Near-surface ground ice variation in ice-wedge polygons in Adventdalen, Svalbard

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Introduction

Near-surface ground ice is a characteristic feature of permafrost, and its thaw may lead to ground subsidence, which can damage infrastructure and change landscape hydrology and ecology[1,2,3]. The thaw of upper permafrost also mobilizes previously-frozen organic carbon[4]. Little data exist on the distribution of ground ice in the top of permafrost in the high Arctic archipelago of Svalbard. Polygonal terrain is widely distributed on Svalbard, and hosts both wedge ice and segregated ice in fine-grained sediment. Here we present early results from part of the Lowperm project, which broadly seeks to understand nutrient transport in permafrost landscapes that may lead to changes in GHG production and fertilization of the Arctic Ocean.

The poster aims to:

(1) Quantify near-surface ground ice variation in polygonal terrain

(2) Estimate potential amount of groundwater released from the thaw of upper permafrost

Adventdalen study site

The study area is Adventdalen, a 12 km x 4 km U-shaped glacial valley by the town of Longyearbyen [Fig 1]. The area is underlain by continuous permafrost. The investigated polygon field is on an aggrading loess (predominantly sandy silt) terrace adjacent to the Adventelva river. Primary polygons average ~20 m in diameter, and many are dissected by secondary or tertiary ice wedges. Vegetation is sparse on polygon ridges, but more developed in the wetter centres and wedge troughs.

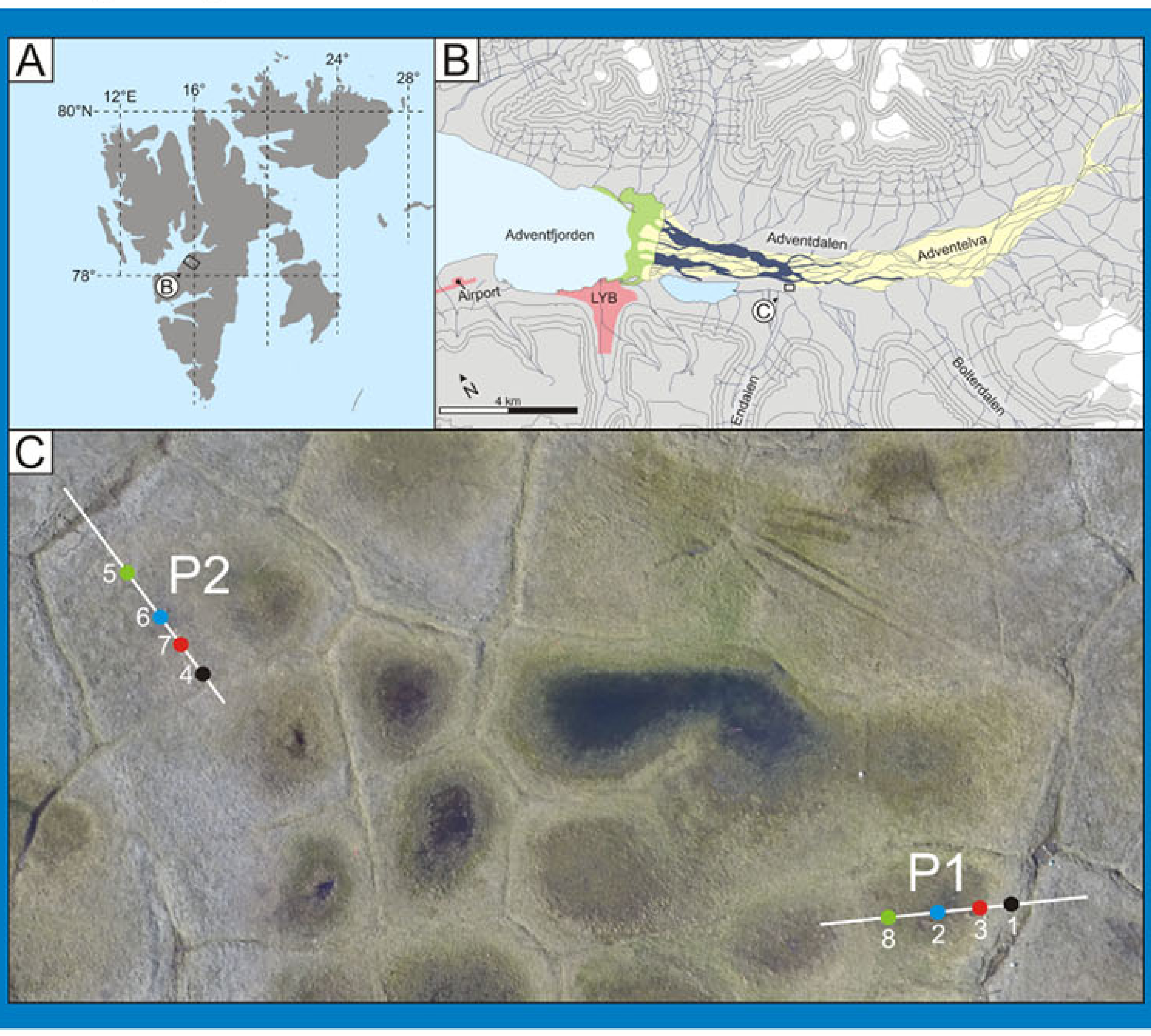


Fig. 1. The study site position on (a) Svalbard, (b) in the Adventdalen valley, and (c) transect and borehole locations in the investigated polygons P1 and P2. The transect lines are approximately 35 m in length. Insets (a) and (b) produced by G. Gilbert.

Methods

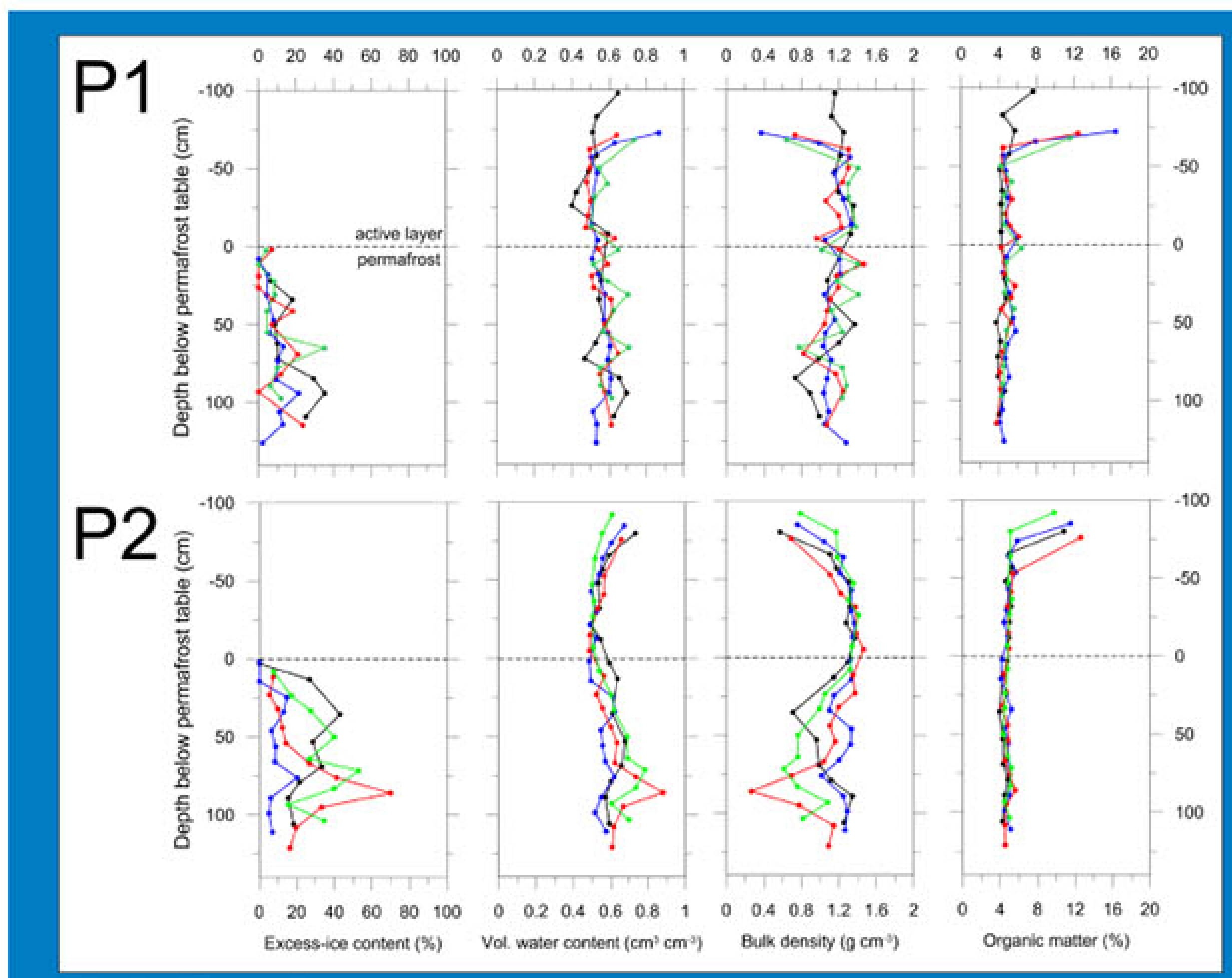
Transects were established across two polygons with different topography, vegetation, and moisture conditions. Eight cores of the frozen active layer and upper permafrost were obtained by hand-drilling along the transects in winter 2017 [Fig 1,2]. Core segments were processed in a cold laboratory to determine the excess-ice content (vol. of ice in excess of pore space), moisture content, bulk density, and organic matter content. The transects were surveyed with an optical level to define polygon topography, and active-layer thicknesses on the transect and at each drill site were measured by probing in September 2016.

Fig. 2. (Above) The permafrost cowboys drilling in Adventdalen, February 2017,
(Right) Ice-rich core segment with segregated ice lenses.

Results and discussion

P2 had higher ground ice contents than P1 [Fig 3]. The average excess-ice content in the top metre of permafrost was 10% in P1 and 21% in P2. There was greater excess ice from 0.5 – 1.0 m below the permafrost table than in the upper 0.5 m. If the upper metre of permafrost thawed, the ground surface subsidence at boreholes would be between 8 and 16 cm in P1 and 9 and 27 cm in P2 [Fig 4]. Such differential subsidence, particularly at P2, could lead to ponding in thaw depressions and significant changes to surface hydrology.

The volume of excess water available upon thawing of the top metre of permafrost was estimated by assuming a simplified polygon geometry [Fig 5]. The calculated contribution from wedge ice is 90,000 to 177,000 $m^3 km^{-2}$ and from segregated ground ice 73,000 to 82,000 $m^3 km^{-2}$ for the average excess-ice content measured in P1, and 154,000 to 172,000 $m^3 km^{-2}$ for P2. The large range in these values, due to the variation in ground ice content between polygons, highlight the uncertainty inherent in upscaling from a limited number of ground ice measurements. Numerical simulations of regional hydrological and/or biogeochemical fluxes from thawing permafrost must account for such sub-grid variation.



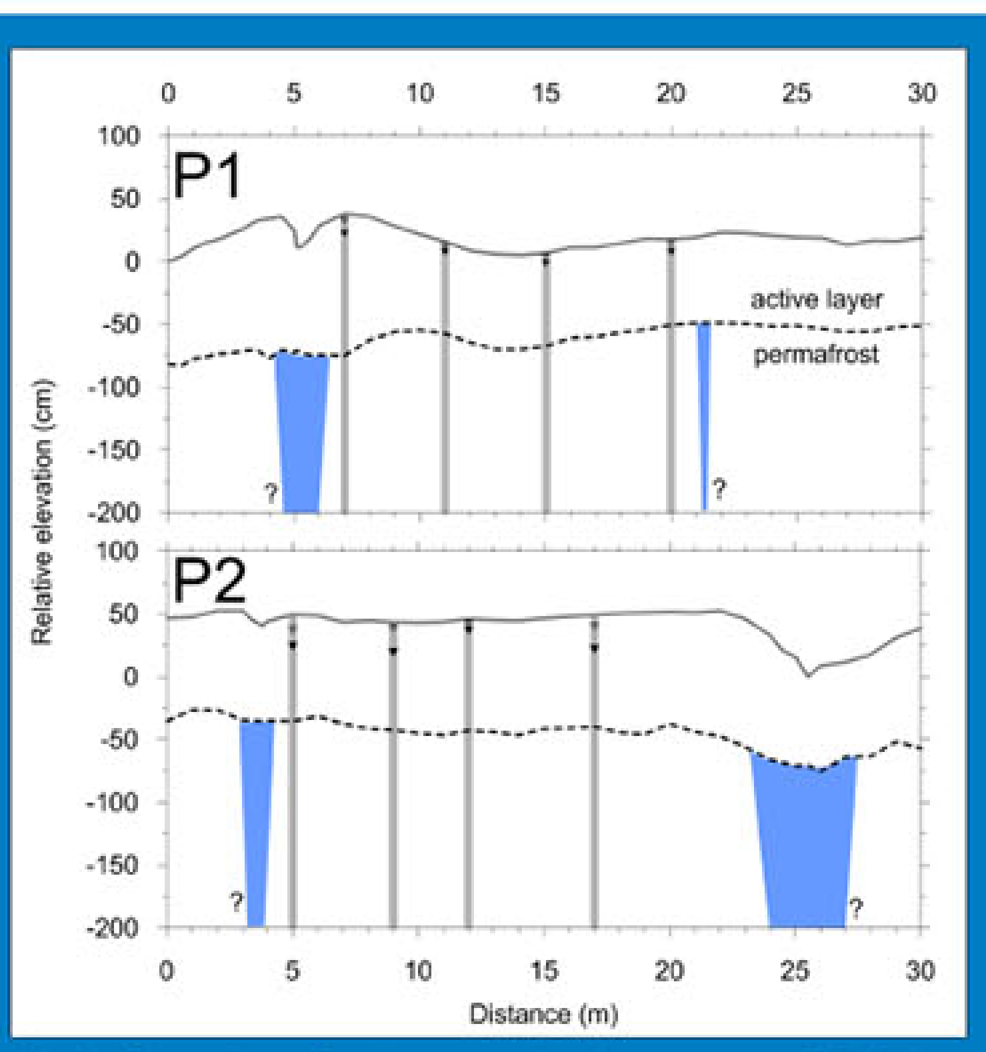
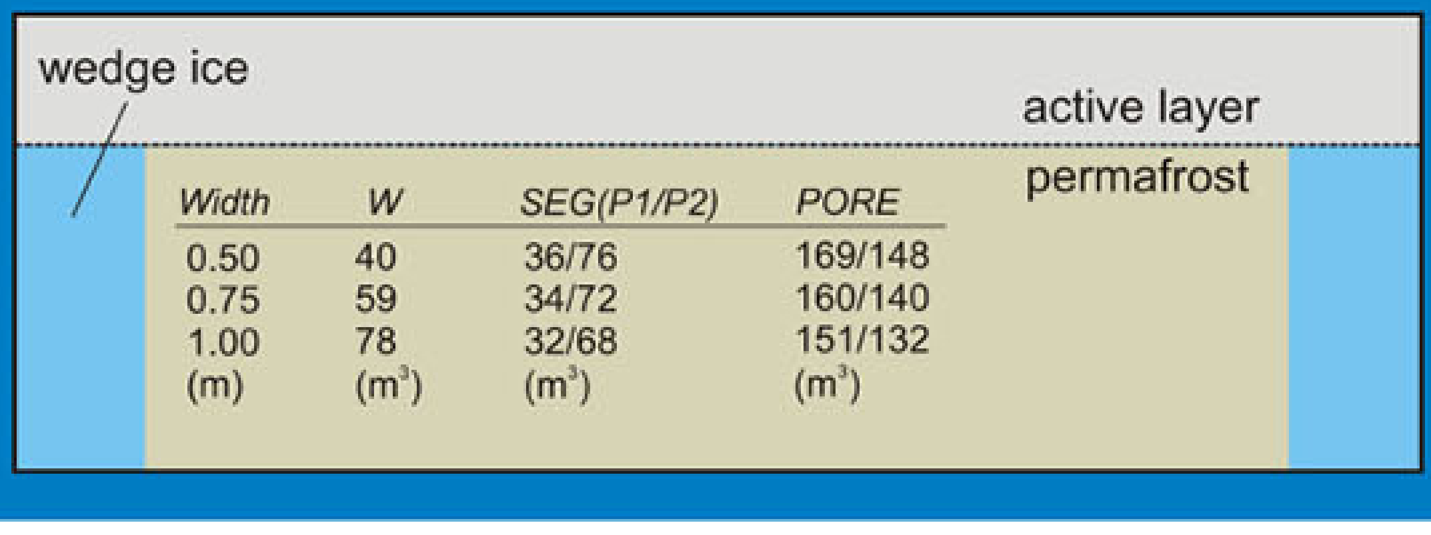


Fig. 4. Ground surface topography, late summer 2016 thaw depths, borehole locations, and ice-wedge top delineation. The empty and filled triangles indicate, respectively, the amount of potential subsidence following 0.5 and 1.0 m of permafrost thaw, based on the excess-ice content. Question marks indicate unknown ice-wedge geometry.

Fig. 3. Excess-ice content, volumetric water content, soil dry bulk density, and organic matter content for all boreholes in P1 and P2. Colours are as in Fig 1. The dots represent the average depth of each analyzed core segment.



Width	*W*	*SEG(P1/P2)*	*PORE*
0.50	40	36/76	169/148
0.75	59	34/72	160/140
1.00	78	32/68	151/132
(m)	(m^3)	(m^3)	(m^3)

Fig. 5. The idealized polygon geometry. The polygon is a box measuring 20 x 20 m, bounded on all sides by ice wedges. Since wedges are syngenetic in the study area, they are assumed to be rectangular in cross section. The table shows the wedge width, volume contribution of wedge (W), excess segregated (SEG) and pore (PORE) ice for the top metre of one polygon (i.e., 400 m^3).

Summary and next steps

These results offer the first data on the site-scale variation in ground ice in polygonal terrain and of the potential hydrological contribution from permafrost thaw in lowlands on Svalbard. The large differences in ice content between the two investigated polygons highlight the necessity for adequate field data for incorporation in regional-scale hydrological and biogeochemical models seeking to define fluxes from permafrost to the atmosphere and oceans. Next, additional sites in different geomorphological settings on Svalbard will be characterized, and carbon distribution of the upper permafrost will be defined.

More on Lowperm

The main objects of LowPerm are to quantify microbial processes, changes in microbial populations and their functional potential, as well as to understand the physical process dynamics of permafrost soils at field observatories in West Spitsbergen. Seasonal microbial-driven greenhouse gas production and fjord fertilization, due to runoff export of nutrients and organic matter, are being quantified, and responses of microbial communities to different temperatures, water, oxygen, and nutrient substrate conditions will be determined. Semi-empirical tuning parameters will be developed for integrating these biogeochemical processes into biophysical models, while taking sub-grid heterogeneity into account.

Acknowledgements

This project has been supported by the Joint Planning Initiative of the European Union. Field assistance from Graham Gilbert, Brittany Main, and Sarah Strand is greatly appreciated

European Commission
JPI Climate
The University Of Sheffield.
AARHUS UNIVERSITY
HØGSKULEN i SOGN OG FJORDANE

References

[1] Mackay, JR. 1972. The world of underground ice. *Annals of the Association of American Geographers* **62**, 1-22.
[2] Nelson et al. 2001. Subsidence risk from thawing permafrost. *Nature* **410**, 889-890.
[3] Liljedahl et al. 2016. Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology. *Nature Geoscience* **9**, 312-318.
[4] Schuur et al. 2008. Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle. *BioScience* **58**, 701-714.