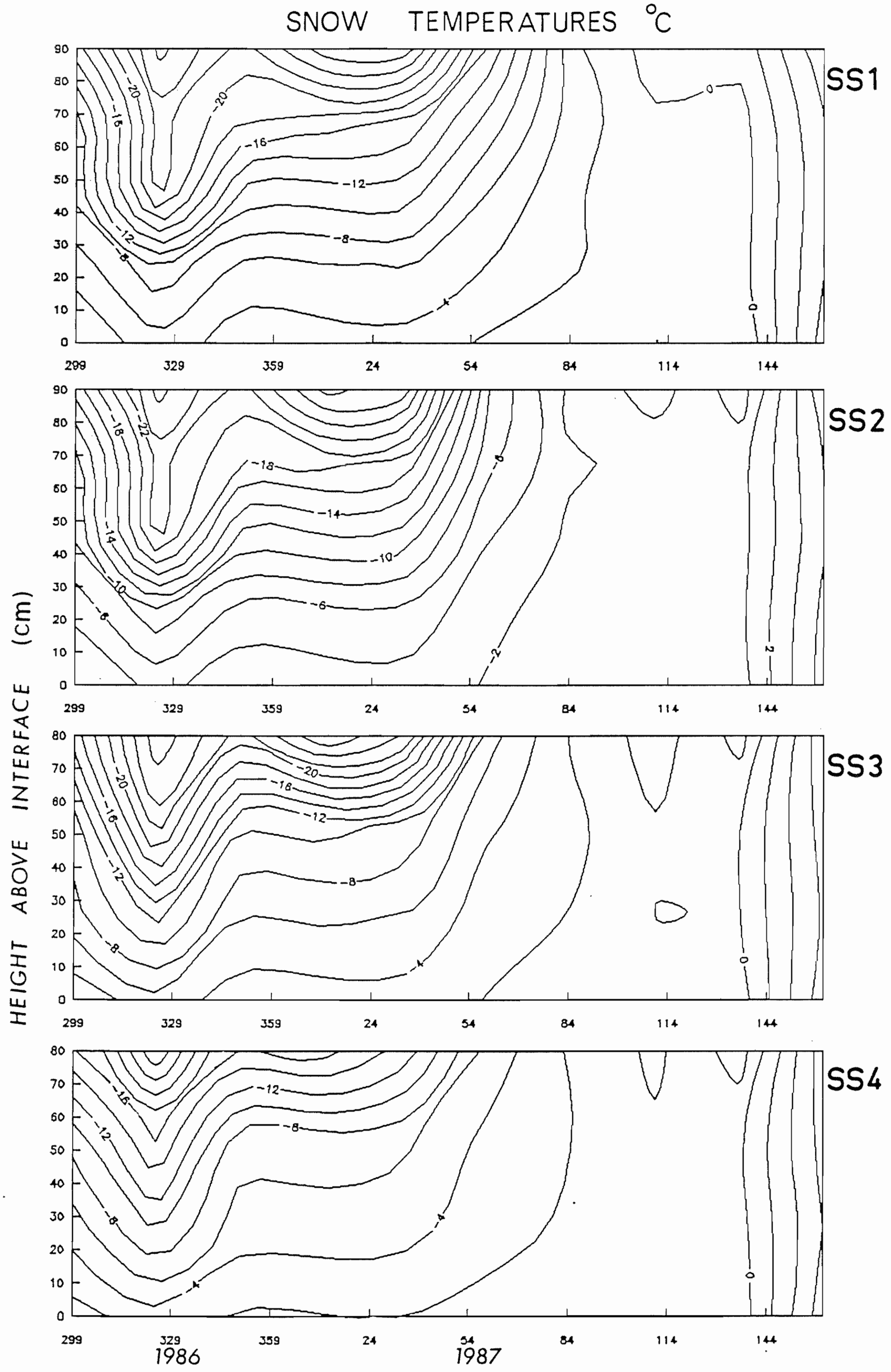


Figure 1. Time-depth patterns of mean daily snow temperatures for four snow sensors located on the study array (Oct. 26, '86 - Jun. 8,'87).

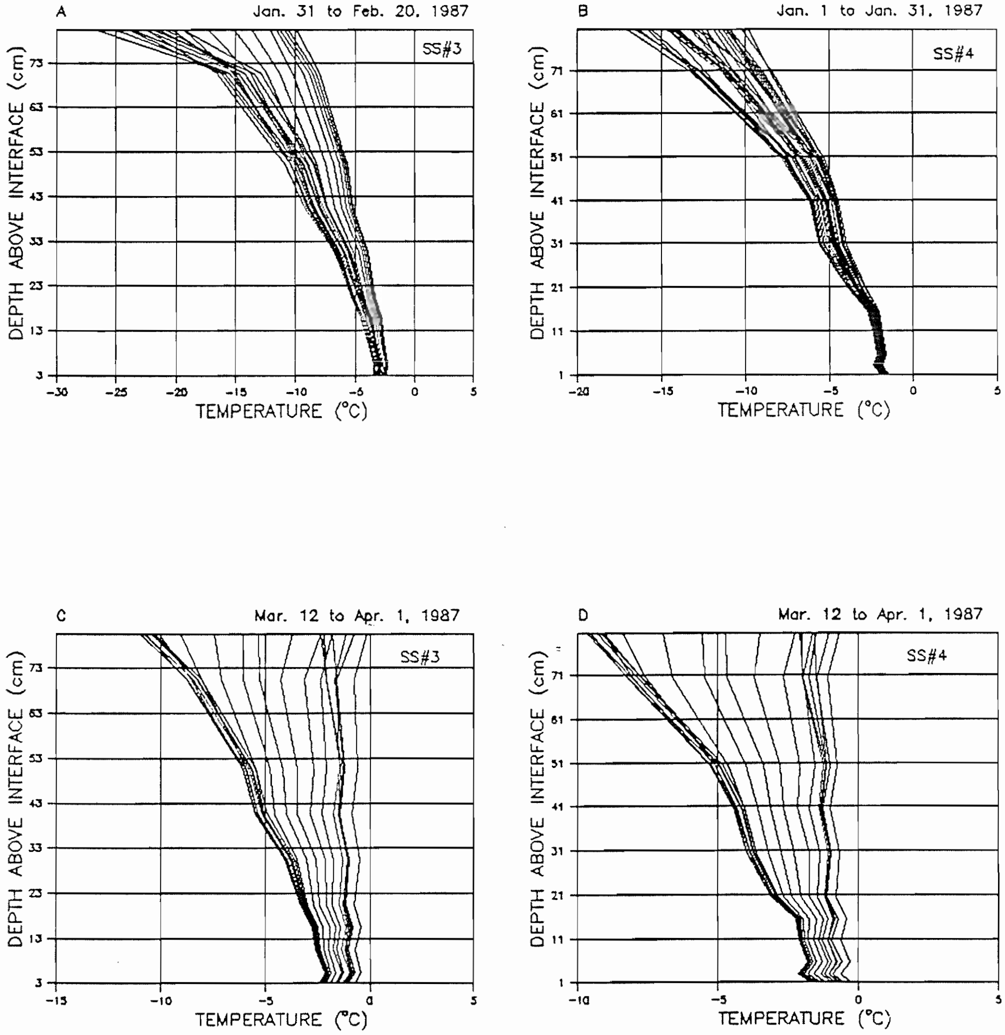


Figure 2. Mean daily snow temperature profiles for two snow sensors in mid-winter and springtime snowpack conditions.

Figures 3a and 3b indicate snow temperatures that are 3 to 8^{o}C cooler at Snow Sensor #1 (SS#1) than at Snow Sensor #4 (SS#4). The latter is located within a tree canopy and the former in a forest opening. Warm temperatures within the snowpack were first detected near day 81 at 50 and 80 cm above the ground surface and not fully isothermal at the interface until day 131. The 80 cm level at SS#1 is not covered by snow and thus indicates the time lag of the high and low temperature values within the snowpack. The same level at SS#4 is only 15 cm below snow surface and the influence of the low air temperatures were felt at the 50 cm level but not at the interface. Each snow sensor experienced different radiative effects since forest cover density ranged from 8 to 20% and such obstructions as branches and shadows were always present on the study array during clear sky conditions. Therefore, the occurrence of radiation cooling on certain sensors is probable and also dependent on the presence of obstructions.

As reported by LaChapelle and Armstrong (1977), temperature gradients within a snowpack are dependent on long-term mean air temperatures and snow depth conditions. Mean daily snowcover temperature gradients at all four snow sensors fluctuated in response to low air temperatures, shallow snowcover conditions in early winter (i.e. November to January) and in some cases outgoing long-wave radiation. Temperature gradients decreased with increasing snow depth at various times during the study, and SS#4 was the first sensor string to indicate gradients below 0.1^{o}C cm^{-1} in late January while SS#3 and SS#2 did not reach this value until mid-February.

Depth hoar varied from 10 to 50 cm in thickness during the observation period. Temperatures in the depth hoar layer remained very stable from early December to mid-February and increased over a one week period thereafter as a result of increasing snow depth. Snow characteristics showed deterioration of the depth hoar layer, an increase in pore space between grains, a decrease in temperature gradient and a gradual transformation from dry solid forms to saturated round forms for snow in contact with the snow-ground interface.

Variations in snow depth were primarily caused by exposure to wind and interception of snowfall by trees and shrubs. Maximum snow depths ranged from 65 cm at SS#1 to 105 cm at SS#4 between mid-February and mid-March. These snow depths were representative of snow conditions in nearby woodlands with exception only to slight snow drifting in strategic locations and lack of snow beneath trees with large crowns.

Interface Temperatures

Mean weekly snow-ground interface temperatures for five weekly periods between October '86 and April '87 for the lower half of the study array are shown in Figure 4. The resolution of the temperature data and the proximity of the interface sensors indicate that spatial and temporal variations are greatly affected by the thermal regimes of both the overlying snowcover and underlying ground material. The interaction of these two mediums appear to create a layer or zone that, at times buffers incoming and/or outgoing amounts of energy.

According to Goodrich (1982), both the insulating snowcover and the soil latent heat maintain interface temperatures near the freezing point

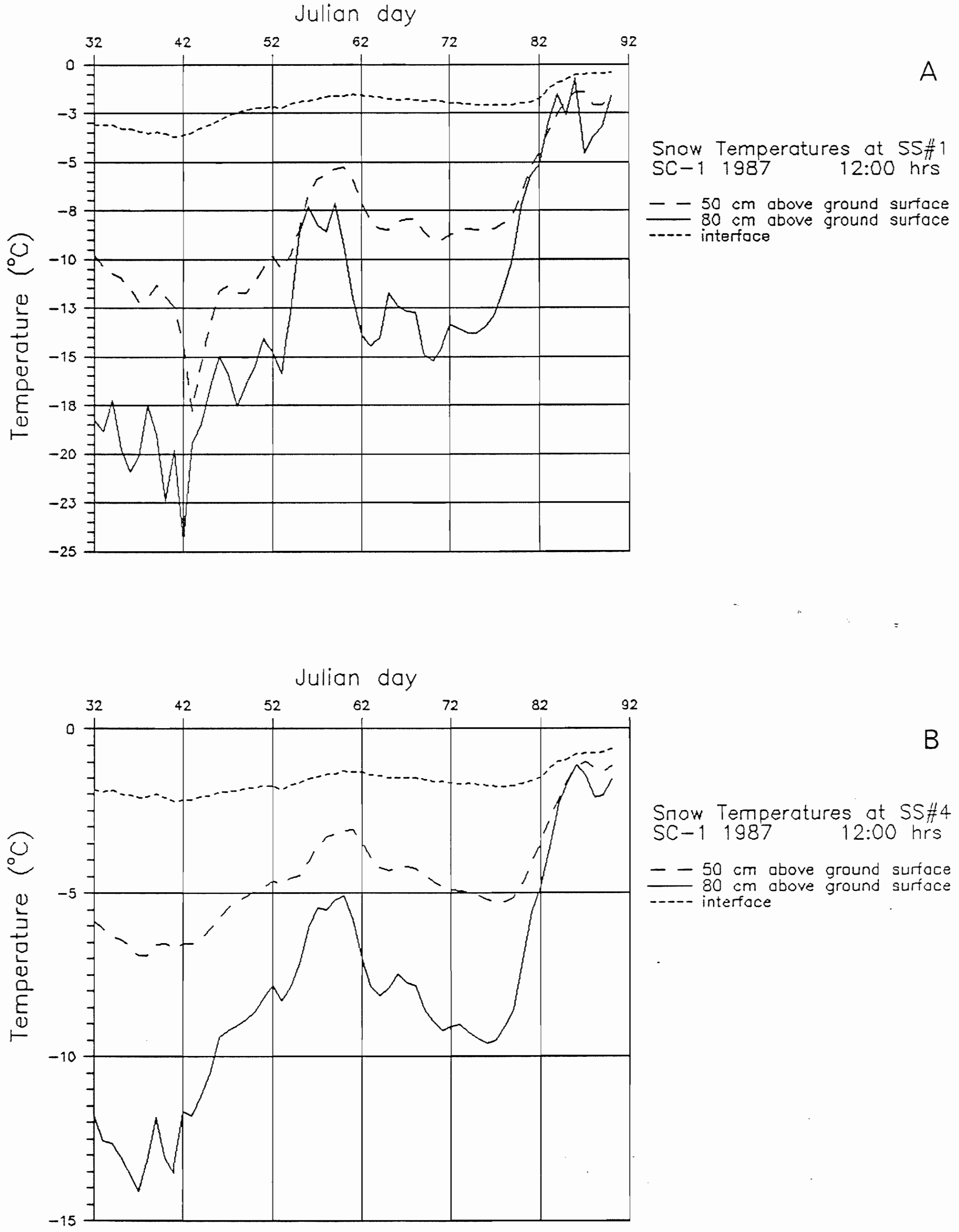
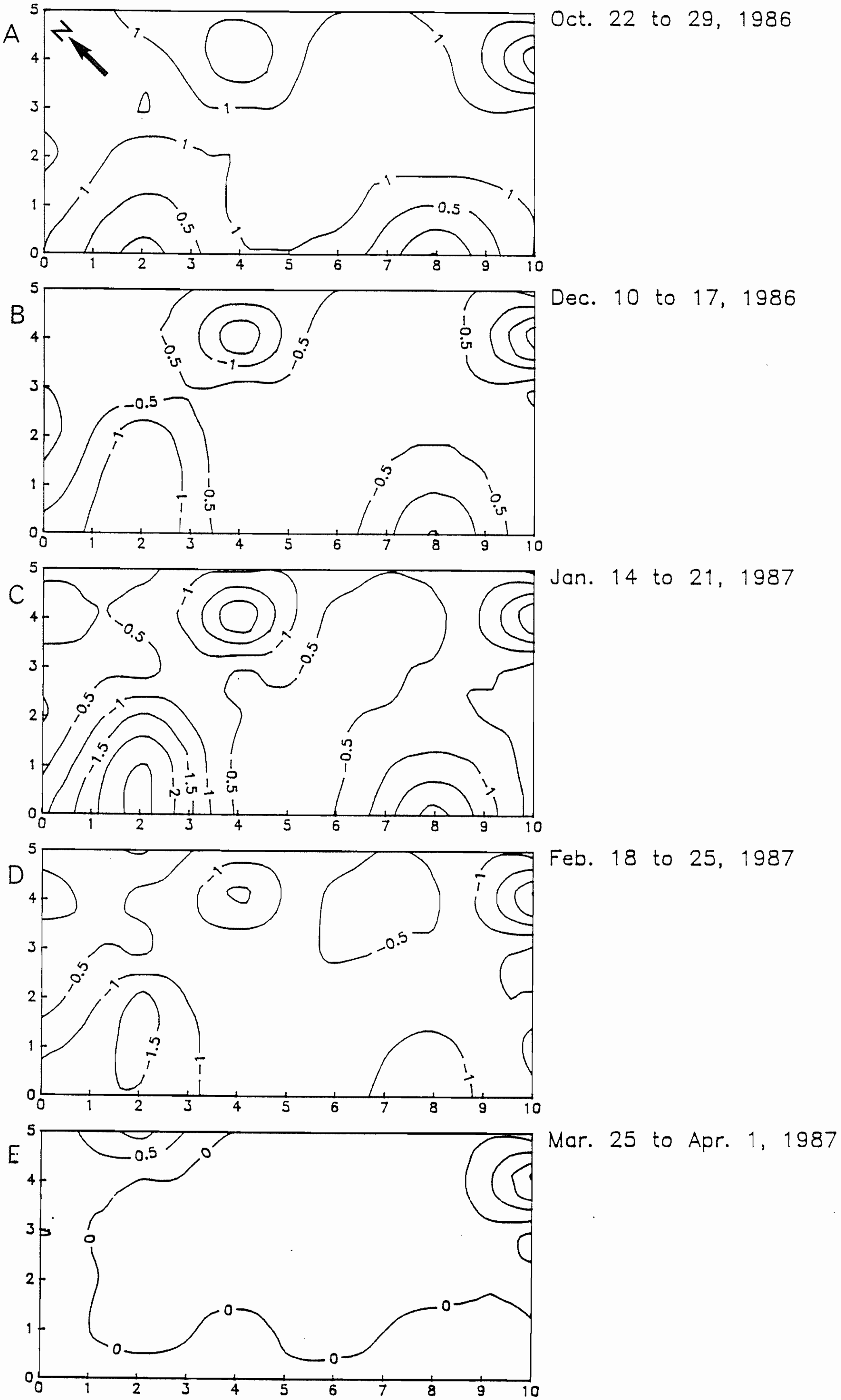


Figure 3. Time-depth patterns of two snow sensors at the 50 and 80 cm levels within the snowpack and at the interface on the study array. (A) beneath a tree. (B) forest opening.


A Oct. 22 to 29, 1986

B Dec. 10 to 17, 1986

C Jan. 14 to 21, 1987

D Feb. 18 to 25, 1987

E Mar. 25 to Apr. 1, 1987

Figure 4. Contour plots of mean weekly snow-ground interface temperatures for the lower half of the study array. Units for axes are in metres and temperatures are in degrees Celsius.

throughout winter. Observations at this site indicate that a number of temperatures at the interface are indeed near the freezing point (i.e. ± 0.5°C) and that many are also distant from it. The stability of interface temperatures at certain times over the winter is attributed to the overlying cold snow temperatures. Mean interface temperatures in early to late winter were consistently in the range of -0.5 to -1.0°C in medium to deep snowpack conditions and -1.0 to -5.5°C in shallow snowpack conditions and locations beneath trees.

The pattern and progression of temperatures on the study plot between early winter and spring are also shown in Figure 4. The presence of fallen tree trunks and thick vegetation mat at the interface had an important influence on the transfer of heat between the ground surface and the snowpack. For example, the contours tended to follow the patterns and/or shape of certain obstructions on the ground surface. The contours in Figure 4a display temperatures above freezing point for most locations on the array following the first major snowfall. Cooling interface temperatures allowed air temperatures to penetrate near-ground surface material to a depth of 5 to 10 cm. These conditions were maintained well into mid-December (Figure 4b) and January (Figure 4c) until a significant increase in snow depth and air temperature in February (Figure 4d) kept interface temperatures very stable throughout the array. Isothermal conditions during snowmelt appeared consistent in that temperatures were within ± 0.5°C while interface temperatures following snow depletion showed greater variation as a result of microrelief, vegetation, surface moisture and exposure (Figure 4e).

A remarkable relationship exists between snow depth and temperatures at the interface. The spatial variations in Figure 5 show that snow depth and interface temperatures reflect the extent of the spatial variations for a 10 x 11 m array near the open woodland site. The coldest temperatures in the array on February 21, 1985 between 11:00 and 16:45 hrs ranged from -3 to -13°C and the warmest temperatures hovered below freezing point. The data for this particular survey were obtained from a temperature probe technique described by Desrochers and Granberg (1986b). The effect of cold air temperatures during the survey were still in evidence at the 10 cm level below snow surface, particularly near tree trunks where temperatures were up to 4°C cooler than ambient air temperature (Figure 5b). At 60 cm below snow surface, the thermal regime still reflected cold temperatures near vegetation obstructions (i.e. underbrush and branches), but also indicated relatively uniform temperatures in forest openings (Figure 5c). In addition, snow-ground interface temperatures showed much warmer temperatures in forest openings than in areas beneath trees and shrubs (Figure 5d).

Ground Temperatures

A great deal of the spatial and temporal variability in ground temperatures are associated with freezing in the fall and winter periods, thawing in the spring and gradual warming over the summer. The snowcover at this site acted as a thermal insulator during the early stages of frost penetration and spurred the rise of ground temperatures in thawing periods. It has been shown that the release of soil latent heat during winter maintains cooling at depth, but also induces greater freezing intensity

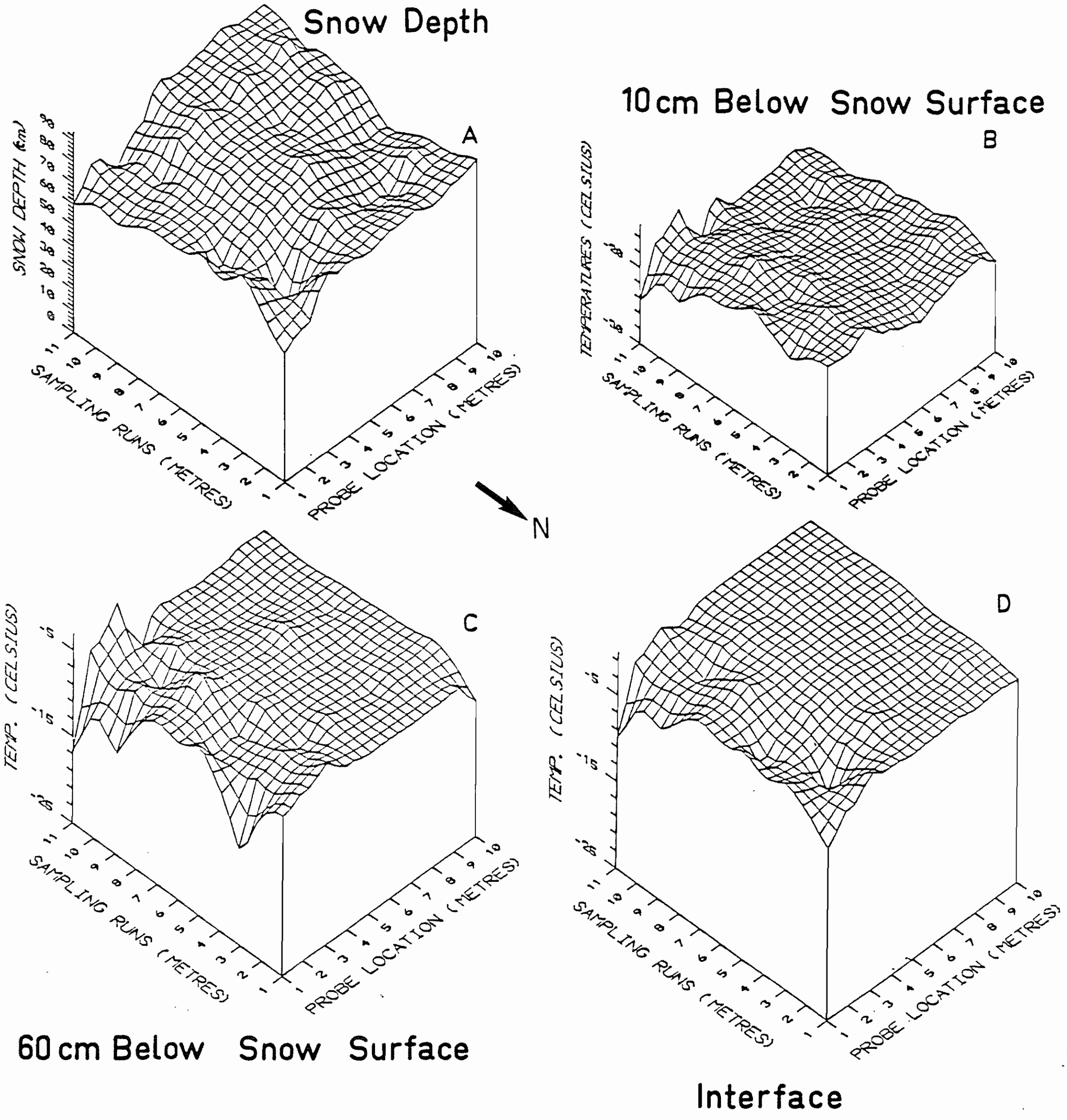


Figure 5. Spatial variations in snow depth and snow temperature on a 10 by 11 metre array obtained by a snow thermometry technique (February 21, 1985).

(Goodrich, 1982).

Mean daily ground temperatures for each ground cable at the site are shown in Figures 6a to 6d. The zero curtain effect, denoted by the ± 0.5°C isotherms, at Ground Cables #1, #3 and #4 were very similar with depth throughout the monitoring period. Sudden fluctuations in the temperature regimes are attributed to microrelief conditions and/or location on the array. For example, GC#1 experienced the coldest mean ground surface temperature on the array (3°C). Its location beneath a 4 m high black spruce favored very shallow snow conditions and allowed cold temperatures to penetrate throughout the winter period. Frost penetration following the first snowfall represents the greatest effect because of lack of snow beneath trees, exposure to cold temperatures and no insulating barrier on the ground surface, as well as effects from thermal and physical properties of the soil.

During the observation period, frost penetration (i.e. the maximum depth of 0°C in soil) varied from 10 to 50 cm. Thawing depths were very similar for each cable (i.e. they followed the depth of the zero curtain) and initiated in late March with temperatures remaining stable for about 30 days thereafter. This coincided with depletion of the snowpack above and near each cable. Positive zero curtain temperatures were maintained until mid-May to a depth of at least 100 cm only to be increased by seasonal air temperatures thereafter.

Summary

In summary, ground temperature profiles and surface temperatures displayed great variability with changes in air temperature, snow depth, and different microtopographic and microclimatic parameters. Although soil moisture and specific microclimatic parameters are not discussed in this paper, they also cause thermal variability in the ground and on the interface. Mean annual ground temperatures for near-surface layers varied by 1 to 1.5°C at four locations on the study array and the deep snowpack conditions maintained seasonal frost to a depth of 30 cm for 35 days.

The spatial and temporal variability of the thermal regime within the snowpack was controlled by snow depth, air temperature, forest cover and the insulating properties of the snow. These variations revealed that, as ambient air temperatures stabilize, temperature variations in the top portion of the snowpack usually decrease significantly. In isolated cases, snow temperatures at these levels were warmer than air temperatures as a result of passage of cold fronts following major snowfalls or nocturnal cooling effects; and at times cooler depending on microclimatic situations and/or snow characteristics (i.e. presence of a thick ice layer within the snowpack).

Temperatures within a deep snowcover varied by as much as 15°C from 10 cm below the snow surface to the interface. Snowpack temperatures monitored with a mobile probe system near the study site showed similar spatial variabilities in temperature to those obtained by the datalogging system. As such, the thermal range of the snowpacks observed was dependent on snow depth, air temperature, snow properties, obstructions and microclimatic conditions at the snow surface.

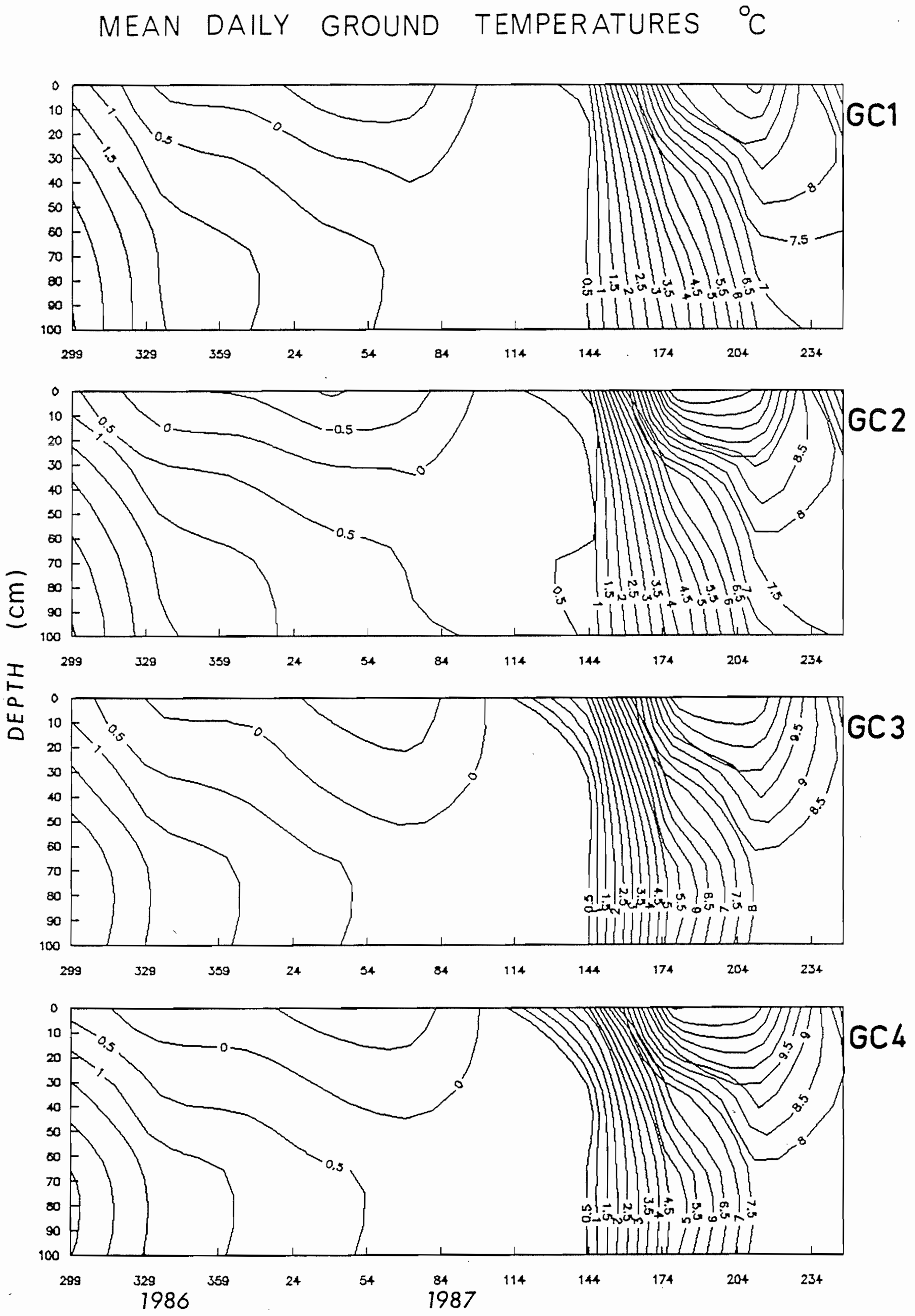


Figure 6. Time-depth patterns of mean daily ground temperatures for four ground cables located on the study array (Oct.26,'86 - Sept.6,'87).

Lastly, temperature measurements at the snow-ground interface revealed that temperatures are not necessarily near the freezing point when shielded by a snowcover and can vary by 1.5°C. The spatial and temporal variability in interface temperatures during the winter period were highly controlled by the insulating properties of the overlying snowcover and the consistent ground temperature gradient beneath it.

ACKNOWLEDGMENTS

The project was funded by grants from the Centre for Northern Studies & Research of McGill University, the Permafrost Group of the Terrain Sciences Division of Energy, Mines and Resources in Ottawa and the Department of Geography of McGill University. I am grateful to Dr. H.B. Granberg of Université de Sherbrooke for providing the funds and datalogging equipment needed to complete the fieldwork in the initial stages of the study. Many thanks also go to C.A. Nadeau and the staff of the McGill Subarctic Research Station in Schefferville for field assistance.

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