# Revealing permafrost thaw in Canada using multiple metrics and temperature data from many boreholes

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## Motivation

Faced with changing permafrost conditions, effective adaptation planning is needed. This hinges on the **usefulness of permafrost thaw knowledge** presented to policy and decision-makers.

Longstanding borehole temperature records have allowed tracking of changes to the permafrost thermal regime over time in Canada. However, the use of this data is often limited in three ways: (1) a small subset of the available borehole sites is used; (2) within this subset, there is a predominant focus on natural terrain; and (3) the reliance on temperatures measured at a single depth, typically near the depth of zero annual amplitude (ZAA), hinders our ability to detect permafrost thaw.

We aim to address these gaps by (1) integrating a **larger temperature dataset**, (2) including diverse landscapes and regions impacted by **human activity**, and (3) using **four main metrics** derived from the data to investigate the occurrence of thaw.

## Current dataset

We use openly available data from the Yukon Geological Survey, Nordicana D and individual researchers/ organizations. The dataset (Figure 1) currently contains 87 boreholes in and outside of areas of human activity and continues to grow with additions from the Northwest Territories Geological Survey and other sources.

Each site has a data spanning a minimum of five years, permafrost is present at all sites, and sensors are both in the active layer and below the permafrost table.

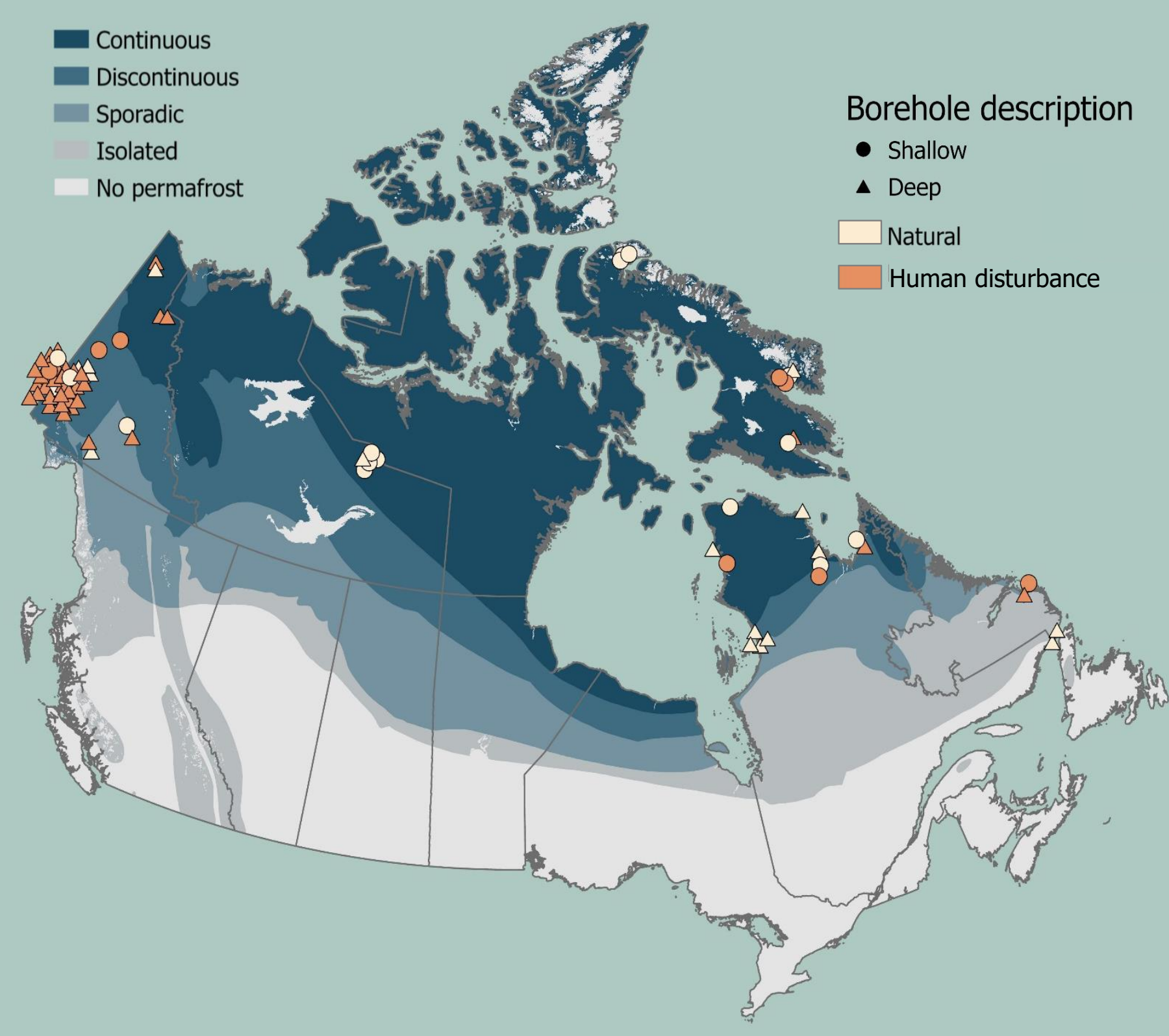

Figure 1. Distribution of 87 borehole sites in Canada, expanded where densely clustered. Sites classified as deep if the DZA is reached, and disturbed if subject to any human disturbance.

Figure 2. A borehole drilled and anchored into the permafrost. Installing temperature sensors at defined intervals allows for ground temperature to be recorded over many years and permafrost change to be tracked.

## Methods

We use four temperature-derived metrics, which are currently undergoing testing on simulated temperature data that resembles borehole observations. These metrics are adapted to account for data gaps and to be computed semi-automatically, producing summaries of permafrost change at each site.

1) **Thaw penetration** (units: m): Position of the permafrost table with reference to the ground surface at the time of installation. Permafrost table position is interpolated between sensors.
2) **Thaw depth duration** ($\bar{D}$)[1] (units: $m^3/m^2$): The volume of thawed soil per unit area in a year. Thaw is integrated with respect to depth and time. This value is normalized by number of days in the year.
3) **Depth of zero annual amplitude** (ZAA) (units: m): The depth at which the annual amplitude is dampened below 0.1 °C.
4) **Mean annual ground temperature** (MAGT) near the ZAA (units: °C).

## Visualizing permafrost thaw

We are working toward developing quantifiable methods for evaluating permafrost thaw based on the above metrics. However, visually, we can begin **revealing thaw** by studying the **temporal change** in the metrics, as shown in Figure 3 for two selected sites.

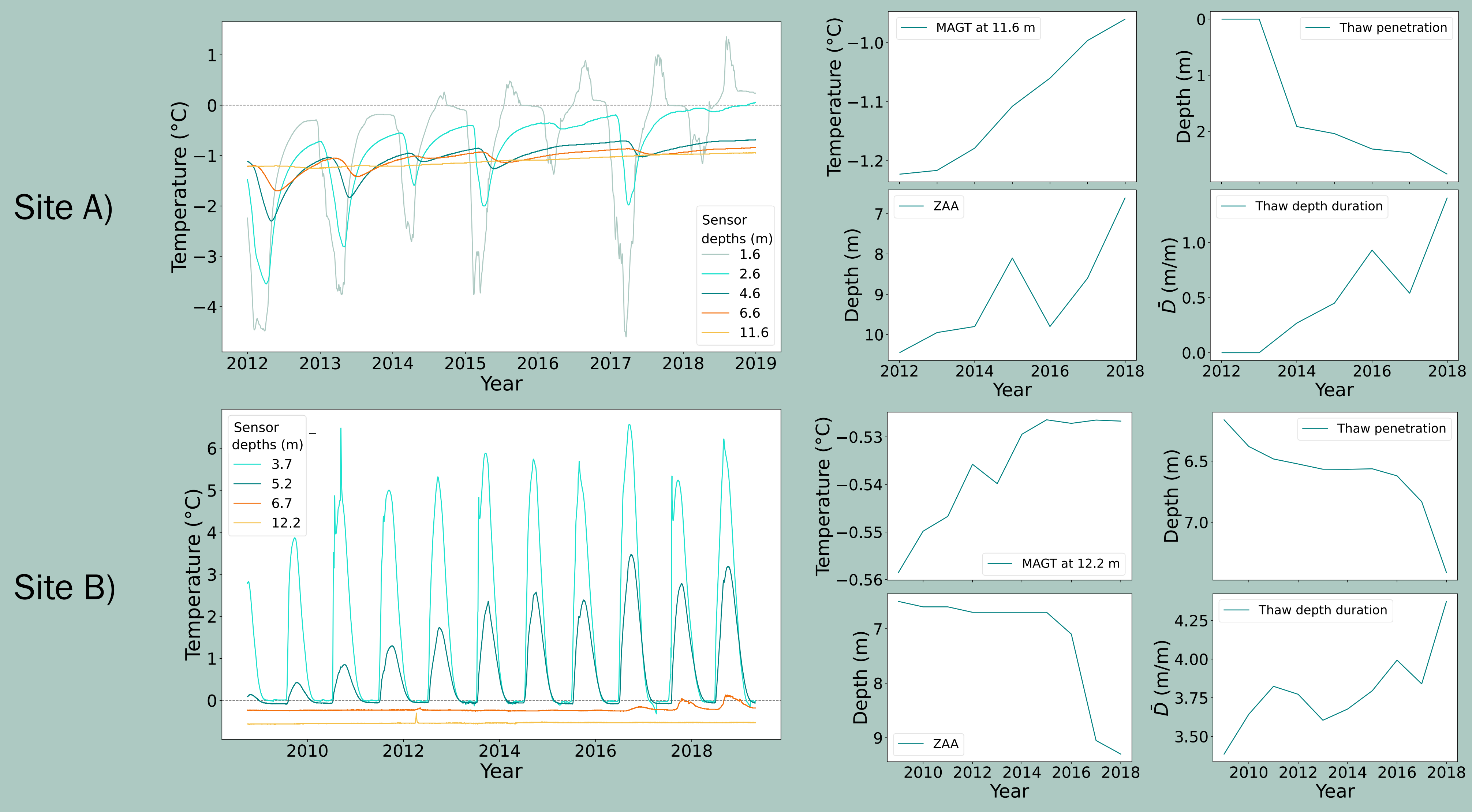

Figure 3. Timeseries of select sensors and corresponding annual metrics for sites A) CAS-DH11-23B located near the end of road ~150 km south of Dawson City, Yukon, and B) HPW_Shakwak_8_slope located on the slope embankment of the Alaska Highway, Yukon and subjected to the heat drain mitigation technique. Data from the Yukon Geological Survey[2].

Figure 3 shows two sites experiencing both warming and thaw. At both sites we observe a deepening of the permafrost table and increasing permafrost temperature. We also note two **contrasting ZAA trends**, resulting from **latent heat** uptake, that suggest permafrost thaw:

- A **rise** at **site A** resulting from the dominating effects of latent heat as the ground temperature rises until stabilizing for an extended period as the ground material thaws.
- A **lowering** at **site B** following the zero-curtain period (2009–2016) at 6.7 m once the ground material has thawed and begins fluctuating near 0 °C.

The patterns we observe allow us to detect permafrost thaw at sites across Canada, irrespective of their location or disturbance classification.

## Summarizing metrics from many boreholes

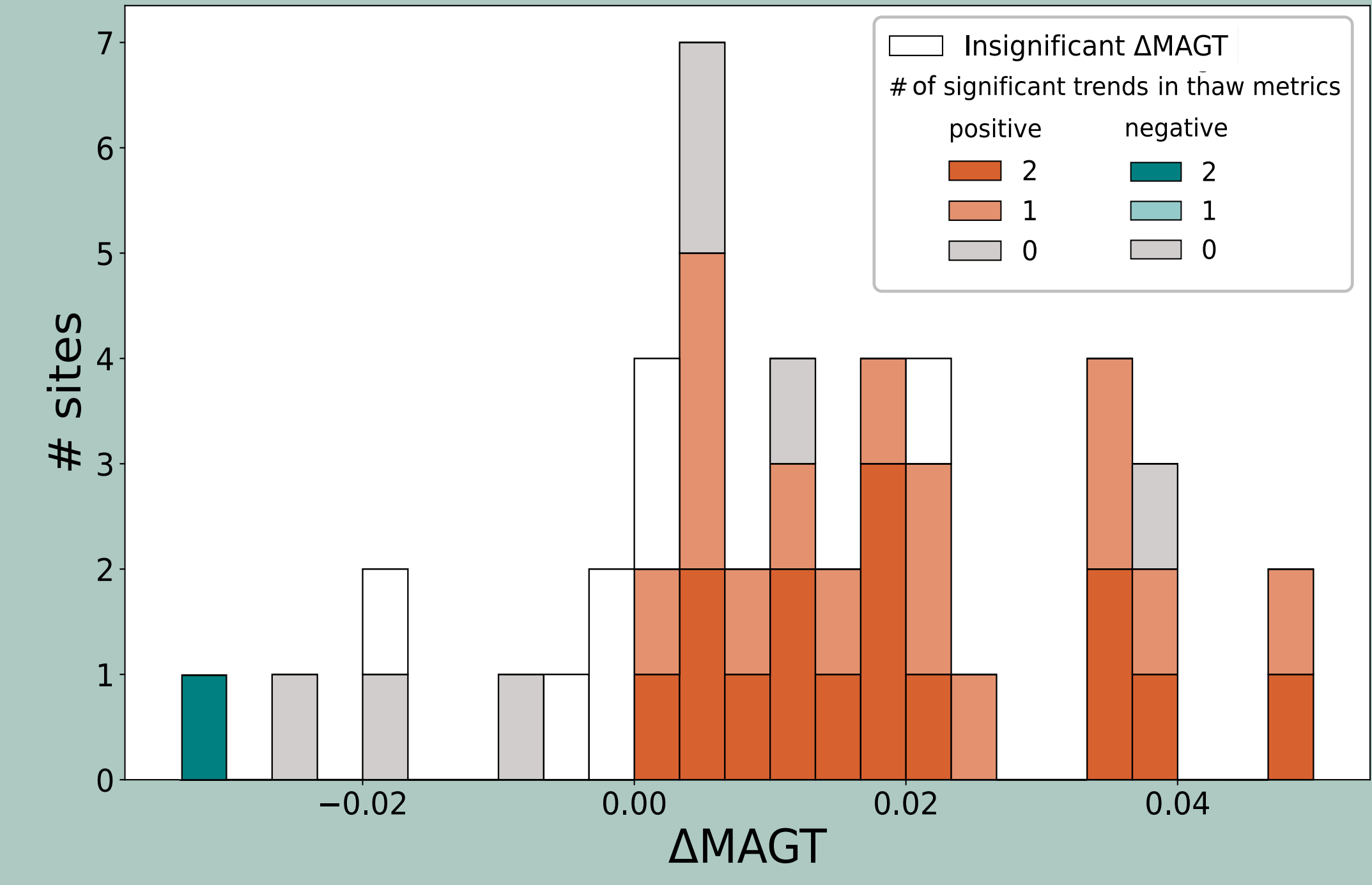

Figure 4. Temporal change in MAGT near the ZAA for deep boreholes (n = 44). Linear regression used to estimate metric change. MAGT is significant (*p*-value <= 0.05) unless otherwise stated. Thaw penetration and ZAA are the 2 thaw metrics reported for each site.

## Take-away messages

- Diverse metrics complementing the temperature change near the ZAA provide a more complete picture of permafrost degradation.
- A denser and spatially extensive array of borehole temperature data will enable a more accurate representation of thaw in Canada.
- Qualifiable methods allow us to detect thaw, and early analysis shows permafrost degrading in both natural and anthropogenically disturbed regions.

## Next steps

As a first step, qualifiable methods serve as tool for identifying permafrost thaw. Future work will involve deriving **new metrics**, developing **quantifiable** methods for detecting thaw based on the metric results, investigating the **variability in thaw** driven by site specific characteristics including disturbances, and **publishing a dataset** of the assembled borehole temperature observations.

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## Contact information

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## References

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