EST. 1785
UNIVERSITY OF NEW BRUNSWICK

Extracting Subtle Anomalies from Distributed Temperature Sensing data for Dam Seepage Investigations

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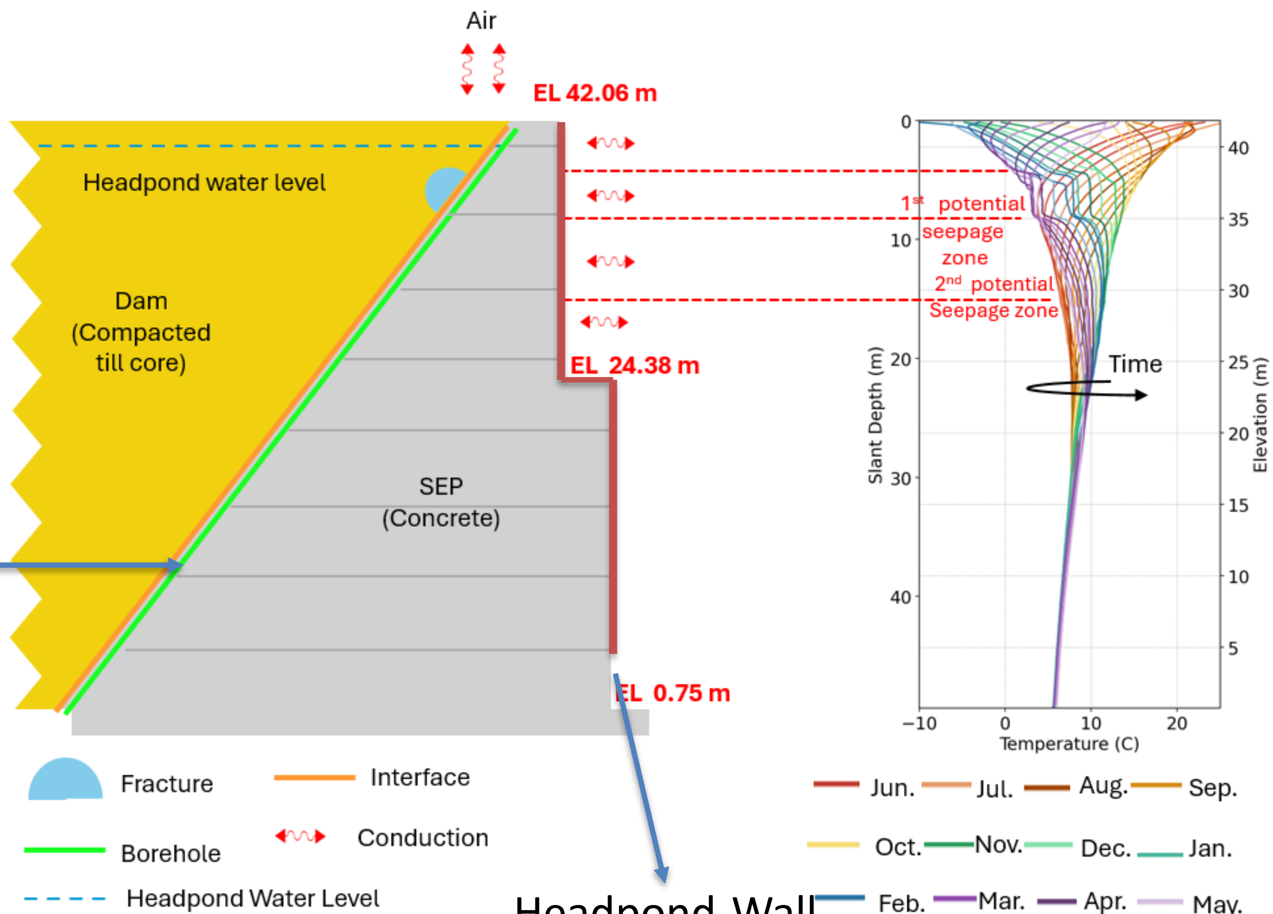
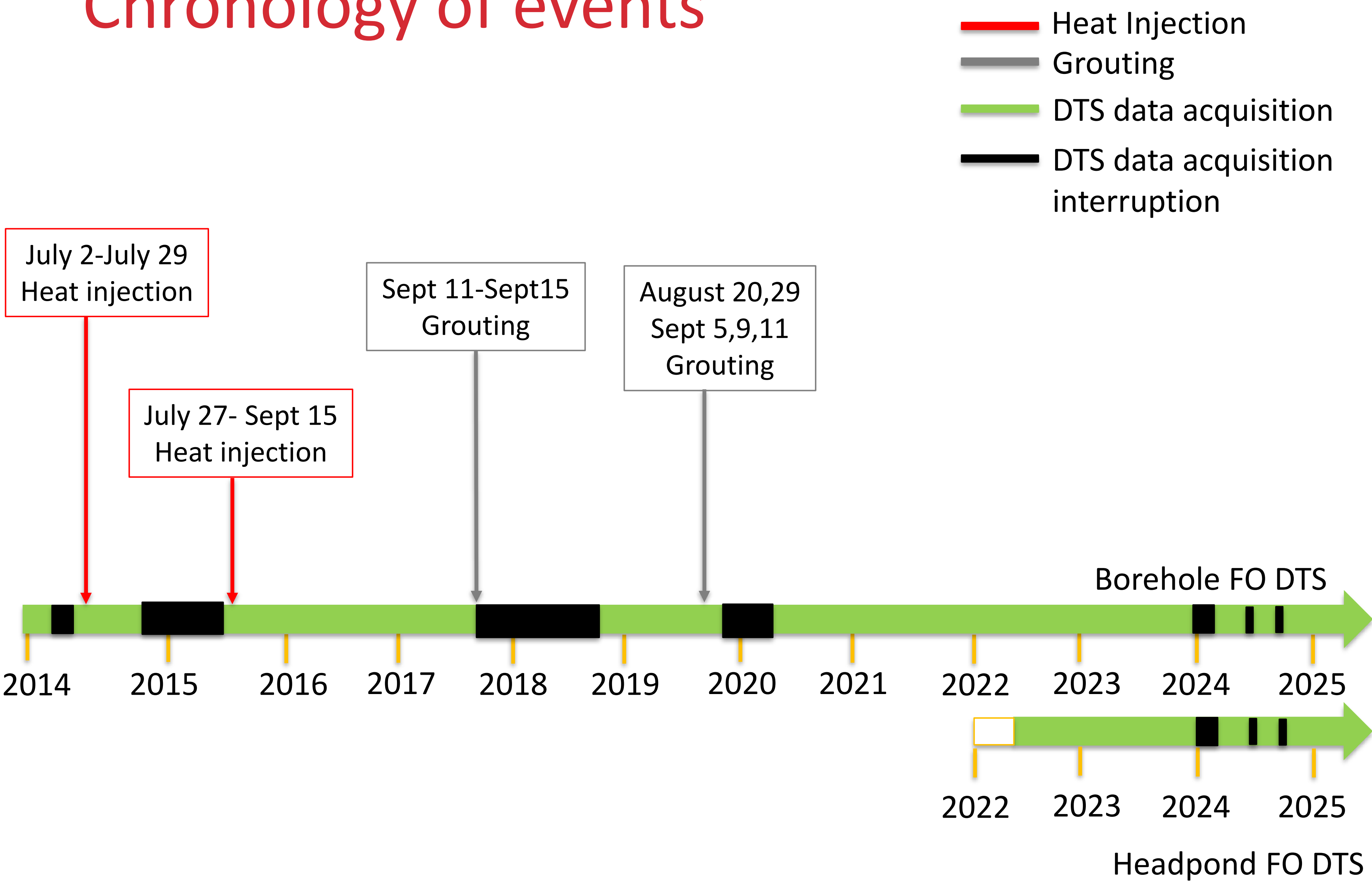
DTS Fibre optic cable



Borehole DTS

Headpond-Wall DTS

Chronology of events



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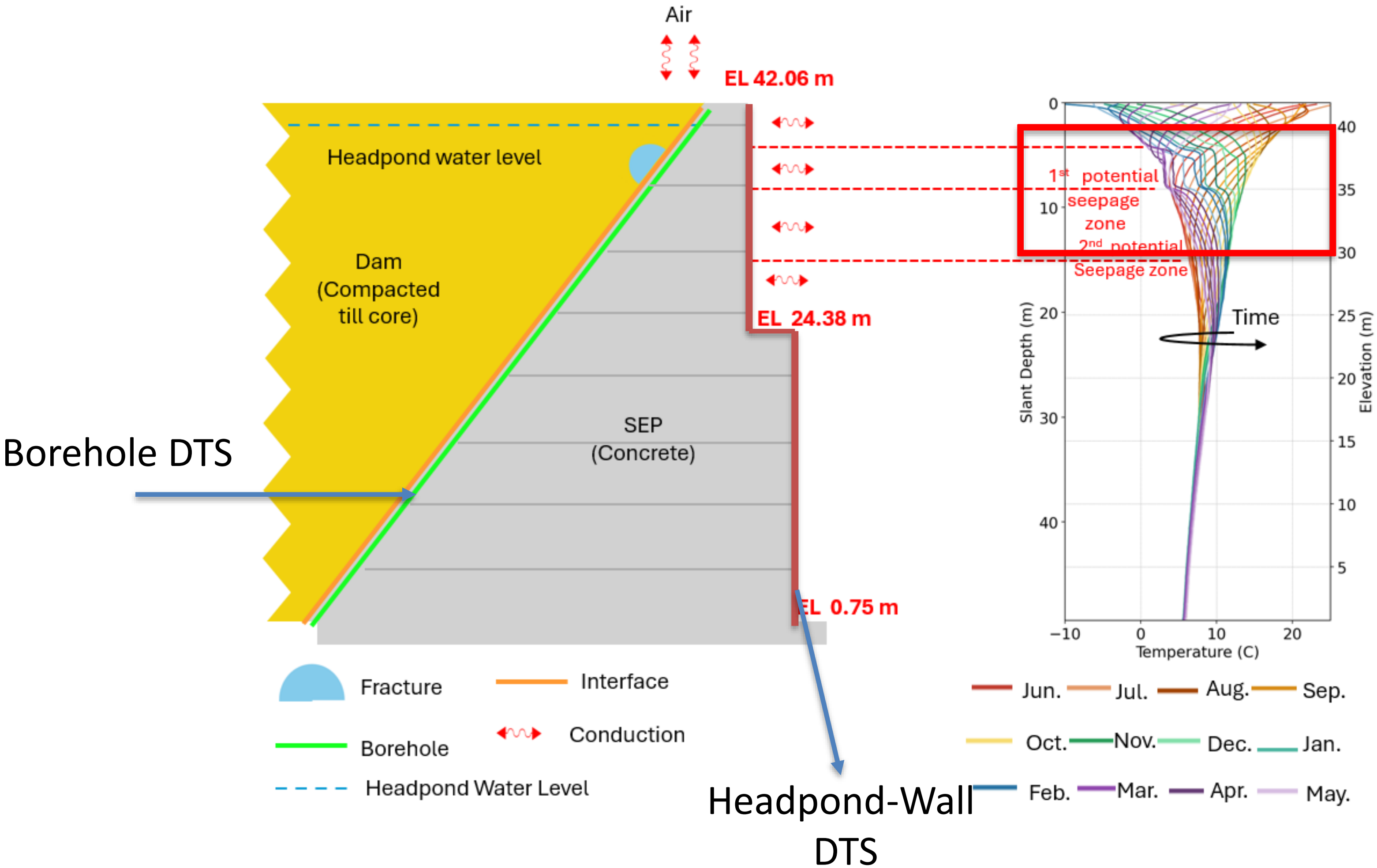
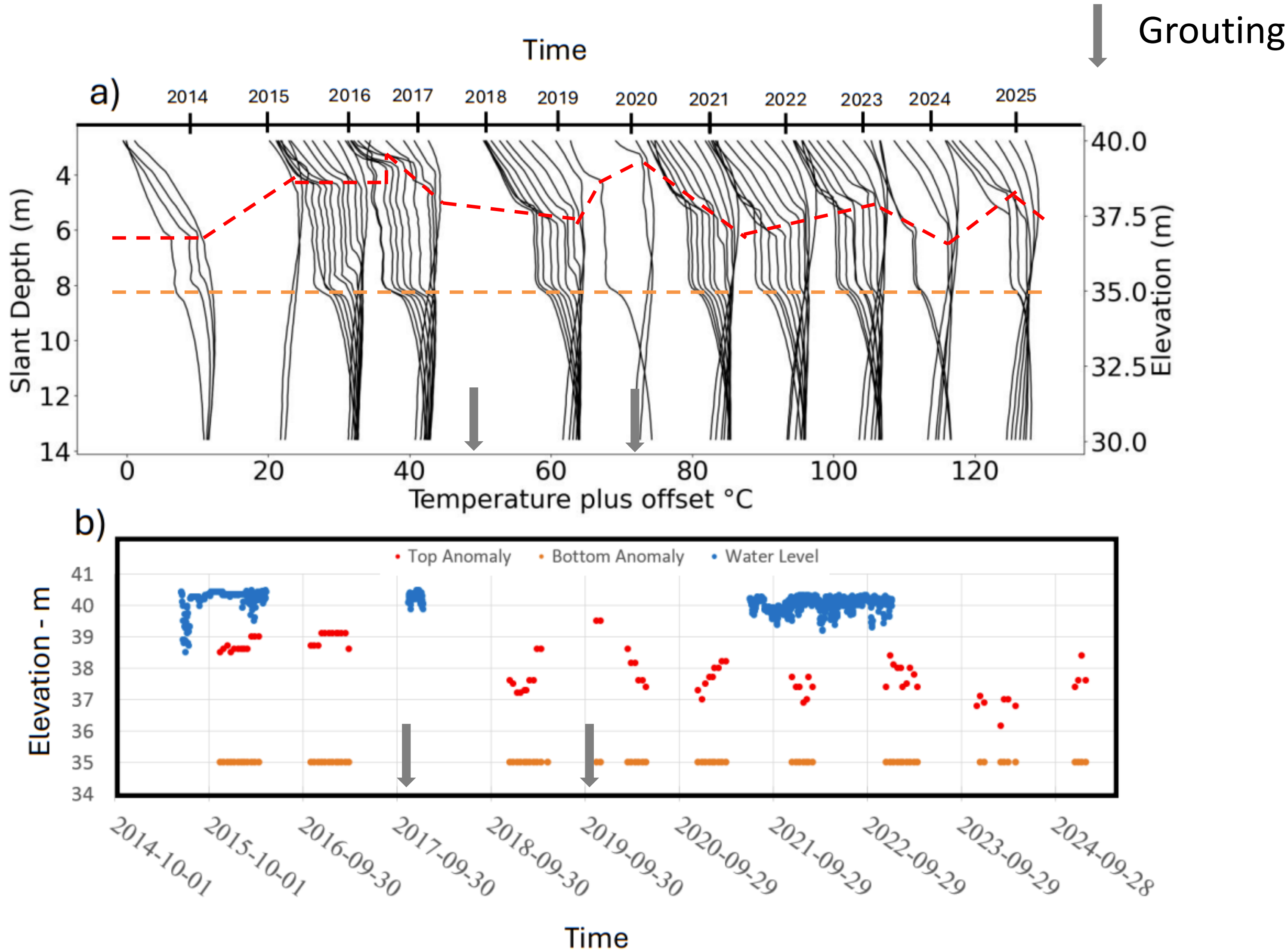
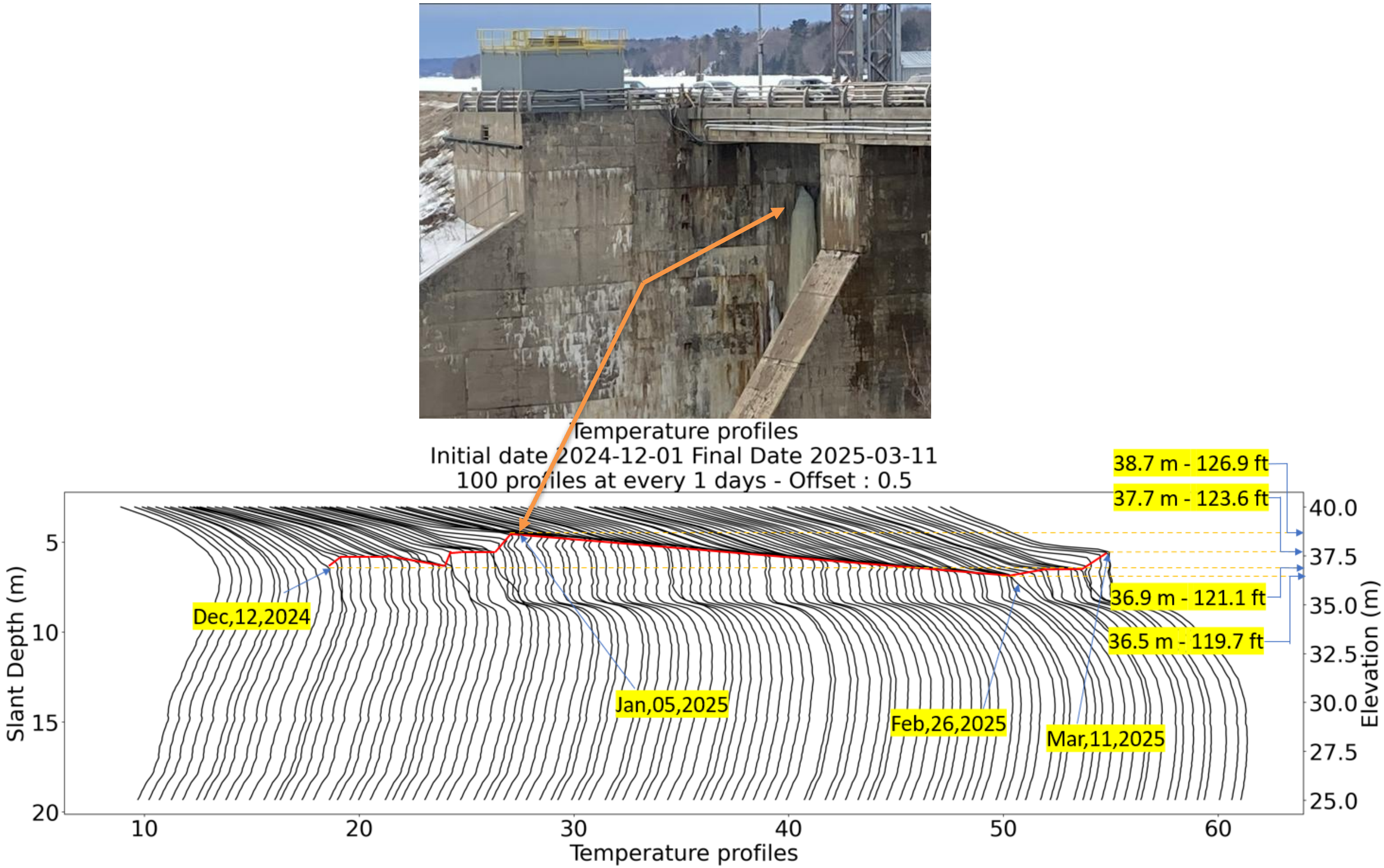


Evolution of the shallow anomaly ~ 38.5 m – 35 m elevation



Confirmation-Water coming out of the north wall of the SEP

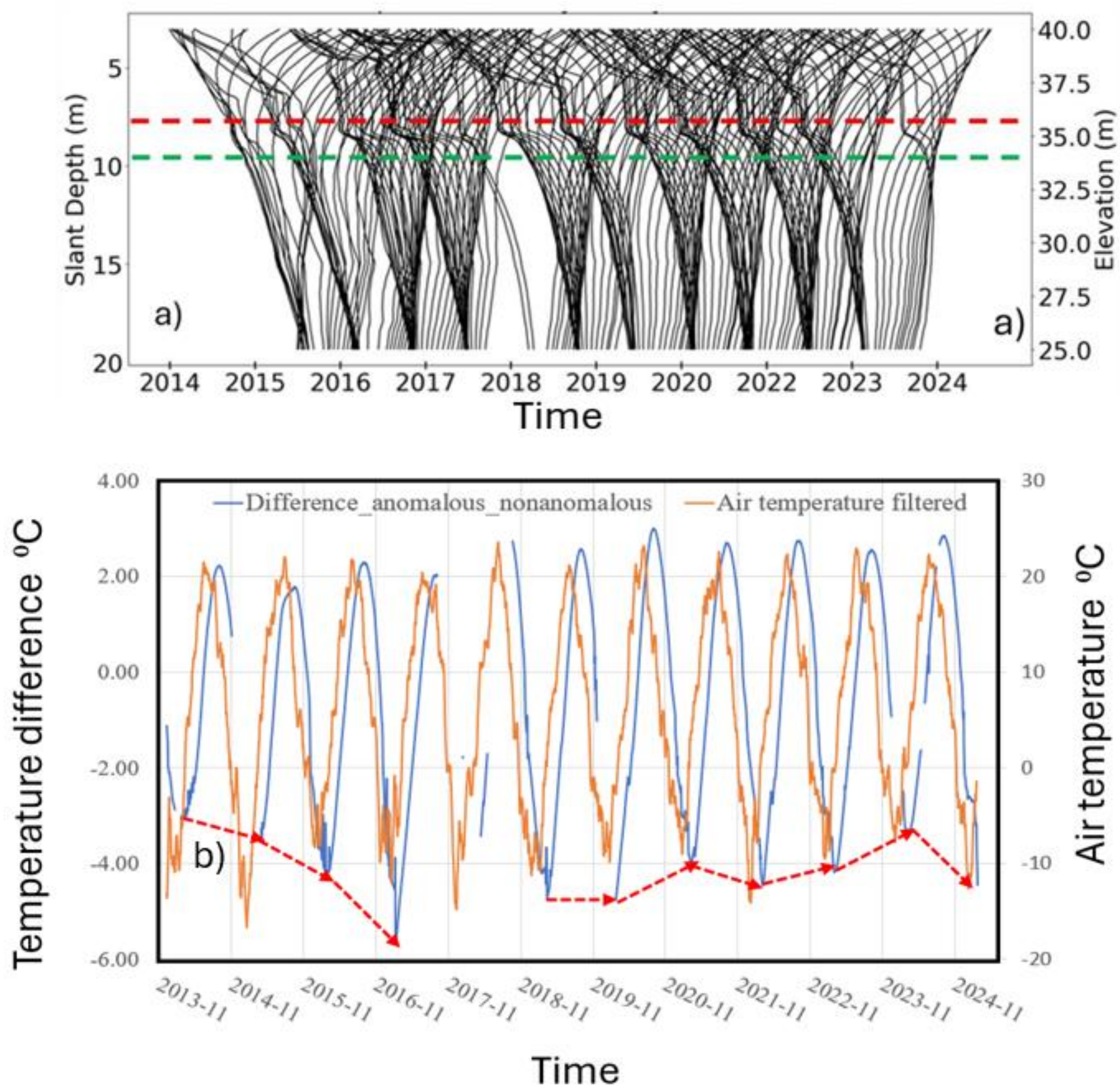


Shallow anomaly magnitude* since 2014

* Difference between temperatures at 35.8 m and 34.1 m (i.e., within and immediately below the anomaly)

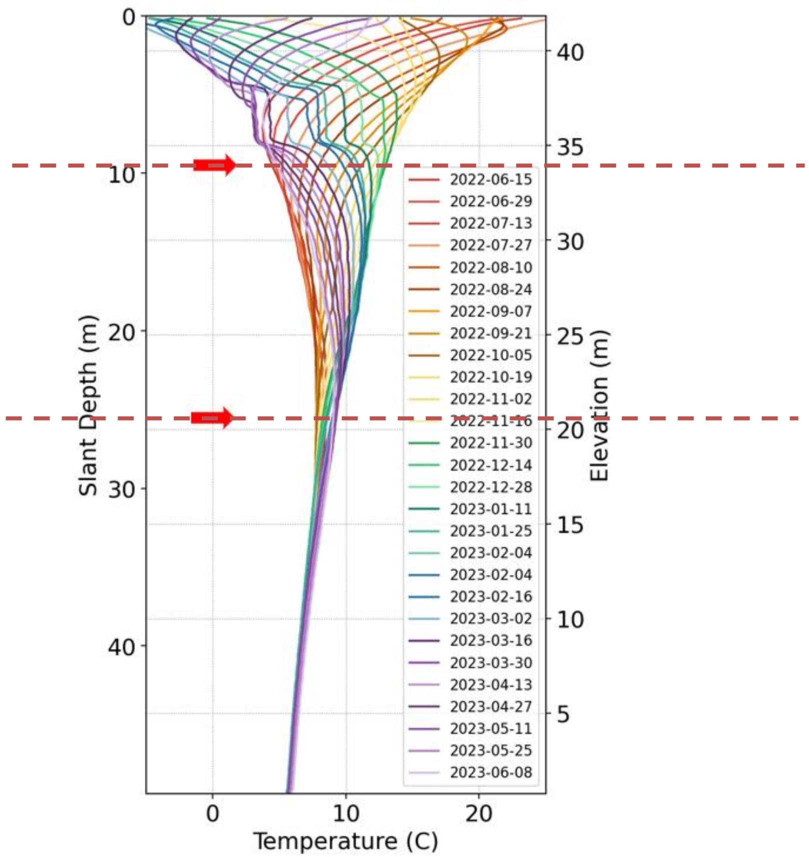
Appeared to be increasing before 2017 grouting.

Seemingly stable since 2018, varying with air temperature



Deep anomaly zone of investigation

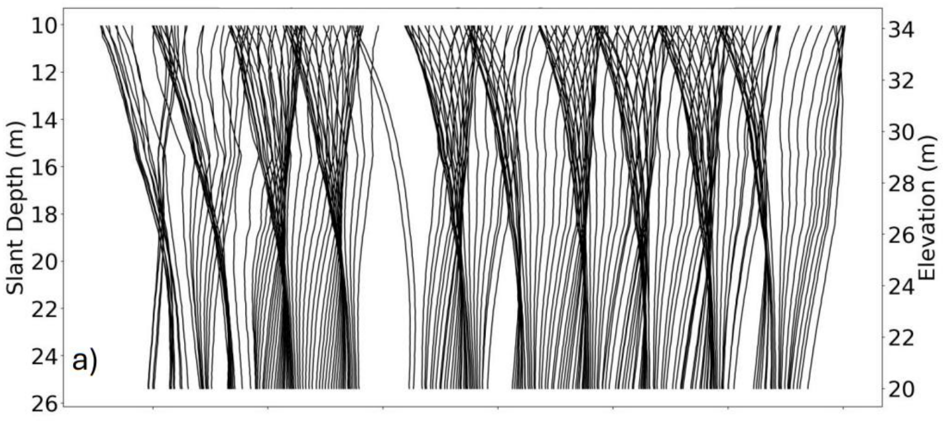
- 34.4 m to 21.4 m elevation
- 91 pseudonodes (every 14 cm)
- 11 years of data (some downtime)
- Unlike the shallow anomaly, the deep anomaly is much weaker than temperature variations caused by conductive heat transport from the concrete surfaces
- Methods required to emphasize and extract seepage anomalies associated with advective heat transport



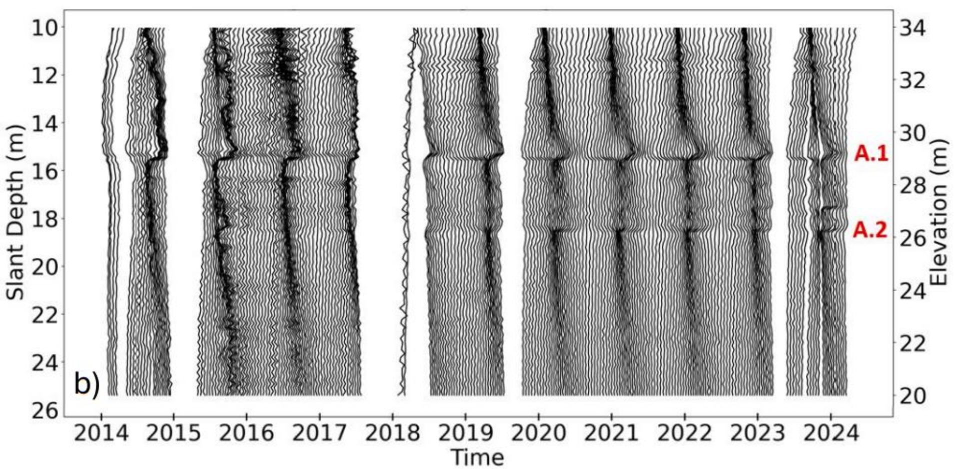
Method 1
Gradient Method

- Rate of change of temperature with depth (vertical gradient).
- One anomaly located at 29 m.
- Anomaly located at 26 m.

DTS temperature data



Vertical gradient temperature data



Method 2
Estimation and removal of surface seasonality

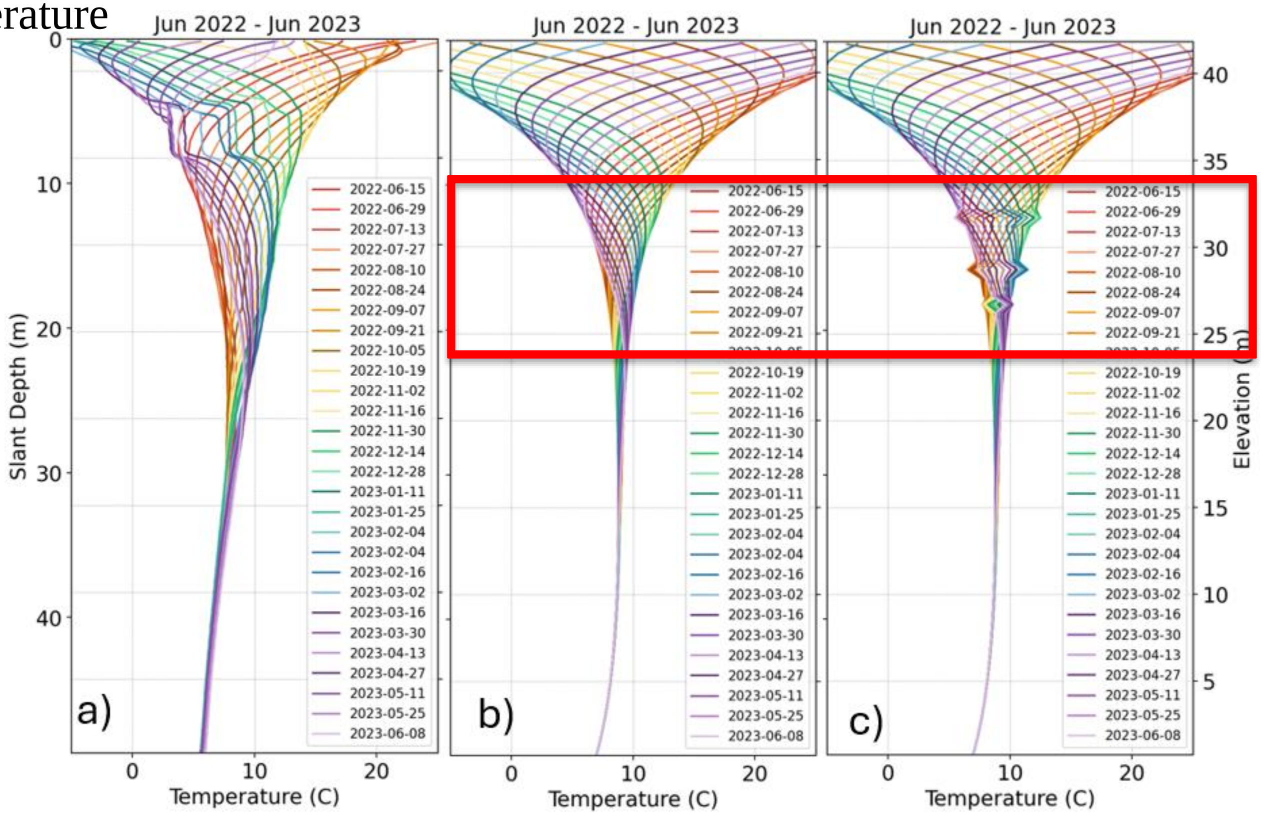
- Calculate estimate of temperature variations due to conductive heat transport

- Subtract estimate from DTS data.

- Residual should contain advective heat transport component (concentrated seepage anomalies)

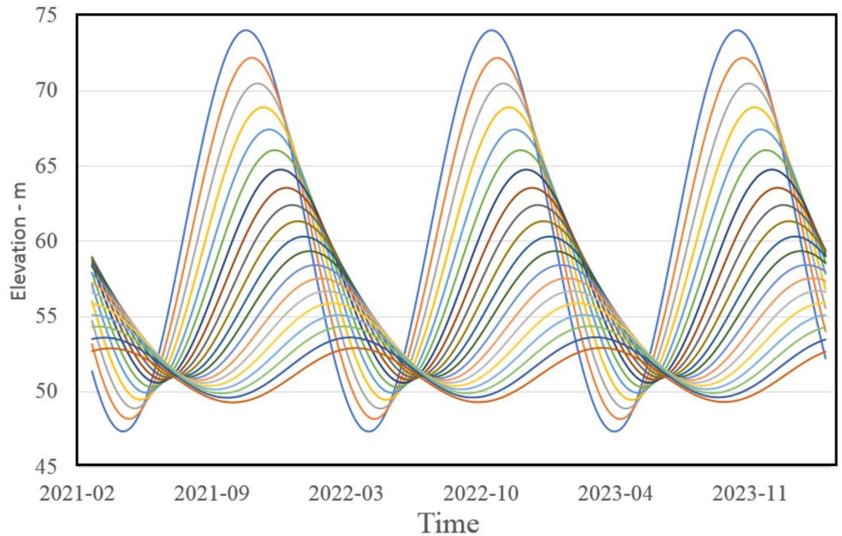
Method 2 – DBM
Synthetic data set

Developed based on the one-dimensional vertical simultaneous flow of fluid and heat in the Earth (Stallman, 1965; with corrections by O’Neill, 2023), emulating conductive heat from surface defined by a seasonal sinusoid simulating earth temperature

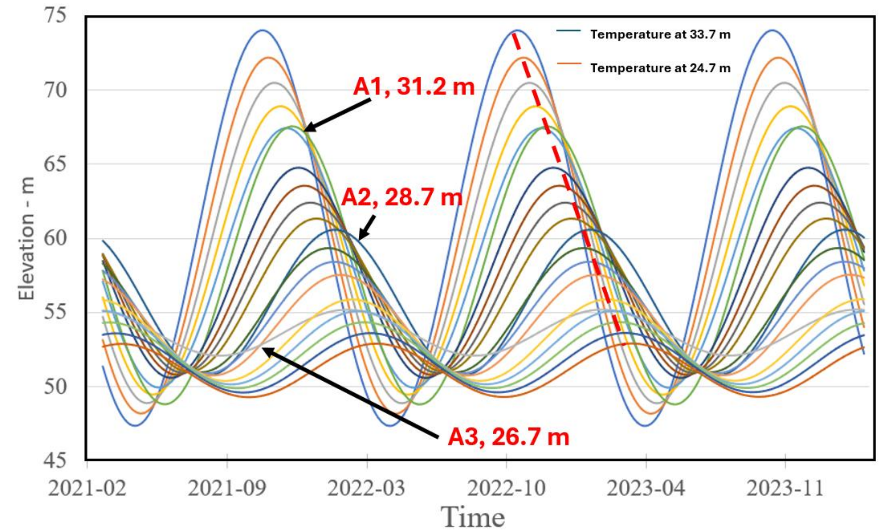


Method 2 - DBM
Synthetic data set:

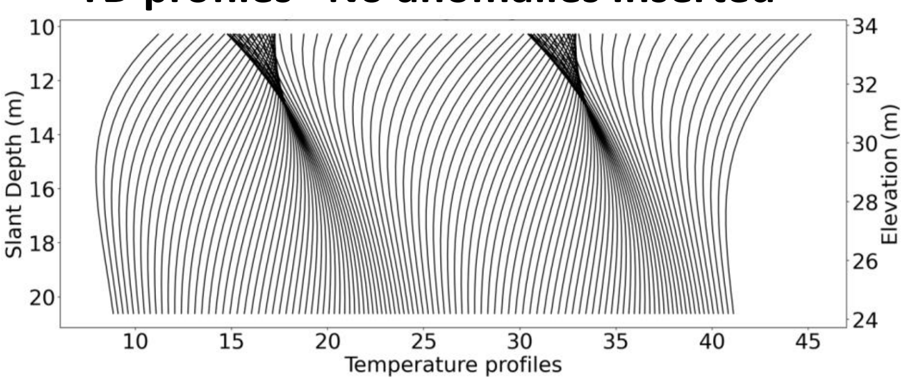
Time Series – No anomalies Inserted



Time Series – Three anomalies Inserted



TD profiles– No anomalies Inserted



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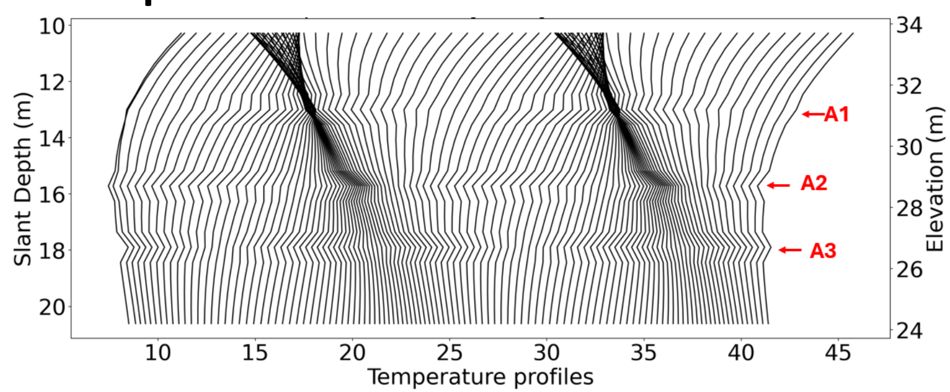
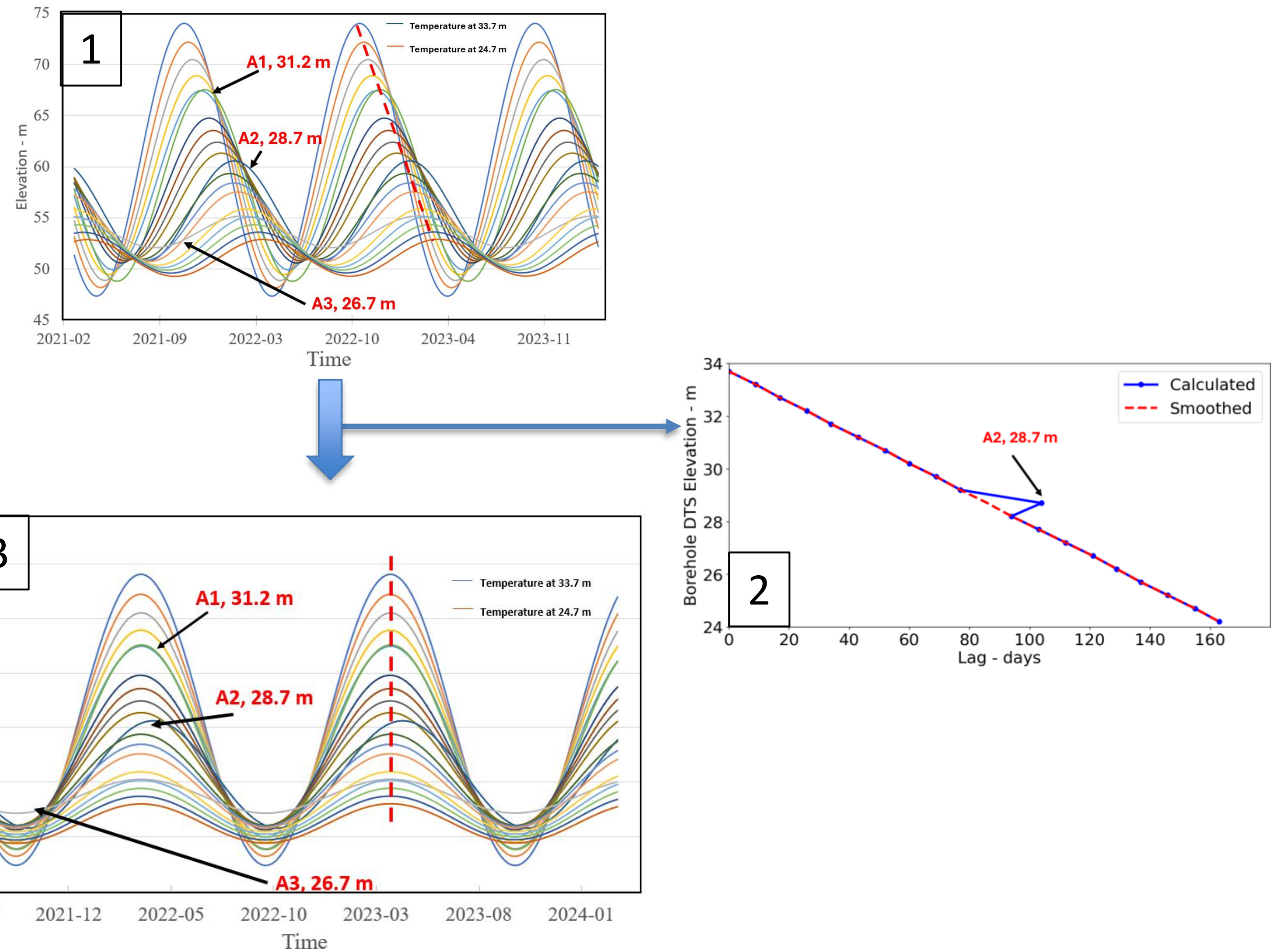


Method 2 - DBM

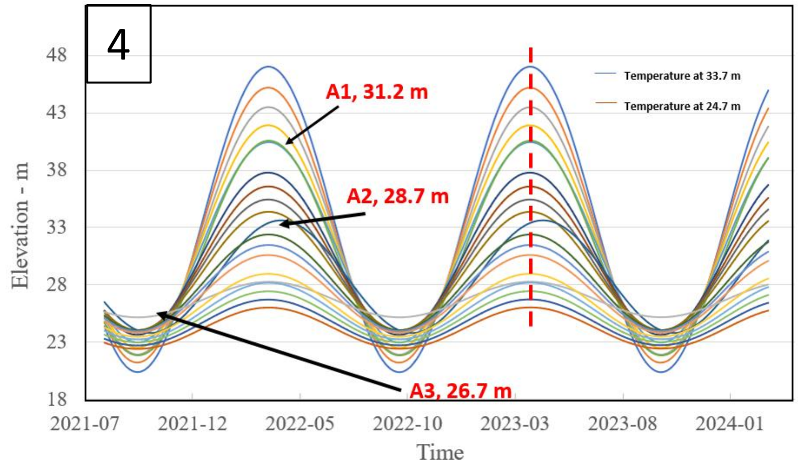
Development of DBM - 1

Step 1
Align time series by
Cross - correlation



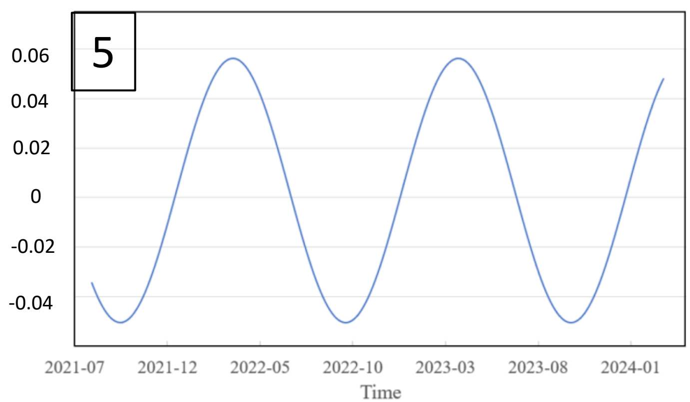
Method 2 - DBM

Development of DBM - 2

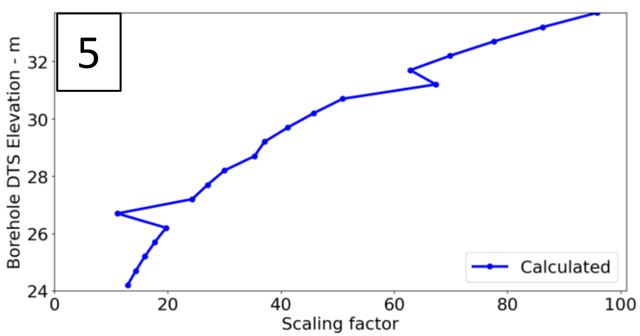


Step 2,
Compute Principal Components
using KL - Transform

Extract most common signal (1st PC)
by KL-Transform



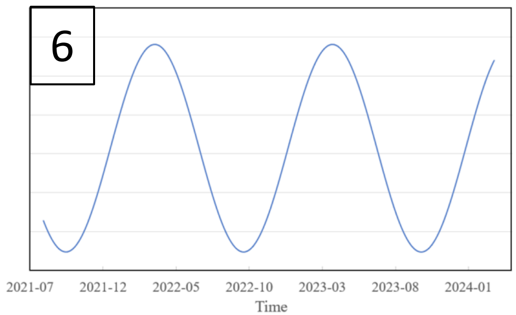
Scaling factor vs depth

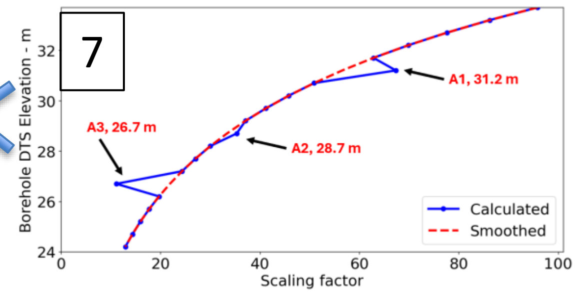


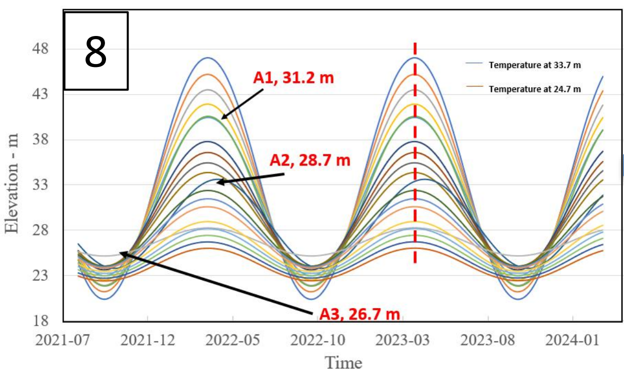
Method 2 - DBM

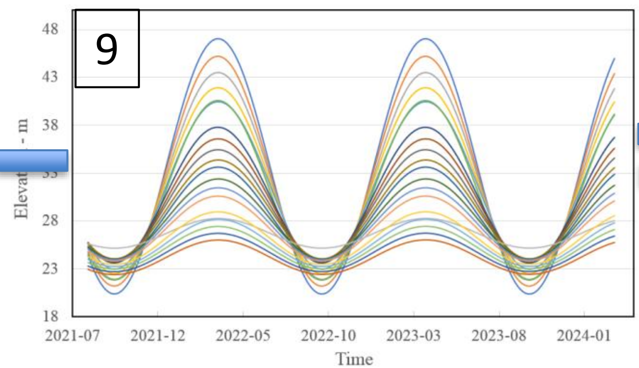
Development of DBM - 3

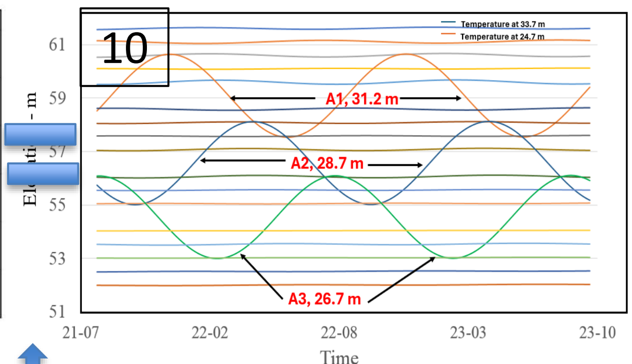
Step 3, Subtract principal components reconstructed using smoothed Scaling factor function from DTS time series with new alignment







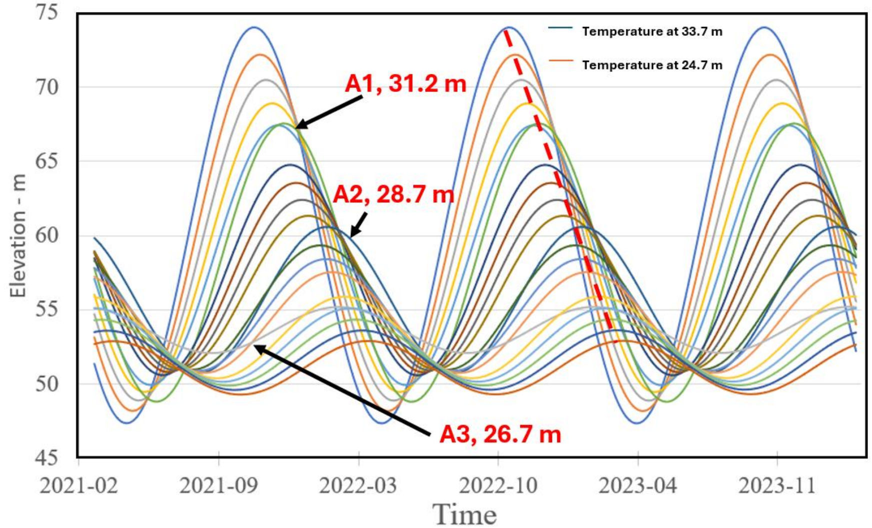




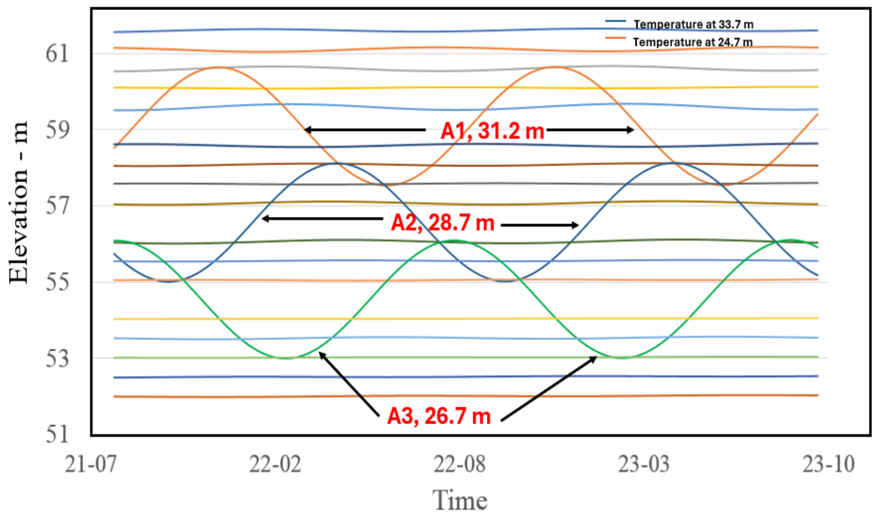
Remove alignment

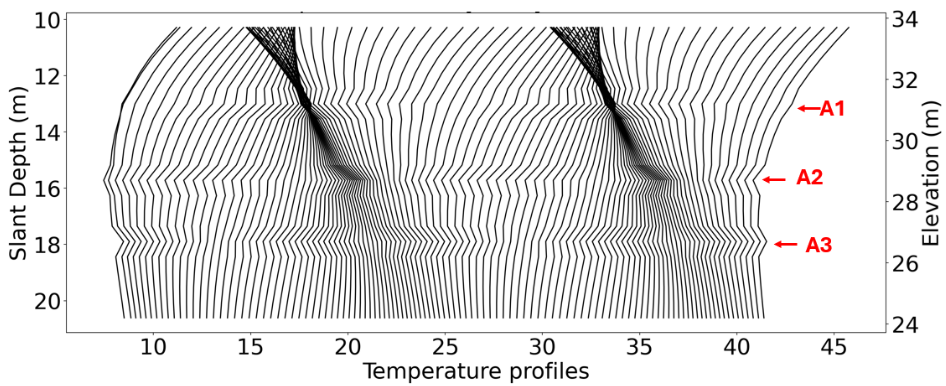
DTS Temperature vs DBM Temperature

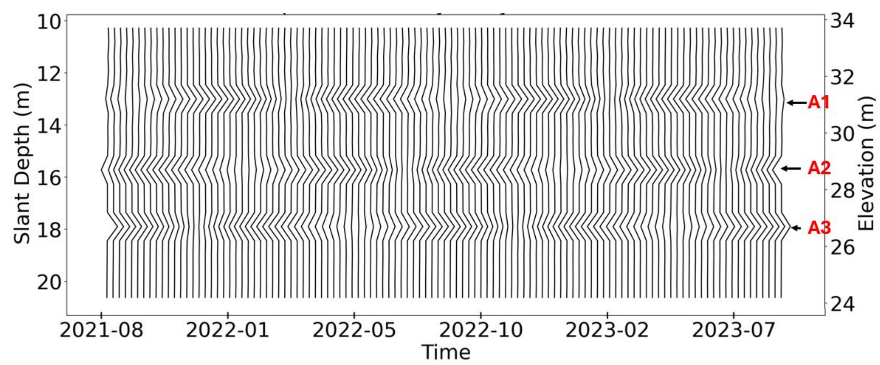
Synthetic Data set with three anomalies inserted



DBM data with surface seasonal component removed and anomalies preserved

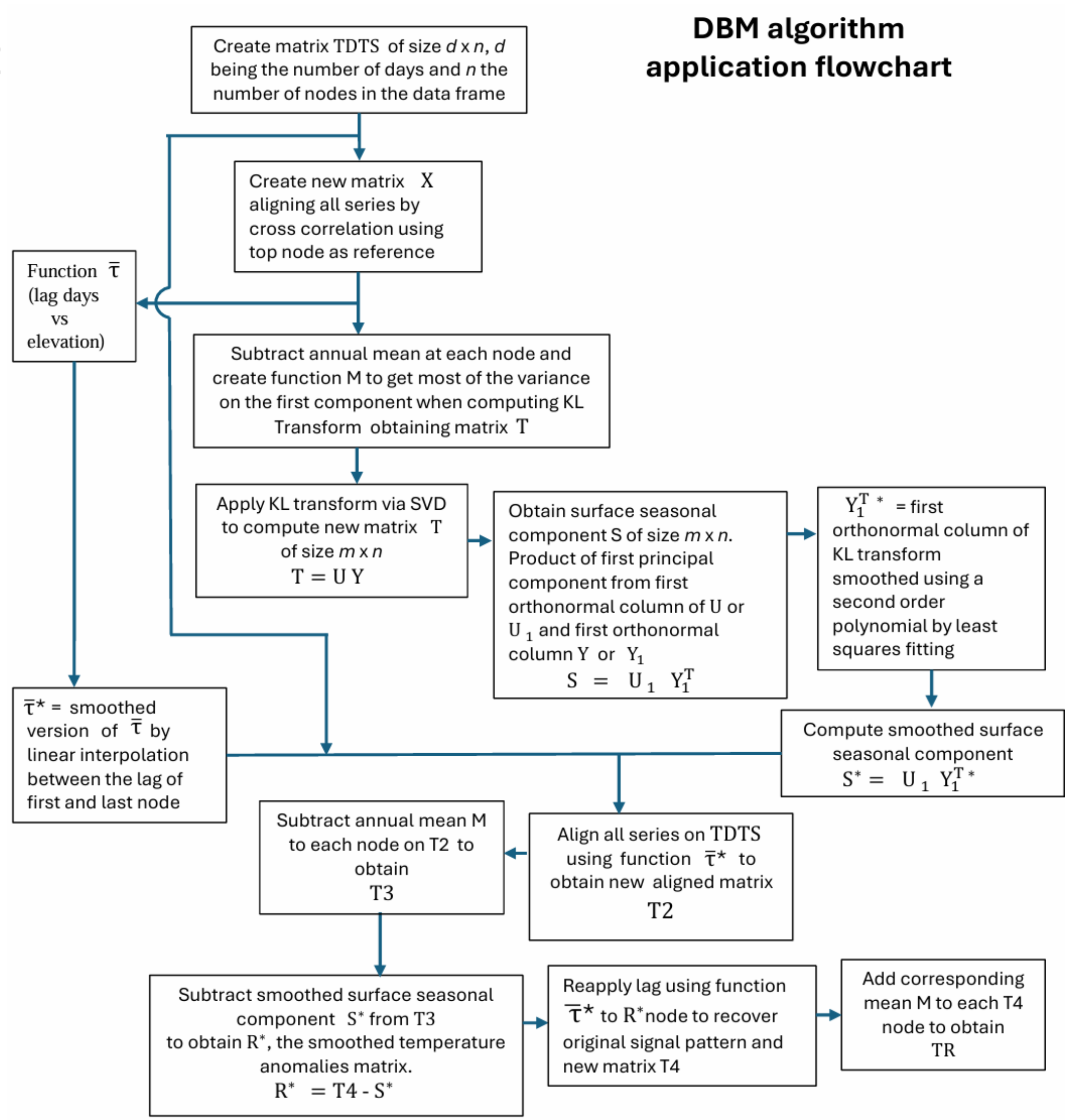






Method 2 - DBM

DBM flowchart



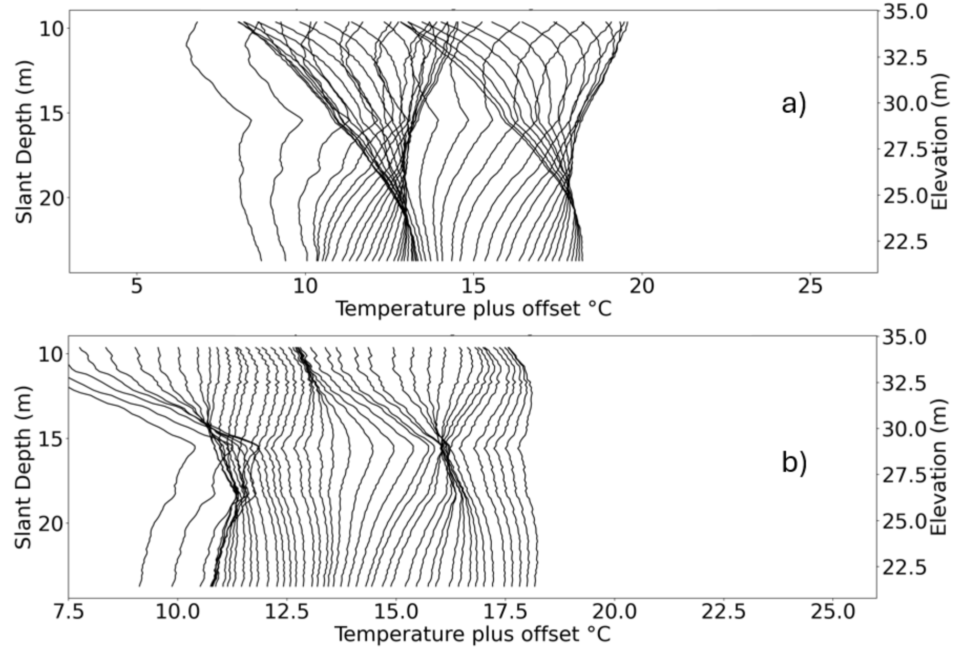
Pre-Grouting (2015 – 2017)

a) TD profiles from August 19,2015 to July 24, 2017. with a cumulative offset of 0.1 ^{o}C at 14-days intervals

b) Represents DTS temperature TD profiles

c) DBM processed temperature TD profiles

d) Red (raw DTS) and Blue (DBM processed) for c) February 15, 2017 and d) September 15, 2016



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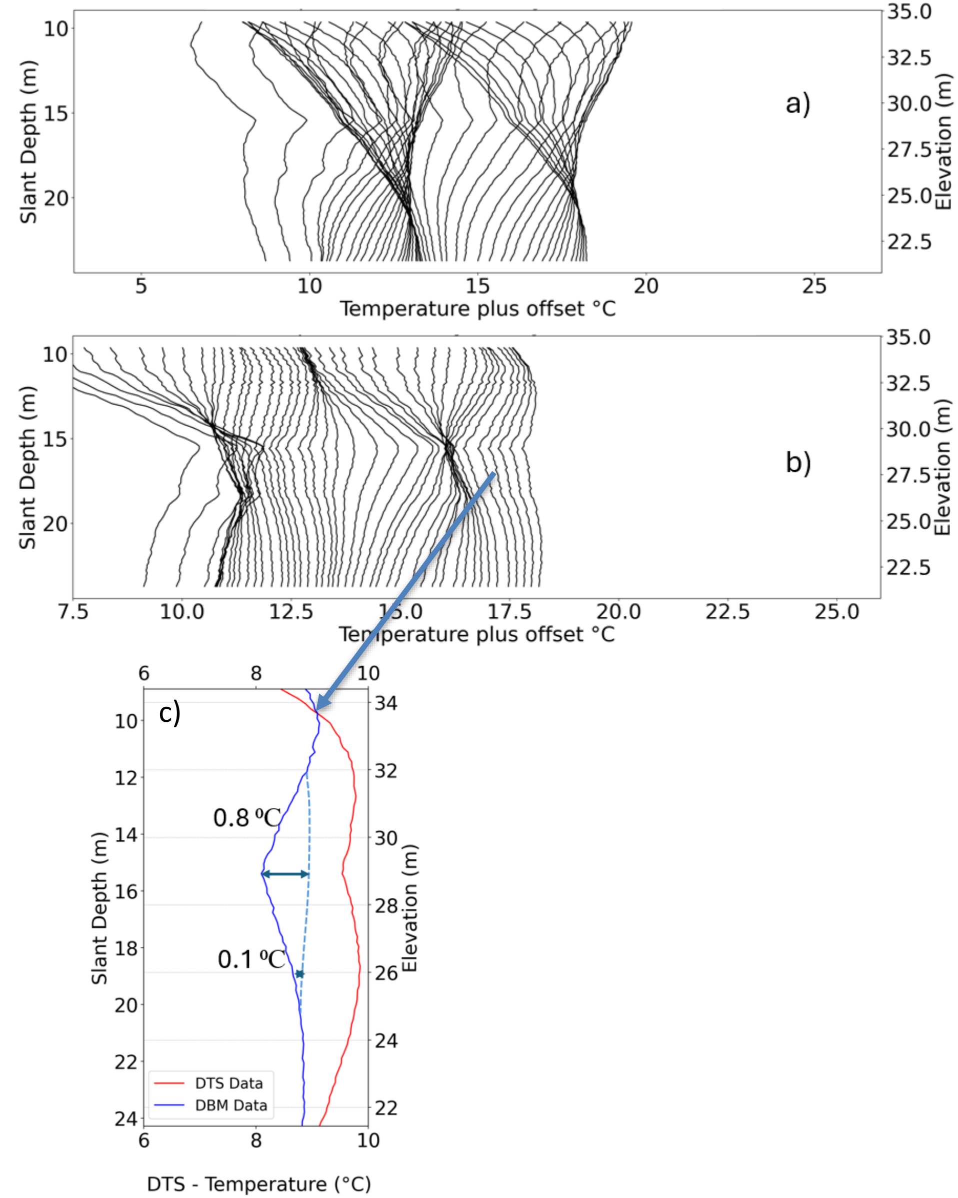

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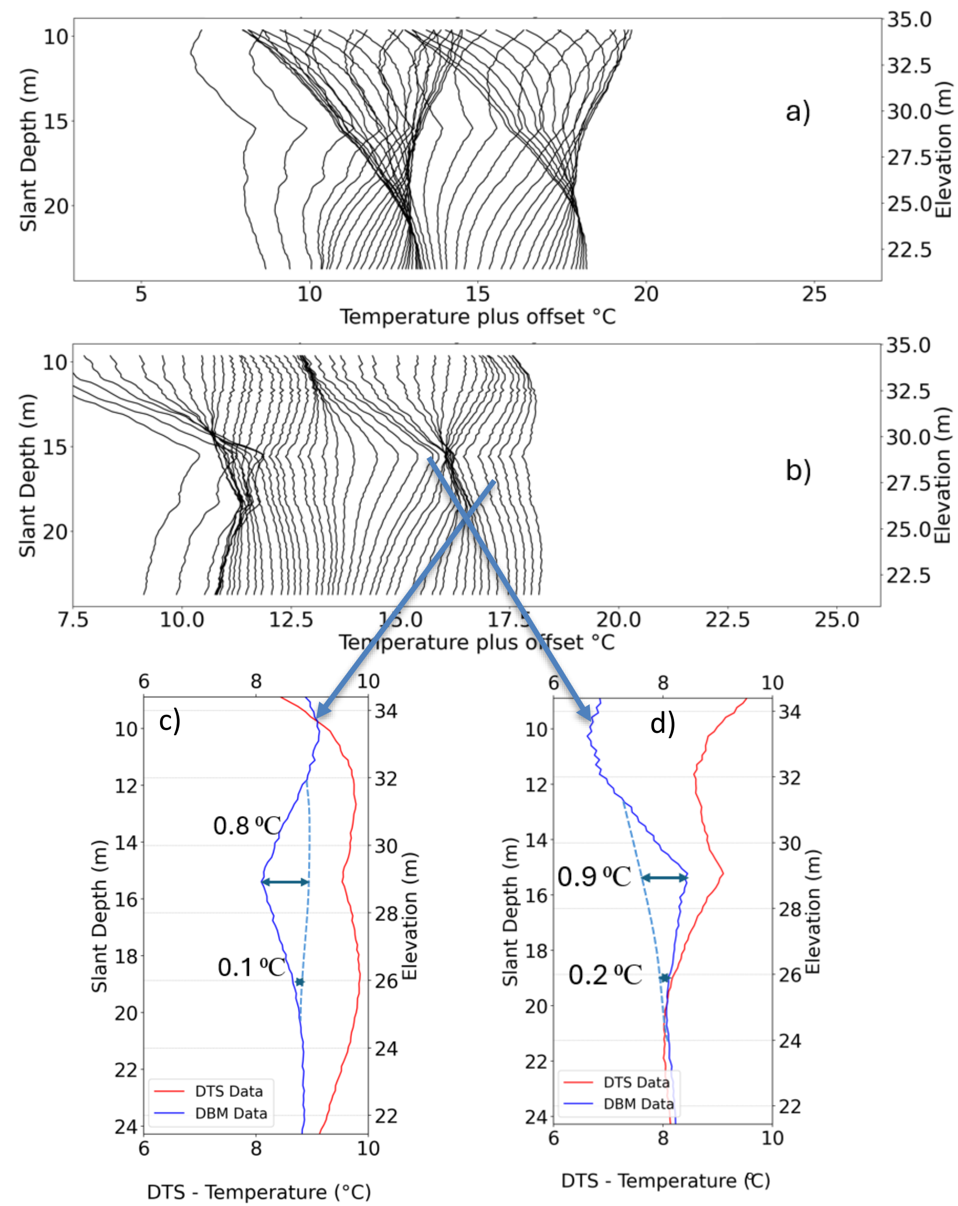


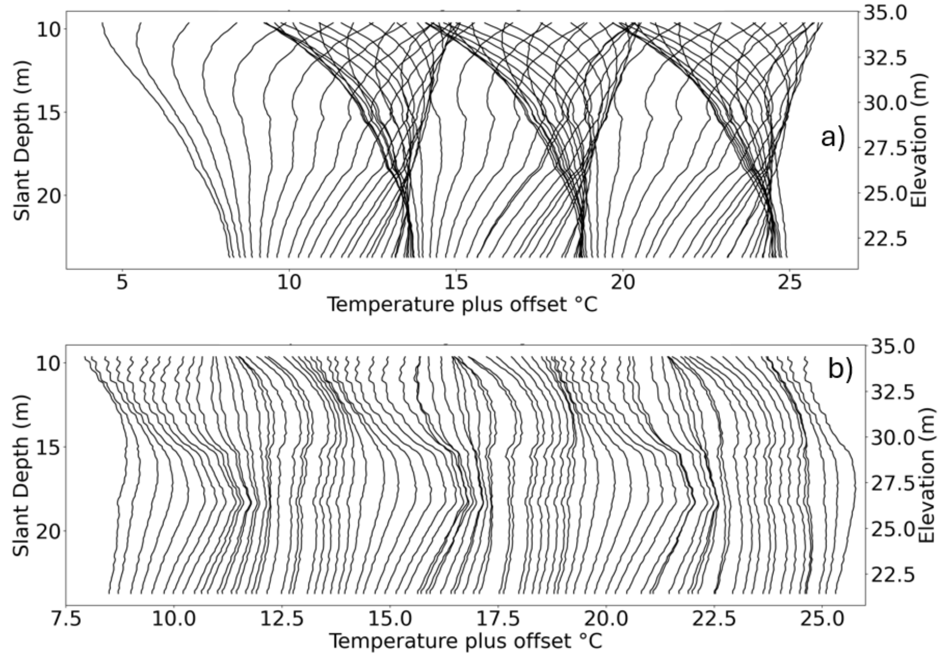
Post-Grouting (2020 – 2023)

a) TD profiles from July 8,2020 to August 8, 2023. with a cumulative offset of 0.1 ^{o}C at 14-days intervals

b) Represents DTS temperature TD profiles

c) DBM processed temperature TD profiles from DTS

d) Red (raw DTS) and Blue (DBM processed) for c) April 15, 2012 and d) October 15, 2022



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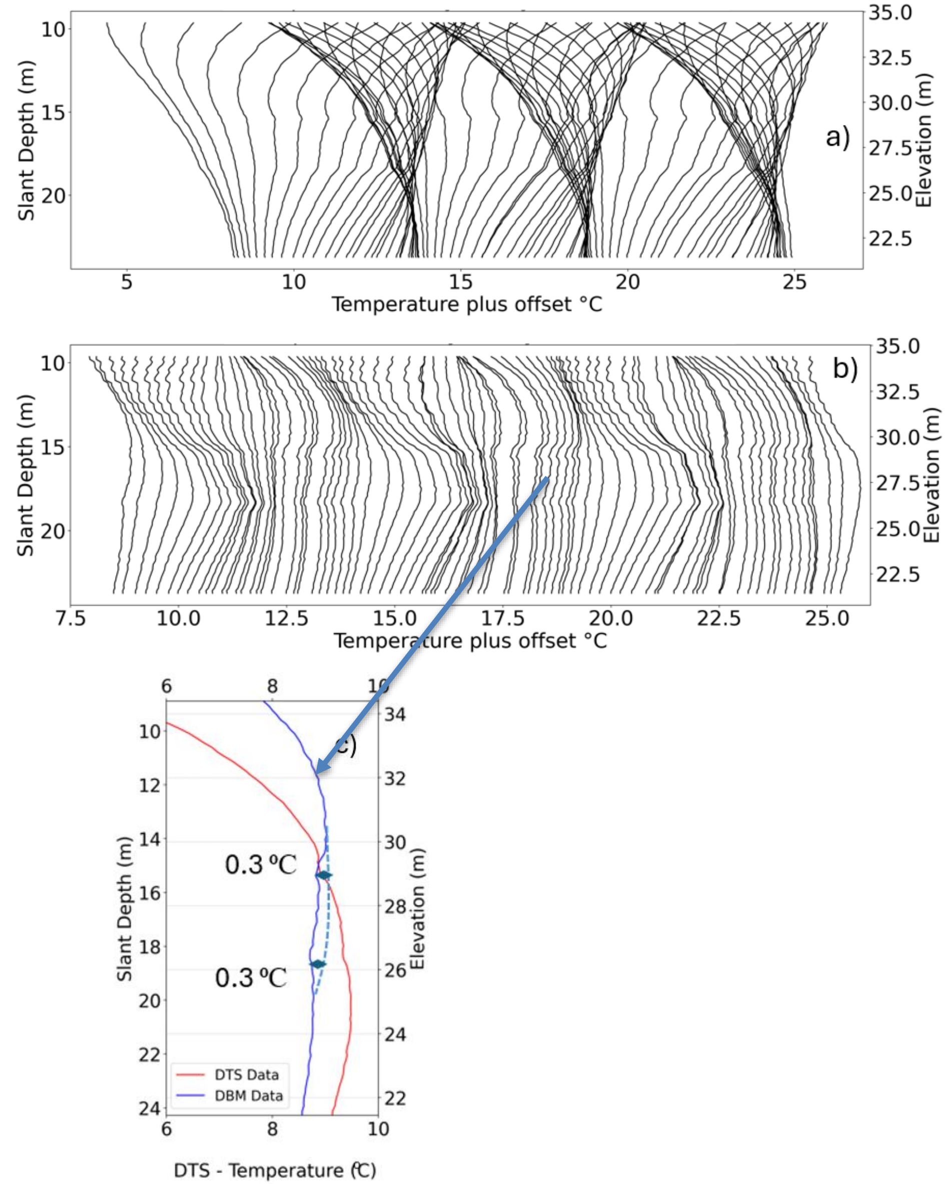

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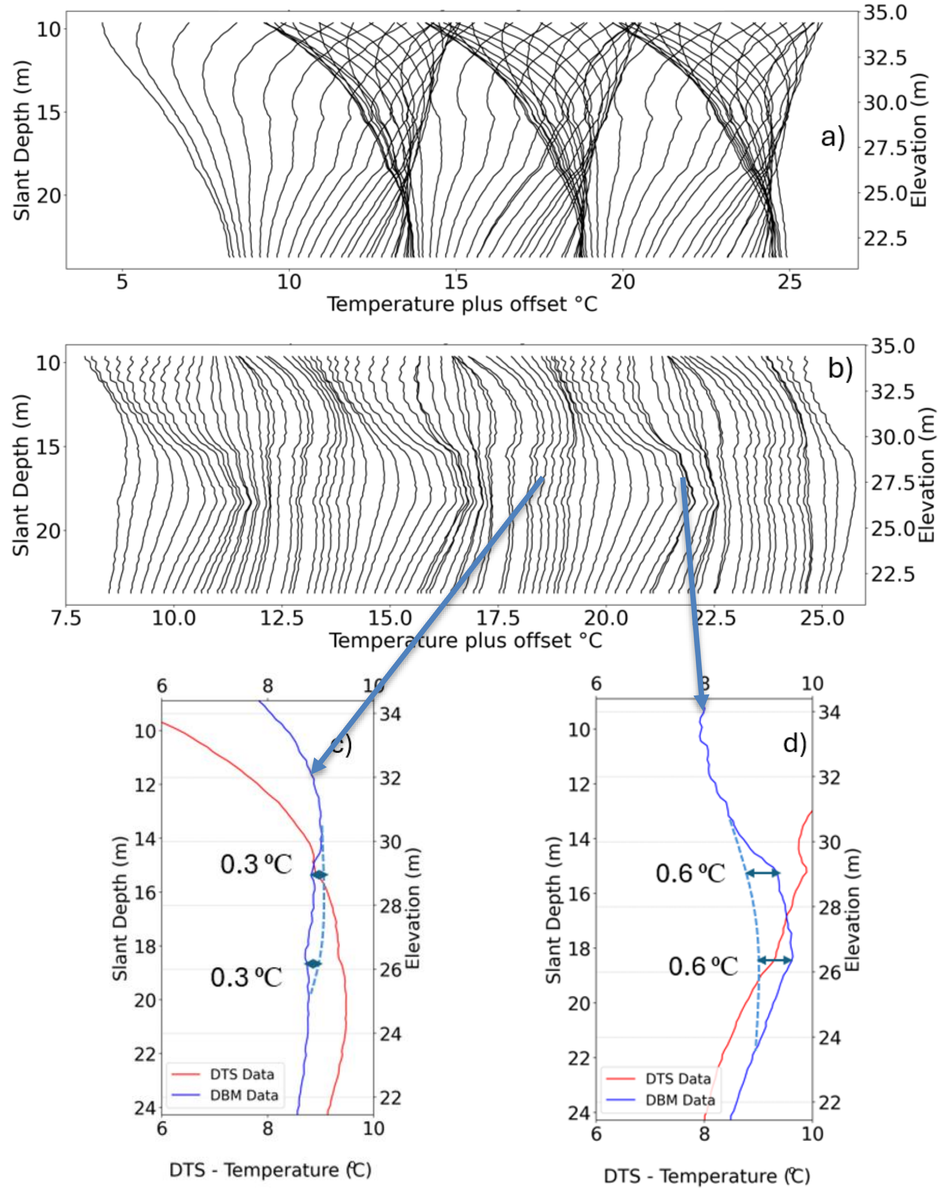
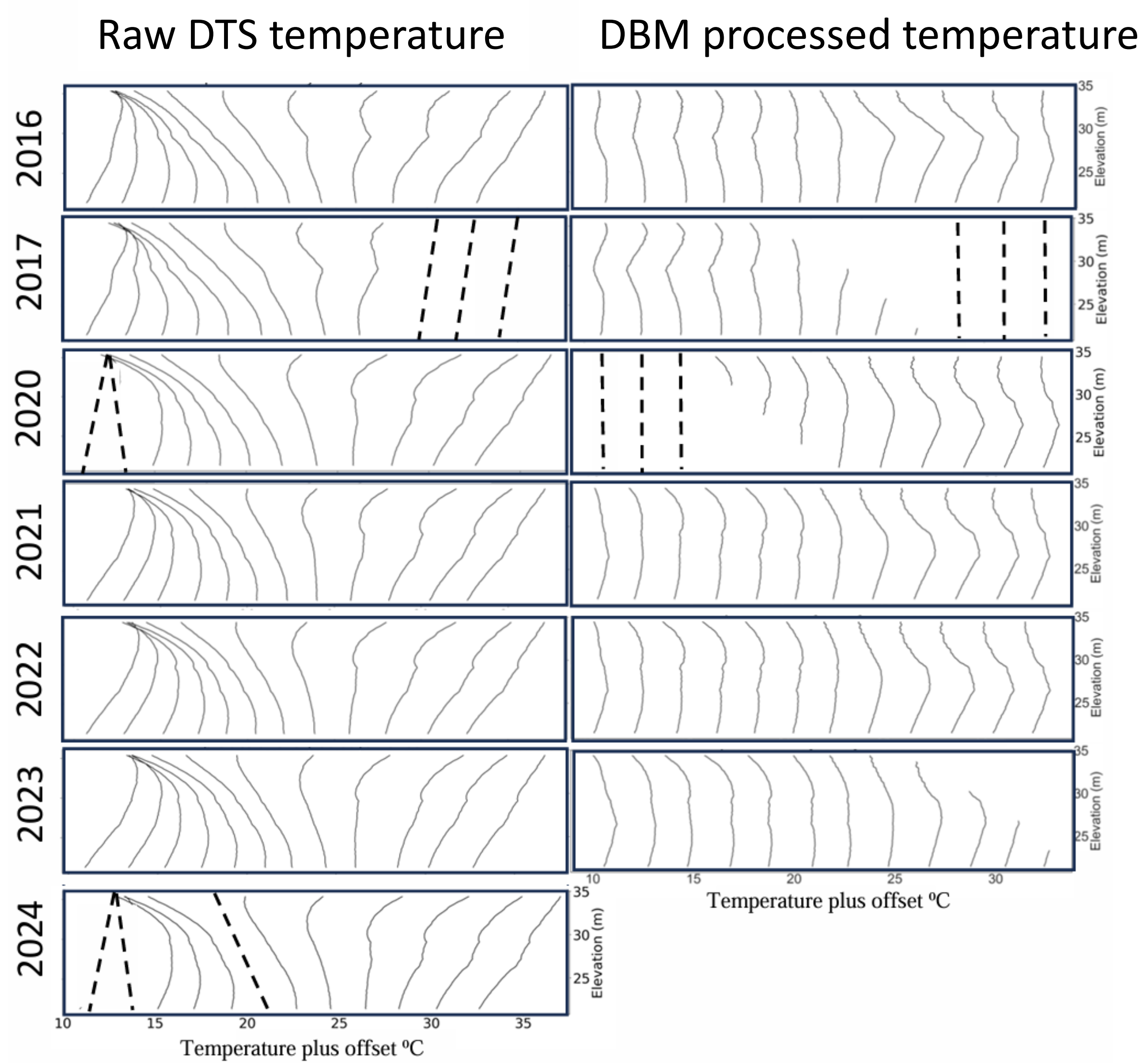


TD profiles: 1 profile per month, 7 years



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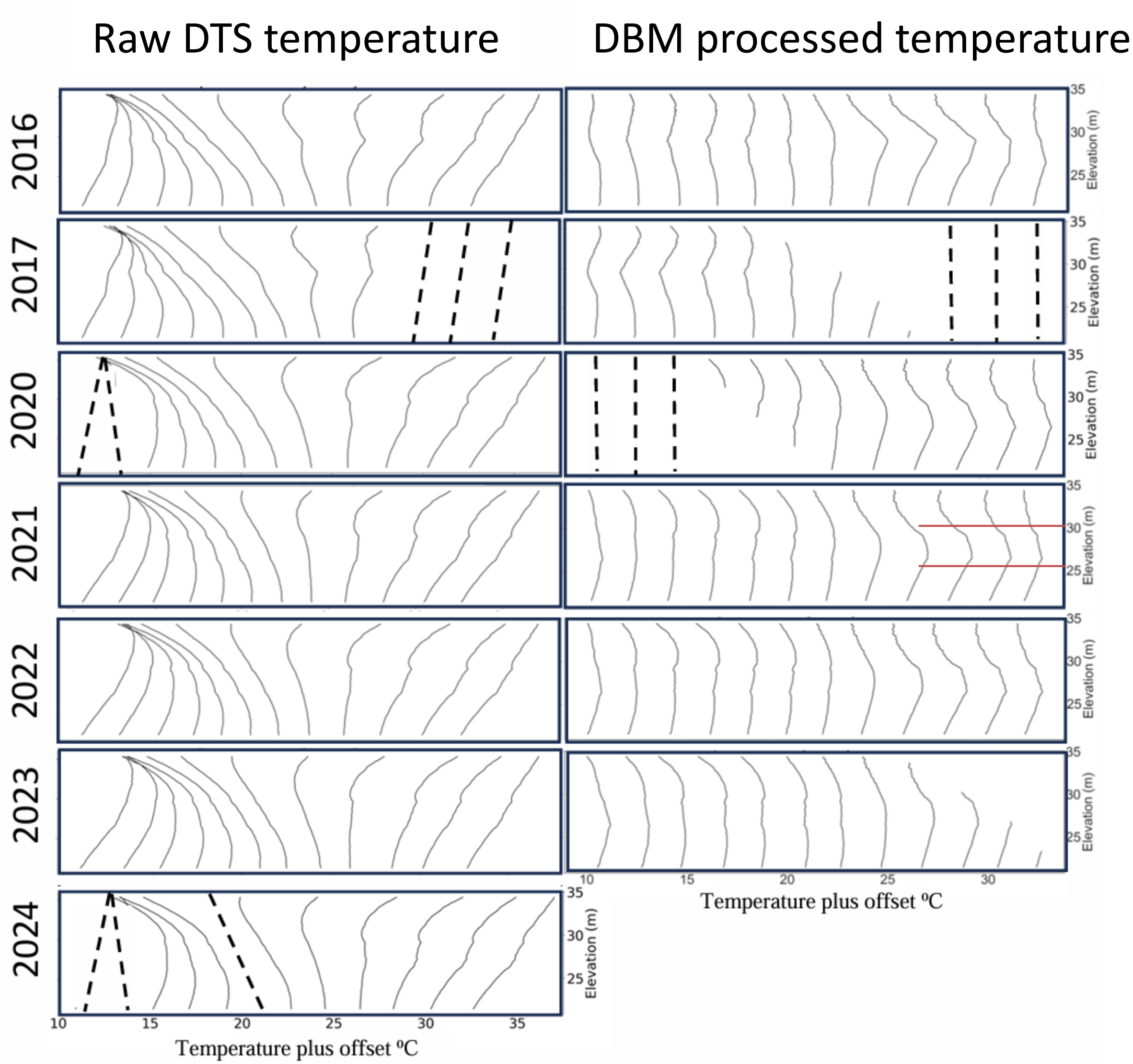

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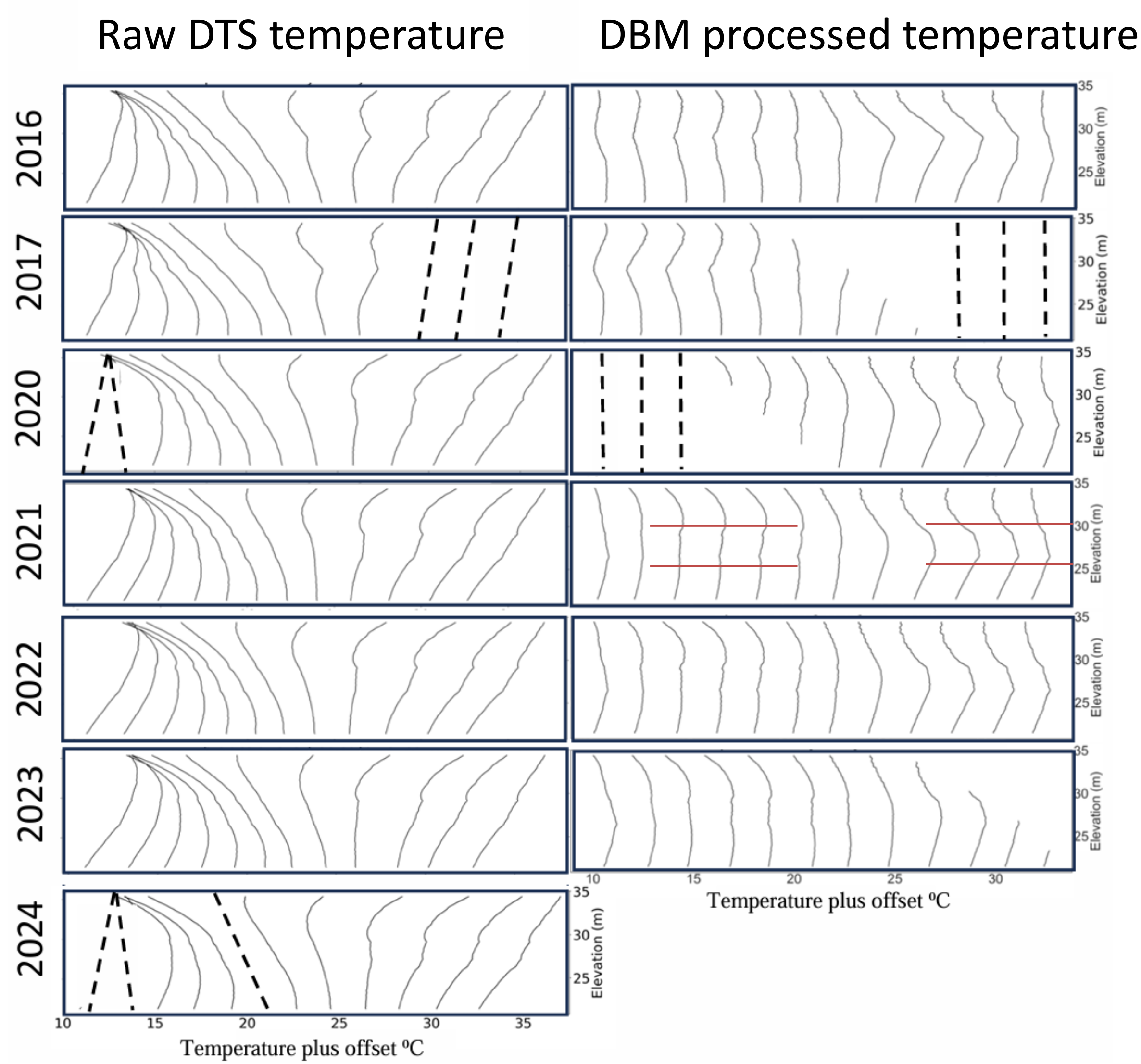

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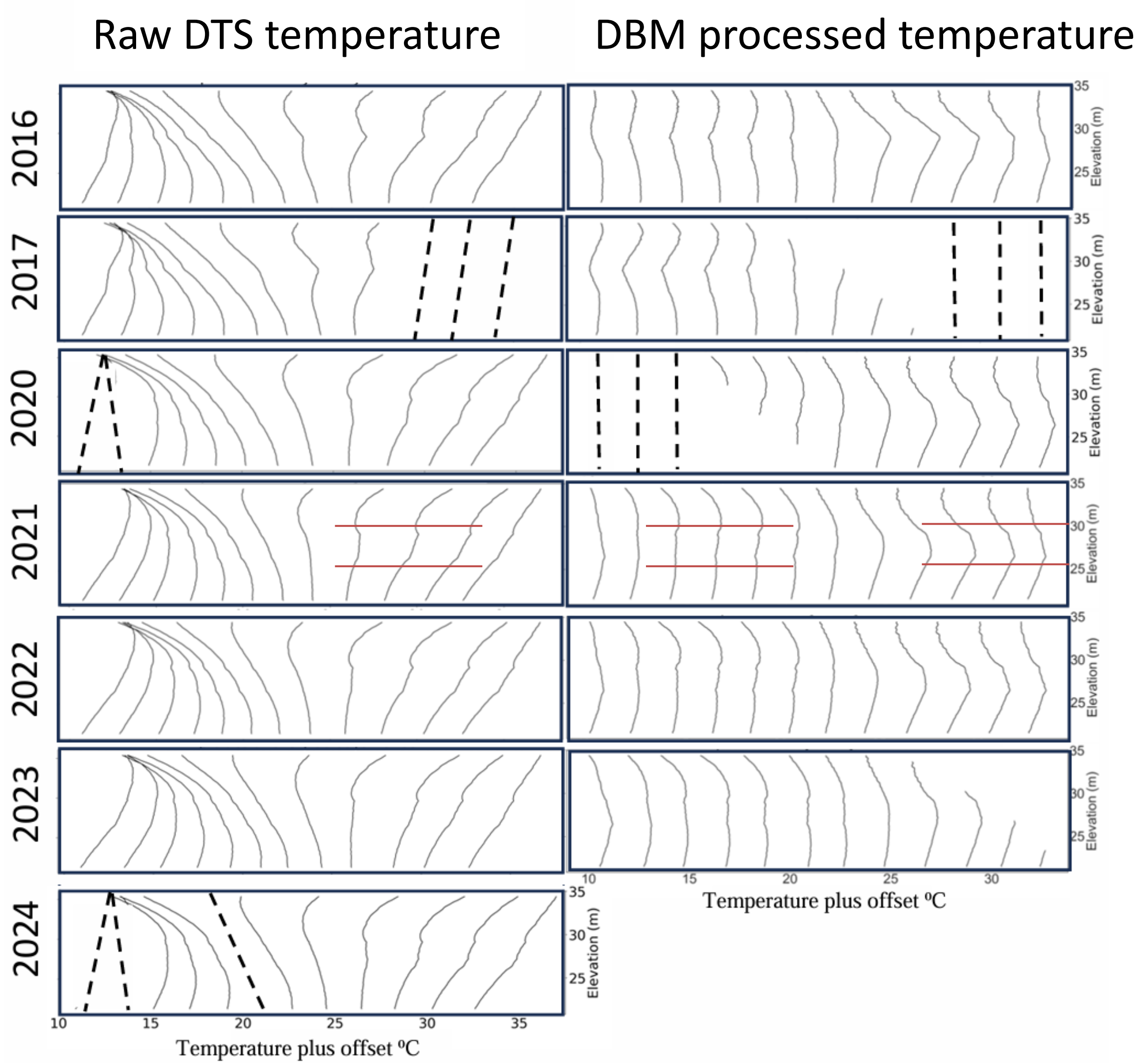

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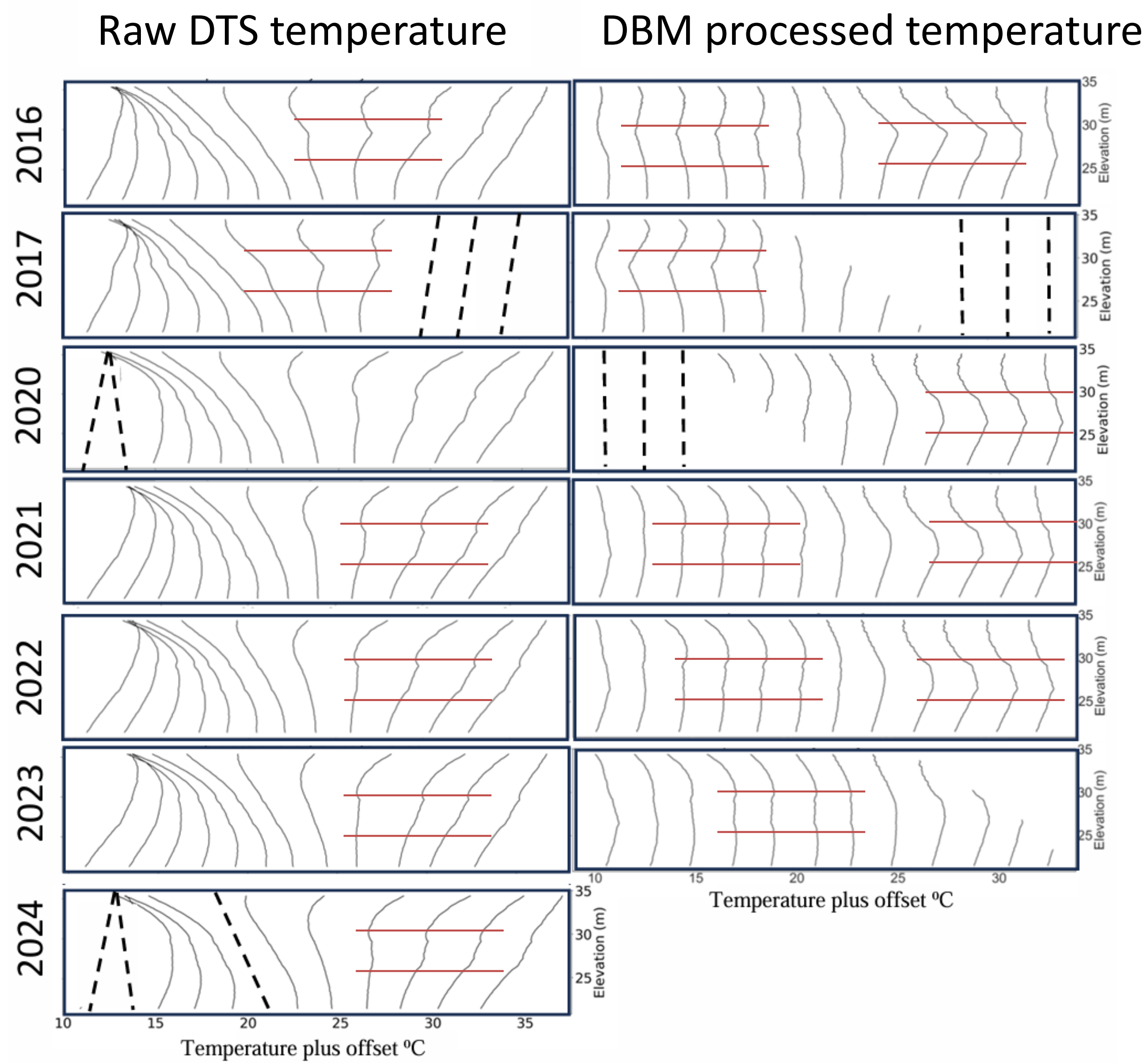
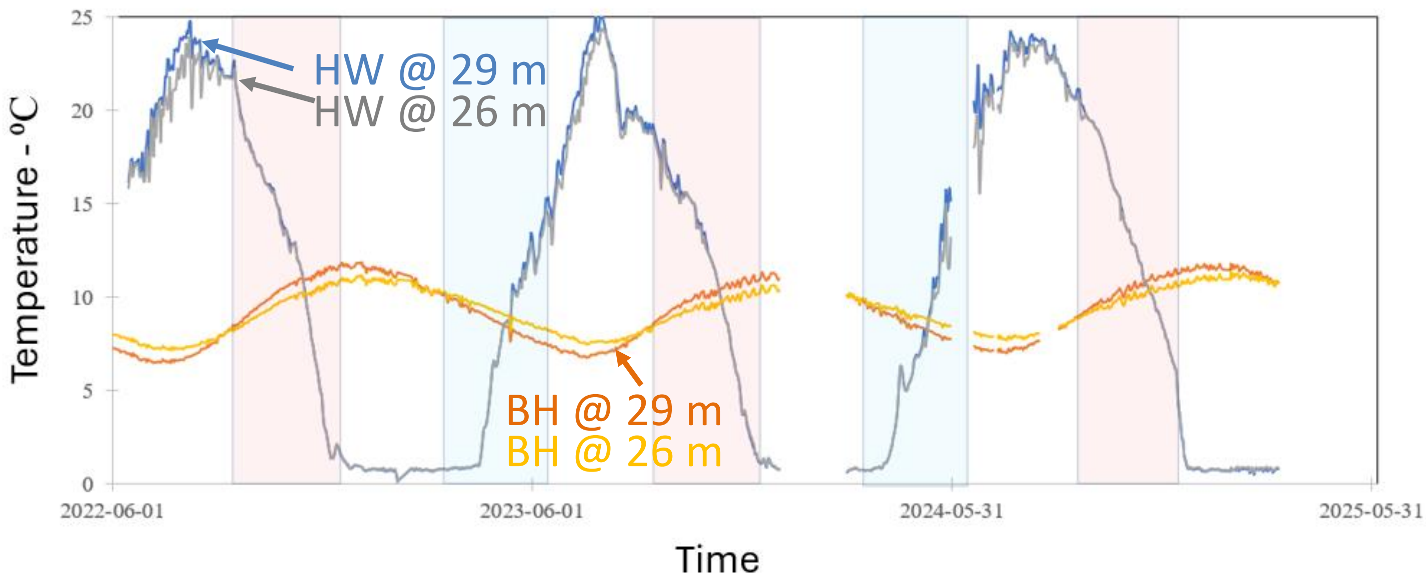


DTS headpond wall & DTS Borehole



Pink: September – December. Anomalously warm at 26 -29 m (13-16 m depth)
Blue: March – June. Anomalously cool at 26 -29 m (13-16 m depth).

It takes a significant time for headpond water temperature to impact borehole temperature. It Implies a relatively slow seepage path

Conclusions

Shallow anomaly

1) Anomaly present since start of monitoring in 2014

2) Only present from November to April

3) Bottom consistently at 35.1 m elevation

4) Top has varied over time as low as 36 m and as high as 39.5 m elevation (temporarily lowered by 2017 grouting, no long term trend evident)

5) Anomaly strength was reduced by 2017 grouting

6) Seemingly stable since 2018, varying with seasonal air temperature (with a lag)

Conclusions

Deep anomaly

<u>Gradient Method</u>

1) Gradient method was able to detect two anomalies at 29.3 m and 26.4 m

<u>DBM Method</u>

1) DBM algorithm removes the surface seasonality component

2) Able to detect the dissipation of heat injection during summer of 2015

3) Anomaly strength at 29.3 m
   - Dominant before grouting
   - Reduced by grouting 2017/2019 (as noted by Yun (2018))

4) Anomaly strength at 26.4 m
   - Very weak before grouting
   - Prominent after grouting 2017/2019

5) Instead of two anomalies a 3 m wide anomaly is identified

Thank you