Estimation of Ice Wedge Volume on the Fosheim Peninsula, Ellesmere Island, Canadian High Arctic

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References

Methodology

Main steps of our methodology, performed using ArcGIS (Version 10.3.1, ESRI):

1. Choice of four sample areas (250 m x 250 m) in the Eureka Sound Lowlands with various ice wedge polygon morphologies on WorldView 2 and 3 high-resolution images (0.5 m/pixel)

2. Test/Adapt different techniques to delineate ice wedge polygons on each sample area:
   - Thießen Polygons: create Thießen polygons from approximated center points of ice wedge polygons chosen by the analyst. Used at few sites in Ulrich et al. (2014).
   - Watershed Segmentation: interpretation of the pixel values as a height function and use of “Hydrology tools” to create watersheds representing each ice wedge polygon. Inspired from an image segmentation software algorithm used in Barrada et al. (2006) for petrographic analysis.

3. Create 3D subsurface models at each sample area for each technique: following the Ulrich et al. (2014) methodology, use of mean ice wedge width (1.46 m) and depth (2.23 m) from field data, here from Couture & Pollard (1998).

4. Calculate the percentage of ice wedge volume at each sample area for each delineation technique using the “Surface Volume tool”: consider only the top 5.9 m of permafrost to compare results with Couture & Pollard (1998).

5. Determine the potential coverage area of ice wedges on the Fosheim Peninsula from the digitization of the surficial geology map of Bell (1992)

6. Estimate the volume of ice ice for the Fosheim Peninsula using the mean percentage ice wedge volume of the four sample areas obtained from the manual delineation technique.

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Results

1. Ice wedge polygons delineation

The Thießen polygons technique is the least time consuming but simplifies polygon shapes as it cannot output curved lines and underestimates the ice wedge ice volume (Fig. 4). The Watershed Segmentation technique is the most accurate in trough localization and in ice wedge ice volume but requires supplementary manual editing to delete wastered boundaries over segmenting polygons. Implementation of both techniques in ArcGIS Model Builder greatly accelerated polygon delineation and demonstrates their potential to be applied to much larger areas in a time-efficient manner.

2. Ice wedge volume estimation

Half of the Fosheim Peninsula surface area is potentially covered by ice wedges (~3,000 km²), Fig. 5). Considering only the top 5.9 m of permafrost, this is equivalent to a volume of frozen material of 17.7 km³. The total ice wedge ice volume is 0.6 km³, when assuming an ice wedge volume of 3.81, by averaging the results from the manual delineation at the four sample areas. Our results are comparable to the study by Couture & Pollard (1998) in the Eureka Sound Lowlands region. From delineating ice wedge polygons on air photos, they defined low polygon density as 1.8% of volume and high density as 3.5%. Our sample areas EL1 and EL3 have a much higher ice wedge ice volume percentage, redefining “high density” polygon nature on the Fosheim Peninsula (Fig. 6).

future work

Time constraint and required level of precision in the estimation of ice wedge volume are two criteria to be considered when choosing one of the delineation techniques presented above. Offering promising remote sensing methods to detect topographic and subsurface change and to map ground ice distribution include LiDAR, InSAR and structure-from-motion technology (Jorgenson & Grosse, 2016). High resolution digital terrain models can be derived from these methods on which our watershed segmentation delineation technique could be applied with more confidence.

Fieldwork in the Eureka Sound Lowlands region could improve the ice wedge volume estimates by linking surficial geology and physiographic units with ice wedge polygon characteristics. The widespread nature of ice wedges will contribute to significant permafrost instability and ground subsidence once thermokarst processes are initiated. Associated with other ground ice estimates, large scale ice wedge volume estimations will help to assess the vulnerability of permafrost to climate change in the High Arctic and wherever they are present.

Introduction

Estimating ground ice volumes is necessary to predict the sensitivity of permafrost terrain to temperature increase (Gilbert et al., 2016). The active layer is the portion of the ground that warms to above freezing each summer. The sub-layer is the portion of the ground that remains frozen throughout the year. The permafrost is the portion of the ground that is always frozen. The thickness of the permafrost is measured in meters and varies from a few tens of meters to a few kilometers. The permafrost is a frozen layer of soil or rock that is continuously frozen throughout the year. The permafrost is a critical component of the global carbon cycle because it stores large amounts of carbon in the form of organic matter. The permafrost is also a major contributor to the global methane budget because it releases methane into the atmosphere. The permafrost is a major source of runoff and sediment to the Arctic Ocean.

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