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# Multi-methodological investigation of a retrogressive thaw slump in the Richardson Mountains, Northwest Territories, Canada

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Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Environment Canada

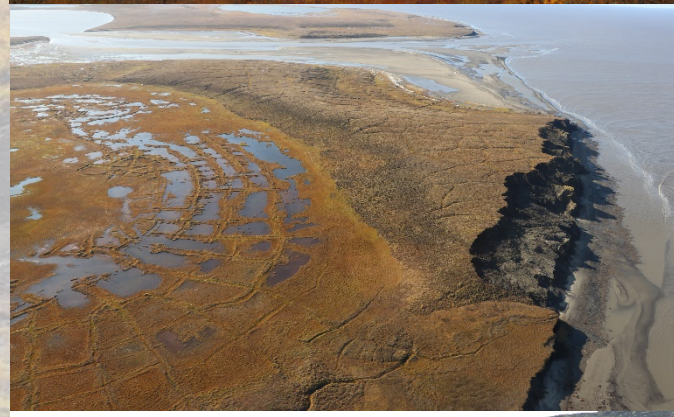
AWI

# Introduction

- 2.5°C temperature increase since 1970 in the Mackenzie Delta region leads to an increase in morphological surface dynamics and permafrost degradation[1]

- rapid thaw of massive ground ice or supersaturated permafrost forces the formation of retrogressive thaw slumps (RTS) in shore areas of lakes, at the coast or along rivers and creeks in the Mackenzie Delta region[2]

- the dynamic of RTS and especially the affecting aspects like relief, ground ice conditions or permafrost hydrology are not understood adequately



# Study site & methods



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# Study site

- the investigated RTS is located at the eastern side of the Richardson Mountains within the transition zone to the Peel Plateau (67°11‘0‘‘N, 135°48‘40‘‘W, aprox. 730 m a.s.l.)

- geology in this part of the Richardson Mountains is dominated by dark Cretaceous (Jurassic) and Devonian shales and siltstones[3,4]
  - eastern flank of the Richardson Mountains is covered by glacial sediments of the Laurentide Ice Sheet up to an elevation of ca. 750 m a.s.l. [5,6]

- climate (Fort McPherson 1981-2010)[7]:
  - mean annual air temperature: - 7.3°C
  - mean annual precipitation: 298 mm

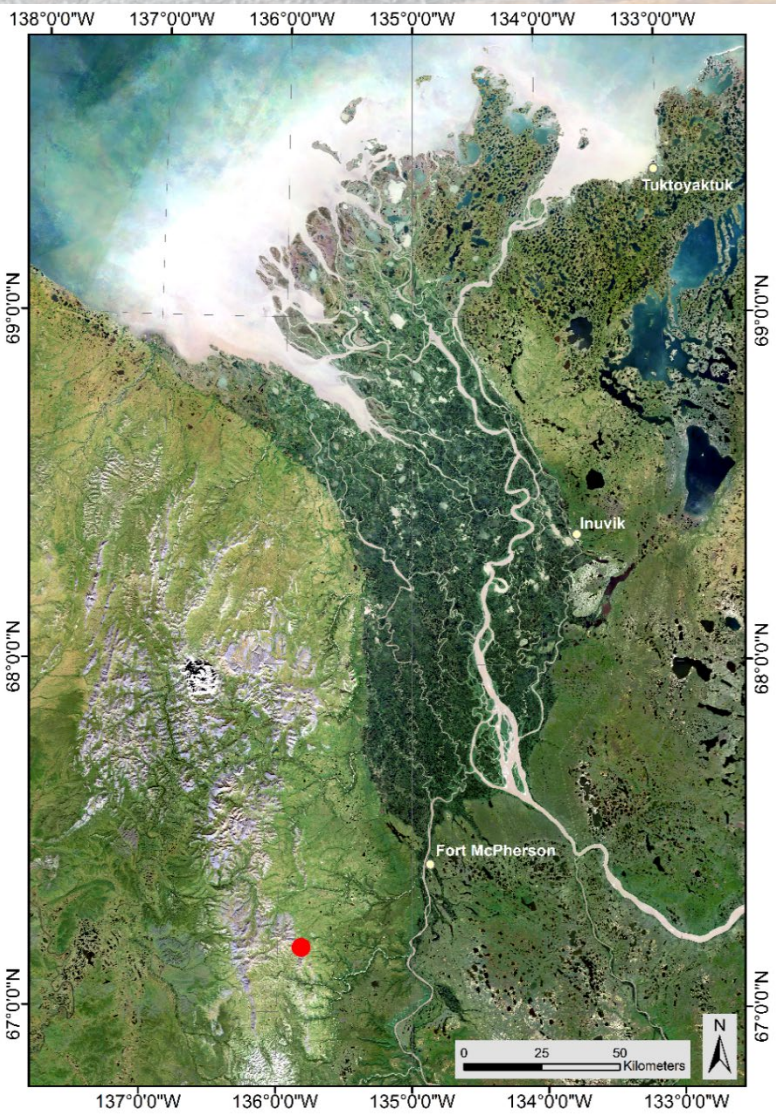


Fig. 1: Landsat-8 RGB true-color image composite of the Mackenzie Delte Region (after Nill et al[8]) and the marked location of the study site (red dot).

# Study site



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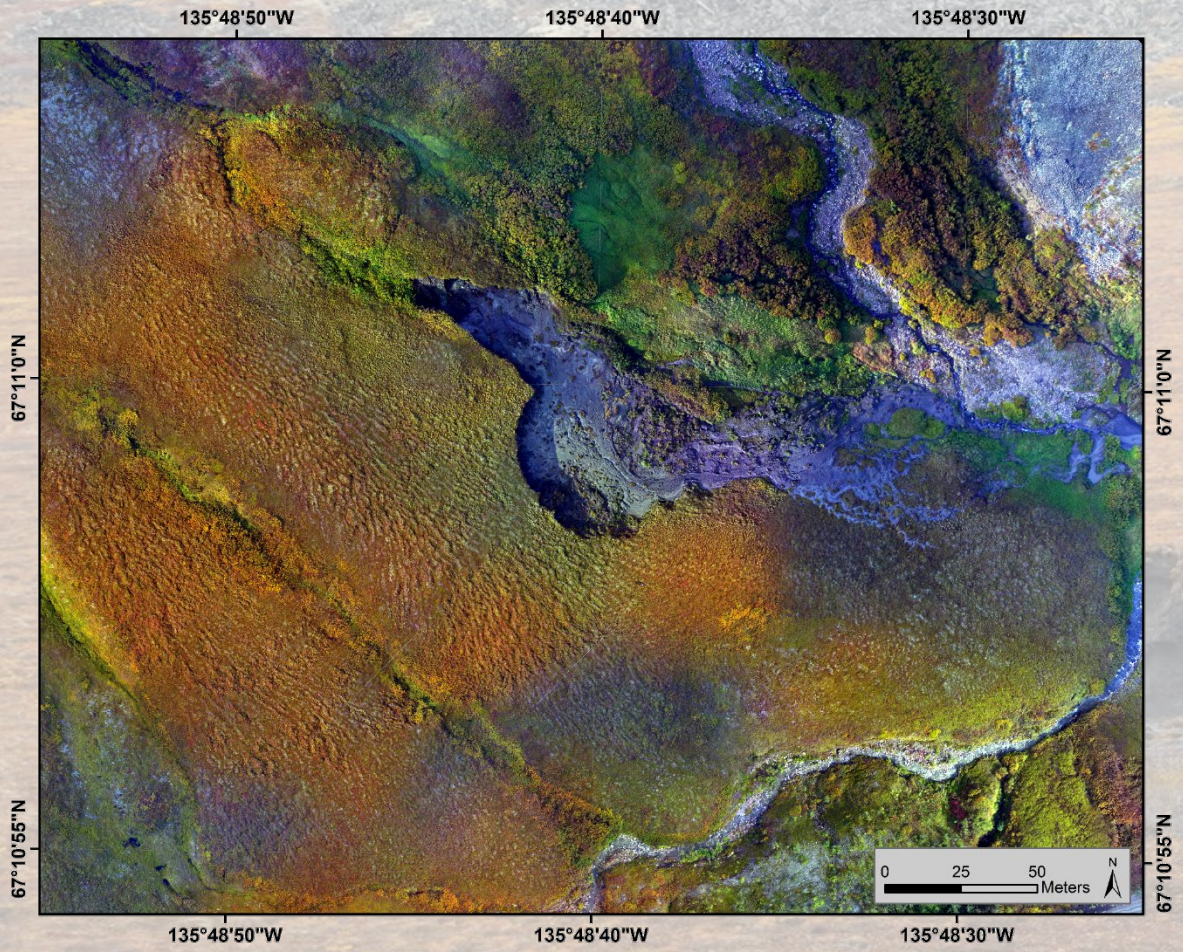


Fig. 2: UAV based orthoimage of the investigated retrogressive thaw slump and the surounding area. Clearly visible is the active part of the slump. North of the actual slump floor a stable and vegetated slump scar is located.

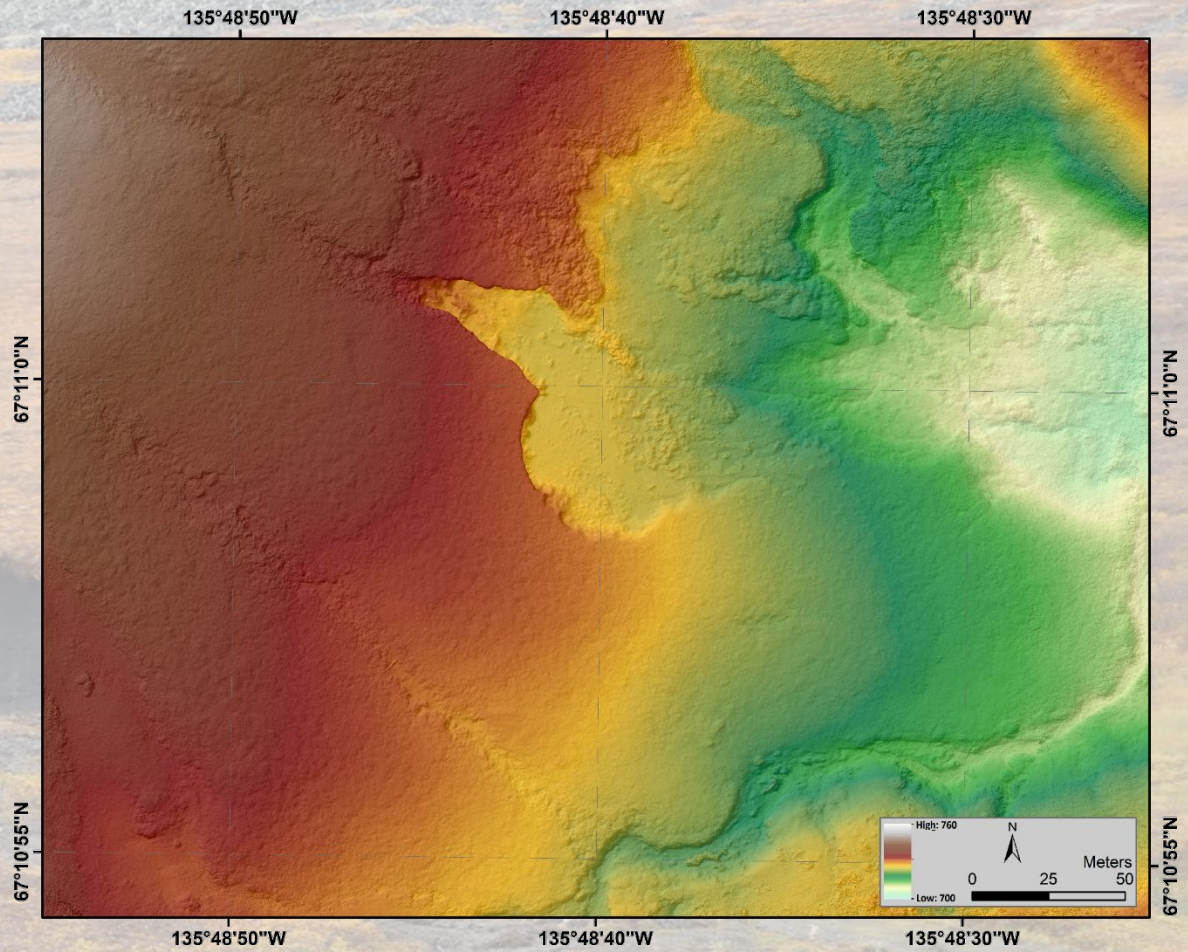


Fig. 3: UAV based digital elevation model (DEM) of the study site (same extent as Fig. 2).

# Study site



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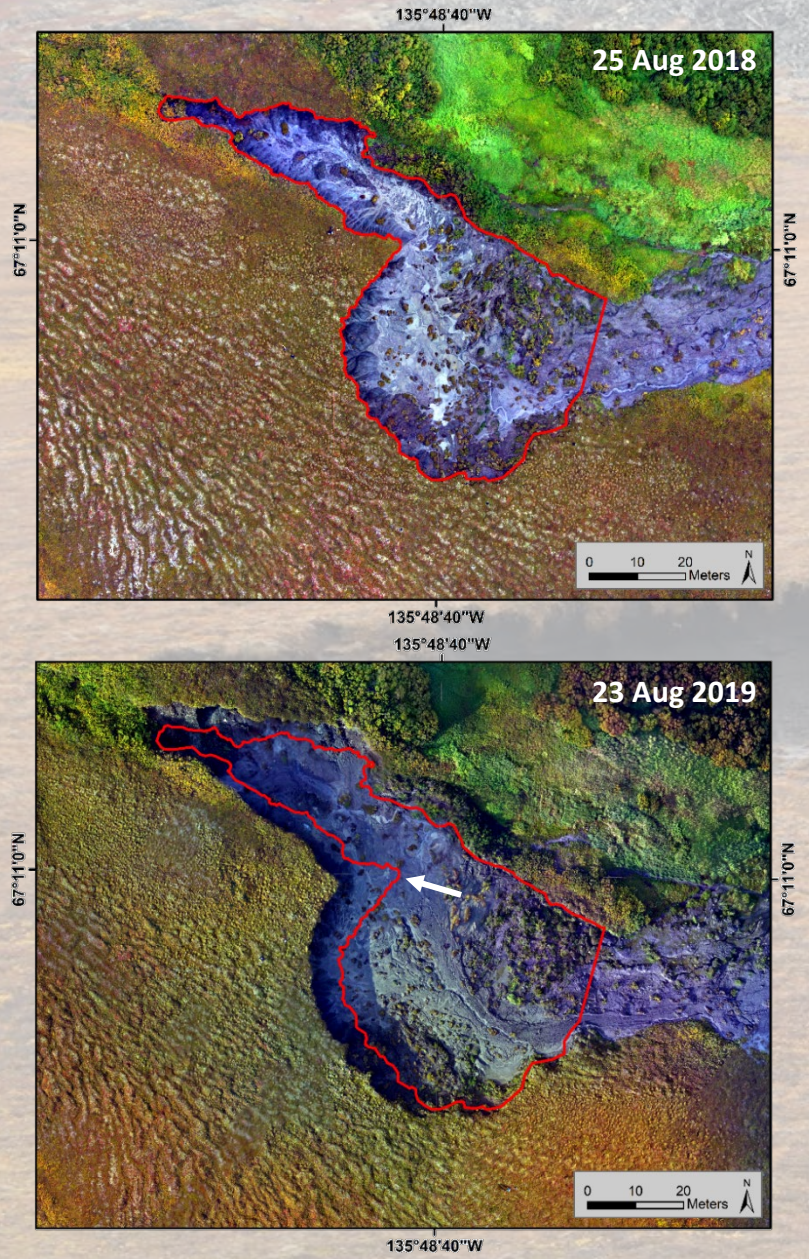


- the RTS covers an area of approx. 3,800 $m^2$ (23 August 2019) and the retreating headwall reaches a height of up to 6 m
- small sheet floods exit from the slump floor and partly cover the adjacent area in downstream direction
- headwall retreat predominantly in western and southwestern direction, along the creek also in northern direction
  - retreat rates of the headwall between 4 m and 7 m (even 11 m at the small spit (cf. arrow)) between August 2018 and August 2019
- older and seemingly stable slump scar at the northern site of the creek

Fig. 4: Comparison of the slump extent in August 2018 (top) and August 2019 (bottom) based on UAV orthophotos.

# Methods

- UAV-based orthoimage and digital elevation model (DEM) generation
- frost probing using a 120 cm long steel rod
- ground-penetrating radar (GPR)
  - 250 MHz antennas (shielded)
  - 100 MHz antennas (unshielded)
- quasi-3D Electrical Resistivity Tomography (ERT)
  - 3 m electrode spacing, dipole-dipole array
  - longitudinal profiles: 36 / 72 electrodes, 6 m interline spacing
  - cross profiles: 36 electrodes, 12 m interline spacing

Photo: Tim Wiegand

# Methods



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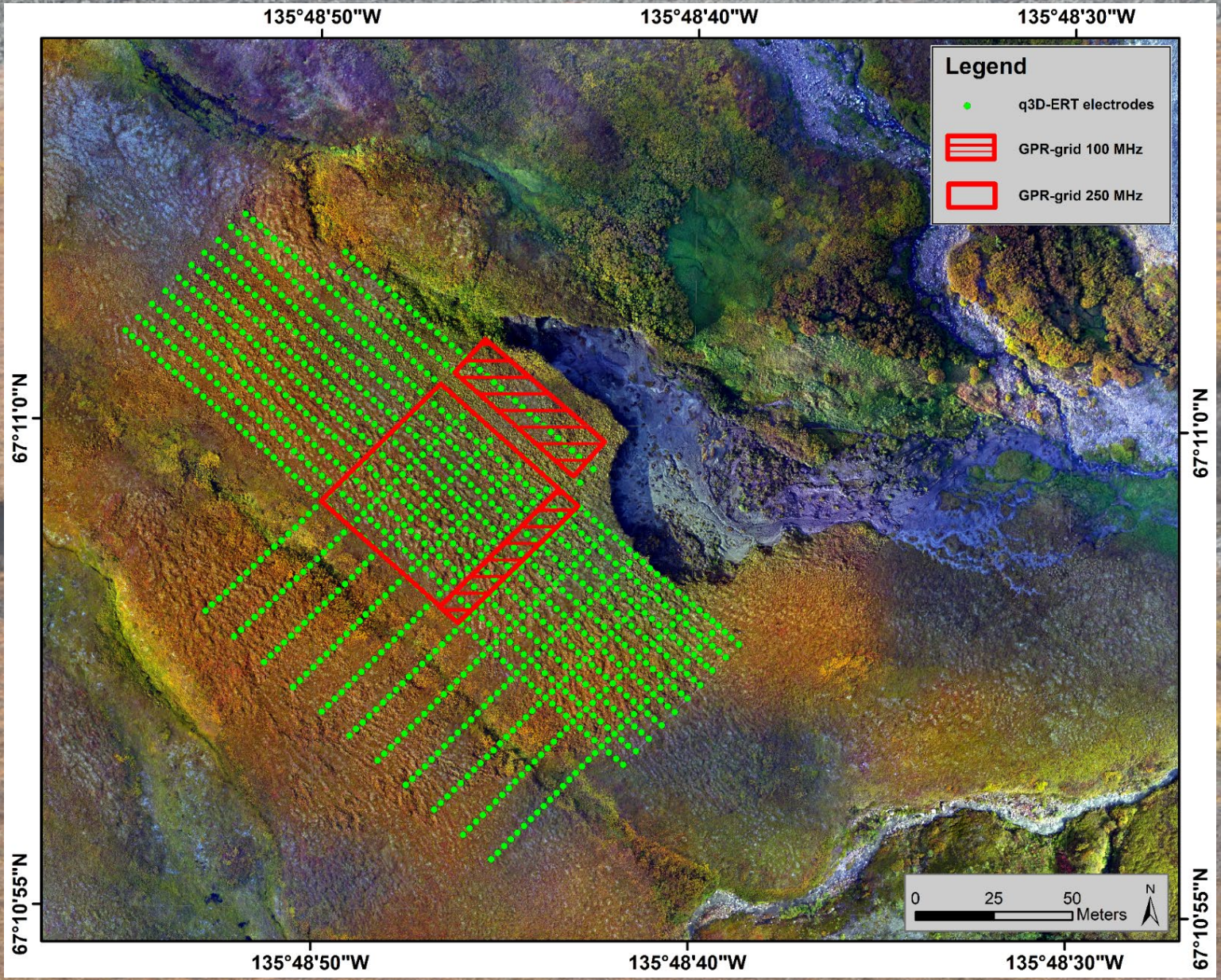


Fig. 5: Location of the performed geophysical measurements. Green dots mark the position of each electrode, which were located using the UAV based high-resolution orthoimage. The red polygons mark the grid extents of the different GPR grids.

# Results



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# Active Layer Depth (frost probing)



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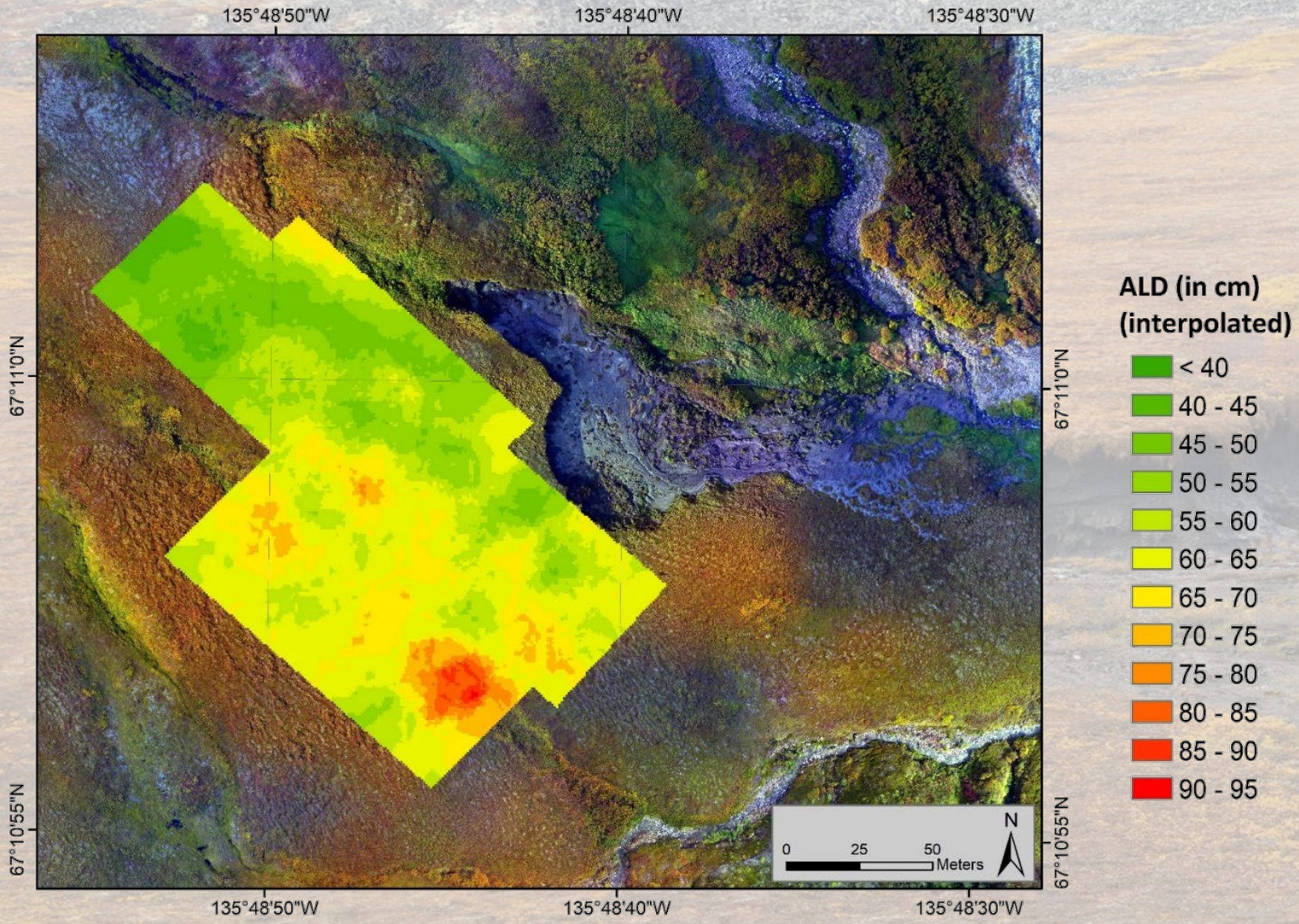


Fig. 6: Interpolated ALDs derived from manual frost probing.

- zonation of active layer depth depending on the relief
- ridge between the two incised creeks is characterized by low ALDs
- sinks along the creeks show higher ALDs
- anomaly of high ALDs below the southern part of the southern creek
- low or medium ALDs adjacent to the retreating headwall

# Ground-Penetrating Radar (250 MHz)



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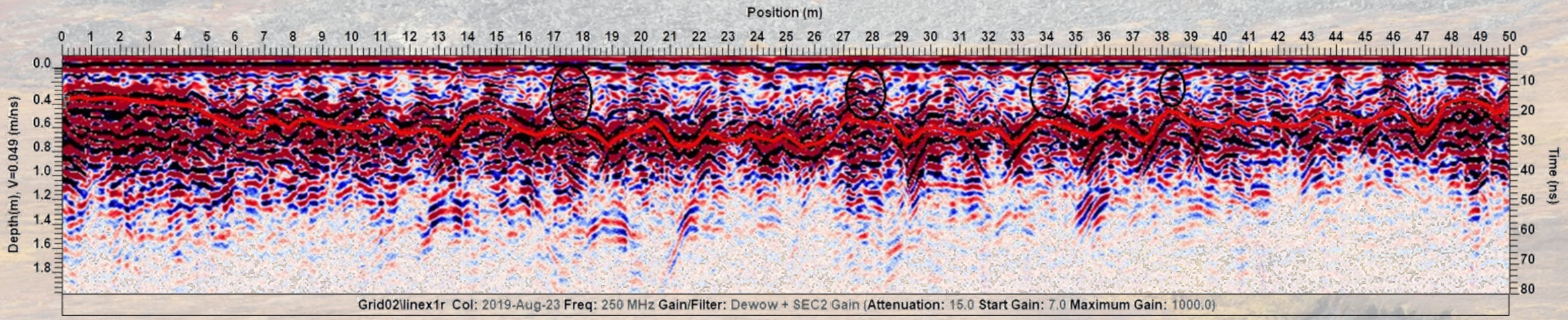


Fig. 7: Example of 250 MHz GPR data. Red line marks the permafrost table, the black ovals highlight areas of high reflection intensities within the active layer. Profile location is ilustrated in Fig. 8.

- 250 MHz data enable a clear and extensive detection of the permafrost table (red line) and the ALD
- variation in substrate distribution and grain size within the active layer is displayed by varying reflection intensities
  - areas of low ALDs show higher reflection intensities (marked with black ovals above permafrost table), above local sinks the reflections are significantly less intense
  - variations in near surface substrate distribution and grain size are also visible in vegetation patterns

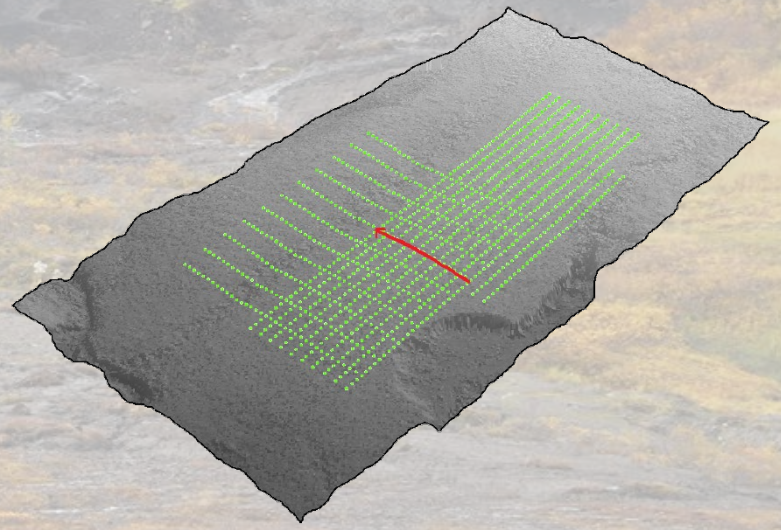

Fig. 8: Location of the GPR profile in Fig. 7.

# Ground-Penetrating Radar (100 MHz)



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- 100 MHz data also display the location of the permafrost table, but deliver less information about active layer structure
- in a depth between 4.5 and 6 m (close to the maximim penetration depth) stronger reflections appear in some of the profiles (black ovals), which possibly indicate higher water contents or impurities within the massive ground ice

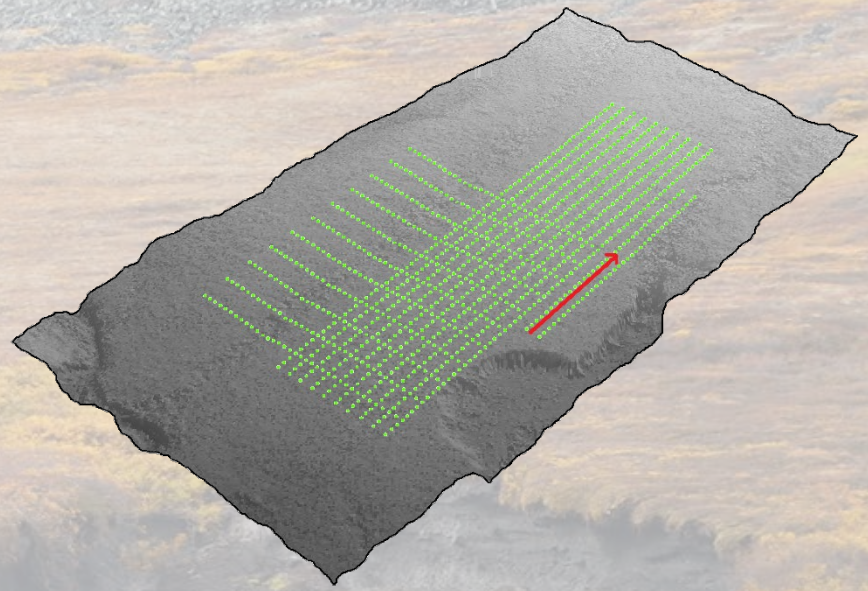

Fig. 9: Location of the GPR profile in Fig. 10.

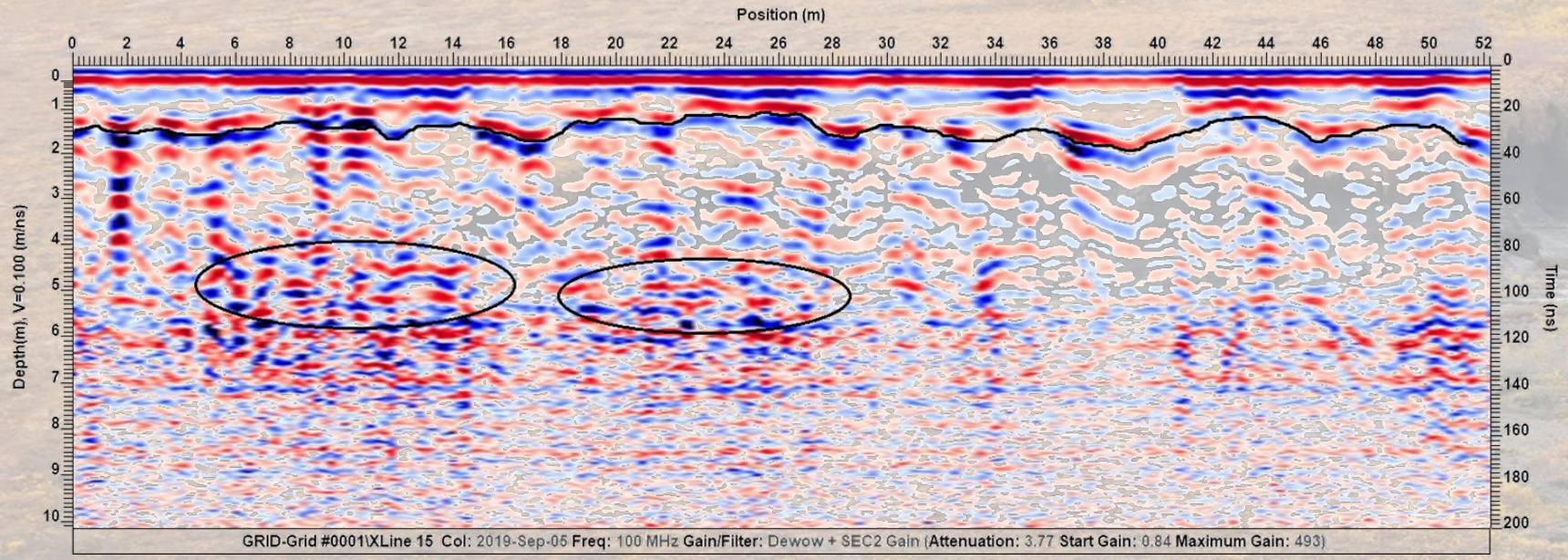


Fig. 10: Example of 100 MHz GPR data. Black line marks the permafrost table, the black ovals highlight areas of high reflection intensities within or beneath the permafrost body. Profile location is ilustrated in Fig. 9.

- due to heterogeneous soil moisture and substrate patterns a time-depth-conversion for localisation of the permafrost table is quite difficult and therefore a three-dimensional model of permafrost table topography is still missing

# 2D Electrical Resistivity Tomography



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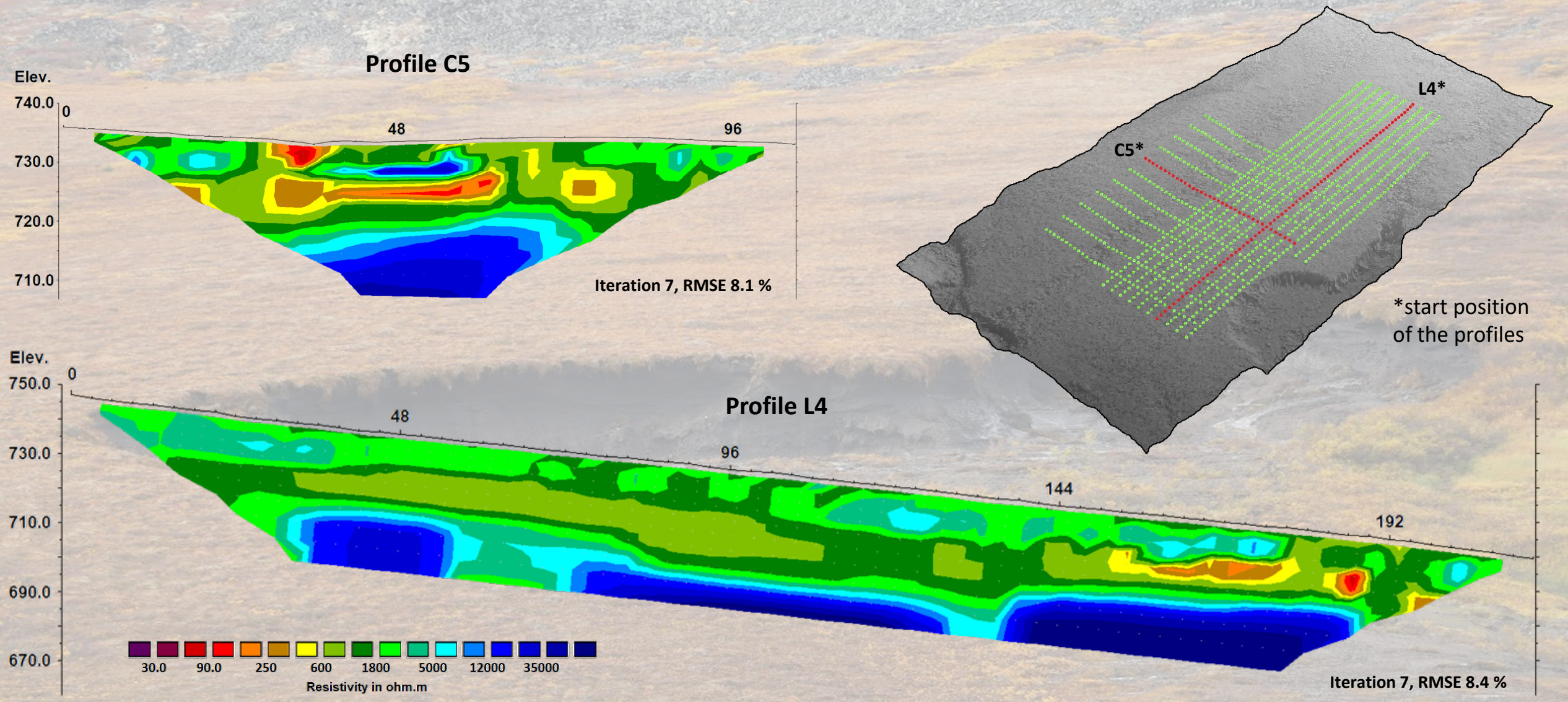
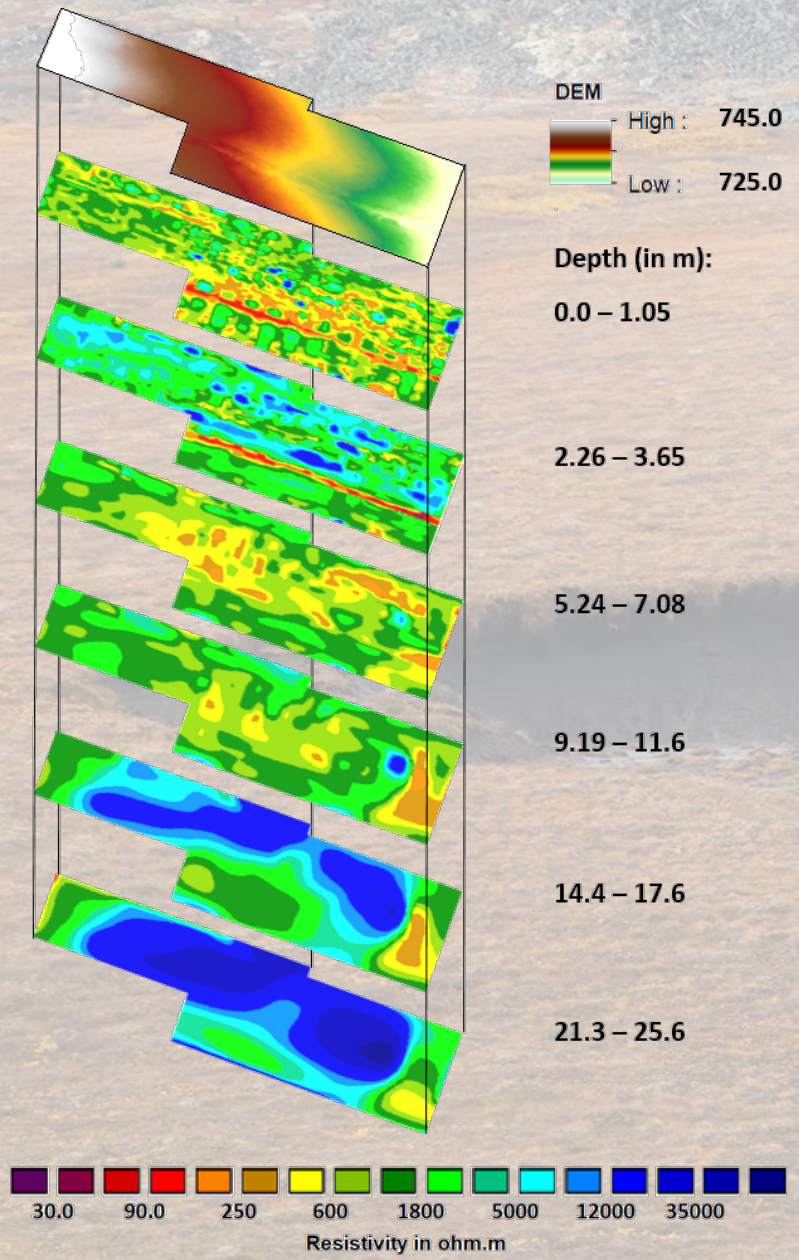



Fig. 11: 2D-ERT profiles C5 (top left) and L4 (bottom) and their positions in the q3D-grid (top right).

# q3D Electrical Resistivity Tomography




- ERT data present heterogeneous distribution of electrical resistivity values in the area adjacent to the retreating headwall
- resistivity values between 1.2 and 35 kΩm between 2 and 4 m depth are indicative for (partly) ice-rich permafrost or massive ground ice[9]
  - elongated lenses (>12 kΩm) in slope direction may indicate a link to topography related hydrology and/or the detected sorting of the material
- low resistivity values (<100 Ωm) indicate unfrozen conditions and a thermal impact of the small creek that crosses the grid
- in 4 - 10 m depth a low resistive layer (<1000 Ωm) is detectable nearly throughout the whole grid area
  - low resistivity values are indicative for unfrozen or water-rich layers in this depth[9]
- below a depth of 12 m there is a sharp increase of the resistivity values up to 35 kΩm across the main part of the grid
  - this layer continues to the lowermost layer of the model
  - because of the morphological situation, but also because of the electrical resistivity values of a nearby bedrock outcrop (data not shown), this layer probably represents the underlain frozen bedrock

Fig. 12: Depth-slices of the q3D-ERT model (Iteration 5, RMSE 7.7%).

# q3D Electrical Resistivity Tomography



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Fig. 13: Q3D-ERT block model. (Klick to start!)

# Conclusions



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# Conclusions



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- headwall retreat of 4 - 11 m between August 2018 and August 2019
- zonation of active layer depth indicates a relation to the topographic position with lower ALDs in elevated and well drained areas whereas sinks are characterized by higher ALDs
- GPR data enabled an area-wide detection of the permafrost table and of substrate variations within the active layer
- ERT data show heterogenous distribution of resistivity values within the subsurface adjacent to the retreating headwall
  - unfrozen or water-rich layer beneath a 3 - 4 m thick ice-rich permafrost layer, which possibly contributes to fast permafrost degradation in the slump vicinity

→ possible impact on subsurface hydrology and slump development?

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Photo: Christof Kneisel

# References



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