Ice-rich permafrost thaw under sub-aquatic conditions

by

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OVERVIEW

Degradation of sub-aquatic permafrost can release large quantities of methane into the atmosphere, impact offshore drilling activities, and affect coastal erosion. The degradation rate depends on the duration of inundation, warming rate, sediment characteristics, the coupling of the bottom to the atmosphere through bottom-fast ice, and brine injections into the sediment (Overduin et al., 2012). The relative importance of these controls on the rate of sub-aquatic permafrost degradation, however, remains poorly understood.

This poster presents a conceptual evaluation of sub-aquatic permafrost thaw mechanisms and an approach to their representation using one-dimensional modelling of heat and dissolved salt diffusion. We apply this model to permafrost degradation observed below Peatball Lake on the Alaska North Slope and compare modelling results to talik geometry information inferred from transient electromagnetic (TEM) soundings.

OBJECTIVES

- Adopt permafrost model with hypothetical inundation scenarios (terrestrial to sub-aquatic conditions) and analyze model sensitivity to different soil types

- Model hypothetical inundation scenario of silty permafrost with salt diffusion in a saline waterbody

- Model talik formation at Peatball Lake (Alaska North Slope) and compare the results with geophysical data
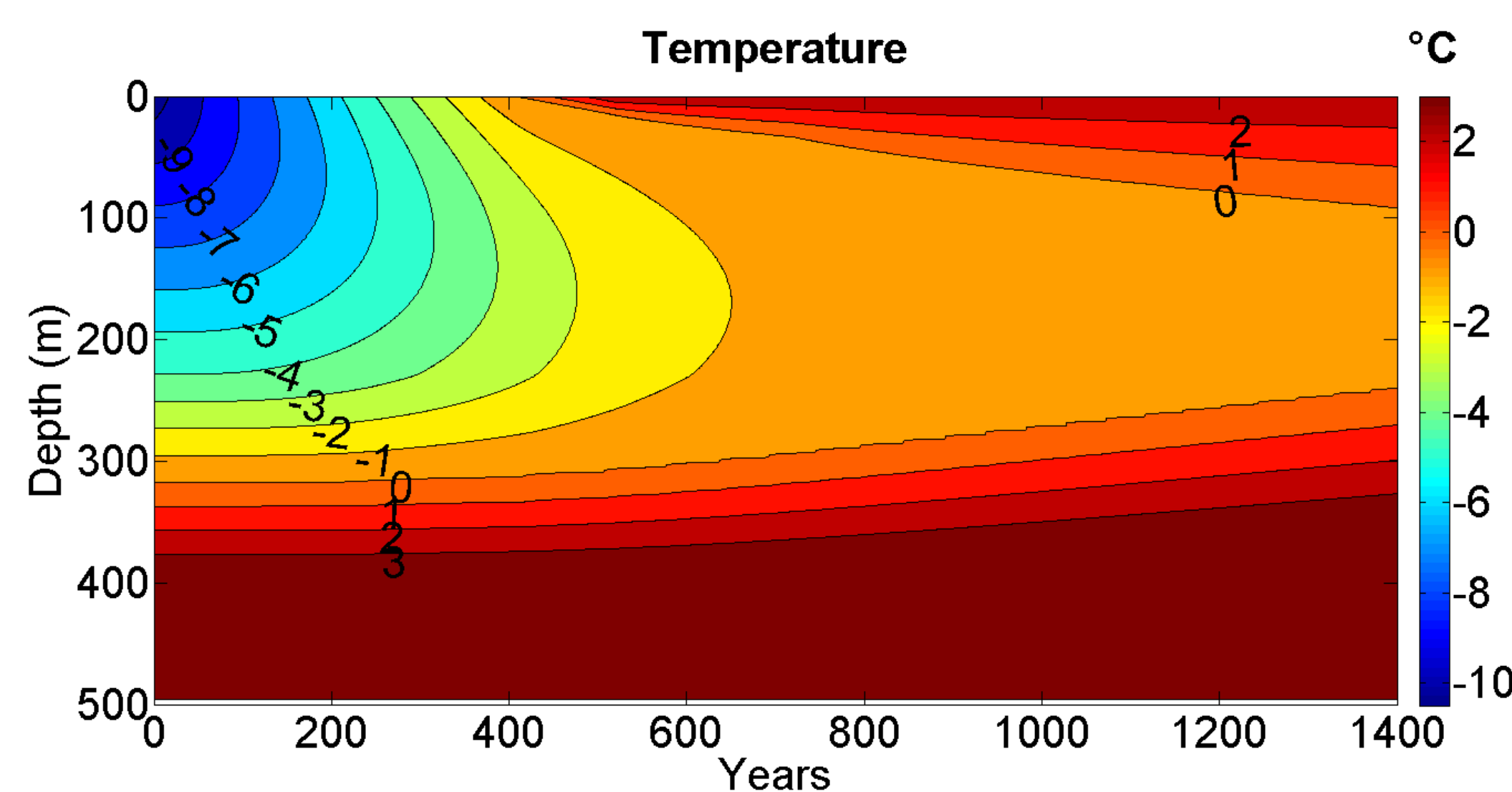
MODELLING TALIK DEVELOPMENT AT PEATBALL LAKE, ALASKA NORTH SLOPE
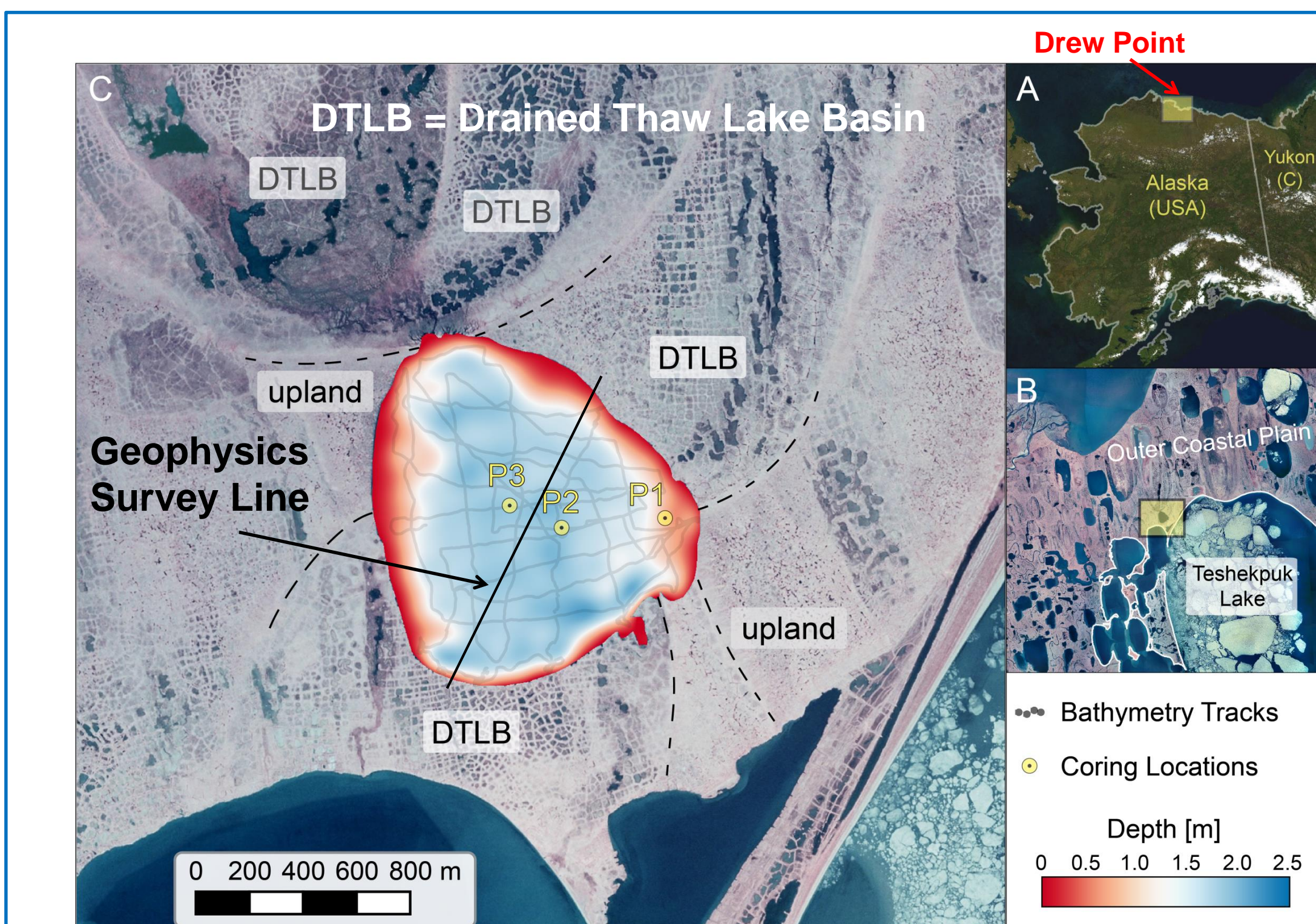
Peatball Lake on the Alaska North Slope (from Lenz et al., 2016)
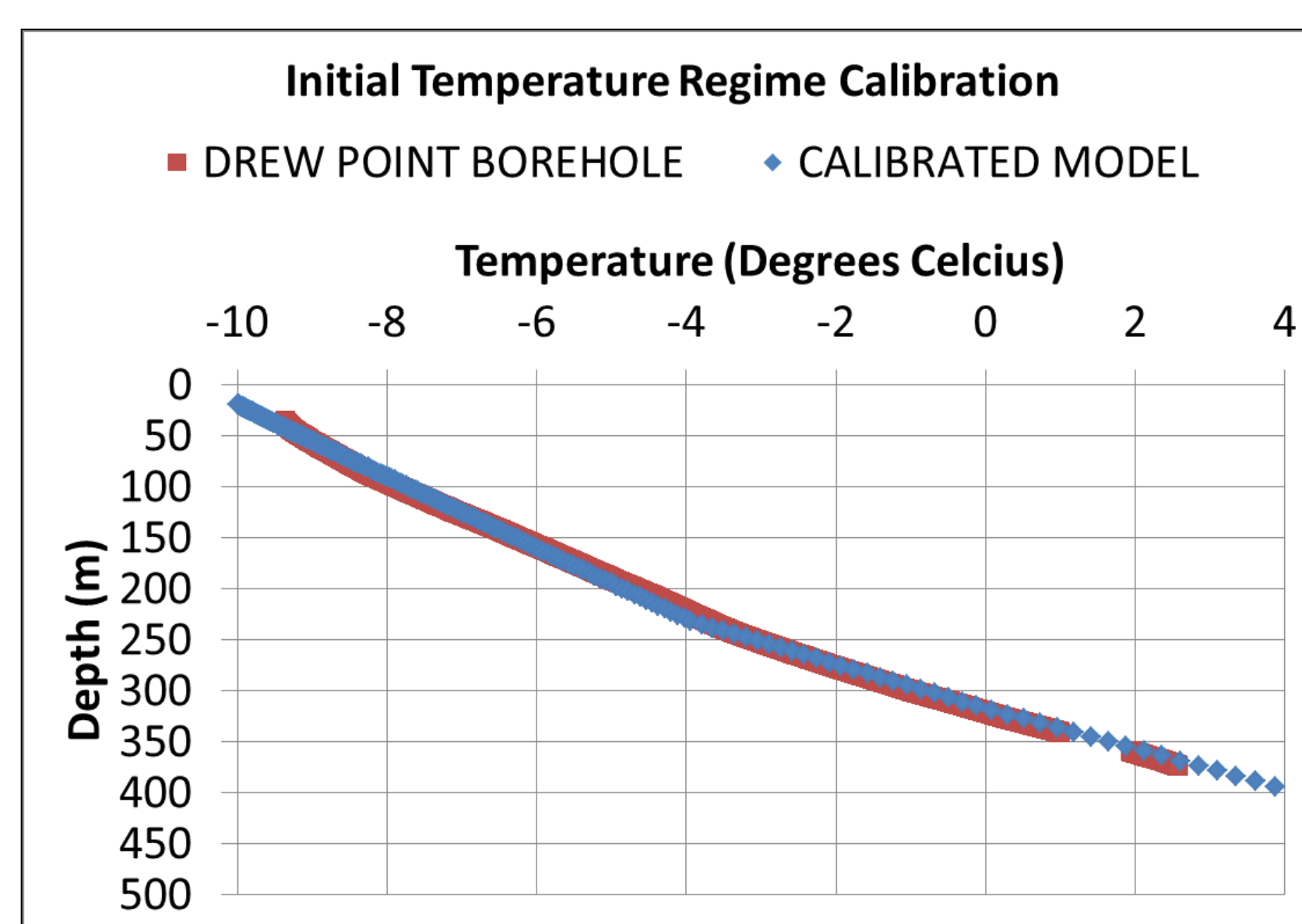
Using a ground surface temperature of -10.5 °C and a heat flux of 70mW/m², the mineral thermal conductivities of the different units were calibrated.

Temperature field below Peatball Lake from flooding (time=0) until 1400 years later (at right).

MODEL DESCRIPTION
Sediment model:
Stratigraphy from Drew Point borehole, USGS (1983):
1. Loose sediments (0-34 m), porosity = 0.4
2. Sandstone (34-217 m), porosity = 0.18
3. Shale (>= 217m), porosity = 0.10
- Model depth of 6 km
- Salt diffusion was not included in this model
- Freezing characteristic curve parameterization was based on Dall'Amico et al. (2011)
- Geothermal heat flux of 70 mW/m², based on Batir et al. (2013)
- Initial thermal regime calibrated to match Drew Point borehole temperature data (Clow, 2013) using a steady-state function
- Calibrated thermal conductivities were within the range of values reported by Andersland and Ladanyi (2004) for loose sediments (3.0 Wm^{-1} K^{-1}), sandstone (2.5 Wm^{-1} K^{-1}) and shale (1.5 Wm^{-1} K^{-1})
- Lake age assumed to be 1400 years based on Lenz et al. (2016)

Upper boundary condition function:
- Initial ground surface temperature was -10.5 °C
- Average hourly lakebed temperature at the center of Peatball Lake (P3) was 2.9 °C from May 2012 to April 2015. Lake ice has not frozen to the bed at the lake center (P3) since 2012 (total period of record).
- We assumed that bedfast ice does not occur when water depth exceeds 1.7 m. The area between the 1.7 m contour and the lake edge was divided by the total lake area in ArcGIS to generate a "ramp-up" time (transition from terrestrial to bedfast-ice-free conditions). The "ramp-up time" from terrestrial boundary condition (-10.5 °C) to subaquatic (2.9 °C) was 518 years.
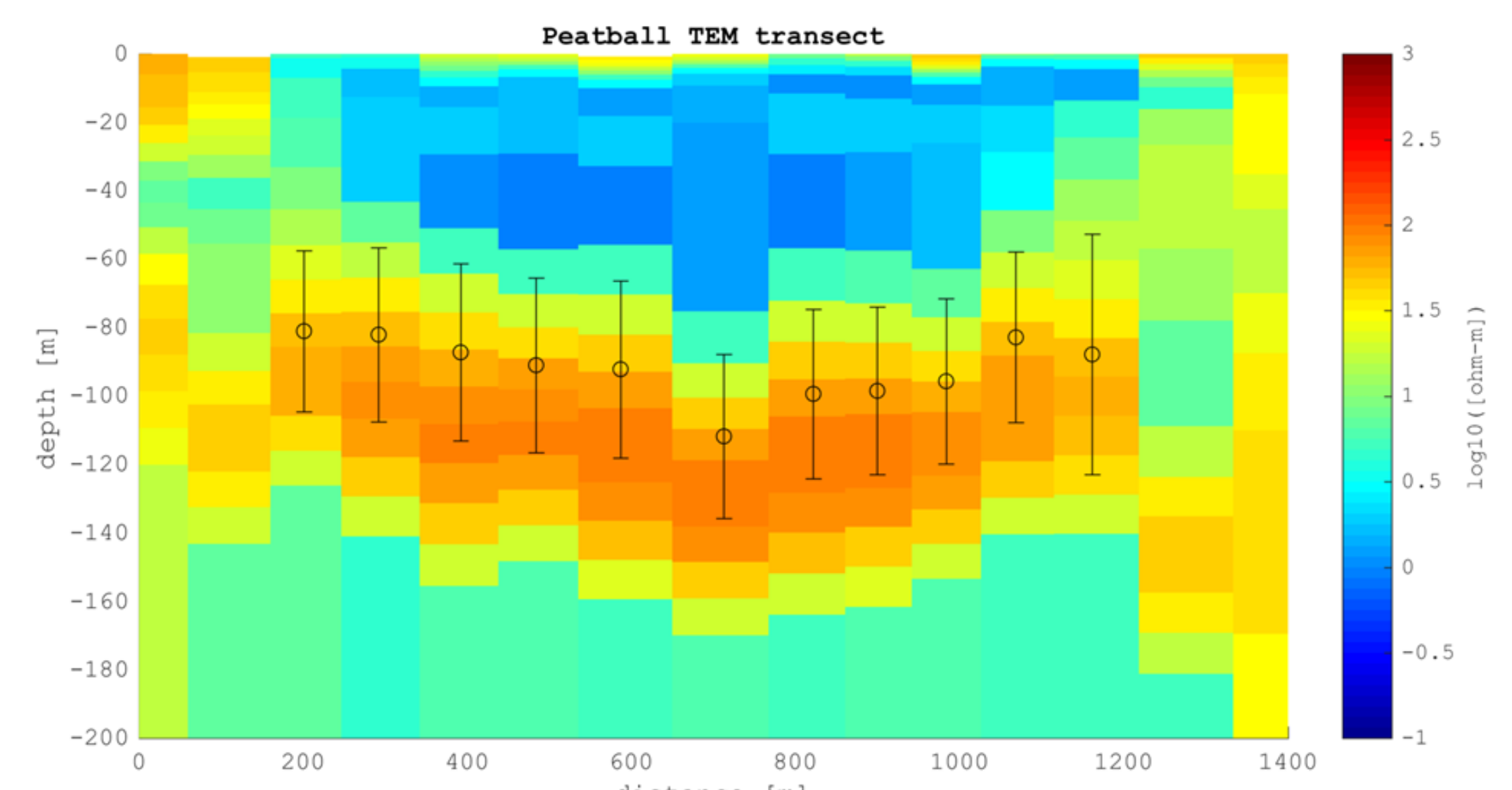

Transient electromagnetic (TEM) integrated image of Peatball Lake. Talik depth is given by the maximum value in the 1st derivative of the resistivity versus depth. Error bars were generated by inversion sensitivity tests.

## SENSITIVITY ANALYSES FOR SUB-AQUATIC PERMAFROST EVOLUTION
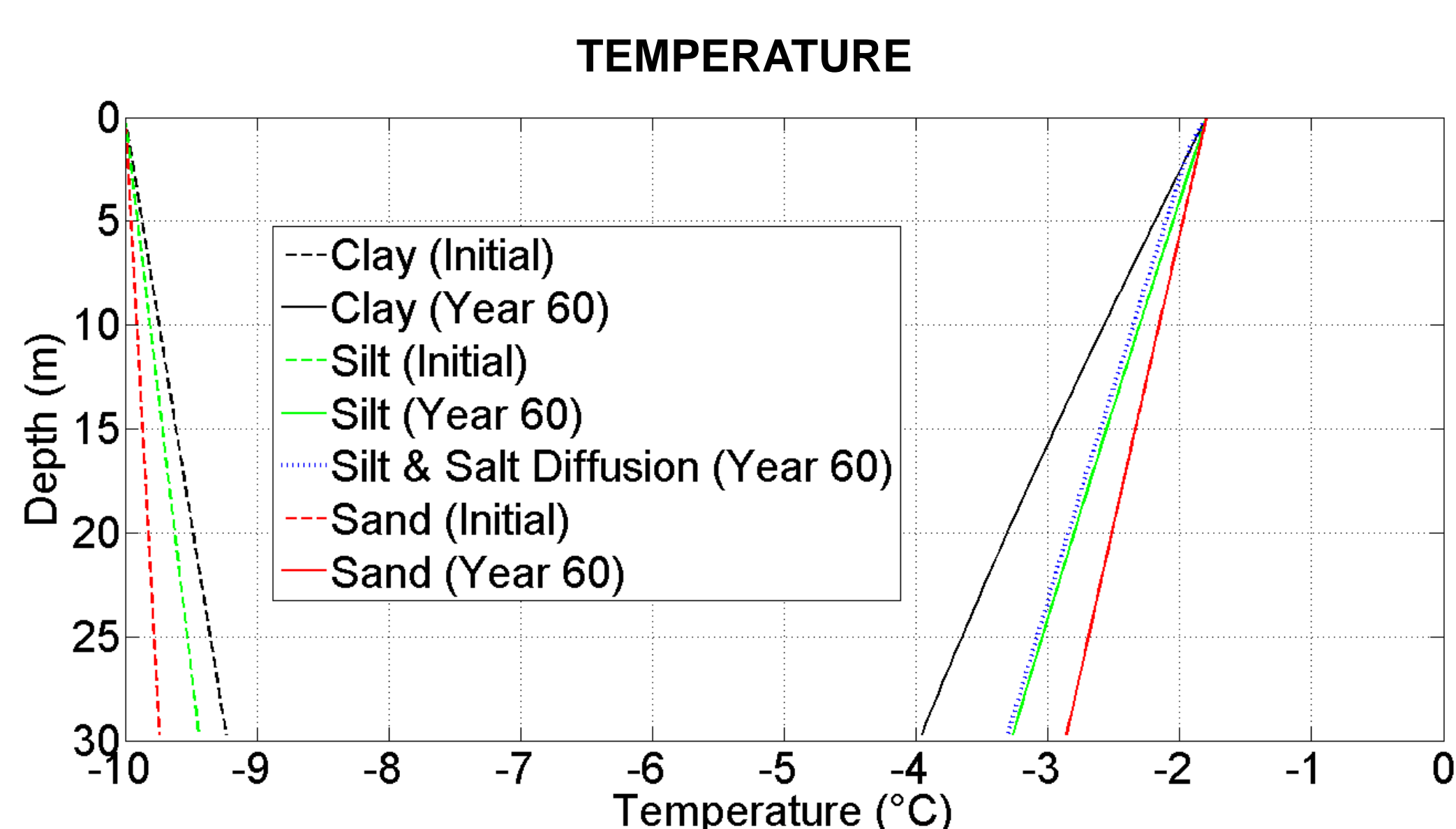
MODEL DESCRIPTION:
- Homogeneous soil type for each model
- Maximum porosity of 0.5 (Clay), 0.4 (Silt), and 0.3 (Sand)
- Model depth of 6 km
- Terrestrial to sub-aquatic ramp-up time of 1 year
- Mineral thermal conductivity of 2.0 Wm^{-1} K^{-1} (clay), 3.0 Wm^{-1}K^{-1} (silt), and 7.7 Wm^{-1} K^{-1} (sand)
- Water body bed temperature of -1.8 °C
- For models with salt diffusion, salinity of 840 moles NaCl/m³ (i.e. freezing point of -3 °C)
- Model runs of 60 years with daily time steps
- Model mesh has 500 layers from 0.1 to 76 m thick (increasing logarithmically)
- Geothermal heat flux of 50 mW/m²
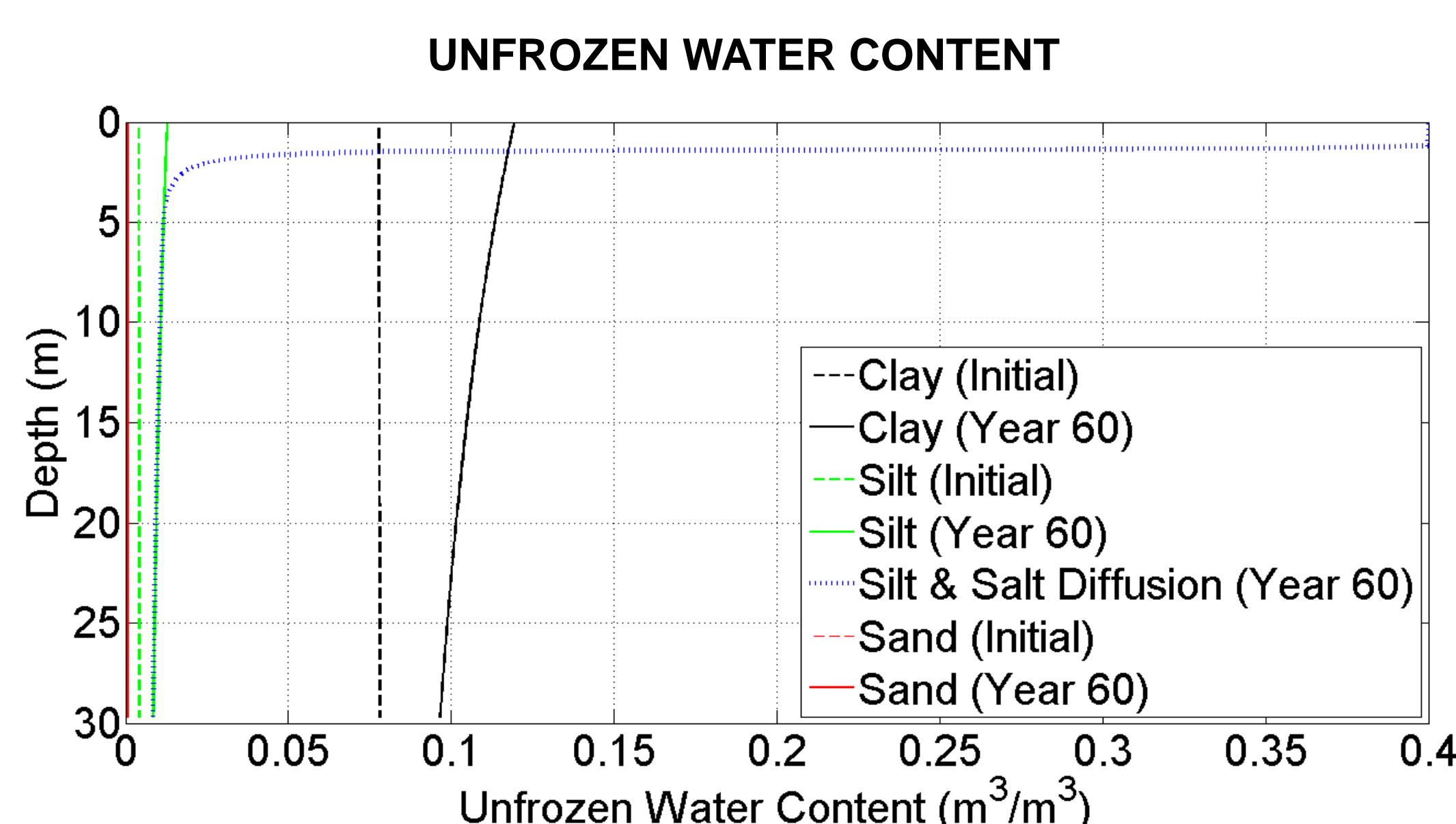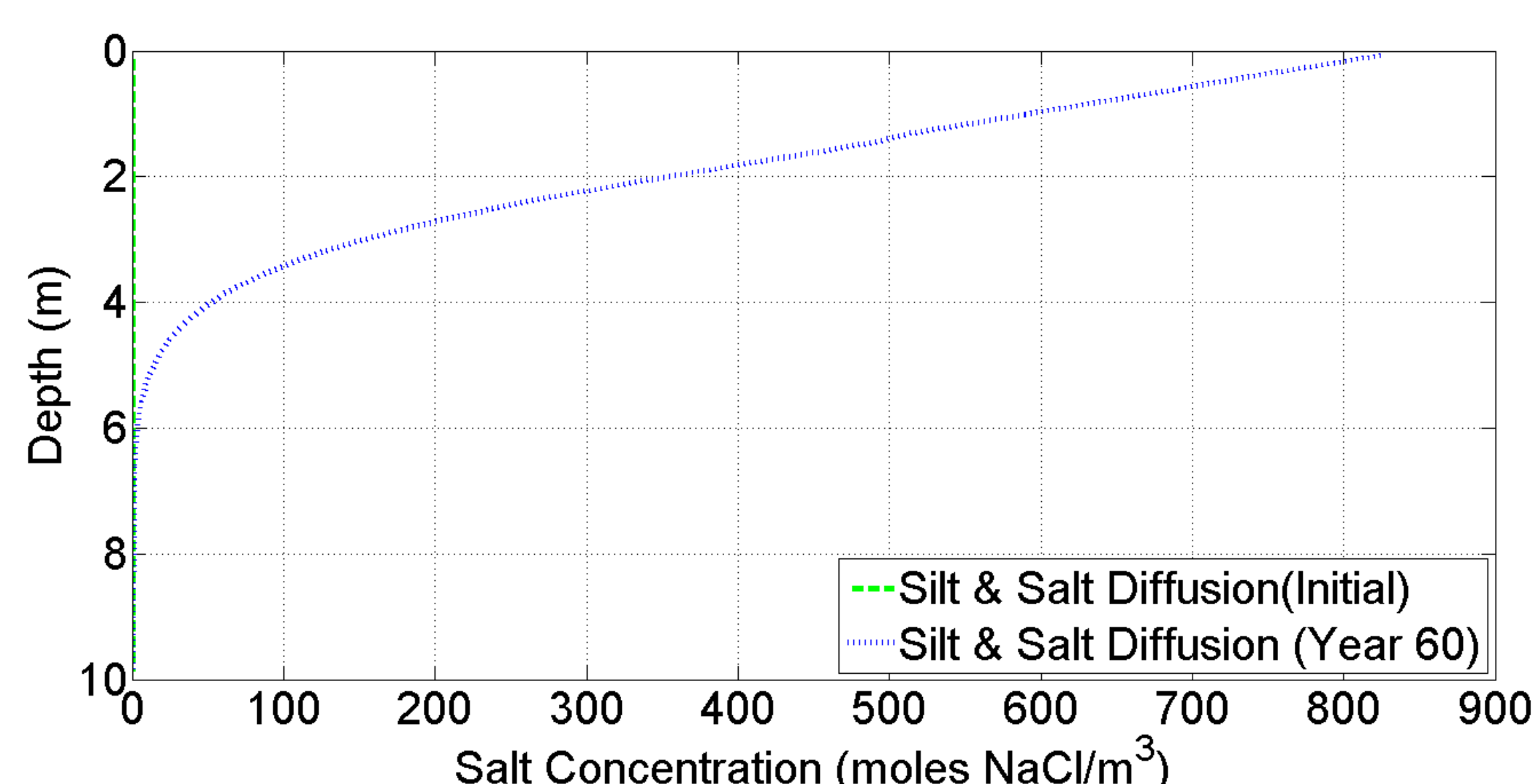
CONCLUSIONS

- Sand warms most rapidly for sand and clay least rapidly, due to i) high porosity of clay and thus high ice content, ii) high unfrozen water content of frozen clay, iii) high mineral thermal conductivity of quartz in sand.
- With salt diffusion, sub-aqueous silt developed a 1.5 m thick unfrozen permafrost layer after 60 years of inundation. The frozen permafrost below was only slightly cooler (max 0.1°C) compared to a flooding scenario without salt diffusion.
- The modelled talik depth for Peatball Lake was approximately 94 m and the maximum talik depth from the TEM image was approximately 111 m.

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