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CHAMONIX Mont-Blanc 23 June - 1st July 2018 EUCOP5

Repeat terrestrial LiDAR for permafrost thaw subsidence change detection in North Alaska

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Abstract

The distinguishing feature of permafrost in the Arctic is the presence of a large amount of ice below the earth surface. Thermal degradation and subsequent destabilization of ground ice rich terrain cause thaw subsidence. Because these phenomena are hard to detect, they have received not much attention, despite their potentially global significance through the permafrost carbon feedback and implications for active layer thickness monitoring. Clearly, however, detailed local inventories are required to calibrate regional targeted long and short-term assessments for measuring surface deformation due to permafrost thaw. We analyze time series of repeat terrestrial laser scanning (rLiDAR) for quantification of land surface lowering on a tundra upland in the Teshekpuk Lake Special Area on Alaska´s North Slope. Here, considerable negative surface elevation changes have been detected over two years from 2015 to 2017. Spatial patterns of land elevation changes indicate that ice wedge polygon troughs are particularly prone to subsidence. This highlights the vulnerability of arctic tundra lowlands with ice-rich permafrost close to the surface.

Keywords: terrestrial LiDAR, Arctic Coastal Plain, thaw subsidence, ice wedge polygons

Introduction

Permanently frozen ground in the Arctic is being destabilized by continuing permafrost degradation, an indicator of climate change in the northern high latitudes. Accelerated coastal erosion due to sea ice reduction and an increased intensity of ground settlement through ground ice melt result in widespread geomorphological activity (Jones et al., 2013). However, particularly in the light of the enormous area underlain by ice-rich continuous permafrost, still only few observations of permafrost-thaw related landscape dynamics exist.

The objective of our study is to analyze time series of repeat terrestrial laser scanning (rLiDAR) for quantification of extensive land surface lowering through thaw subsidence on an erosional remnant of the Alaskan Arctic Coastal Plain consisting of marine silt (Farquharson et al., 2016).

Methods

We established a subsidence survey grid across the TES-1 upland over 2 km length. The survey area is equipped with benchmarks drilled and anchored deep in the permafrost. These benchmarks serve as long-term position and height reference markers for repeat terrestrial laser scanning. The set-up is generally geared towards a comparison of several measurement campaigns for quantifying recent rates of land elevation change not only with high spatial but also high temporal resolution of interannual intervals.

The first survey was done during the 2nd half of July 2015 and repeat measurements have been made during a follow-up expedition in the same season in 2017. We operated the Leica MultiStation MS50, a hybrid instrument combining high-accuracy surveying with fast laser scanning capabilities, from 26 different positions inside the survey grid that is arranged in two adjacently staggered profiles for optimum coverage. The radius of laser scans was usually in the range of 80-100m in order to ensure overlap between neighboring scans with an equidistancy of 150 m and to capture micro-topographical features resulting from permafrost thaw. The survey covers an area of 460 000 m^2: Accurate positioning of the MS50 is realized using our fixed benchmarks that have been surveyed with precise

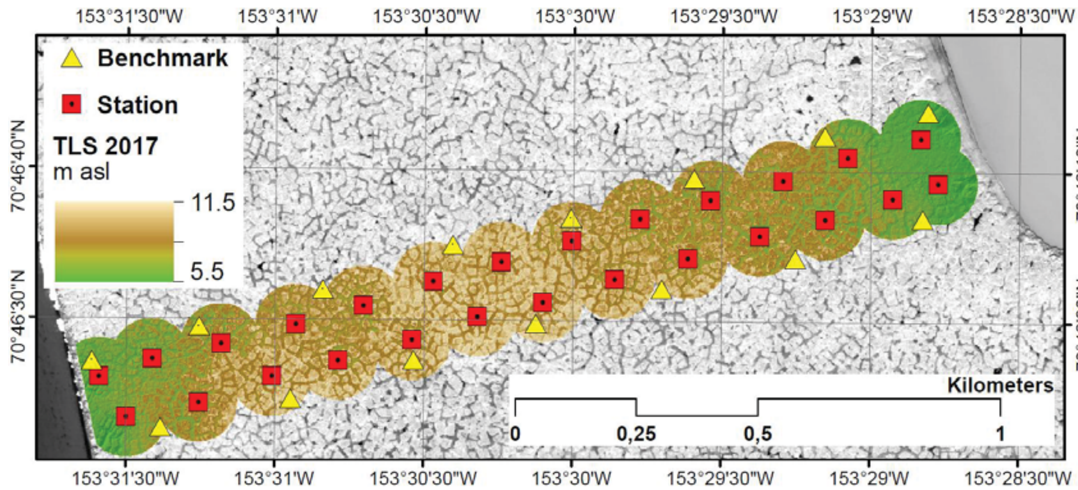

Figure 1. Map showing the 2017 LiDAR DEM stretching across the TES-1 upland between two thermokarst lakes.

local coordinate system that was then re-processed in Leica Infinity, a geodetic software package. Resulting point clouds have been interpolated to regular grids of digital elevation models (DEMs), portraying the land surface in unprecedented detail (Fig. 1).

Results and discussion

Two terrestrial LiDAR DEMs at 25 cm spatial resolution have been used to substract the older 2015 from the newer 2017 one using the geomorphic Change detection tool, an add-on for ArcGIS. Overall, 78 % of the area exhibit detectable change within accuracy thresholds determined by error surfaces that consider point heat maps, slope, and surface roughness. Out of the areas that experienced detectable change, 95 % showed negative surface elevation changes with an average of -12 cm, corresponding to a subsidence rate of -6 cm/yr. These exceptionally high values can be at least in parts explained by very high air temperatures of up to 30 °C recorded in Deadhorse/Prudhoe Bay during summer 2016, highlighting the vulnerability of near surface ground ice to pulse disturbances.

Extensive mapping of ice-wedge polygons complement our remote sensing studies and help differentiating localized elevation change. The mean polygon diameter is 22.7 ±4.9m. We noticed an increasing width of inter-polygon troughs from the upland's interior towards lake shores from 2 to 8 m. In connection with this, enhanced subsidence intensity is particularly pronounced along ice wedge networks compared to the surrounding terrain. Relating this subset of change detection to absolute elevation levels reveals enhanced subsidence with lower elevation ranges that are associated with areas close to the upland's margins where favorable drainage conditions maintain effective removal of ground ice melt water (Fig. 2).

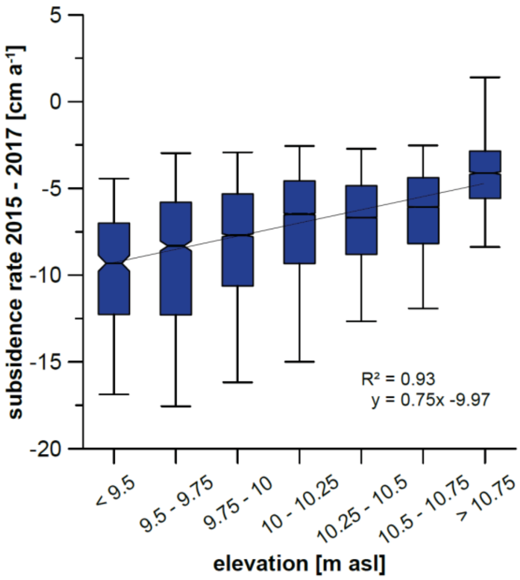

Figure 2. Graph of absolute elevation vs. subsidence rates, indicating increased surface lowering towards the upland margins with enhanced drainage conditions.

References

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