Preliminary evaluation of temperature-derived metrics for more comprehensive permafrost monitoring

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Motivation

Ground temperature is widely used to monitor the condition, extent, and change of permafrost. Long-term changes to permafrost are commonly described using mean annual ground temperature (MAGT) measured near the depth of zero annual amplitude (d_{za}).

As permafrost temperatures approach 0°C, the warming rate is dampened by latent heat uptake. This is important for monitoring because it introduces an extra interpretation step for MAGT measurements, particularly for communicating with a non-specialist audience.

"How well do various temperature-derived metrics reflect impacts of thaw"

Measuring change at a single depth is useful to simplify permafrost change in a borehole to a single statistic. However, in doing so it neglects a great deal of data, and can mask warming or thawing processes taking place elsewhere in the ground.

Thawing permafrost does have several observable effects on the ground temperature regime such as reduction in the amplitude of the annual temperature signal at depth. With this study we aim to:

1. Review existing thermally-derived metrics used to describe permafrost change and identify possible novel metrics.
2. Evaluate how well these metrics reflect surface displacement and sensible and latent heat gain in permafrost using simulated observations.
3. Investigate how permafrost change can be visualized and communicated using these metrics at multiple scales from single depths to coarser levels ofaggregation

Simulation

We use a modified versionof FreeThaw1d (Tubini et. al. 2021), a one dimensional heat transfer model. The model is capable of representing excess ice in the soil column and tracking the change in surface .

Meteorological data from the ERA5 reanalysis drives the simulation at the surface data between 1980 - 2022. Spin-up is achieved by repeating the first two years of data while future warming is simulated by repeating the last five years and adding a warming trend based on predictions from climatedata.ca

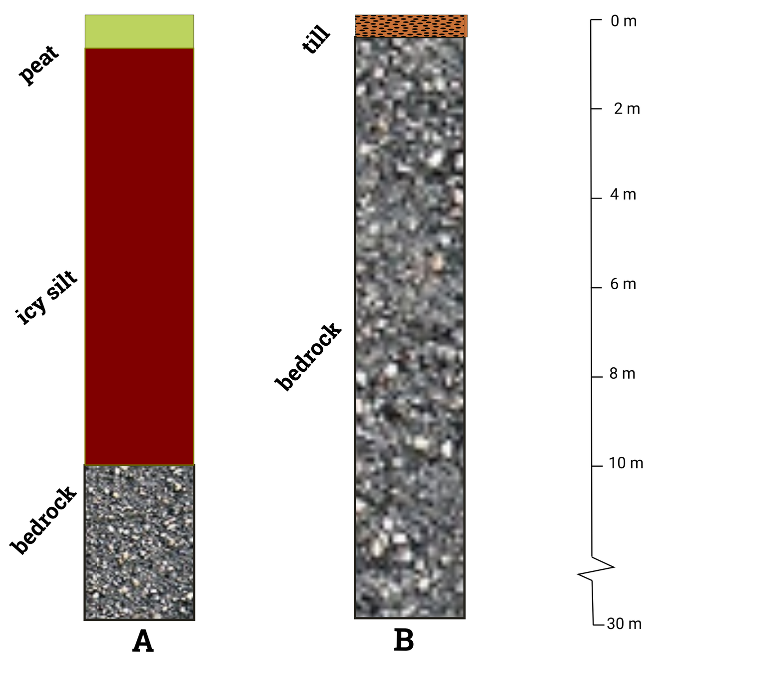

Figure 1: This preliminary work uses two soil profiles to explore how the metrics behave in different environments: (**A**) an ice-rich silt overlain by peat, and (**B**) bedrock with a till veneer;

Metrics

After simulation is complete, we calculate a number of metrics. These can be categoriesed according to whether they apply to a single depth or the entire borehole.

borehole metrics

- $\bar{D}$ — *Thaw-depth duration*: time- and depth- integrated
- d_{za} — *Depth of zero annual amplitude*: expected to increase
- N_w — *Number of sensors in warm (>2 °C) permafrost*
- N_p — *Number of sensors in permafrost*
- ALT — *Active-layer thickness*: common
- MAGT — *Mean annual ground temperature*: most common permafrost thermal monitoring metric

single-sensor metrics

- $\mathcal{R}_a$ — *Amplitude ratio relative to next-shallowest*
- $\mathcal{R}_m$ — *Amplitude ratio relative to shallowest*

Results

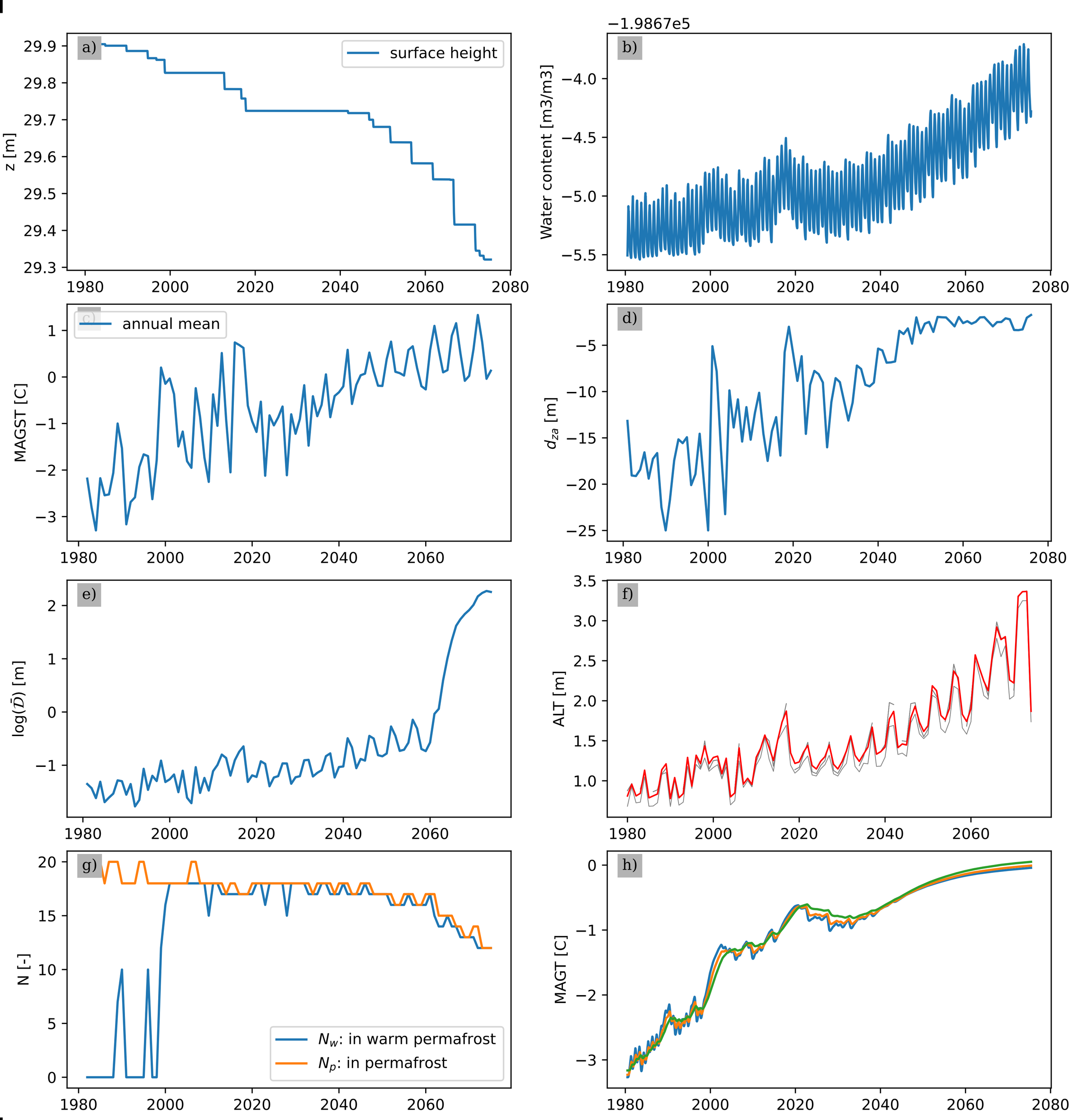

Figure 2: Surface subsidence and total column water content (a, b) and select thaw metrics (c-h) for 100 years of warming in an icy soil profile (**A**).

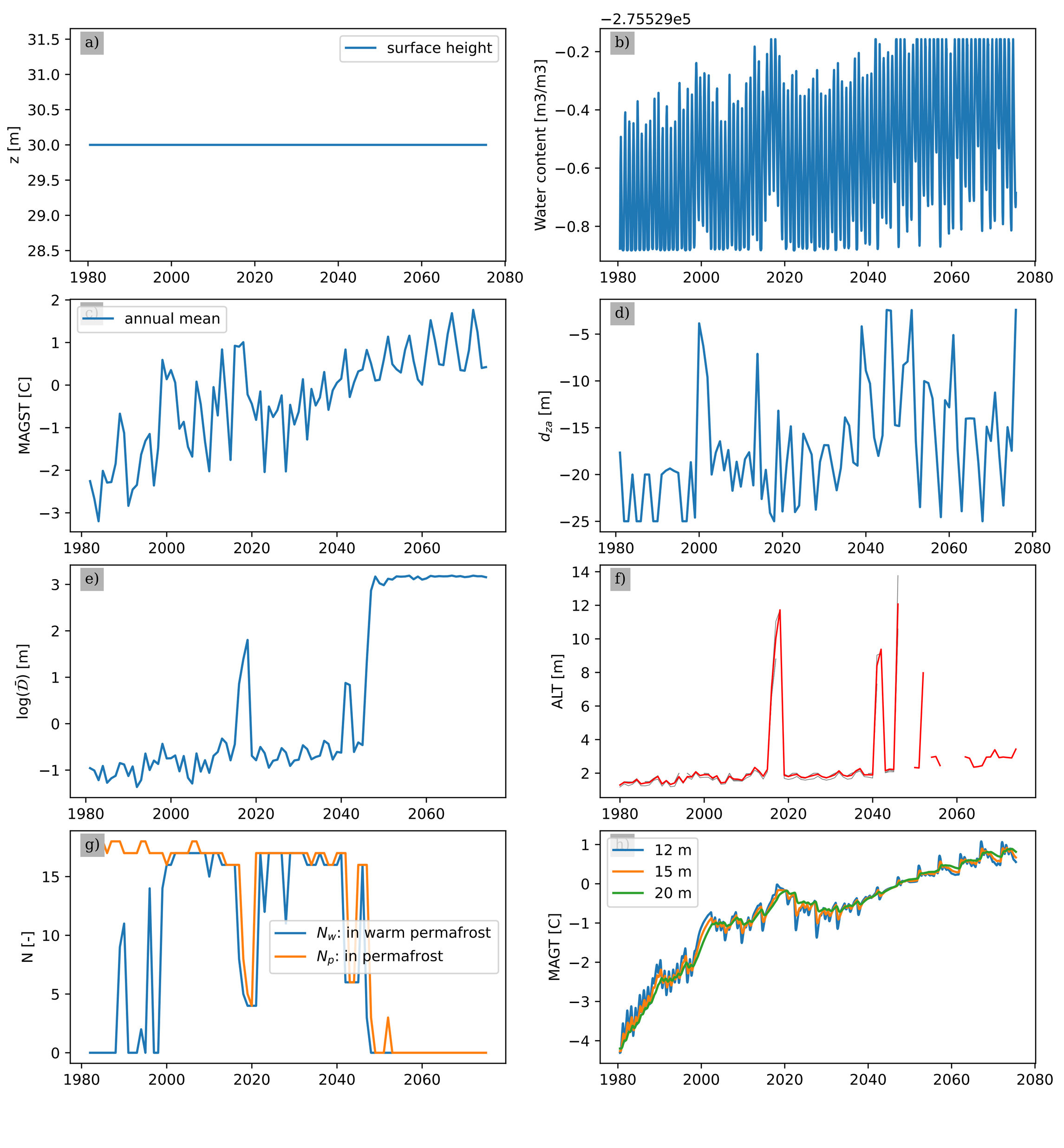

Figure 3: Surface subsidence and total column water content (a, b) and select thaw metrics (c-h) for 100 years of warming in a bedrock soil profile (**B**).

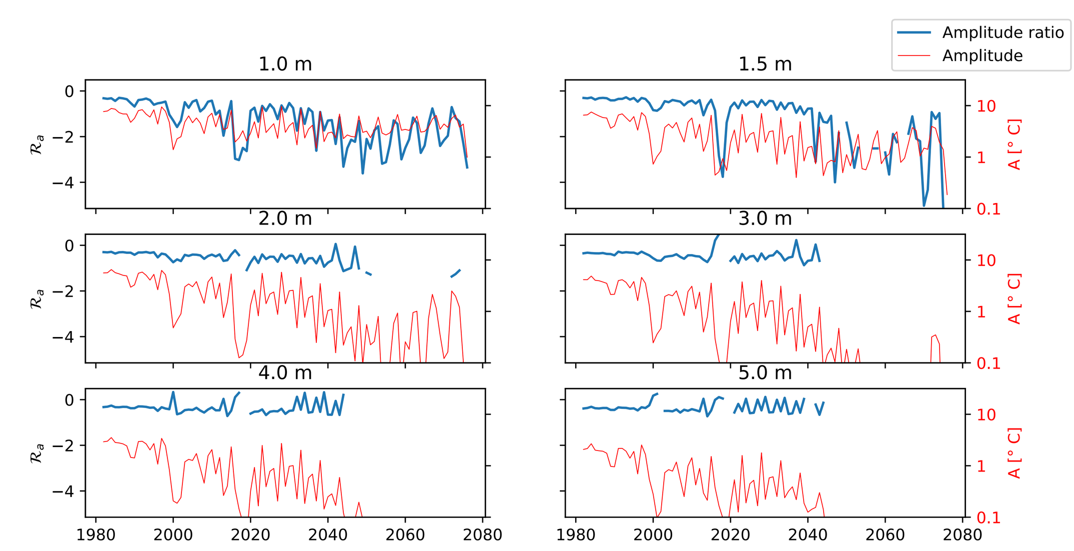

Figure 4: Amplitude ratios relative to next shallowest sensor for an icy soil profile (**A**).

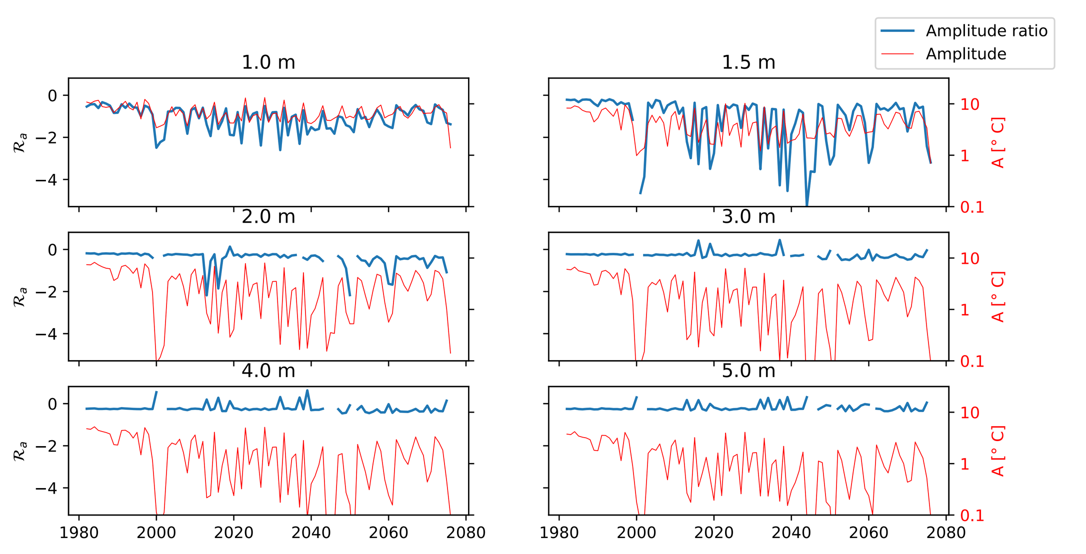

Figure 5: Amplitude ratios relative to next shallowest sensor for bedrock profile (**B**).

Next steps

1. Run additional simulations to capture variability in soil conditions and meteorology
2. Develop methodology to assess correlation of metrics with variables of interest
3. Develop methods for aggregating:
   a. Single-sensor metrics to borehole metric
   b. Time series to trend or rate
4. Incorporate metrics into tsp python package (Brown, 2022) to facilitate re-use

References and acknowledgements

Tubini, N., Gruber, S., and Rigon, R.: A method for solving heat transfer with phase change in ice or soil that allows for large time steps while guaranteeing energy conservation, The Cryosphere, 15, 2541–2568, https://doi.org/10.5194/tc-15-2541-2021, 2021.

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