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Overcoming data scarcity of active layer thicknesses using geophysics

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Abstract

The thermal imprint of a typical river in the continuous permafrost of Central Yakutia (Siberia, Russia) is studied by active layer thickness measurements along six cross sections, either directly or with geophysical methods. Ground-Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) measurements provide permafrost depths comparable to direct measurements acquired in boreholes and pits when available. Geophysical data interpretations complement non-instrumented cross-sections and show that the unfrozen/frozen interface is deeper below the riverbed for all studied cross sections and depends on the local river width. GPR data provide depths of 1 to 2 m with a sampling step as small as 5 cm when the riverbed width is less than 8 m. Where riverbeds are wider, ERT data are more adapted than GPR in imaging the unfrozen layer. ERT data indicates a permafrost boundary as deep as 6 m for the wide river cases, compared to less than 2 m for the narrower ones. The geophysical data enabled us to reveal an exceptional spatial variability in active layer depths that could not be attributed with *in situ* measurements before.

Keywords: Ground-Penetrating Radar; Electrical Resistivity Tomography; Active Layer; River Influence.

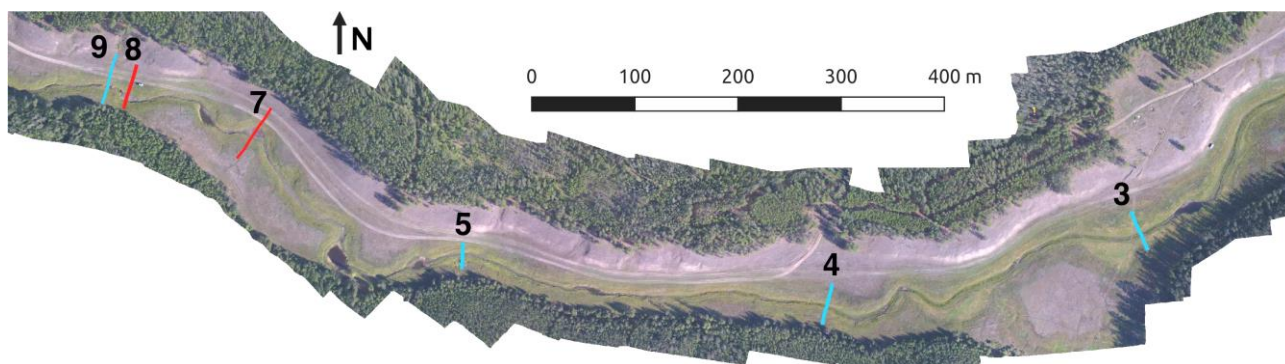


Figure 1 : Positions of the six studied cross-sections (CS3, CS4, CS5, CS7, CS8 and CS9) along a river close to Syrdakh (Central Yakutia). Blue (red) lines are CS with a river width of less (more) than 8 m.

Introduction

Typical landscape features in Yakutia are small rivers that connect thermokarstic lakes within Alas valleys. Due to latent heat effects, rivers create a warmer soil below the riverbed compared to the surroundings. They influence the thermal equilibrium of the soil and the depth to permafrost in their vicinity. Here, we focus on a small river in a valley 100-km East of Yakutsk, close to Syrdakh village. The river is flowing from E to W, resulting in a S-facing right bank and a N-facing left bank, the latter largely covered with forest. The river width varies along its course from 2.5 m up to 15 m when the river forms larger water pools (Fig. 1). In September 2017, exceptional conditions occurred because of two consecutive very dry years. The river had mainly dried out and facilitated access to the riverbed

allowed us to apply Ground-Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) in order to measure detailed permafrost depth variations in 6 cross sections along the river (Fig. 1). Recently, Léger *et al.* (2017) successfully combined these two techniques to quantify the active layer depths in Arctic soil.

Geophysical data

GPR data were acquired using the Russian OKO system using two sets of antennas with nominal frequencies of 250 and 150 MHz. Measurements were acquired while walking at a constant speed, taking marks every 1 or 2 m. Traces were evenly interpolated every 5 cm in between each marks. The parameter settings of the GPR measurements were adjusted depending on the antenna size, using a time window from 100 ns down to 300 ns.

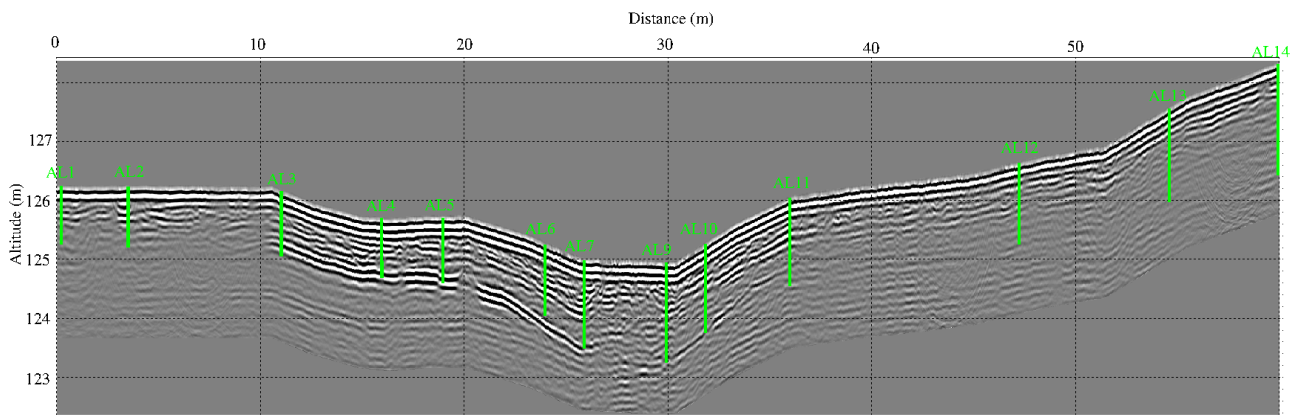


Figure 2 : GPR profile (250 MHz) acquired on CS9 from S to N. Green bars localize boreholes with permafrost depths.

One cross-section, CS9, is intensively equipped with 11 piezometers and 14 boreholes down to the permafrost as described in Pohl *et al.* (companion submission). These measurements were used to calibrate geophysical data (Fig. 2). In addition, four pits were dug after GPR data were acquired over a test profile (not shown here). Diffraction hyperbolas analysis and adjusting depth measured *in situ* of the unfrozen/frozen interface with reflection arrival time observed on radargrams with reflection arrival time observed on radargrams, give an estimated electromagnetic wave velocity of 0.052 m/ns. All radargrams were migrated using Stolt's method (1978) using this velocity.

ERT data were acquired along CS7 and CS9 using a 16-channel instrument SibER-64 system (made in Novosibirsk) with 64 electrodes and a 0.5-m spacing between electrodes, using Schlumberger and gradient protocols. Data were inverted using three different softwares (Res2Dinv, ZondRes2D and BERT).

Results

Permafrost depths are estimated from GPR data and ERT data acquired in September 2017 (Fig. 3). All permafrost depths estimated from geophysical data are in reasonable ranges compared with those estimated from boreholes. The influence of the river on these depths is visible on all CS. GPR data suggest that for river channels narrower than 8 m, permafrost below the river is at least 0.5 m deeper than 10 m away. Insolation differences between right and left bank are also visible at some CS (*e.g.* CS3 and CS9), which are not completely shadowed by the forest (*e.g.* CS5). When the riverbed is wider than 8 m, electromagnetic loss is too strong for clearly resolving permafrost depth below the river with GPR data. ERT data acquired on CS7 show a high conductivity zone as deep as 6 m below the river (Fig. 3). Even though the limits of this zone are subject to some uncertainty and depend on the inversion software, ERT provides first order estimates where GPR cannot resolve the permafrost interface.

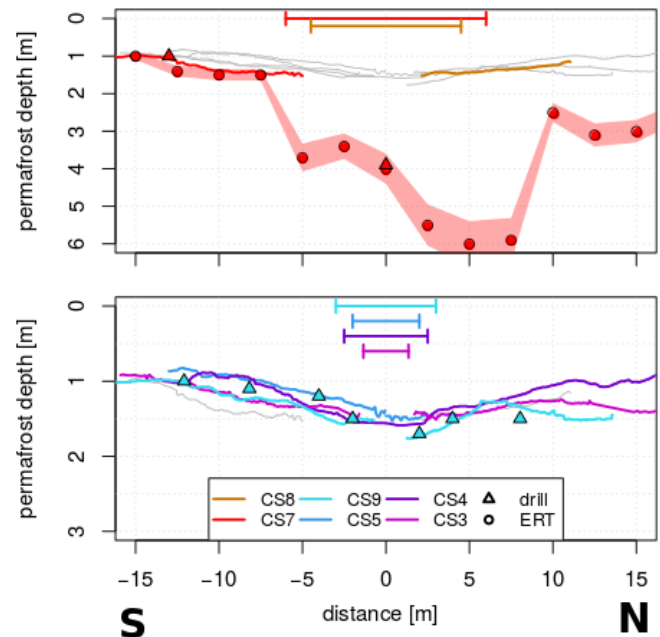


Figure 3 : Summary of permafrost depths from boreholes, GPR and ERT profiles (bottom: narrower riverbed, top: larger riverbed). River widths are provided on top of each graphics.

Acknowledgments

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