Sentinel-1 InSAR measurements of surface elevation changes over yedoma uplands on Sobo-Sise Island, Lena Delta

Jie Chen[1,2]
Frank Günther[3]
Guido Grosse[3,4]
Lin Liu[2]
Hui Lin[1]

[1]*Institute of Space and Earth Information Science, The Chinese University of Hong Kong, Hong Kong, jiechen@link.cuhk.edu.hk*

[2]*Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong, Hong Kong*

[3]*Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, 14473 Potsdam, German*

[4]*Institute of Earth and Environmental Sciences, University of Potsdam, 14476 Potsdam, German*

Abstract

Yedoma is vulnerable to thawing and degradation under climate warming, which can result in lowering of surface elevations due to thaw subsidence. Quantitative knowledge about elevation changes can help us better understand the freeze-thaw processes of the active layer and yedoma deposits. In this study, we utilize C-band Sentinel-1 InSAR measurements, characterized by frequent sampling, to study the elevation changes over ice-rich yedoma uplands on Sobo-Sise Island, Lena Delta. We observe significant seasonal thaw subsidence during summer months and inter-annual elevation changes from 2016 to 2017. Here, we demonstrate the capability of Sentinel-1 to estimate elevation changes over yedoma uplands. We observe interesting patterns of stronger seasonal thaw subsidence on elevated flat yedoma uplands when compared to surrounding yedoma slopes. Inter-annual analyses from 2016 to 2017 revealed mostly positive surface elevation changes that might be caused by delayed thaw seasonal progression associated with mean annual air temperature fluctuations.

Keywords: Sentinel-1, yedoma uplands, surface elevation changes, thaw subsidence, InSAR

Introduction

Yedoma, extremely ice-rich permafrost with massive ice wedges formed during the Late Pleistocene (Schirrmeister et al., 2011), is vulnerable to thawing and degradation under climate warming. Yedoma deposits also alternate with the thermokarst lake and basin development (Morgenstern et al., 2011). The surface elevation change, associated with the freeze and thaw cycling processes, is of importance to help us understand the response of yedoma uplands to surface disturbance and/or climatic changes.

Interferometric Synthetic Aperture Radar (InSAR) methods have been successfully used to remotely sense and quantify seasonal subsidence and inter-annual subsidence trends in permafrost regions (Liu et al., 2015). However, the space-borne C-band or L-band SAR missions prior to the Sentinel-1A/B satellites only provided a limited number of repeat images, making it difficult to fully resolve the temporal evolution of seasonal thaw subsidence and/or inter-annual variabilities. The frequent Sentinel-1 InSAR measurements (regular revisit time is 12 days; shortest is 6 days if both Sentinel-1 A and B images are acquired) provide an excellent opportunity to study seasonal and inter-annual thaw processes in permafrost regions.

The objective of this research is to demonstrate the capability of Sentinel-1 InSAR measurements to estimate surface elevation changes over yedoma uplands. We also analyzed the spatial pattern of seasonal thaw subsidence and the temporal evolution of inter-annual elevation changes.

Study site and methods

Sobo-Sise Island, located in the eastern Lena Delta, is largely dominated by yedoma uplands (Fuchs et al., 2017; Morgenstern et al., 2011). The mean annual air temperature in the region is about -12.5 ℃ and the mean annual precipitation is about 180-200 mm. The vegetation coverage is sparse and the growing season is short (Fuchs et al., 2017).

The basic principle of InSAR is to compare the phase of two complex radar images that were acquired from slightly different positions at different times. The phase differences measure the displacements along the line of sight between the two SAR acquisitions. In this study, we use four individual interferograms to calculate the accumulated seasonal subsidence during the thaw season of 2017. We also use four interferograms between the thaw season of 2016 and 2017 to conduct the averagely inter-annual elevation changes.

Results and discussion

We observe seasonal thaw subsidence up to 2-3 cm from June 23 to September 9 in 2017. Seasonal subsidence is pronounced most on top of flat yedoma uplands (Fig. 1). We also observe differences between the years, where subsidence during the thaw season of 2017 was less intense when compared with the preceding year 2016. This results in mostly a net inter-annual heave from late season 2016 to 2017 (Fig. 2), and is possibly caused by delayed thawing associated with differences in summer air temperatures. Degree days of thawing in 2016 were 812, in 2017 only 667. We also observed a shift of the warmest month from typically July to August. Mean air temperature in July 2016 was 7.8 °C and in August 7.3 °C. In 2017, July temperature was only 7.2 °C, while August was warmer with 8.3 °C. Even more pronounced were differences between September 2016 and 2017 (164 vs 63 degree days of thawing).

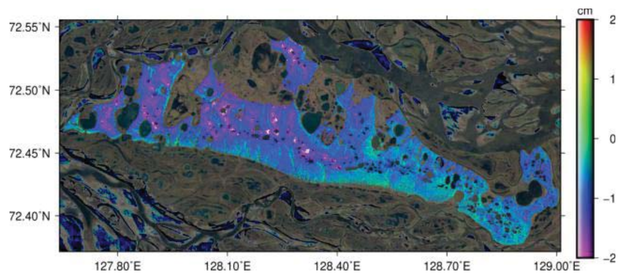

Figure 1. Map of elevation changes over yedoma uplands on SoboSise Island from June 23 to September 9 in 2017. Minus values denote subsidence.

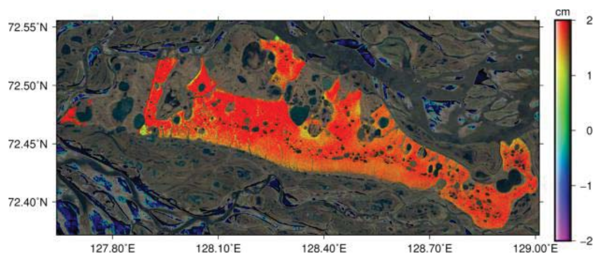

Figure 2. Map of inter-annual surface elevation changes between the thaw seasons of 2016 and 2017.

Conclusions

We explored and successfully tested the ability of Sentinel-1 InSAR measurements for quantifying both, thaw subsidence over one thawing season and the inter-annual elevation changes between two thaw seasons. In particular, the latter profits strongly from high SAR coherence values also between the years. We find that the top of yedoma uplands exhibit the highest elevation change amplitudes, suggesting that these areas are especially vulnerable for permafrost degradation through thaw subsidence processes. We also find that delayed thawing associated with air temperature fluctuations affects inter-annual elevation change magnitudes, highlighting the importance of a careful and comprehensive selection of time intervals for InSAR processing from interferogram creation.

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