Snow Cover and Ground Temperatures, Garry Island, N.W.T.

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ABSTRACT. Field measurements of the influence of snow on ground temperatures, at a depth of 90 cm., were carried out during 1968-73 at Garry Island, N.W.T. The results show that the ameliorating effect of snow can be expressed by a regression equation. The side slopes tend to have the highest mean annual temperatures; the flats the lowest; and the ridges intermediate. At Garry Island, where permafrost is thick, variations in snow cover are probably not reflected in the position of the bottom of permafrost. By contrast, in the nearby alluvial islands of the Mackenzie Delta, where permafrost is thin, the effects of snow on the position of the lower permafrost surface are probably considerable.

RÉSUMÉ. *Couvert neigeux et température du sol, île de Garry. T.N.O.* De 1968 à 1973 inclusivement, dans l'île de Garry, T.N.O., les auteurs ont mesuré l'influence de la neige sur les températures du sol, à une profondeur de 90 cm. Les résultats démontrent que l'effet "améliorateur" de la neige peut s'exprimer par une équation de régression. Les pentes latérales tendent à avoir les plus hautes températures moyennes annuelles, les plats les plus basses, et les crêtes les intermédiaires. Dans l'île de Garry, où le permagel est épais, les variations de la couverture nivale ne se reflètent probablement pas dans la position de la limite inférieure du permagel. Par contraste, dans les îles alluviales voisines du delta du Mackenzie, où le permagel est mince, les effets de la neige sur la position de la surface inférieure du permagel sont probablement considérables.

РЕЗЮМЕ. *Снежный покров и температура почвы, о.Гарри, Северо-Западные территории/Канада/.* Для установления влияния снежного покрова на температуру почвы на о.Гарри в 1968-1973 гг. велись полевые измерения температур на глубине 90 см. Полученные результаты показали, что смягчающее действие снега может быть выражено уравнением регрессии. Наивысшая среднегодовая температура обнаруживается на склонах, наинизшая — в низинах, промежуточная — на гребнях. На о.Гарри, где вечная мерзлота проникает на большую глубину, изменения в толщине снежного покрова, вероятно, не отражаются на положении уровня промерзания. Напротив, на соседних наносных островах дельты р.Макензи, где слой вечной мерзлоты тонок, влияние снега на положение уровня промерзания, по всей вероятности, значительно.

INTRODUCTION

The insulating effect of a snow cover on ground temperatures is well known, although often difficult to assess. In areas of discontinuous permafrost, the snow cover is often the critical factor in determining the presence or absence of permafrost (*e.g.* Annersten 1964, 1966; Gill 1973; Granberg 1973; Nicholson and Granberg 1973; Nicholson and Thom 1973; Thom 1969). The insulating effect of a snow cover is also important in areas of continuous permafrost (*e.g.* Bird 1967; Brown 1970; Judge 1973), but measurements of ground temperatures

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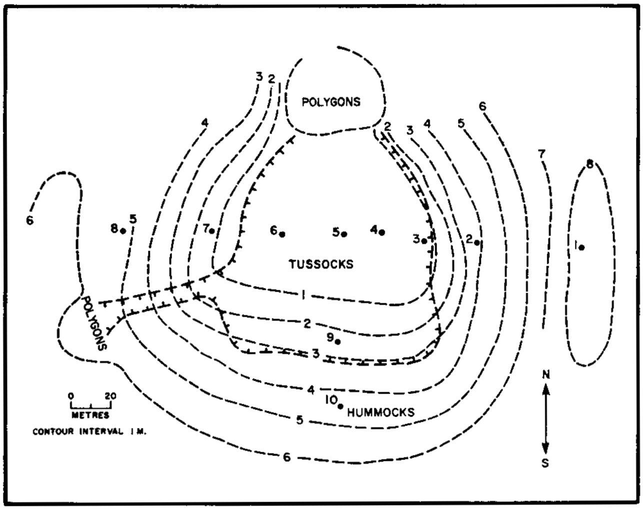

FIG. 1. Map of field site at Garry Island, N.W.T. The numbers 1 to 10 refer to the ground- and snow-measurement sites.

beneath snow are very meagre. The purpose of this paper is to discuss some of the insulating effects of snow on ground temperatures as measured at Garry Island, N.W.T. (69°30′N., 135°45′W.) for the 1968-73 period.

FIELD SITE

In the summer of 1968, a field site was selected at Garry Island, N.W.T., for snow and ground temperature measurements (Mackay and MacKay 1972). Garry Island lies 150 km. northwest of Inuvik, N.W.T., 100 km. west of Tuktoyaktuk, N. W.T., and 75 km. northeast of Blow River, Yukon Territory, the nearest sites with climatic data. Garry Island is not part of the Mackenzie Delta, but rises well above it. The field site is bowl shaped (Fig. 1) with the centre at an altitude of about 10 m. above sea level and 500 m. from the coast. Eight measurement stations (sites 1 to 8) were placed along an east-west line and two (sites 9 and 10) on a north-south line (Fig. 2). Each station was marked by a snowpole, and a thermistor was inserted to a depth of 90 cm. in an augered and backfilled hole. The thermistors

FIG. 2. Photographs of the field site looking west, taken from near measurement site 1. Sites 2 to 10 are numbered. Note the tundra vegetation and micro-relief of earth hummocks.

were connected to a battery-operated thermograph located in a nearby field cabin. Thermograph calibration checks were made in the winter, spring, and summer.

The 90 cm. depth was chosen for a year-round temperature record for three main reasons: first, all probes would lie below the active layer, and thus in permafrost; second, the depth was sufficient for temperature fluctuations caused by the local hummocky microrelief to be damped out; and third, recorded temperatures at a depth of 90 cm. would remain unaffected by a slight drift in the timing mechanism of the thermograph, as compared to actual temperatures.

Nearly continuous (*i.e.* daily) temperature records were obtained for the 1968-71 period. For 1971-73, temperatures were taken each summer, winter, and spring and, in addition, additional temperature data were recorded daily for two nearby sites. The ground temperatures are reported to the nearest 0.1 °C, and they are believed accurate to within 0.2 °C.

Garry Island is in the tundra (Fig. 2). The ridges and slopes are well drained. The flats, such as that in the centre of the snow course, have sedgy tussocks and are ill drained. The active layer on the ridges and slopes may reach a thickness of 60 cm., but on the flats, thicknesses of 20 to 40 cm. are typical.

SNOW COVER

The snow cover of the windblown western Arctic coast, which Garry Island typifies, contrasts sharply with the more protected forested areas (*e.g.* Aklavik and Inuvik, N.W.T.) not far to the south. The coastal snowfall is less than that inland, but the density is greater. At Garry Island, the snowdrifts are often elongated into sastrugi, which are sharp, irregular ridges formed parallel to the prevailing wind by erosion and deposition (Fig. 3).

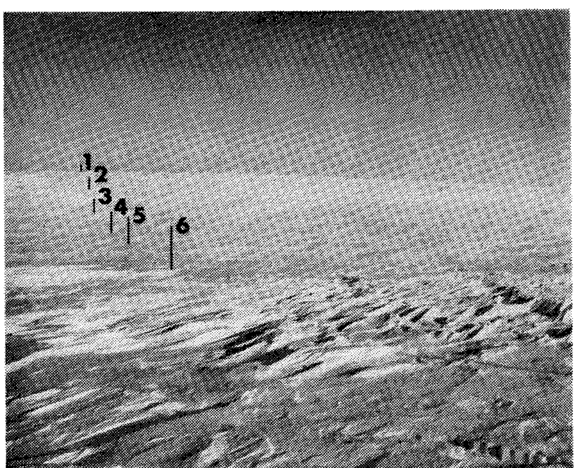

FIG. 3. Photograph of the field site in March, looking east. The long shadow, on the right, is from the snowpole at site 7. The wind-eroded "sastrugi", in the foreground, are also numerous on hillslopes and other areas of snow accumulation.

At least half of the total snowcover has normally accumulated by the end of December (Table 1). The mean snowcourse depth for 1 April (1969-73) was 50 cm. This depth exceeds that for Tuktoyaktuk, N.W.T. and Blow River, Y.T., and also that inferred for the western Arctic coast (Potter 1965). The higher

TABLE 1. Snow depths for the 10 sites, 1968-73.

	Mean (cm)	Snow depth as a percentage of the March/April depth
1968-69		
28 December	36	78
30 March	46	100
1969-70		
16 December	24	60
15 February	28	70
3 April	40	100
1970-71		
16 January	42	79
26 March	53	100
1971-72		
10 December	35	52
24 March	67	100
1972-73		
18 January	33	77
29 March	43	100
1969-73		
1 April (approximately)	50	

snow depth, for the Garry Island site, can probably be attributed to a disproportionate snow accumulation in the bowl-shaped depression. On a representative areal sampling basis, about six more windblown ridge sites, like 1 and 8, would be required for a reliable estimate of the total snowfall.

Snow densities in the spring range from about 0.35 to 0.40 g./cm.^{3} for most sites. The density is typical of arctic stations with low temperatures and strong

TABLE 2. Mean ground temperatures (°C) at Garry Island, N.W.T., 1969-70 and 1970-71.

Date	Probes									
	1	2	3	4	5	6	7	8	9	10
July 1969	− 2.8	− 2.7	− 2.6	− 3.2	− 3.2	− 3.5	− 2.8	− 2.9	− 3.1	− 2.8
Aug. 1969	− 2.5	− 2.2	− 2.3	− 3.2	− 3.2	− 3.5	− 2.5	− 2.7	− 2.8	− 2.5
Sept. 1969	− 2.5	− 2.2	− 2.3	− 3.0	− 2.8	− 3.2	− 2.5	− 2.6	− 2.6	− 2.6
Oct. 1969	− 2.3	− 2.1	− 2.3	− 2.8	− 2.7	− 2.8	− 2.3	− 2.7	− 2.7	− 2.5
Nov. 1969	− 2.5	− 2.5	− 2.6	− 3.5	− 3.0	− 2.8	− 2.4	− 2.8	− 3.1	− 2.6
Dec. 1969	− 6.9	− 6.9	− 7.1	− 7.6	− 7.6	− 7.1	− 6.8	− 6.9	− 7.7	− 7.0
Jan. 1970	−12.2	− 9.5	−10.1	−12.1	−11.8	−11.6	−10.1	−11.6	−11.5	−10.6
Feb. 1970	−16.4	−13.1	−13.5	−15.9	−14.8	−15.0	−12.6	−15.6	−15.0	−14.4
March 1970	−16.4	−13.7	−13.5	−16.3	−15.5	−15.5	−13.4	−16.2	−14.9	−14.6
April 1970	−14.9	−12.8	−12.5	−14.6	−13.8	−14.0	−12.7	−14.5	−13.8	−13.6
May 1970	−10.2	−10.1	−10.9	−11.0	−10.4	−10.8	−10.2	−10.5	−11.0	−11.5
June 1970	− 4.1	− 3.9	− 4.5	− 4.1	− 4.2	− 4.3	− 3.9	− 4.3	− 4.4	− 4.5
Annual mean temperature (1969-70)	− 7.9	− 6.8	− 7.0	− 8.1	− 7.8	− 7.9	− 6.8	− 7.8	− 7.7	− 7.4
July 1970	− 2.2	− 2.0	− 2.3	− 2.7	− 2.7	− 3.0	− 2.1	− 2.6	− 2.7	− 2.4
Aug. 1970	− 1.6	− 1.4	− 1.5	− 2.2	− 2.0	− 2.3	− 1.6	− 1.9	− 2.0	− 1.6
Sept. 1970	− 1.1	− 0.9	− 1.0	− 1.8	− 1.6	− 1.8	− 1.1	− 1.3	− 1.6	− 1.1
Oct. 1970	− 1.4	− 1.4	− 0.9	− 1.9	− 1.7	− 1.7	− 0.9	− 1.6	− 1.6	− 1.2
Nov. 1970	− 5.6	− 5.4	− 4.4	− 5.9	− 5.8	− 5.1	− 2.0	− 5.4	− 4.9	− 4.7
Dec. 1970	−12.1	−10.5	− 9.9	−11.4	−11.3	−10.3	− 5.4	−11.1	− 9.8	−10.4
Jan. 1971	−15.9	−11.7	−11.0	−13.5	−14.4	−12.6	− 7.2	−14.2	−11.8	−11.3
Feb. 1971	−19.8	−14.5	−13.3	−16.8	−17.8	−14.1	− 8.8	−17.8	−14.6	−12.9
March 1971	−.−	−14.9	−13.7	−16.7	−17.4	−14.1	−10.0	−17.8	−15.0	−13.6
April 1971	−.−	−14.6	−13.2	−16.0	−16.2	−13.5	−10.1	−16.9	−14.6	−13.2
May 1971	−.−	−11.0	−10.2	−11.1	−10.9	−11.1	− 8.9	−11.5	−11.0	−10.4
June 1971	−.−	− 3.5	− 3.1	− 3.8	− 3.8	− 4.3	− 3.0	− 4.2	− 3.9	− 3.4
Annual mean temperature (1970-71)	−.−	− 7.6	− 7.0	− 8.6	− 8.7	− 7.8	− 5.1	− 8.8	− 7.7	− 7.2

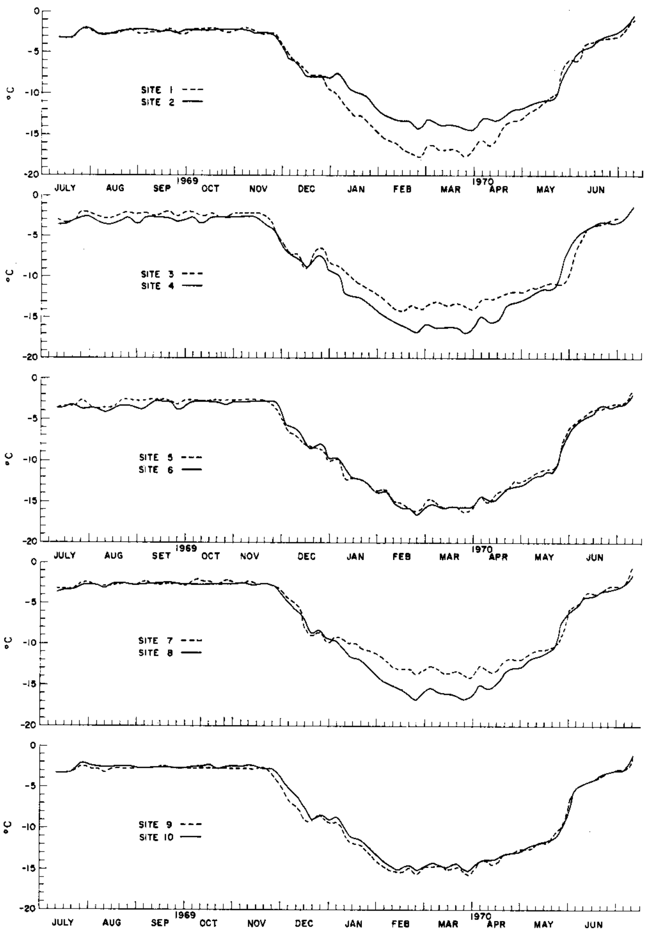

FIG. 4. Ground temperatures, at a depth of 90 cm., plotted for the 10 sites for one calendar year, July 1969 to June 1970.

winds (Bilello 1967; Gold and Williams 1957; Williams 1957). The snow becomes so cohesive that ice-wedge cracks may be propagated upwards through a cover of 75 cm. of snow to the snow surface.

SEASONAL TEMPERATURE CHANGES

The mean monthly ground temperatures for the ten sites for the two year period of July 1969 to June 1971 are given in Table 2. A one-year record (July 1969 to June 1970) is plotted in Fig. 4 and both air temperatures and snow depths, for the nearest weather stations (Blow River, Y.T., Tuktoyaktuk, N.W.T., and Inuvik, N.W.T.), are plotted in Fig 5 for the same period.

Active layer thaw

Thaw of the active layer begins with the first disappearance of snow in May and early June. Contrary to expectation, there are no major summer temperature differences for sites with east, west, and north exposures (Fig. 6). If there had been

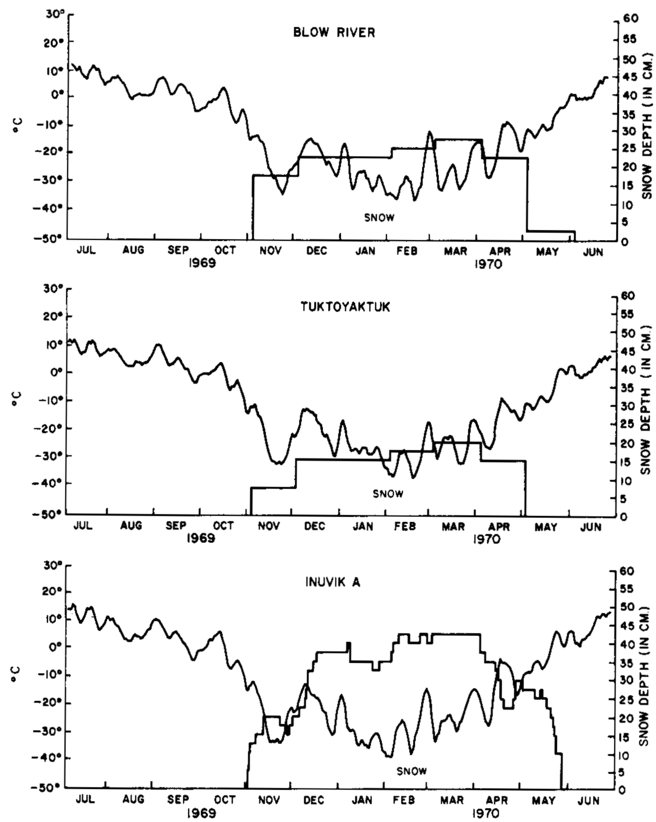

FIG. 5. Five-day running mean air temperatures and snow depths for Blow River, Y.T., Tuktoyaktuk, N.W.T., and Inuvik A, N.W.T., the three nearest climatological stations to Garry Island, N.W.T. Note the greater snow depth at Inuvik as compared to Tuktoyaktuk

a southerly exposure, perhaps north-south differences would show up, as they have elsewhere (French 1970; Hannell 1972). Sites 4, 5, and 6, located on the poorly drained tussock flat, are usually colder than the side slopes and ridges, in part because of evapotranspiration cooling.

Fall freeze-back

During the fall freeze-back, a thinning sandwich of the active layer is cooled by two freezing fronts, the upper one moving downwards from the ground surface, and the lower one moving upwards from the frost table. Consequently, the temperature at a depth of 90 cm. tends to remain quasi-stationary, or it may even rise slightly, until the active layer is frozen through. Fig. 4 shows that the temperatures, for all sites, were nearly constant from July to late November. The rapid temperature drop at the end of November marked the completion of the active layer freeze-back, by which time air temperatures were far below 0°C (Fig. 5).

Winter cooling

Ground temperatures in winter show a greater range than in summer because of the dominating influence of the snow cover (Fig. 7). There is normally a temperature lag of about a month between the lowest air temperatures, which tend to occur in January and February, and the lowest ground temperatures at a depth of 90 cm., which occur in February or March.

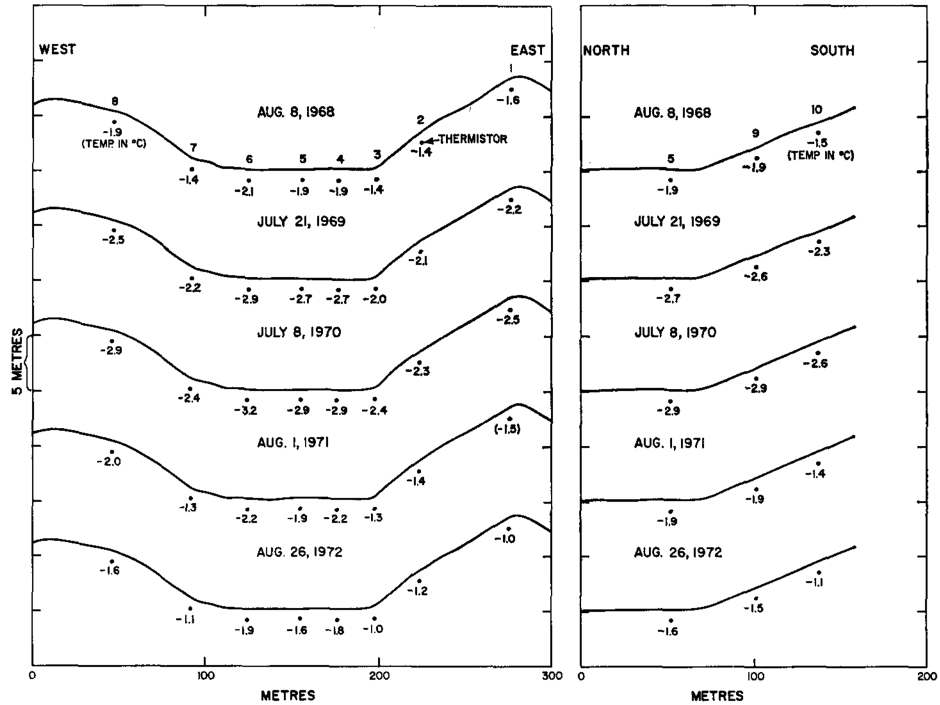

FIG. 6. The left-hand diagram shows an east-west profile across the field site, and the right-hand diagram a north-south profile, with summer temperatures, for five years, plotted for the 10 sites. Note the generally lower summer temperatures in the flat, as compared to the slopes and ridge positions.

DISCUSSION

The insulating effect of the snow cover shows up very clearly in Fig. 7. The windblown ridges and the central depression are much colder than the slopes, which are blanketed by deep snow drifts. The effect of snow on ground temperatures can be illustrated by Fig. 8 where the three regression lines are of the form:

$$T_{90} = a + 5 \log_{10} x \quad (1)$$

where T_{90} is the ground temperature (°C) at a depth of 90 cm.,
a is a constant, and represents the ground temperature (°C) without a snow cover,
5 is the slope of the regression line,
x is the depth of snow in centimetres.

The logarithmic term in Equation 1 shows that ground temperatures are most sensitive to changes in snow depths when the snow cover is thin, an observation which has been made by others (*e.g.* Krinsley 1963). The mean standard error for eleven sets of observations (1968-73), using the form of Equation 1 is 0.6°C, a considerable improvement over the standard deviation of 1.8°C.

The mean annual ground temperatures at a depth of 90 cm. for the ten sites show considerable yearly variations (Table 2). For example, the mean annual temperature of site 7 in 1970-71 was 3.7°C higher than that of site 8, which was

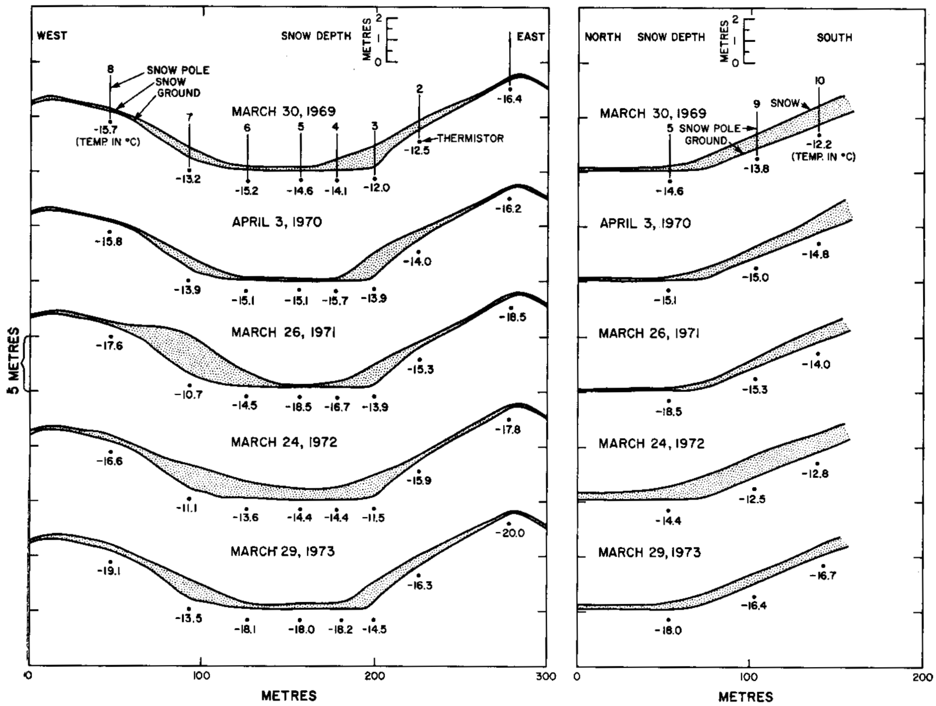

FIG. 7. The diagrams are similar to those of Fig. 6, except that spring conditions are plotted. The insulating effect of the snow cover shows up clearly.

only 50 m. distant. The difference can be attributed to the abnormally thick snow cover at site 7 in 1970-71.

The seasonal waves, measured at a depth of 90 cm., propagate downwards and become negligible at the depth — often taken to be 15 m. — where the temperature has become more or less constant and corresponds closely to the mean annual ground surface temperature of the immediate past (*e.g.* 10 years). Thirteen temperature cables are at present installed in drill holes, to a depth of 15 m., at representative locations along the 10 km. length of Garry Island. Recorded temperatures range from −7.5°C to −8.8°C, with a mean of −8.2°C. The variations are believed mainly to reflect changes in depth of winter snow. In an area with thick permafrost (*e.g.* 350 m.) such as at Garry Island, such snow-induced local variations in ground temperature will become attenuated with depth and probably have no effect on the bottom undulations of permafrost. However, in the nearby low alluvial islands of the Mackenzie Delta, where temperatures at a depth of 15 m. are in the −1°C to −3°C range — except near channels and lakes — permafrost is thin (usually less than 80 m.), and snow may play a very important role in determining the depth to which it extends.

CONCLUSION

Measurements carried out at Garry Island, N.W.T., for the 1968-73 period, show that the insulating effect of a snow cover on ground temperatures, at a depth

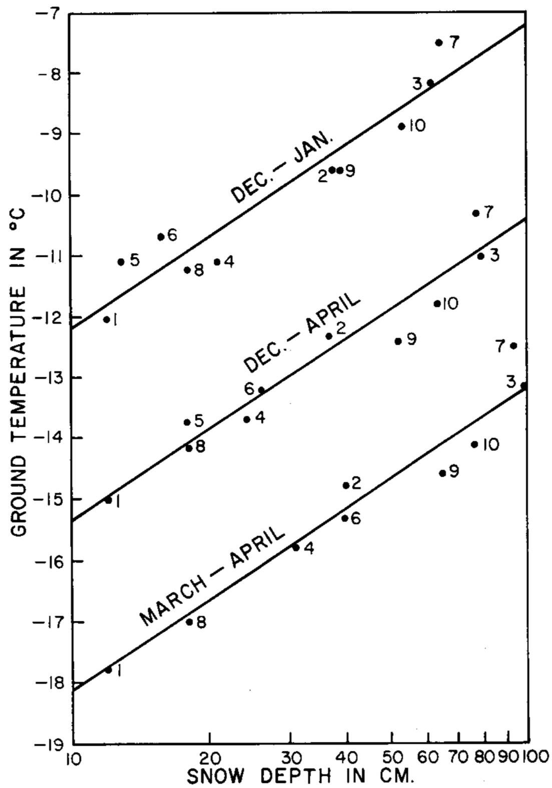

FIG. 8. Plots of ground temperatures against snow depths. The Dec.-Jan. data are the average temperatures and snow depths as measured at each of the ten sites during each of five successive winter visits made during 1968-73; the March-April data are the averages for five successive spring visits; and the Dec.-April data are the averages in respect of eleven visits (the preceding plus one made in February) at each of the ten sites during 1968-73.

of 90 cm., can be estimated by means of a regression equation. In winter, the windblown areas, which comprise the ridges and portions of some flats, are the coldest. In summer, the ridges and side slopes tend to be the warmest. Consequently, for the year as a whole, the highest mean annual temperatures occur on the slopes, which are "warm" in both summer and winter; intermediate in temperature are the ridge sites where summer warmth is counterbalanced by winter cold; and the coldest sites are the flats which are ill-drained and cold in summer, and windblown and cold in winter.

These general conclusions drawn for Garry Island, N.W.T., are probably applicable to the western Arctic coastal zone where similar windpacked snow, tundra vegetation, and sub-soil conditions exist. In the distal part of the Mackenzie Delta, adjacent to Garry Island, the snow cover is probably a major determinant of permafrost depth.

ACKNOWLEDGEMENT

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