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Sensitivity of surface NMR to sediment properties and structure below permafrost lakes.

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SUMMARY

Thermokarst lakes form due to the infilling of decayed ground ice with water. Taliks are unfrozen bodies within the permafrost that occur under these thermokarst lakes and play an important role in permafrost hydrology and carbon cycling. Due to the possible depths of these taliks, extending tens of meters, direct measurement of talik depth is costly and surface NMR provides a direct measurement of the liquid water content without ambiguity. We utilize forward modelling of NMR data to explore the effect of liquid water column thickness to accurately resolve talik depth beneath thermokarst lakes with as few input parameters as possible.

Field data was collected at a thermokarst lake near Fairbanks, Alaska, which had a known structure. Smooth inversions of field data yielded better results than did blocky inversion models. Forward models were created to test the effect of varying water column thickness to resolve the depth of taliks with parameters similar to the geometries most likely to be seen in late-winter thermokarst lake field studies. Blocky inversion models were used to invert the forward model data as they more accurately represent the sharp water content transitions expected in the environment; however, they currently do not accurately account for the high water content of the liquid water column or constrain the talik depth at water column thicknesses of greater than 0.5 m.

Key words: thermokarst, talik, forward modelling, sediment

INTRODUCTION

Approximately twenty precent of the earth's surface is periglacial, meaning that freeze-thaw processes and permafrost principally govern the geomorphological processes in the area. In the arctic coastal plains regions of Alaska, Siberia, and Canada a significant portion of the landscape, up to forty precent, is covered in shallow thermokarst lakes. A thermokarst lake is a water body that occupies a closed depression created by subsidence following the decay of ground ice (Ritter et al., 2011). Over winter, shallow lakes freeze solid to the bottom, leaving no liquid water. Deeper lakes retain some unfrozen water column throughout the winter. The high thermal conductivity of the liquid water column enables talik expansion to occur year round; therefore, these lakes tend to have deep talik development beneath them that can extend to depths of tens of meters or more (Brewer et al., 1993).

Due to the possible depth of the taliks, extending to tens of meters, direct measurement of the talik depth and geometry is costly and difficult. Surface nuclear magnetic resonance (NMR) provides direct measurement of liquid water content without ambiguity (ice in frozen permafrost has negligible signal) by measuring the bulk nuclear magnetization associated with the nuclear spins of hydrogen nuclei in water. Parsekian et al. (2013) demonstrated the ability of surface NMR techniques to estimate the depth of taliks below thermokarst lakes of different depths with limited known field parameters. Here we utilize forward modelling to explore the effect of liquid water column thickness to accurately resolve talik depth beneath thermokarst lakes with as few input parameters as possible.

METHOD AND RESULTS

Field Measurements

In October 2014, an NMR data set was acquired from a small thermokarst lake outside of Fairbanks, Alaska. The lake was chosen for its proximity to Fairbanks, known talik depth, and available talik sediment samples from cores. The ice thickness was measured at the site. Multiple loop geometries were utilized, including circle and figure eight loops with diameters ranging from 20 to 40m . Several pulse sequences were also tested including FID, CPMG, and T1 measurements. These variations were employed to determine if field acquisition strategies may be preferred over data post-processing methods.

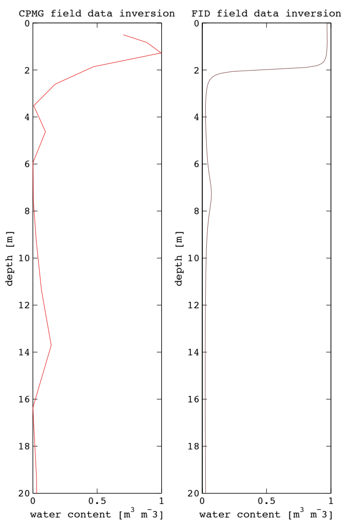

Figure 1: Field-measured CPMG and FID inverted water content data that capture the high water content of the liquid water column as well as resolving the talik depth that extends to 6m.

Field data was pre-processed in the Vista Clara GMR software and then imported into MRSMatlab software package (Mueller-Petke & Yaramanci, 2010) for inversion. Although the subsurface structure of this particular lake was well known, those parameters were not used to inform the inversion model to determine how well talik depth could be resolved in lakes where the structure is unknown. The blocky inversion model more resembles the conceptual structure of thermokarst lakes with ice (no liquid water) overlying liquid water lake and low water content talik sitting atop permafrost (nearly no liquid water); however, the smooth model yielded better inversion results for this set of field data (blocky inverson results not shown).

The smooth inversion accurately captures the high water content of the liquid water column in the field data as well as the water content within the talik below (Figure 1). This can be also be clearly seen in the raw and modelled raw data where the water column generates a high amplitude anomaly at high pulse moments and a separate anomaly with smaller amplitude and different relaxation time character is observed at later pulse moments. At the latest pulse moments, little measureable signal is observed (Figure 2a). A similar pattern is observed in comparable modelled data (Figure 2b).

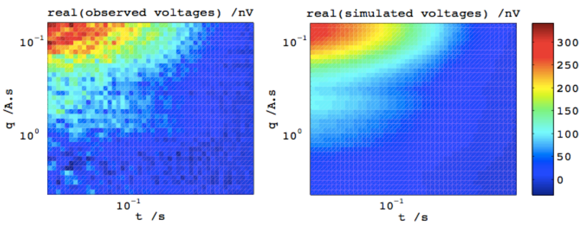

Figure 2: Observed voltages (left) and simulated voltages (right) from an FID field experiment. The high voltages correspond to the liquid water column, the intermediate voltages beneath is the detection of the water content within the talik.

Forward Modelling

Forward models were created to test effect of varying water column thickness on the ability to resolve the depth of taliks. The parameters to create the forward models were chosen based upon the lake geometries we are most likely to encounter in late winter on the Alaskan North Slope (Grosse et al., 2013). Ice was set to 1.5 m thick, water column varied from 0.1m to 3 m, and talik depths were set to 6m, 12m, and 24m, with a resistive permafrost half space beneath.

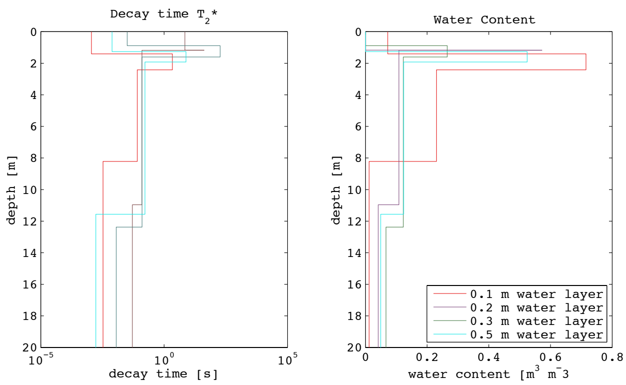

Figure 3: Relaxation time (left) and water content (right) for forward modelling of varying water column thickness.

Forward models were created and inverted in the MRSMatlab software program package (Müller-Petke and Yaramanci, 2010). The blocky inversion, which more closely resembles the sharp transitions in water content seen in thermokarst lake environments works for water column thicknesses between 0.1 and 0.5m (Figure 3) for an FID pulse sequence. Future work on different pulse sequences and loop sizes will be completed.

CONCLUSIONS

From this work talik depth beneath thermokarst lakes can be determined from using smooth inversion models; although, a smooth transition in water contents is not expected in this environment. Blocky inversion models more accurately represent the expected water content transitions, but currently do not accurately account for the high water content of the liquid water column or constrain the talik depth at water column thicknesses of greater than 0.5 m. The ability to determine the depth of taliks beneath thermokarst lakes without prior knowledge of the lake structure is important for ongoing research in arctic hydrology and carbon cycling studies.

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