Ice-wedge volume calculation in Yedoma and thermokarst deposits

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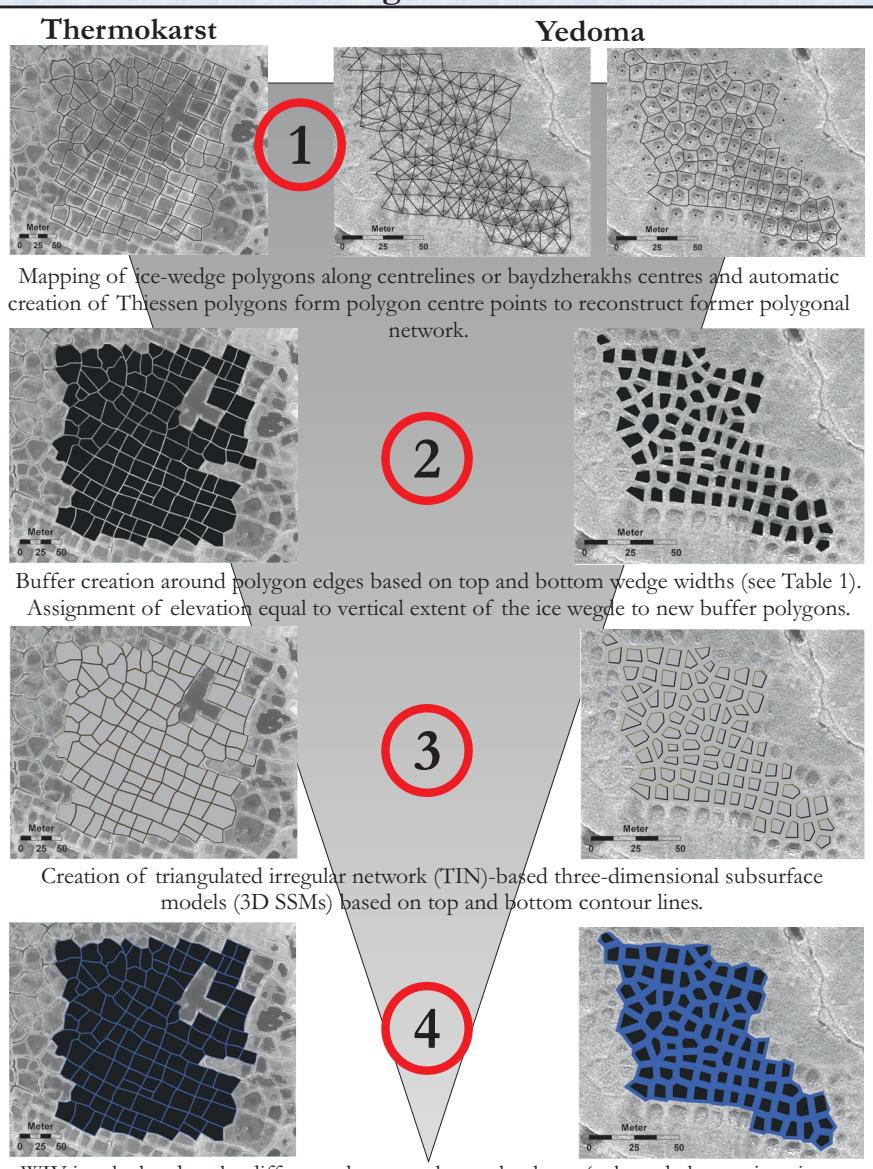
Introduction and Background

Detailed knowledge of ground-ice content and distribution is necessary to predict local-scale landscape changes and to safely plan infrastructure in permafrost regions. In addition, ground-ice content is a major factor for assessments of organic carbon (OC) pools in permafrost deposits. Estimates for OC pools below the active layer have especially large uncertainties due to limited data on ground-ice. While the volume of pore and segregated ice can be readily quantified from sediment samples of known volume and weight taken from cores or exposures, it is challenging to quantify the volume of large ice bodies, such as ice wedges that are rarely exposed to their full extent.

A simple GIS-based tool for WIV calculations is presented that relies on remote sensing and limited ground data, which can easily be modified and applied to other permafrost regions with polygonal-patterned ground. The approach is based on mapping ice-wedge polygonal networks from very-high-resolution satellite remote-sensing imagery in addition to basic field knowledge of wedge-ice type, depth, and width. We further compare WIV results from ice-rich permafrost landscapes in Siberia and Alaska as well as differentiate WIV in landscape units containing late Pleistocene syngenetically frozen ice-rich deposits (Yedoma) and Holocene, epigenetic permafrost deposits in drained thermokarst-lake basins.

Procedure for wedge-ice volume calculations



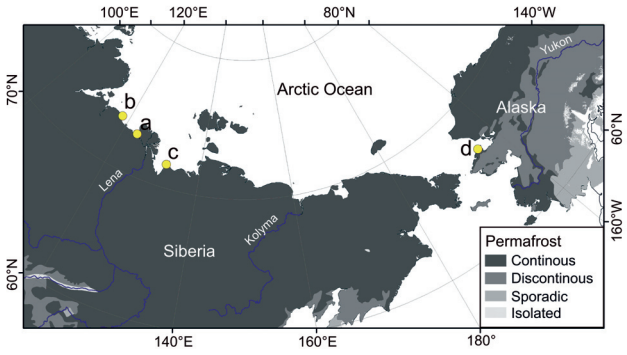
Mapping of ice-wedge polygons along centrelines or baydzherakhs centres and automatic creation of Thiessen polygons form polygon centre points to reconstruct former polygonal network.

Buffer creation around polygon edges based on top and bottom wedge widths (see Table 1). Assignment of elevation equal to vertical extent of the ice wedge to new buffer polygons.

Creation of triangulated irregular network (TIN)-based three-dimensional subsurface models (3D SSMs) based on top and bottom contour lines.

WIV is calculated as the difference between the total volume (volume below an imaginary surface plane) and the 3D SSMs. The resulting vextor layer divides the volumes for the ice wedges (blue) and the polygon centre sediments (black).

Study sites



Case study sites were chosen based on the availabilty of remote sensing data and field or literature data on ice-wedge dimension (see Table 1).

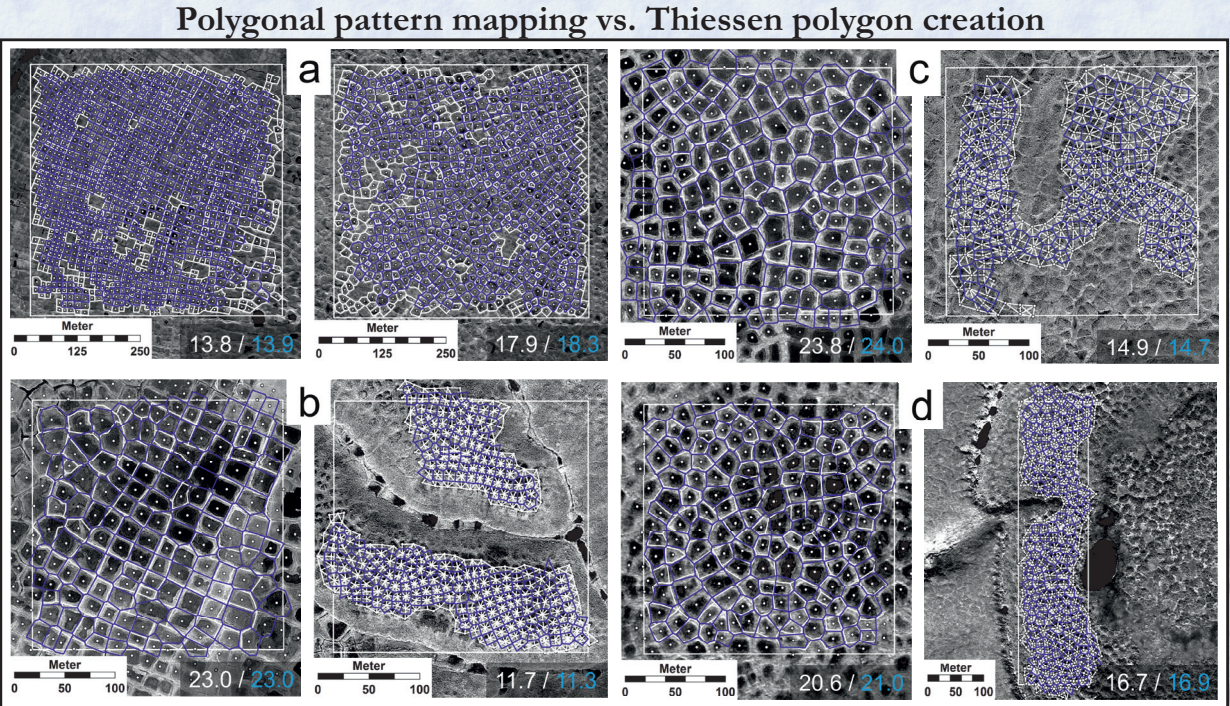
a) Ebe-Basyn-Sise Island
(SW Lena Delta, NE Siberia, Russia)

b) Cape Mamontov Klyk
(Laptev Sea coast, NE Siberia, Russia)

c) Buor Khaya Peninsula
(Laptev Sea coast, NE Siberia, Russia)

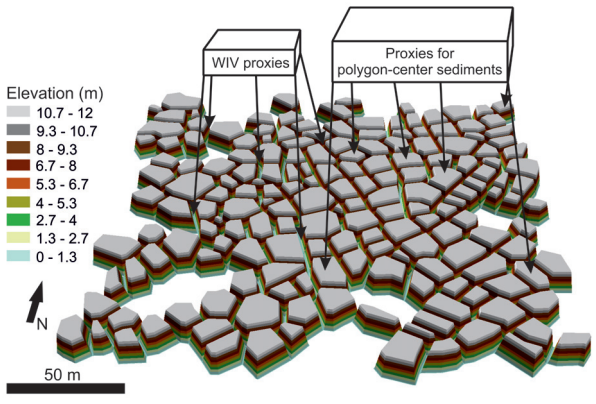
d) Seward Peninsula
(Chukchi Sea coast, Alaska, USA)

Polygonal pattern mapping vs. Thiessen polygon creation



Manually-mapped polygonal patterns (white lines) and automatically-derived Thiessen polygons (blue lines). For each site, polygonal networks on thermokarst-basin deposits are shown on the left and polygonal networks on Yedoma deposits are shown on the right side. White values correspond to the average of mapped polygon sizes and baydzherakh distances. Blue values indicate the average of Thiessen polygon sizes.

Results: WIV and potential surface subsidence



3D SSM for a reconstructed polygonal network on Yedoma deposits of Ebe-Basyn-Sise Island.

Site	Ice-wedge size in thermokarst deposits, m top width/bottom width/depth		Ice-wedge size in Yedoma deposits, m top width/bottom width/depth		Wedge-ice volume in thermokarst deposits (%)		Wedge-ice volume in Yedoma deposits (%)	
	Min	Max	Min	Max	Min	Max	Min	Max
Ebe-Basyn-Sise[1]	N/A	1.0/0.0/3.0	3.0/0.5/8.0	5.0/0.7/12.0	N/A	8.2	20.2	31.4
Cape Mamontov Klyk[2]	0.2/0.0/1.0	1.4/0.0/3.0	1.0/0.8/8.0	4.0/3.0/20.0	1.0	6.6	16.7	56.1
Buor Khaya Peninsula[3]	0.9/0.0/2.0	3.0/0.0/6.0	2.0/1.5/5.0	6.0/5.0/18.0	4.0	13.2	23.9	63.2
Seward Peninsula[4]	0.8/0.0/1.5	1.5/0.0/3.0	2.5/1.0/5.0	4.0/2.0/8.0	4.2	7.7	21.0	34.5

[1]Data on ice-wedge sizes by Schirrmeister et al. (2003); [2]Data on ice-wedge sizes by Meyer and Dereviagin (2004), and Schirrmeister et al. (2008, 2011); [3]Data on ice-wedge sizes by Strauss and Schirrmeister (2011); [4]Ice-wedge sizes by Parsekian et al. (2011) and G. Grosse, unpublished data

Table 1 is showing the range of ice-wedge sizes used as input for 3D SSMs and resulting wedge-ice volumes.

Table 2 shows the calculated equivalent ground-ice thickness (EGIT) from the WIV range of all study sites for Yedoma deposits of various thicknesses.

Deposit thickness (m)	EGIT Yedoma (m)	
	Min (WIV = 16.7%)	Max (WIV = 63.2%)
5	0.8	3.2
10	1.7	6.3
15	2.5	9.5
20	3.3	12.6
25	4.2	15.8
30	5.0	19.0
35	5.8	22.1
40	6.7	25.3
45	7.7	28.4
50	8.4	31.6

Related Publications

Strauss J. et al., 2013. The deep permafrost carbon pool of the Yedoma region in Siberia and Alaska. Geophys. Res. Lett. 40 (23), 6165–6170.

Ulrich M. et al., 2014. Quantifying wedge-ice volumes in Yedoma and thermokarst basin deposits. Permafrost and Periglac. Process., In press.

Acknowledgements

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