Detection and quantification of lateral thermokarst lake expansion processes in periglacial landscapes based on Sentinel and RadpidEye imagery

Soraya Kaiser[1,2]
Thomas Schneider von Deimling[1,2]
Stephan Jacobi[1]
Richard Mommertz[1,3]
Moritz Langer[1,2]

[1] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2] Department of Geography, Humboldt-Universität zu Berlin, Berlin, Germany
[3] University of Potsdam, Potsdam, Germany
Correspondence to: Soraya Kaiser (soraya.kaiser@awi.de)

Abstract

While there are abundant erosional features throughout the Arctic – ranging from landslides, thaw slumps or river bank to gully erosion – one of the most dynamic periglacial elements are thermokarst lakes. Due to their lateral thermal and mechanical erosion they shape their surrounding topography and hydrological network, leading to a further destabilization of permafrost soils. This study aims at the remote sensing based identification and quantification of these lateral erosion processes and their incorporation into the land surface model CryoGrid3 to estimate their effect on Arctic ecosystems and infrastructure.

Keywords: Thermokarst lake expansion; erosion rates; Sentinel; RapidEye; CryoGrid3; permafrost

Introduction

Thermokarst ponds and lakes are an abundant and widespread landform throughout the Arctic (Hinkel *et al.*, 2005). They develop in regions underlain by continuous permafrost as a consequence of soil subsidence that is triggered by the thawing of excess ground ice (Langer *et al.*, 2016; Pienitz *et al.*, 2008). When a resulting depression fills with the melt water of the degraded ice, it forms a pond that can cause – due to the waterbody's heating property and the formation of a talik beneath the basin – further thawing processes (Pienitz *et al.*, 2008). As a result of the thermal erosion, the size of the pond increases vertically and horizontally and can turn into a lake. Several studies conducted to understand thermokarst lake dynamics state that the area of the Arctic's land surface covered by these landforms is steadily growing (Jones *et al.*, 2011). Especially ponds – being the primary waterbody type (Nitze *et al.*, 2017) – underlie a strong expansion (Jones *et al.*, 2011) further shaping their surrounding landscape.

While the previous scientific work regards the dynamics of thermokarst ponds and lakes over a substantial time span, this study focuses on a detailed quantification and estimation of seasonal shoreline erosion rates, their spatial patterns and temporal variability. The retrieved information will be incorporated into the land surface scheme CryoGrid3, which simulates permafrost thawing but only regards vertical processes of soil subsidence and thermokarst development yet (Westermann *et al.*, 2016).

Methodology

Our study aims at the detection and quantification of lateral erosion and mass movement processes that occur around thermokarst lakes. For this purpose a study site in Prudhoe Bay, Alaska, is selected due to its vast natural and human-caused thermokarst features.

Figure 1: RGB image of the Prudhoe Bay Area (Alaska, U.S.A.) showing the infrastructure's close proximity to thermokarst features (Spatial Reference: WGS 84 UTM zone 6. Imagery: Planet Team, 2017)

The local infrastructure consists of gravel roads to access the production sites and pipelines for oil transport. Figure 1 shows a production site close to

Prudhoe Bay and underlines the need for a better understanding of landscape changes resulting from permafrost thaw. By applying a combination of high resolution optical imagery and complementary radar and elevation data, the study aims at explaining (i) how thermokarst lakes react to changes in meteorological conditions, (ii) at investigating the spatial patterns of lake expansion (linear/ irregular) and (iii) at identifying the driving factors for lake dynamics (lake ice type, lake size, topography, vegetation etc.).

Our analysis is based on radar data of the Copernicus Sentinel 1A and B for retrieving lake ice characteristics and on multispectral imagery from the Planet Labs Incorporation's PlanetScope and RapidEye products for acquiring information about ground characteristics (soil, vegetation etc.). The (micro)topography – being an important factor concerning mass movement processes – will be analyzed on the basis of the Arctic DEM.

For representing thermokarst lake formation and expansion in the land surface scheme CryoGrid3, it is also crucial to understand the response of thermokarst dynamics to seasonal changes in meteorological conditions. We therefore analyze climate data products to identify changes in temperature, precipitation, wind speed, etc. since these parameters influence the thermal regime of the waterbodies and the susceptibility of the surrounding landscape to soil erosion.

Acknowledgments

The young investigator group PermaRisk is funded by the German Federal Ministry of Education and Research (BMBF) under the funding reference number 01LN1709A.

The RapidEye and Planetscope imagery is provided by Planet Labs Inc. within their Education and Research Program (Planet Team, 2017).

References

Hinkel, K. M., Frohn, R. C., Nelson, F. E., Eisner, W. R., & Beck, R. A., 2005. Morphometric and spatial analysis of thaw lakes and drained thaw lake basins in the western Arctic Coastal Plain, Alaska. *Permafrost and Periglacial Processes* 16(4): 327–341.

Jones, B. M., Grosse, G., Arp, C. D., Jones, M. C., Walter Anthony, K. M., & Romanovsky, V. E., 2011. Modern thermokarst lake dynamics in the continuous permafrost zone, northern Seward Peninsula, Alaska. *Journal of Geophysical Research: Biogeosciences* 116(3): 1–13.

Langer, M., Westermann, S., Boike, J., Kirillin, G., Grosse, G., Peng, S., & Krinner, G., 2016. Rapid degradation of permafrost underneath waterbodies in tundra landscapes – Toward a representation of thermokarst in land surface models. *Journal of Geophysical Research: Earth Surface* 121(12): 2446–2470.

Nitze, I., Grosse, G., Jones, B. M., Arp, C. D., Ulrich, M., Fedorov, A., & Veremeeva, A., 2017. Landsat-based trend analysis of lake dynamics across Northern Permafrost Regions. *Remote Sensing* 9(7): 1–28.

Pienitz, R., Doran, P. T., & Lamoureux, S. F., 2008. Origin and geomorphology of lakes in the polar regions. In W. F. Vincent & J. Laybourn-Parry (eds.), *Polar Lakes and Rivers: Limnology of Arctic and Antarctic Aquatic Ecosystems*. New York: Oxford University Press, 25–42.

Planet Team. (2017). Planet Application Program Interface: In Space for Life on Earth. Retrieved from https://api.planet.com

Westermann, S., Langer, M., Boike, J., Heikenfeld, M., Peter, M., Etzelmüller, B., & Krinner, G., 2016. Simulating the thermal regime and thaw processes of ice-rich permafrost ground with the land-surface model CryoGrid 3. *Geoscientific Model Development* 9(2): 523–546.