COMBINING ALOS DATA AND FIELD INVESTIGATIONS FOR THE RECONSTRUCTION OF THERMOKARST EVOLUTION IN THE NORTH SIBERIAN LENA DELTA

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ABSTRACT

We give an overview on current investigations of the project 'Morphologic characterization of the Lena Delta using remote sensing and terrain modeling' (LEDAM). They are focused on the reconstruction of thermokarst lake and basin evolution on Kurungnakh Island in the central Lena River Delta in northeastern Siberia. Detailed field data derived during the 'Expedition Lena 2008' will be combined with ALOS data analysis to obtain comprehensive information on lake and basin morphology and discriminate factors controlling it. These findings will help to assess the future evolution of thermokarst processes in ice-rich permafrost in the context of climate change.

1. INTRODUCTION

The evolution of Arctic periglacial regions is strongly influenced by climatic conditions. During the Pleistocene a stable cold continental climate led to the formation of permanently frozen ground (permafrost) in vast regions of the Arctic. Permafrost thickness can reach up to several hundreds of meters; the zone of annual thaw and freeze (active layer) is confined to the upper decimeters. The degradation of permafrost, which can be caused by local disturbances on small scales or by climate warming on larger scales, can lead to characteristic processes and landscape features such as thermokarst and thermoerosion. Thermokarst is defined as the thawing of ice-rich permafrost or the melting of massive ice with resulting surface subsidence and the formation of characteristic, mostly circular depressions and lakes [1]. During previous epochs of climate warming, e. g. the Holocene optimum, thermokarst processes have changed Arctic landscapes to a great extent, which is still obvious from the high abundance of thermokarst lakes and basins throughout Arctic periglacial regions. The general mechanisms of thermokarst were described decades ago, e. g. [2], but several aspects are still debated in the scientific community. One example is the model of a thaw lake (thermokarst lake) cycle, which has been questioned in a recent publication [3] after it had been well established for decades [4, 5, 6]. As the modern trend of global climate warming is most effective in the Arctic [7], the need of understanding thermokarst processes in the context of past and present landscape dynamics is of high importance. The characterization of thermokarst features, degradation processes, influencing factors and landscape interactions will help to deduce potential future evolution of permafrost environments under a changing climate regarding e. g. regional climate, hydrology, or carbon cycle.

Present investigations of the project 'Morphologic characterization of the Lena Delta using remote sensing and terrain modeling' (LEDAM) (awarded by ESA ADEN, PI Lantuit, ID 3616) are focused on the reconstruction of thermokarst processes in ice complex sediments of the Lena River Delta in northeastern Siberia. Ice complex sediments are widely distributed in the Siberian Arctic and consist of peat, sands, and silts with high ground ice content, mainly in the form of huge ice wedges (Fig. 1). They are very susceptible to thermokarst processes. Preliminary investigations indicate a specific morphometry of thermokarst features in these ice complex sediments. They often show an asymmetry in N-S direction, which is expressed as an elongation of drained or partly drained thermokarst basins in this direction and as lakes in partly drained basins being situated not in the middle, but "shifted" to the northern end of the basins. We assume this asymmetry to be caused by spatially directed thermokarst processes. The findings of detailed local field studies of the morphometric and surface characteristics of thermokarst features in ice complex sediments will be combined with remote sensing analyses on a regional scale to characterize the specific thermokarst morphometry and to reveal its interaction with possible factors of directed thermokarst evolution.

Figure 1. Ice complex sediments overlaying fluvial sands in the Lena Delta

2. STUDY AREA

The Lena River Delta is situated in northeastern Siberia in the zone of continuous permafrost (Fig. 2). This Arctic tundra landscape is widely affected by thermokarst. It is characterized not only by alluvial sediments and active fluvial processes, but also by large non-deltaic units. Ice complex sediments are distributed as insular remnants of a Late Pleistocene accumulation plain in the southern delta. They clearly differ from other geomorphological units of the Lena Delta in relief height, sediment composition, hydrological regime, and surface characteristics, which makes them visually distinguishable even on satellite imagery (Fig. 3a). Kurungnakh Island in the south central Lena Delta (Fig. 3b) is one of the ice complex remnants and was chosen as the main study area as it is a representative area for thermokarst in ice complex sediments and most easily accessible for field work. Field investigations were conducted in a large (ca. 6 km²) thermokarst depression with three large and numerous small thermokarst lakes (Fig. 3c, Fig. 4).

Figure 2. Permafrost distribution on the northern hemisphere and location of the Lena River Delta

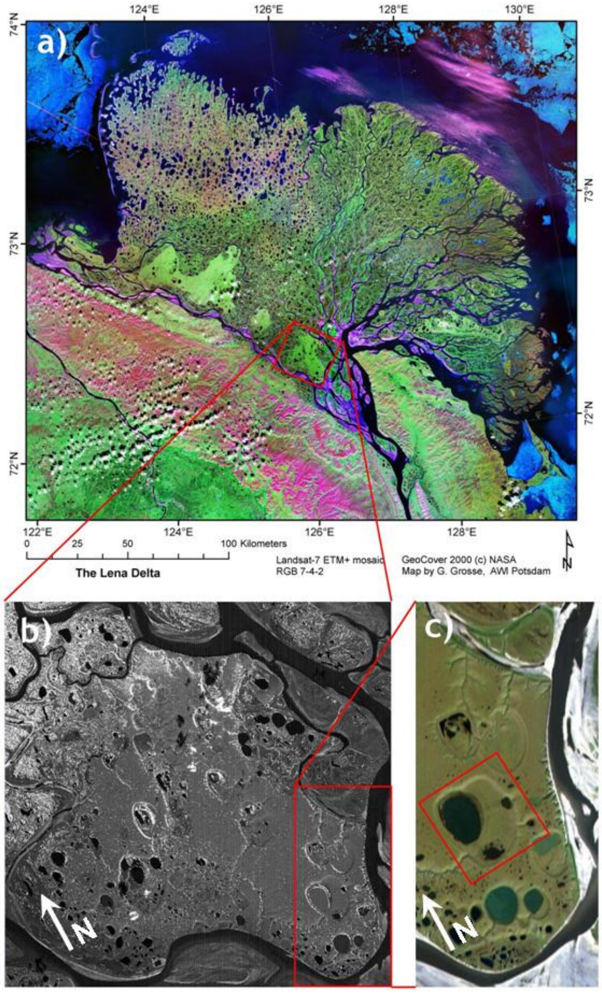

Figure 3. Location of the study area: a) Landsat-7 ETM+ mosaic of the Lena River Delta, RGB 7-4-2, b) ALOS PRISM subset showing Kurungnakh Island, and c) ALOS AVNIR-2 subset, RGB 3-2-1, showing field site.

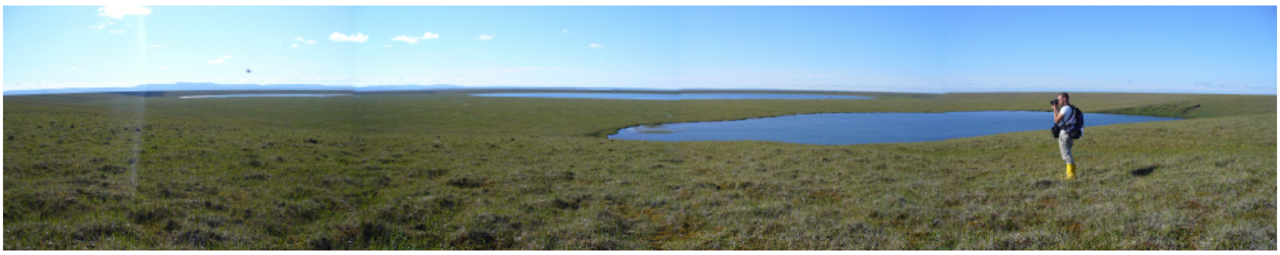

Figure 4. Panorama of the thermokarst basin on Kurungnakh Island (view from East to West).

3. DATA AND METHODS

3.1. Field Investigations

Field work during the 'Expedition Lena 2008' in August 2008 aimed at detailed data acquisition for:

- ground truthing of remote sensing data and analyses,
- investigating thermokarst morphometry and surface characteristics and their controlling factors,
- paleoenvironmental reconstruction.

For detailed investigations of the basin morphometry a tachymetric survey was conducted using a Tachymeter Elta 30C of Zeiss. For the ground truthing of remote sensing analyses surface characteristics have been documented on different distinctive relief units (undisturbed elevated plain, differently exposed basin slopes, basin floor, lake terraces, thermoerosional valleys, etc.) concerning:

- micro-relief,
- surface cover / vegetation characteristics,
- surface moisture / hydrological situation,
- soils,
- active layer depth.

Incident and reflected hemispherical solar radiation was measured on differently exposed slopes and surfaces and under different sky conditions using a Pyranometer CS300 of Campbell Scientific. These data will give an estimation of differences in the radiation balance due to relief exposure and – by calculating the albedo – provide ground truthing for spectral analyses. Samples of lake sediments for paleoenvironmental reconstruction were taken from the deepest parts of the three large lakes using a gravity corer equipped with a 60 cm long and 6 cm wide PVC liner operated from a small rubber boat as well as from two outcrops in drained parts of thermokarst basins.

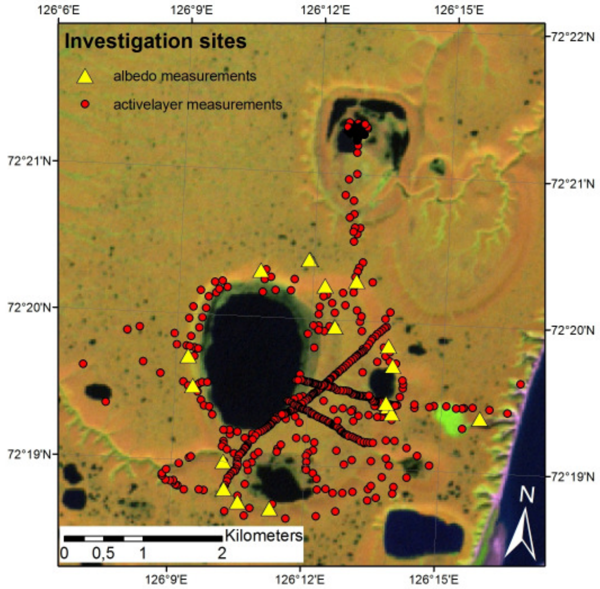

Figure 5. Landsat-7 ETM+ subset, RGB 5-4-3, of thermokarst basin on Kurungnakh Island with locations of albedo and active layer measurements

3.2. ALOS Data Analyses

Due to extensive cloud coverage in the Arctic Lena Delta region during the summer months the acquisition of relatively cloud free optical ALOS data covers only about 10 % of the delta area up to now. One ALOS PRISM scene from 21.09.2006 covers whole Kurungnakh Island and one ALOS AVNIR-2 scene from 18.08.2006 covers the eastern part of Kurungnakh Island including the field site.

ALOS data analyses will be used to upscale the detailed information about characteristics and evolution of thermokarst features and processes from the local (field site) to the regional scale (Kurungnakh Island).

Panchromatic ALOS PRISM data from 2006 will be compared with panchromatic CORONA imagery from the 1960s with similar spatial resolution to detect spatial changes of thermokarst features over this forty years period and to analyze possible spatial patterns. Digital Elevation Models (DEMs) of different spatial resolution and date derived from the tachymetric field survey, digitized topographic maps, ALOS PRISM triplets, and CORONA stereo pairs will be used to calculate volume changes on different scales and to deduce possible factors of the observed changes connected to changing relief situations.

Multispectral ALOS AVNIR-2 data will be used in combination with the ground truth data taken in the field and DEMs for a land cover classification of the study area. We expect different land cover classes to represent specific surface and relief features like elevated plains, basin slopes and floors, different lake terraces, etc. as they are obviously characterized by different drainage situations affecting the surface moisture, soil and vegetation development which in turn are responsible for different spectral signatures [8]. The aim of the land cover classification is the detection, characterization, and quantification of thermokarst features within the permafrost landscape.

4. PRELIMINARY RESULTS AND DISCUSSION

In the DEM derived from the tachymetric survey (Fig. 6) several asymmetries become obvious:

- the northern and the eastern lakes are "interrupting" the otherwise regular contour of the thermokarst basin slope,
- the slope angles of the thermokarst basin are much steeper in "interrupted" areas (Fig. 7),
- the lake terraces of the largest lake are much broader and more concise on the eastern and southern lake side,
- the three lake levels lay on different ground level elevations, the eastern lake is the highest, the largest lake the lowest.

These results indicate that the two northern lakes are laterally propagating into the thermokarst basin slopes in northwestern and northeastern directions, respectively, thus changing the contour of the thermokarst basin, which supposedly had been regularly elliptical. On the south facing slope north of the eastern lake we observed an area (several square meters) of disturbed vegetation cover and slope movement. This shows the present instability of the slope and confirms ongoing changes in the basin contour at this site.
Preliminary results of the surface and geomorphological survey show the following general characteristics:

- flat surfaces are characterized by moist polygonal tundra dominated by mosses and sedges,
- slightly inclined lake terraces show a wet polygonal micro-relief dominated by moss and sedge vegetation,
- steep slopes have a hummocky, well drained surface with a higher abundance in dwarf shrubs,
- dwarf shrubs are more abundant and of higher growth on south facing than on north facing slopes.

These observed characteristics confirm the suggestion, that different relief units are distinguishable in their spectra. Spectral analyses in the course of the land cover classification have to prove how significant these differences are regarding clear allocation to land cover classes.
First results of the albedo measurements indicate differences between differently exposed slopes, but further analyses are necessary to validate the data concerning comparability of different measurement situations and to discuss the observed differences regarding the relief and hydrological situation and vegetation cover.
The hydrological situation seems to be affected to a great extent by precipitation events. After a week of rainfall the flat and slightly inclined tundra surfaces became much wetter and the lake level of the largest lake raised by approximately 70 cm (!), which led to obvious lateral lake expansion. This effect has to be considered in change detection analyses. The compared data sets have to represent similar hydrological conditions, which needs to be proven by meteorological data.

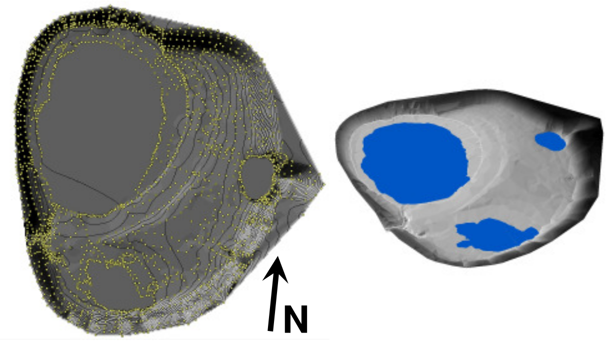

Figure 6. DEM of thermokarst basin on Kurungnakh Island derived from tachymetric survey (yellow on left image: measuring points of the tachymetric survey, blue on right image: three largest thermokarst lakes)

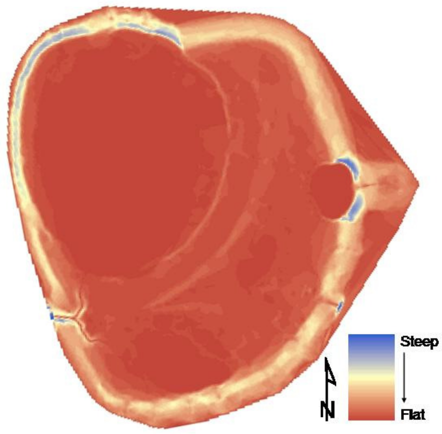

Figure 7. Slope map of thermokarst basin on Kurungnakh Island derived from DEM

5. CONCLUSION

Field work during the 'Expedition Lena 2008' provided highly valuable data for the ground truthing of remote sensing data and analyses and process understanding. Preliminary results of the field campaign confirm the hypothesis of spatially directed thermokarst processes. Advanced analyses will provide comprehensive information on the detailed mechanisms and factors influencing thermokarst evolution in the study area. The information provided by optical ALOS data will make a major contribution in this effort.

6. ACKNOWLEDGEMENTS

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