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Characterizing thermo-erosional landforms in Siberian ice-rich permafrost

Morphometric investigations using high resolution satellite imagery and digital elevation models

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Fieldwork & image fusion

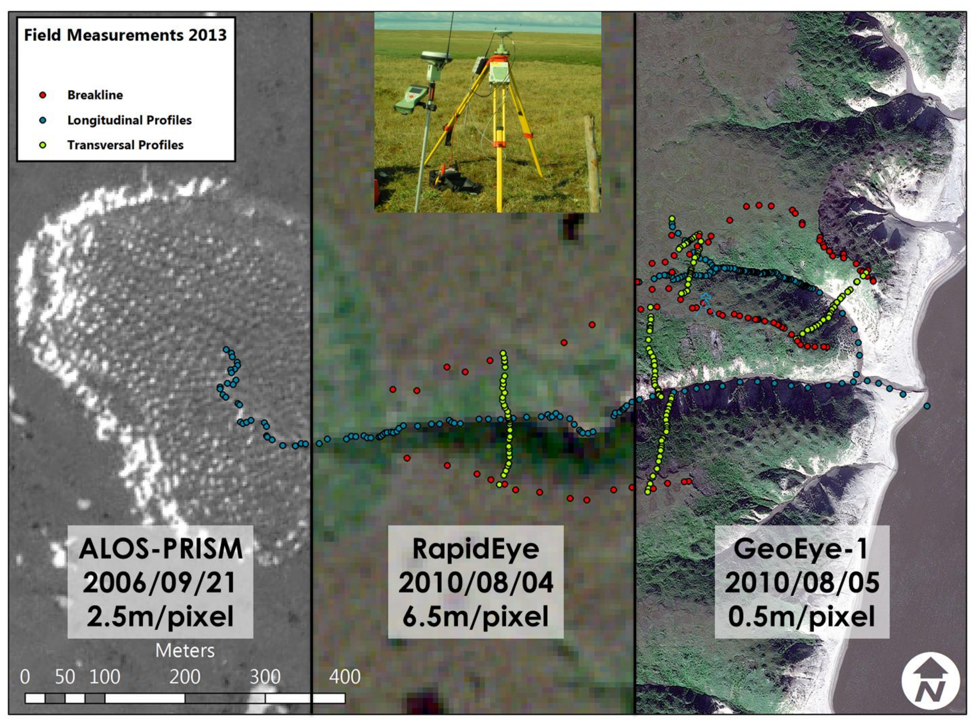


Fig. 1: Exemplary overview of satellite images used for mapping and field data taken during expedition in July 2013 in the „Drained Lake Valley" key site.

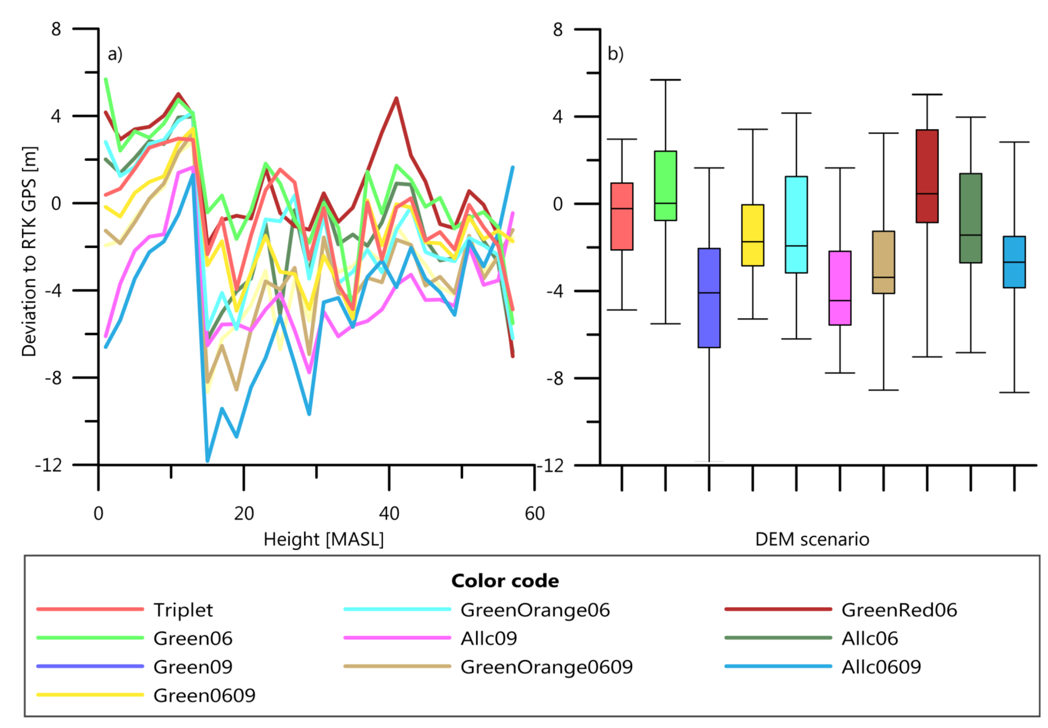
Fieldwork

- 12 GCPs
- 29 Transversal profiles
- 7 Longitudinal profiles
- Surface descriptions

Image fusion

- GeoEye-1(RMSE 0,36 m), RPC-model (Aguilar et al. 2012)
- RapidEye (RMSE 2,86 m), RPC-model
- PRISM (RMSE 2,34 m), Toutins-model, image enhancement (Kamiya 2006)

DEM generation & evaluation



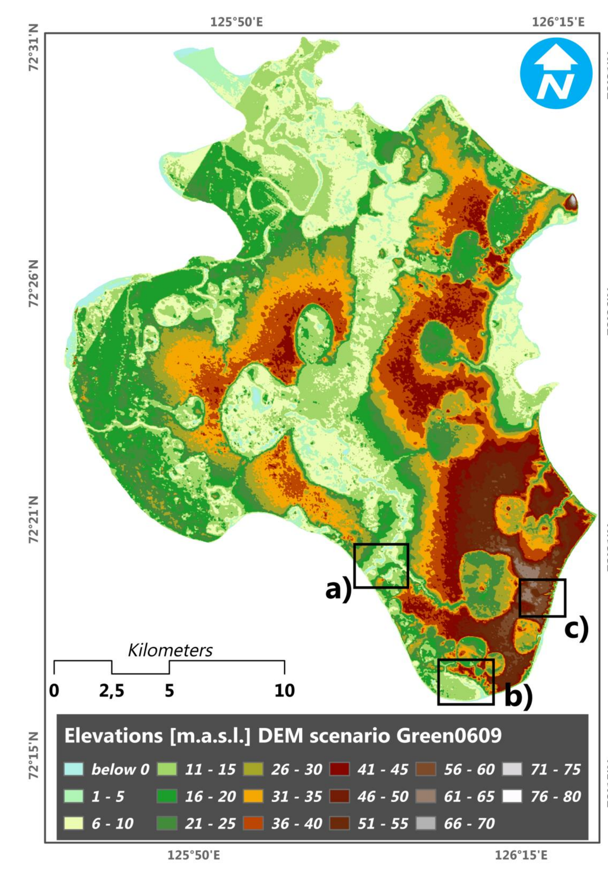


Fig. 2: Ten DEMs from several combinations of 14 ALOS PRISM stereopairs were tested to 1) get better matching results on low-contrast and low-slope gradient yedoma upland; 2) decrease the effect of occlusion in valley floors; 3) decrease error in areas with coastal erosion. DEMs were evaluated using 1104 RTK GPS points (Range 0-58 m a.s.l.), classified in 2 m steps from 0 to 58 m. Values on the y-axis represent the standard deviation of the mean error per class. Scenario Green0609 (right image) shows the best results with an overall vertical **RMSE of 4.41 m a.s.l.**

Background

Accelerated **degradation of Siberian ice-rich permafrost** (Romanovsky et al. 2010) has substantial impacts on regional (e.g. water & energy balances) to global scale(e.g. carbon release to the atmosphere, Koven et al. 2011). In this context **thermo-erosional processes and related landforms** (e.g. gullies and valleys) as well as their impact on the widespread degradation of ice-rich permafrost remains **not well quantified**.(Morgenstern 2014).

Key questions

- Are DEMs extracted from ALOS-PRISM satellite data a suitable basis for the morphometric analysis of thermo-erosional valleys in ice-rich permafrost?
- How are thermo-erosional valleys distributed in the study area?
- What are the driving factors for the presence of the identified valley types?

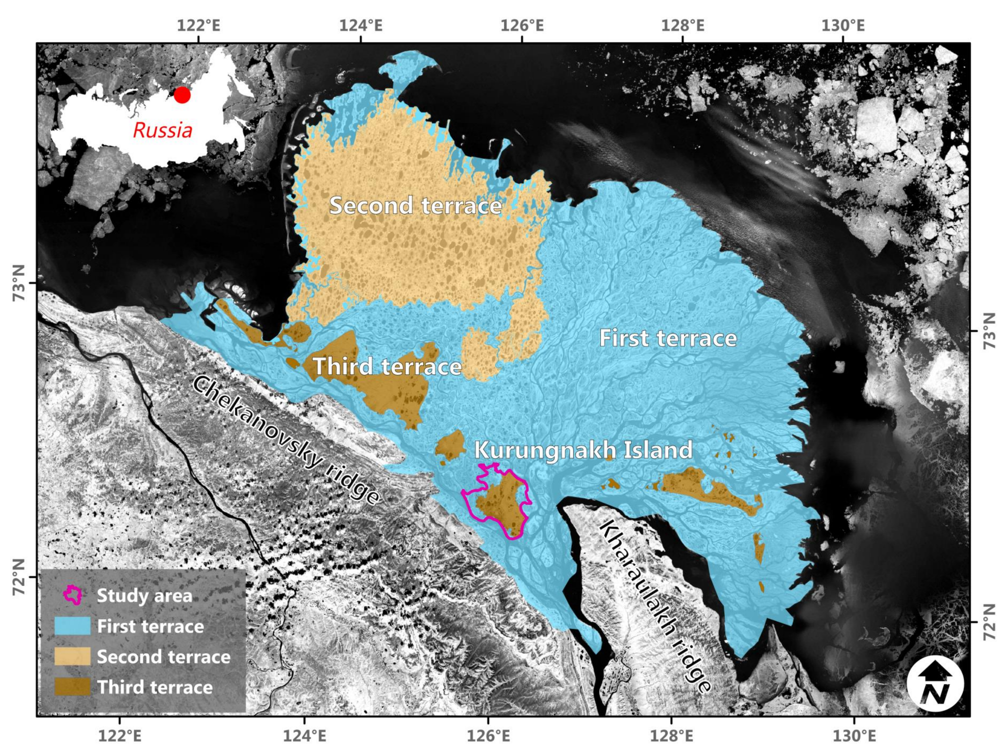


Fig. 3: Geomorphological situation in the Lena Delta and location of the study area Kurungnakh Island.

Study area

- **Kurungnakh Island** (central Lena Delta, Fig.1)
- **Third main terrace** of the Lena Delta (Grigoriev, 1993)
- **Ice- and organic-rich sediments (Ice Complex)** , lower boundary between 15-20 m a.s.l. (Schirrmeister et al. 2011)
- Intensive thermokarst **and thermo-erosional activity → highly** dissected surface (Fig. 2) (Morgenstern et al., 2013)
- Zone with **high neotectonic activity** (Are & Reimnitz 2000)
- Maximum heights around 58 m a.s.l. in the southeast, gradually decreasing towards northwest
- Total area 377 km² / Ice Complex 270 km²
- Broad variety of **thermo-erosional features**

Conclusions

Thermo-erosional features are strongly **connected to thermokarst** activity. **Short and non-complex** thermo-erosional features are the **predominant type** on Kurungnakh Island. **Complex valley networks** develop in areas of ice-rich permafrost that are highly **degraded by thermokarst. Thermo-erosional networks** are mainly responsible for the **transport of thawed sediments** from the terrestrial place of degradation **to the hydrosphere** and therefore **play an important role in permafrost degradation**.

Valley morphometry

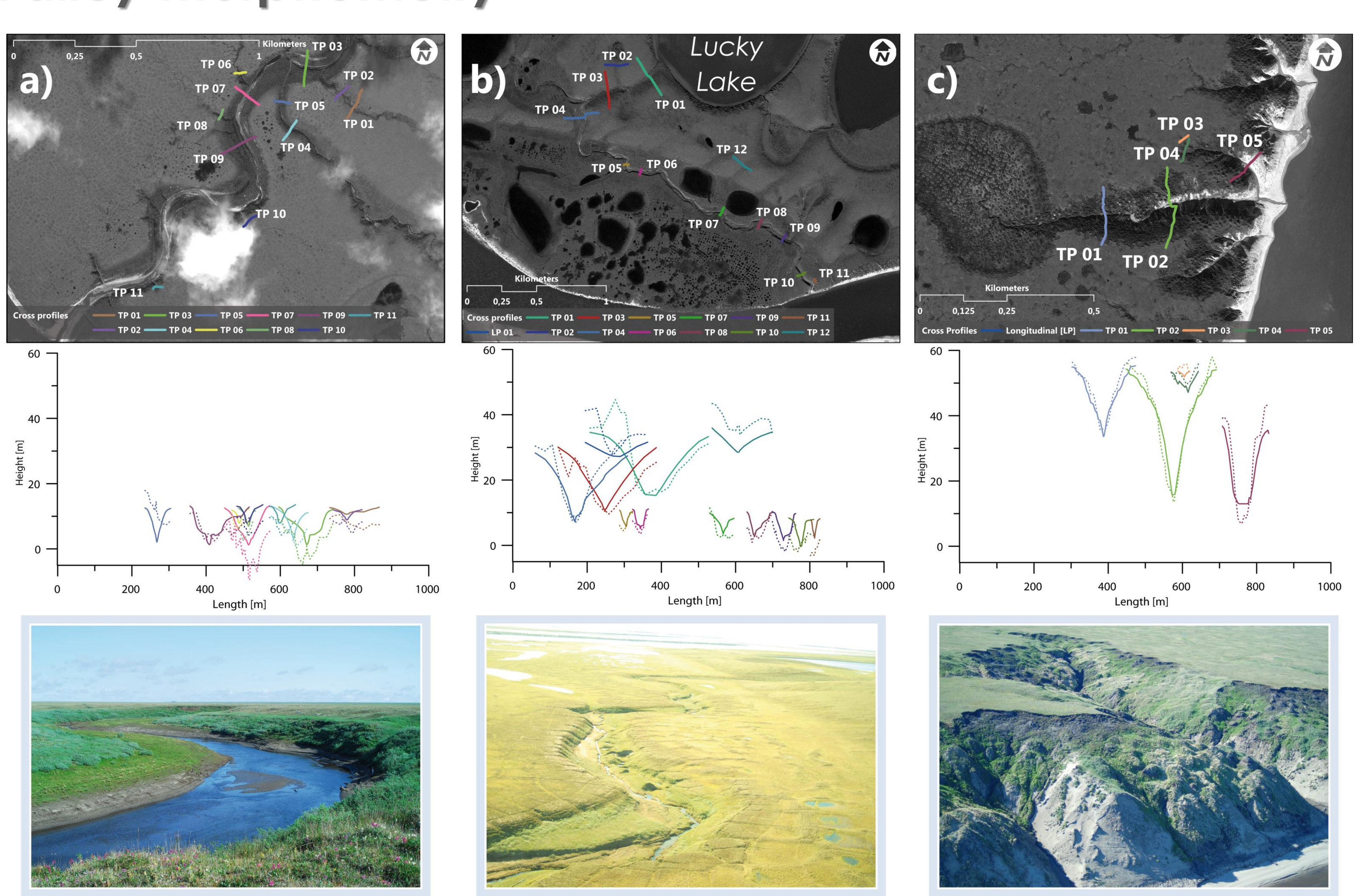


Fig. 4: Transversal profiles of three key sites:
a) "Main Valley" with u-shaped and wide meandering valleys with gentle slopes and terraces that are influenced by Lena River floods representing the most progressed state of valley evolution;
b) "Lucky Lake Valley" showing a transition from third to first terrace, U-shaped valleys with steep slopes and north to northwest facing terraces are influenced by snow patches, outflow of thermokarst lakes and in low areas by flooding of the delta channels;
c) "Drained Lake Valley" with v-shaped valleys that incise deep into the Ice Complex and are driven by exterior thermal erosion due to the Lena Delta channels and or draining events within the study area or gullying due to rapid melting of ice wedges. Dotted lines in all plots show the elevation extracted from the DEM in Fig. 3.

Stream network & stream orientation

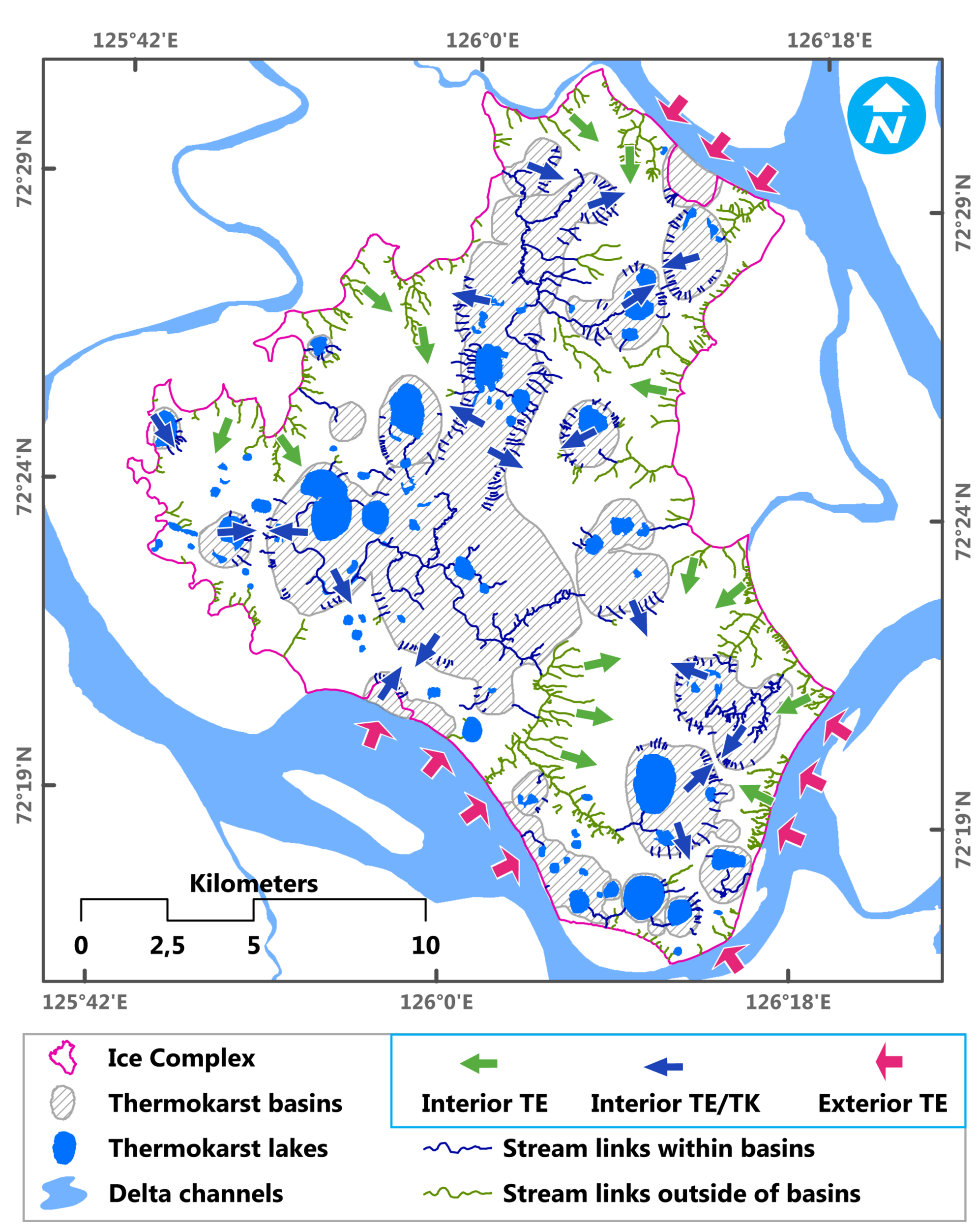


Fig. 5: Thermo-erosional features and processes on Kurungnakh Island: The thermo-erosional stream network will further expand with warming permafrost (interior TE), while the combined activity of thermokarst and thermal erosion (interior TE/TK) will lead to an lateral expansion of thermokarst basins. The Lena River Delta channels will lead to thermo-erosional permafrost degradation at the coastline (exterior TE).

Stream network

- Total flow length = 336 km
- Drainage density = 0,8
- 50 % of the streams are shorter than 230 m
- Short streams occur mainly on slopes of thermokarst basins and at the coastline
- Longer streams with higher order are mainly present within thermokarst basins and connect these with each other and with the delta channels

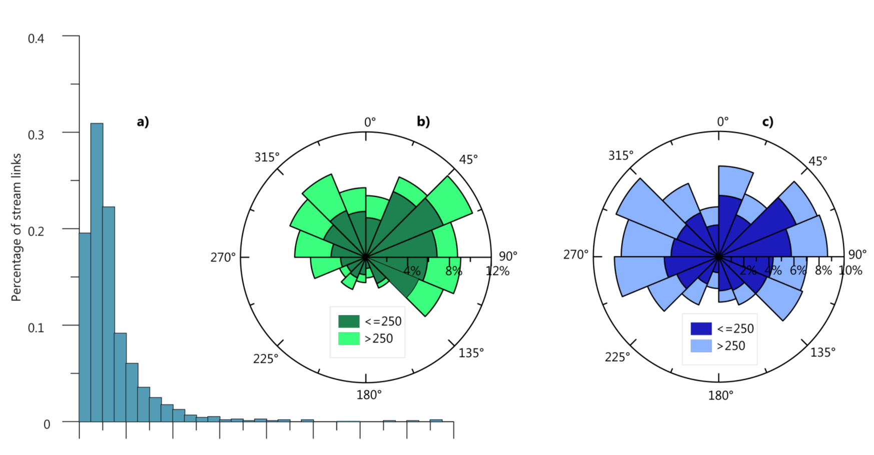


Fig. 6: The **orientation of stream links** follows the height gradient of the study area (northwest). Often radially arranged short and straight streams at the slopes of thermokarst depressions superimpose the signal (east and west). Streams outside of thermokarst basins show two main directions that could reflect the structure of polygonal nets in the ground.

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