Past and present thermokarst lake dynamics in the Yedoma Ice Complex region of North-Eastern Yakutia

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Abstract

Thermokarst lakes are typical components of the yedoma-alas dominated relief in the coastal lowlands of North-Eastern Yakutia and formed as a result of thawing Late Pleistocene ice-rich Yedoma Ice Complex (IC) deposits. The aim of our study is to estimate thermokarst lake area changes from the early Holocene onwards based on RS data. The decrease of thermokarst lake area from the early Holocene, taking into account total alas depression areas, is as much as 81-83 %. Modern climate warming has led to a general trend of thermokarst lake area decrease. Lake drainage occurs mostly on elevated sites with high Yedoma IC fraction while lake area increase is typical for low-lying areas with a small Yedoma IC fraction. The area increase of thermokarst ponds on flat, boggy yedoma surfaces indicates ice wedge degradation in response to rising summer air temperatures and precipitation.

Keywords: North-Eastern Yakuria, Yedoma Ice Complex, Holocene, alas, thermokarst lake dynamics, RS data.

Introduction

Thermokarst lakes are typical for the yedoma-alas relief in coastal lowlands of the North-Eastern Yakutia. The yedoma-alas relief formed as a result of thawing Late Pleistocene ice-rich Yedoma Ice Complex (IC) deposits. The very high total ground ice content of up to 90 % by volume renders Yedoma IC vulnerable to observed climate warming (Günther et al., 2015). Thermokarst lakes, as a highly dynamic landscape component, reflect permafrost dynamics in response to climate change. In order to understand present spatial patterns of thermokarst lake area dynamics, it is necessary to reconstruct their changes from the early Holocene.

Study region and methods

The study region is the Kolyma Lowland tundra with an area of about 44500 km² that is located within the continuous permafrost zone. Radiocarbon dating of Yedoma IC and alas deposits shows that the activation of thermokarst processes and thermokarst lakes formation occured at about 13-12 kyr BP and that most alas depressions formed after thermokarst lake drainage around 10 kyr BP (Kaplina, 2009). Thus modern alas areas can be considered as thermokarst lake areas during the early Holocene. The ratio between alas and modern thermokarst lake areas thus reflects limnicity changes during the Holocene. Mapping of Quaternary deposits, represented here mostly by Yedoma IC, alas and alluvial sediments, has been done based on Landsat images (Veremeeva & Glushkova, 2016). Thermokarst lake coverage was quantified based on Landsat 8 images that have been acquired during 2013 – 2014. The Quaternary deposits map was used to distinguish lakes with thermokarst genesis from other lakes, i.e. on floodplains.

The analysis of thermokarst lake area dynamics for the 1999-2014 period of the all study region was done using the entire available Landsat archive with an automated workflow, including several processing steps, such as masking, calculation of multi-spectral indices, and object-based image analysis (Nitze et al., 2017).

Results

Thermokarst evolution from the early Holocene

We delineated regions with high, medium and low alas fraction (Fig. 1). Generally, alases occupy 72 % of the region and 17.6 % of the alas area are still covered by lakes. The decrease of thermokarst lake area from the early Holocene is similar among sites with different alas fraction area and about 81-83 %. This loss of thermokarst lake area over the Holocene can be considered as the result of a simultaneous development of thermokarst lakes and the fluvial drainage network.

Long-term historic trends (1965- 2015)

For the key site in the region of Bolshoy Oler lake (Fig. 1), based on the comparison of CORONA (21.07.1965), Landsat 7 (25.08.1999), and Landsat 8 (28.08.2015) images the trend of decrease lake area was revealed. For the recent 1999-2015 period lake area decrease has been faster (0.83 km² per year) when compared to the 1965-1999 period (0.7 km² per year).

Regions with high Yedoma IC fraction often represent flat boggy surfaces that feature a high number of small thermokarst ponds with an average diameter of 5-10 m. For another key site around Cape Maly Chukochy (Fig. 1), we investigated their dynamics using optical imagery with very high resolution of 0.5 m. A doubling in the number and areal coverage of ponds from 1972 to 2009 and a further twofold increase until 2013 has been found. This indicates ice wedge degradation in response to rising summer air temperatures, precipitation and active layer depth, which is also reflected in expanding baydzherakh fields on adjacent yedoma slopes.

Short-term trends (1999-2015)

The general modern trend for the entire region is a decrease of thermokarst lake area, predominantly caused by lake drainage (Nitze et al., 2017). Comparison of these trends with the Quaternary deposits map and a DEM revealed that lake drainage occurs mostly on elevated yedoma uplands, while lake increase dominated in low-lying territories with low Yedoma IC fraction.

Analyses of inter-annual thermokarst lake dynamics from 1999 to 2015 and comparison with meteorological data have been carried out for several groups with varying dynamic trends and relief positions. We revealed no significant connections of lake area changes to hydrometeorological parameters (air temperature and precipitation of the summer and winter periods, and the preceding 12 month period). Synchronous lake dynamics were found for lakes with increasing area and lakes that are located within the Yedoma IC distribution. While this suggests that lake increase is largely triggered by external forcing, lake decrease and lake drainage is rather determined by local preconditions such as relief position and proximity to the existing erosional network. However, since lake drainage often succeeds lake expansion, both phenomena cannot be considered separately, suggesting that environmental forcings and interconnections apply to both processes.

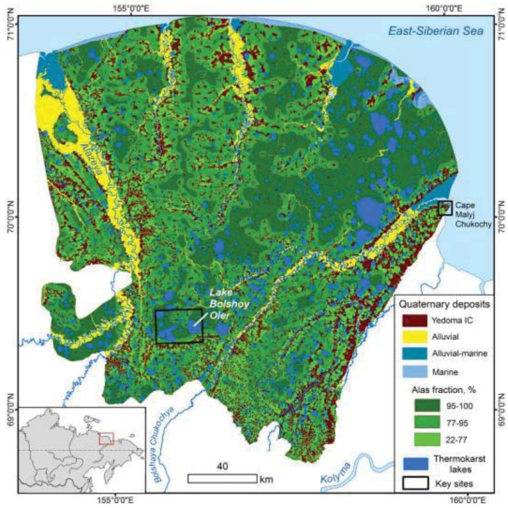

Fig.1. Alas fraction map of the study region. tundra.

We found a significant decrease of thermokarst lake area from the early Holocene until modern time. However, since lake shrinkage rates accelerated in the recent past, modern climate warming likely leads to a reactivation of thermokarst lake dynamics that ultimately follow a general trend of land surface levelling through continued degradation of Late Pleistocene ice-rich permafrost.

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