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Seasonal Variations in Bottom Water Temperatures and their Influence on Subaquatic Permafrost Thermal Regimes

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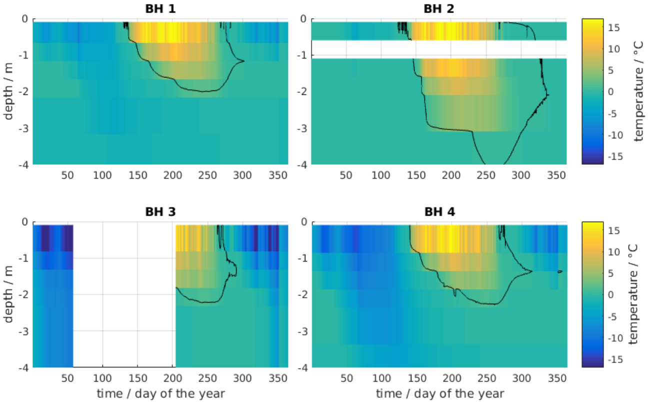
Objective

- Better understand how bottom-fast ice influences subaquatic permafrost
- Numerically model subbottom temperature fields, forcing the thermal model with both observed bottom water temperatures (bwt) and a parameterized bwt function
- Examine how the discrepancy between modeled and observed temperature fields depends on the thermal properties or the timing of bottom-fast ice

Data Set Mackenzie Delta

- 4 boreholes in 0 - 100cm water depth
- 3 boreholes experience bottom-fast ice, one is subaerial
- All boreholes in permafrost below Mackenzie River bed
- Temperature measurements at 0 - 10m below seafloor in 2005 - 2008 [Solomon et al., 2008, Stevens et al., 2010]

Data Set Mackenzie Delta

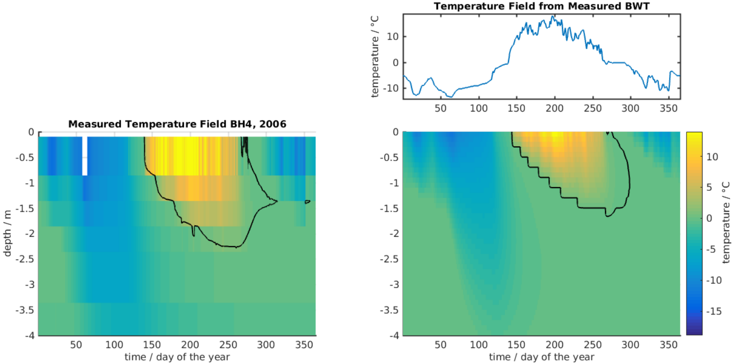


Temperature fields at boreholes in 2006 [Solomon et al., 2008].
BH 3 is subaerial, BH 2 has the shortest bottom-fast ice period.

Modeling Temperature Fields

- 1D heat equation with latent heat effects and freezing characteristic curves but no lateral or advective flux (CryoGrid [Westermann et al., 2016])
- Thermal properties, porosity and composition of sediment influence model results
- Forcing with 10 repetitions of one year measured bottom water temperature (bwt) data or parameterized function

Model with Measured BWT



Measured temperature field at borehole 4 in 2006 [Solomon et al., 2008] (left) and modeled temperature field (right), forced with measured bottom water temperature (upper right). The 0 ℃-isotherm is shown in black.

Preliminary Results

- For some years and boreholes model results fit quite well, while some do not develop permafrost at all
- Assumed thermal properties of the sediment could be too conductive, but higher conductivities would then worsen the good fitted results
- Measured forcing data for ill-fitting years could be warmer than the decadal average

Parameterized BWT?

We approximate the bed temperature as

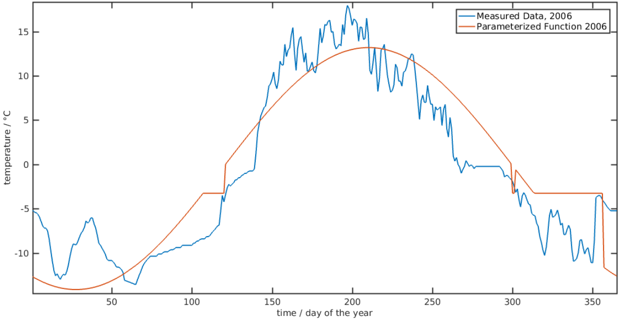
$$\mathrm{BWT}(t) = \begin{cases} T_{\mathrm{cos}}[\mathrm{ice}], & \text{if } h_{\mathrm{ice}}(t) > h_{\mathrm{water}} \\ T_{\mathrm{low}}, & \text{if } h_{\mathrm{ice}}(t) \leq h_{\mathrm{water}} \\ T_{\mathrm{cos}}[\mathrm{water}], & \text{else,} \end{cases}$$

where the ice thickness $h_{\mathrm{ice}}(t)$ is calculated from the freezing degree days (FDD) via the empirical equation

$$h_{\mathrm{ice}}(t) = \alpha\sqrt{FDD(t)}$$

and T_{cos}[water/ice] is a cosine-function fitted to local air temperatures damped through the water/ice column. The parameter α reflects the local conditions and accounts for on-ice snow [Murfitt et al., 2018].

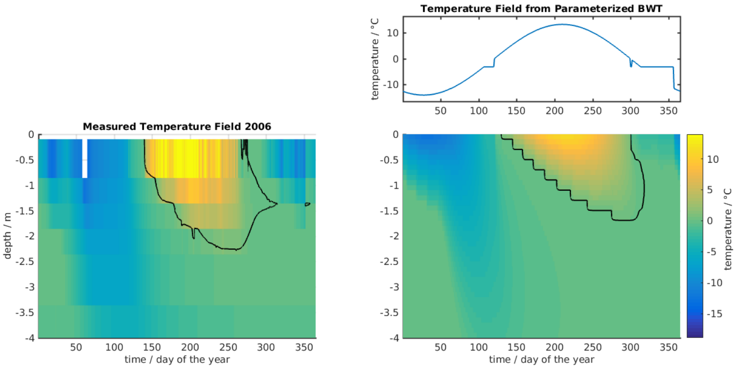
Parameterized BWT



Measured bottom water temperature at borehole 4 in 2006 [Solomon et al., 2008] and parameterized temperature function (bottom).

Parameterized bwt over-estimates the length of the ice-free period and does not catch the peak summer temperatures

Model with BWT Function



Measured temperature field at borehole 4 in 2006
[Solomon et al., 2008] (left) and modeled temperature field (right), forced with parameterized bottom water temperature (upper right).
The 0℃-isotherm is shown in black.

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Preliminary Results

- Inversion of measured bwt yields parameterized bwt function with 30% rmse
- Modeled sediment temperature fields force with measured bwt data and parameterized bwt function are very similar
- That reinforces that the reasons are inherent to the setting, i.e. the *wrong* thermal properties or non-representativeness of the forcing data
- To reach more similar permafrost temperatures below the seasonally-thawed layer, winter temperatures at BH 4 needed to be ≈ 3℃ lower

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