Snow management to reduce ground temperatures beside a road in the boreal forest near Mayo, central Yukon

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Objectives

This poster discusses the results of a field experiment conducted on South McQuesten Road, north of Mayo, YT, to test whether ground surface temperatures beside a road embankment may be lowered by compacting snow. This may be a relatively cost-effective technique to achieve thermal stability in the embankment.

The objectives of this research were to determine:

(1) whether compaction with snow machines can cause a significant reduction in snow depth and increase in density;

(2) how compaction alters the structure of the snowpack and shape of snow grains; and,

(3) if, as a result, there is a significant reduction in ground surface temperatures.

Study Area

Mayo lies in the Stewart Plateau, a region of uplands separated by river valleys. Vegetation is dominated by closed canopy boreal forest interspersed with wetlands. The climate is cold and continental, with a mean annual temperature of -2.2°C (1991 – 2020).[1] The area has widespread discontinuous permafrost up to 40 m thick in valleys and 130 m thick at elevation, most commonly found underlying organic soils. Annual snowfall was 105 cm (1981-2010). Wind speeds in the area averaged 3 km h^{-1} during the study period. The low wind speeds cause the snowpack to accumulate in soft, low density layers.

Site Selection

Two sites were selected in the right-of-way along South Mcquesten Road, North of Mayo (Figure 1). The sites were chosen based on the flat, uniform terrain (Figure 2). Both locations were clear-cut within 15 – 20 m of the road. M1 was in undisturbed forest near km 3, while M2 was in forest that had recently been burned (2019).

Soil at the field sites was dry and without peat, so the area was likely without permafrost. The mean daily temperature during the study period was -15.5°C, colder than the average of -13.5°C (1992-2002), while precipitation was 72 mm, compared to an average of 75 mm.

Figure 1. Location map for study sites in central Yukon.

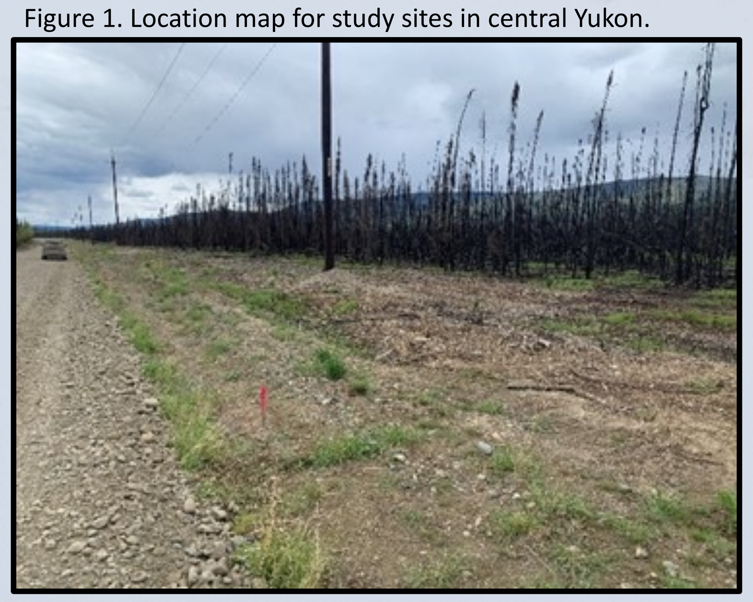


Figure 2. M2 field site on June 4th, 2021.

Abstract

Snow was compacted with snow machines in the right-of-way beside South McQuesten Road, central Yukon, to determine the effect on temperatures at the base of the snowpack. Compacted snow was on average 30cm shallower, 156kg m^{-3} denser, and had basal temperatures 3°C lower than adjacent plots that were left undisturbed.

The paper associated with this poster can be found in the conference proceedings.

Field Methods

Matching 50 m by 5 m plots were staked adjacent to each other beside the shoulder of the road at both sites. One of the plots was compacted monthly using snow machines from late-November to mid-March, while the other was left undisturbed. The snow was driven over repeatedly until further runs caused no visible change in depth.

Figure 3: Compaction of the snowpack at the M2 field site on November 29th, 2020.

Temperature loggers were sealed in PVC pipe and pushed along the base of the snowpack to the centre of each plot from a hole along the edge, which was re-filled with snow.

Following each compaction, snow depth was probed every 10 m along the middle of the plots, providing four measurements per plot. Snow pits were then dug from the shared edge of the plots outwards, separated by about 2-3 m from the previous pit to avoid disturbance.

Within the snow pits, snow layers were categorized based on texture. Snow density, hardness and grain size and shape were measured for each layer. Density was measured by weighing samples collected using a volumetric scoop. Hardness was measured by penetrating the snow with objects of increasing pressure. Grain size and shape were determined by observing samples of snow on fine-scale graph paper and observing using a hand lens. Procedure was based on the International Classification for Seasonal Snow on the Ground.[2]

Figure 4. Snow pits dug at the M2 undisturbed plot, with a depth of 53 cm, and compacted plot, with a depth of 23 cm, on 5 January 2021, following the second compaction.

Snow Depth, Density and Hardness

Mean snow depths at the compacted (red) and undisturbed (white) plots are shown in Figure 4. Average snow depths over four months were 66 and 69 cm at the M1 and M2 undisturbed plots, and 37 cm and 39 cm at the compacted plots.

The snow compressed easily due to its low density. Weighted mean densities of the undisturbed snowpacks were 163 and 160 kg m^{-3} at M1 and M2, compared to 319 and 315 kg m^{-3} at the compacted plots.

Weighted mean hardness was near 0 at the undisturbed plots and over 3 at the compacted plots, indicating they could be penetrated by a closed fist compared to a pencil.

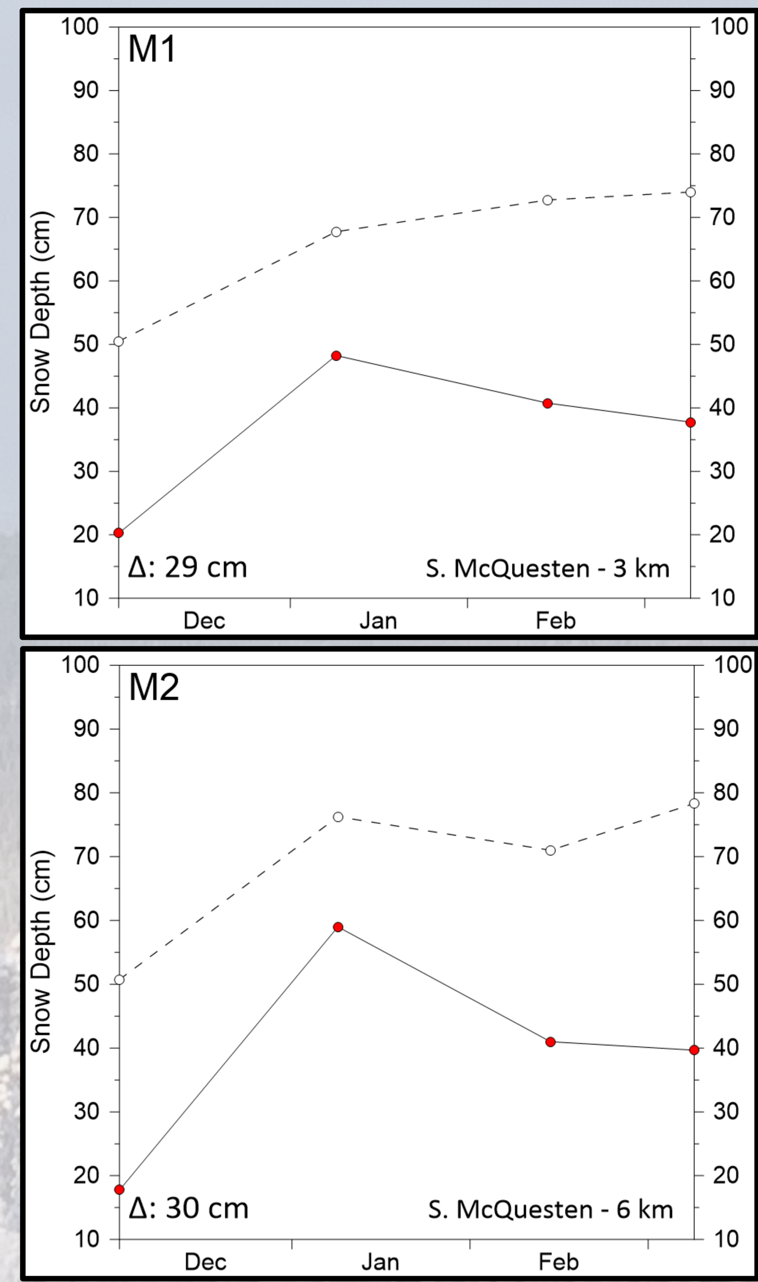


Figure 5. Mean monthly snow depths (cm) at the undisturbed (white) and compacted (red) sites from depth probe measurements. Δ indicates mean difference.

Snow Layering

Figure 6 shows mean total layer thickness of each snow type identified within the snow pits dug following compaction.

At the undisturbed plots, 5-10 cm of fresh, low density dendritic snow accumulated near the surface. Beneath were layers of rounded snow grains, and then the snow became more faceted due to temperature-gradient metamorphism. At or near the base of the snowpack was a layer of depth hoar, typically 10-15 cm deep.

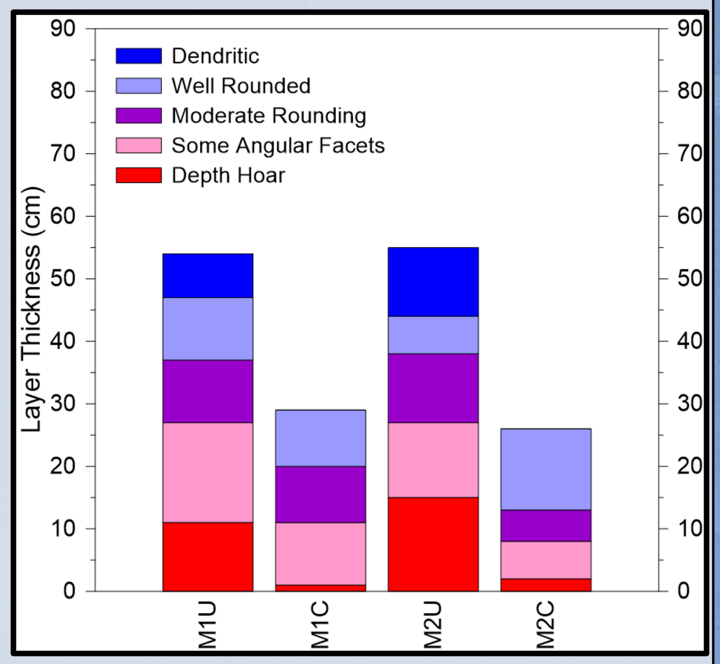


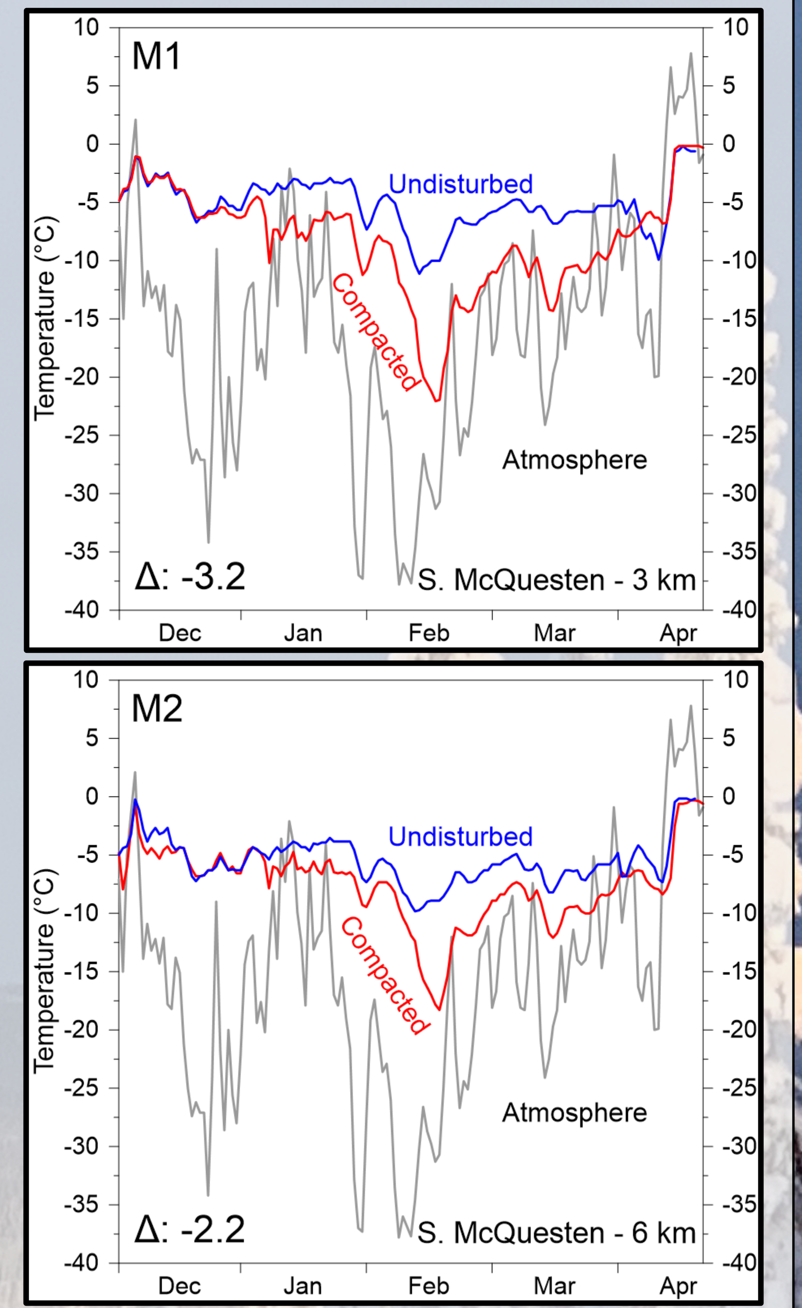
Figure 6: Mean depth of accumulation by snow type at the compacted (MC) and undisturbed (MU) plots from four snow pits.

At the compacted plots dendritic snow was reduced to thin patches between tracks, and depth hoar was crushed and mixed with surrounding snow. Faceting was associated with greater depth reduction compared to rounded snow.

Temperatures at the Base of the Snowpack

Mean daily temperatures at the base of the snowpacks are displayed in Figure 8, along with air temperatures at Mayo Airport, 35 km south of the field sites. Over the winter, mean temperatures at the undisturbed plots were -5.2 and -5.5°C at M1 and M2, respectively. At the compacted plots, mean temperatures were -8.4 and -7.7°C.

Temperatures at the compacted and undisturbed plots were generally closely coupled until January 5th, when temperatures at the compacted plots diverged to be 2-5°C lower than the undisturbed. The sudden divergence may indicate a reduction in the latent heat flux from the freezing front towards the surface that did not occur at the undisturbed sites. This was likely associated with the depth of frost penetration.



Daily mean temperatures measured at the base of the snowpack .The daily mean air temperature recorded at Mayo A is also given. Data from 29 November to 22 April, 2020–21.

Maximum temperature divergence was 12.4°C at M1 and 9.3°C at M2 in mid-February, after mean daily air temperatures dropped to a low of -38°C. Mean freezing *n*-factors at the undisturbed plots were 0.37 and 0.41 at M1 and M2 compared to 0.62 and 0.56 at the compacted plots. Compacted *n*-factors were closer to those typically seen in northwestern Canadian tundra than taiga.[3] The low density of the dendritic snow and depth hoar made them more susceptible to compaction, while also causing them to have low thermal conductivity[4]. Compaction of these layers therefore offered an efficient method of reducing temperatures at the base of the snowpack.

Conclusion

Monthly compaction using snow machines caused snow depths to be reduced by approximately half throughout the winter, with the majority of depth reduction occurring in low density dendritic snow and depth hoar. As a result, temperatures at the base of the snowpack were reduced by 2-3°C on average, with a maximum difference of over 10°C. Due to the effectiveness of the technique, along with its simplicity and low cost, further research is warranted towards its large-scale use in road maintenance to mitigate the risk of damage from thaw subsidence.

Acknowledgements

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