The Cryosphere Discuss.,
doi:10.5194/tc-2016-256-RC2, 2017

The Cryosphere
Discussions
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Interactive comment on "*In situ* nuclear magnetic resonance response of permafrost and active layer soil in boreal and tundra ecosystems" *by* M. Andy Kass et al.

Anonymous Referee #2

Received and published: 2 May 2017

The manuscript under review describes a study of NMR-response of temperate permafrost measured in situ in shallow boreholes. The approach is very innovative and the study is performed in very profound manner. The study contains the following important findings:

- variable state of permafrost can be investigated by means of borehole-NMR. The amplitude and decay-rates indicate qualitatively the amount of free water and its relaxation at the pore walls.

- Conventional approaches of categorization of water quantities by threshold values are not valid for water filled and partly frozen water.

- Numerical modelling of NMR-responses using an approach with frozen water in the center of the pores qualitatively explains the observed NMR-signals.

To my opinion the manuscripts has the following shortcomings:

- Petrophysical models of NMR-response from hydrocarbon exploration base on the assumption of a combination of water in oil in the pore space. In this case, the water will always cover the pore wall due to its bipolar character and thus affinity to the negatively charged pore-wall. The oil volume will be isolated from the relaxing pore wall and thus show relatively long decay-times. For common pore-space geometries this water will be a thin film and is thus called capillary water. Only for large pores or low oil volumes this water will have sufficiently large volume-to-surface ratios to show longer relaxation times > 30ms → free water. The authors recognize this limitation. Nevertheless they refer to this classification throughout the manuscript, even though they show in the course of the paper to be invalid. Additionally, the relaxation spectra in figure 5 give no evidence of a multiexponential distribution indicating different classes of water. The classification by hydrocarbon threshold values is misleading. I suggest to eliminate from the interpretation of the recorded data.

- Water in pores at or below the freezing point will be exposed to the forces of the negatively charged pore-wall and the crystallization to ice. As the numerical model clearly shows a model with ice-covered pore-walls cannot explain the measured data, while an ice-filled pore center qualitatively fits. Nevertheless, a description of the model with a homogeneous center of crystalline ice and a film of fluid water at the relaxing pore-wall is somewhat over-simplified. At the local freezing point (probably below 0°C, due to the presence of the pore wall) water will most probably not form a homogeneous crystal, but more likely a slush of ice and water. While solid ice at low temperatures has no measurable NMR-signal, in temperate ice, intercrystalline water is present in quantities that generate measurable NMR-signals at long relaxation times. A slush of ice and water will generate similar signals as the ice-filled pore in the study. Thus the model may be used to qualitatively differentiate the two models of ice crystals in the center vs. ice covered pore walls. For a more quantitative analysis of the NMR-responses, the model is not suitable.

To conclude:

+ Detection of NMR-signals in-situ in temperate permafrost is a major finding. My congratulations!

+ Numerical analysis of the distribution of ice throughout the pore space is consistent with observed data and expected results.

- The classification according to oil-industry standards, valid for oil-water mixtures, is misleading an should be eliminated.

- The applied model with solid ice-crystals in the pore center and fluid film at the pore wall qualitatively matches the situation of freezing water within pores, but is limited for quantitative analysis.

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-256, 2017.