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SLF WSL-Institut für Schnee- und Lawinenforschung SLF

University of Zurich UZH

On the potential of modeling thermal diffusivity to identify water fluxes in permafrost rock slopes

S. Weber & A. Cicoira

Challenge

- ❯ Permafrost is often the first suspect in rockfalls.
- ❯ Permafrost warming is considered one of the factors leading to periglacial rock slope instabilities.
- ❯ Liquid water creates non-linear feedback close to 0°C.
- ❯ Process understanding hindered by limited field data.

Approach

- ❯ Investigate frozen ground's thermal regime at depth and over time based on PERMOS borehole data.
- ❯ Model thermal diffusivity (statistically & numerically) and investigate the effect of morphology.
- ❯ Identify periods with non-conductive heat fluxes.

Findings

- ❯ Typical values for thermal diffusivity in permafrost rock slopes are in the range of 0.5 to 4.5 mm^2 s^{-1}.
- ❯ Thermal diffusivity depends on morphology and thermal conditions, and shows seasonal variability.
- ❯ Successful identification of days with water fluxes.

Permafrost rock slope failures in a warming climate

Permafrost and the role of water in rock slope failures

- ❯ Nowadays, permafrost is often quickly suspected of triggering slope failures
- ❯ Speculation about the role of water in permafrost
  - … affecting hydraulic properties, e.g. permeability
  - … advective heat transfer through percolating water
  - … increased water pressure due to local damming effects

} ❯ ***very limited field data***

Piz Cengalo, 23 August 2017 (9:30 am)

- ❯ 3.15 Mio m^3 permafrost rock slope collapse
- ❯ Visual evidence of the presence of ice in the failure plane
- ❯ Unfortunately, no *in-situ* data available

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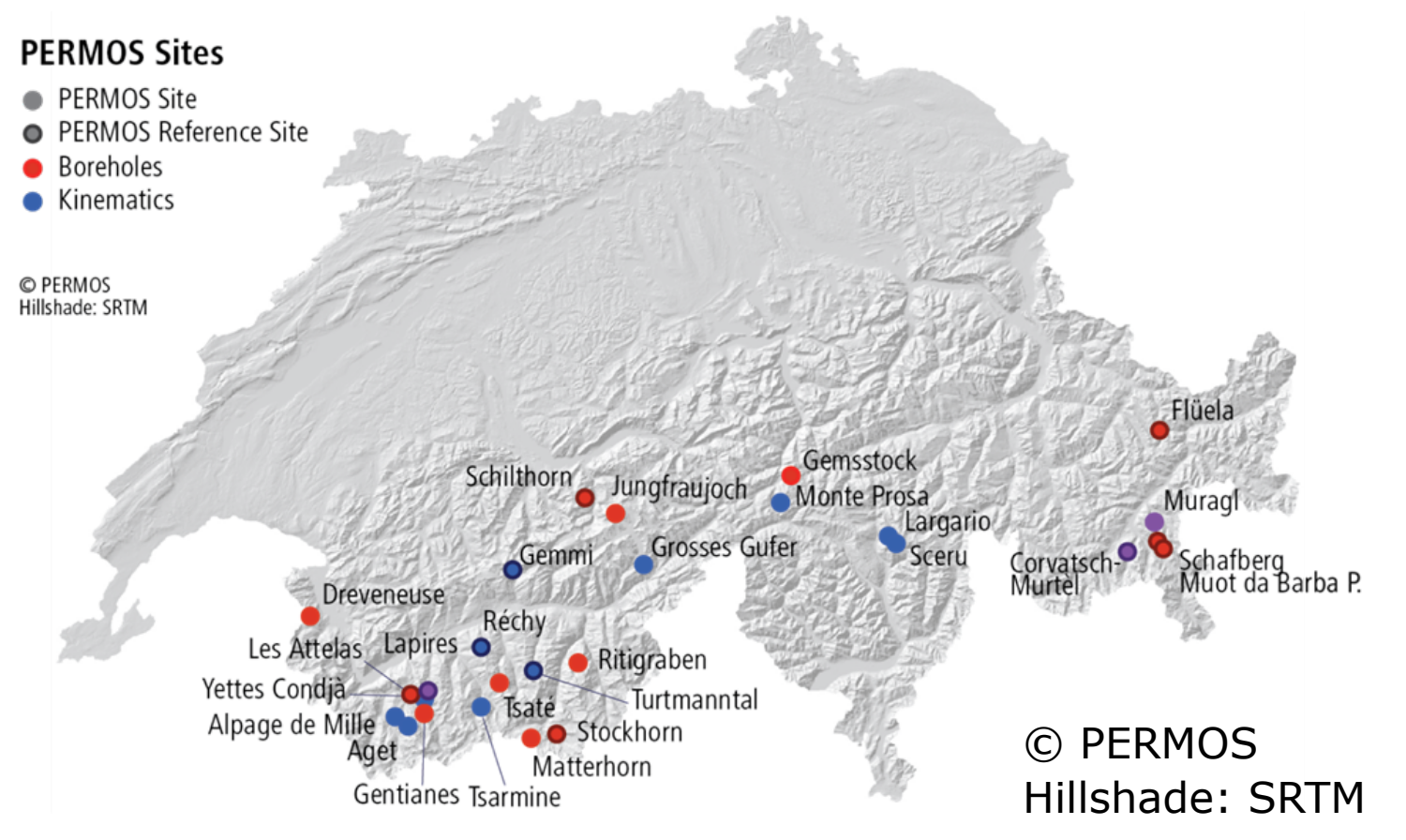
Borehole temperature data

Swiss Permafrost Monitoring Network PERMOS

Permafrost temperatures are measured

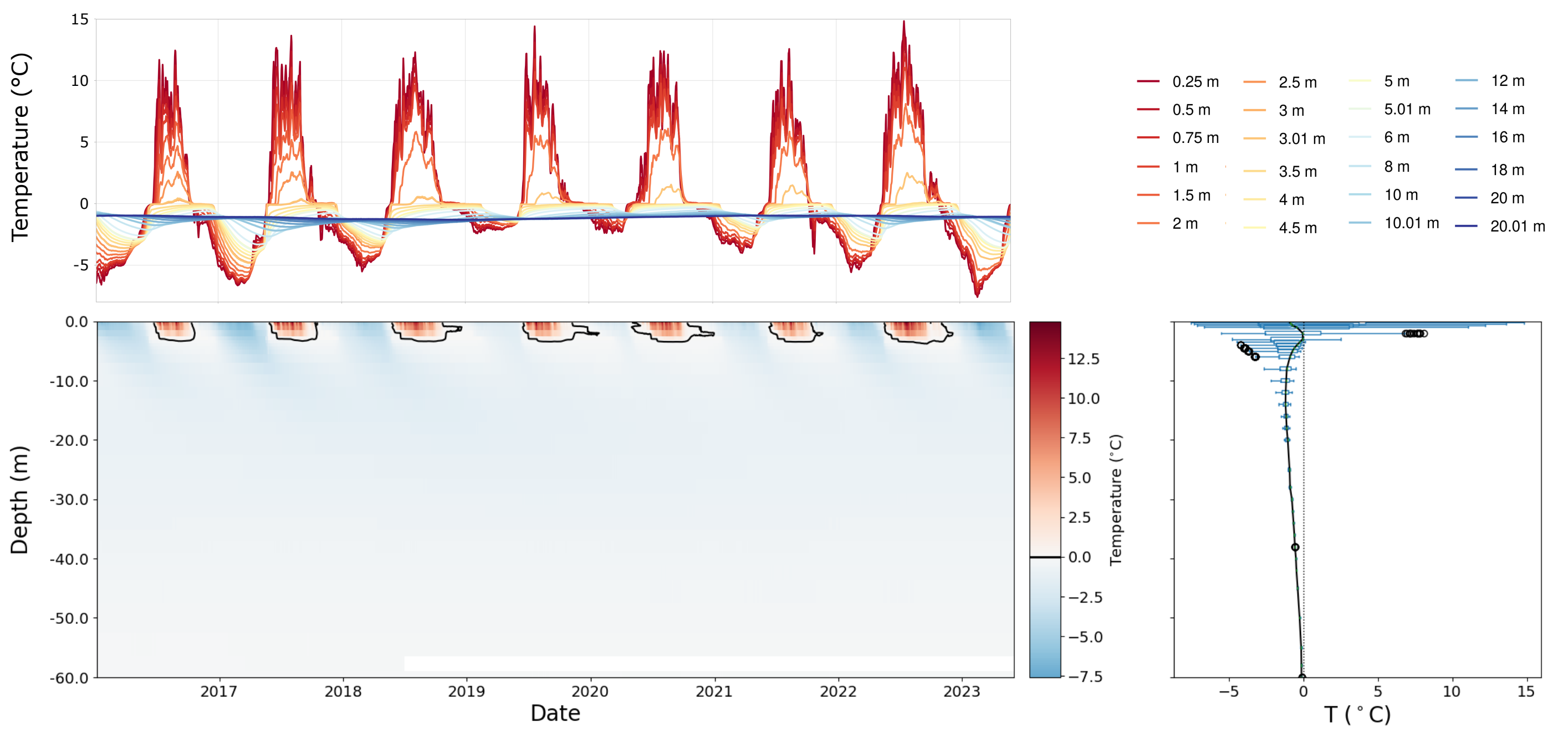
- ❯ in 29 boreholes of 14–100 m depth at 15 sites
- ❯ with three morphologies: bedrock, talus slope and rock glacier

PERMOS



© PERMOS
Hillshade: SRTM

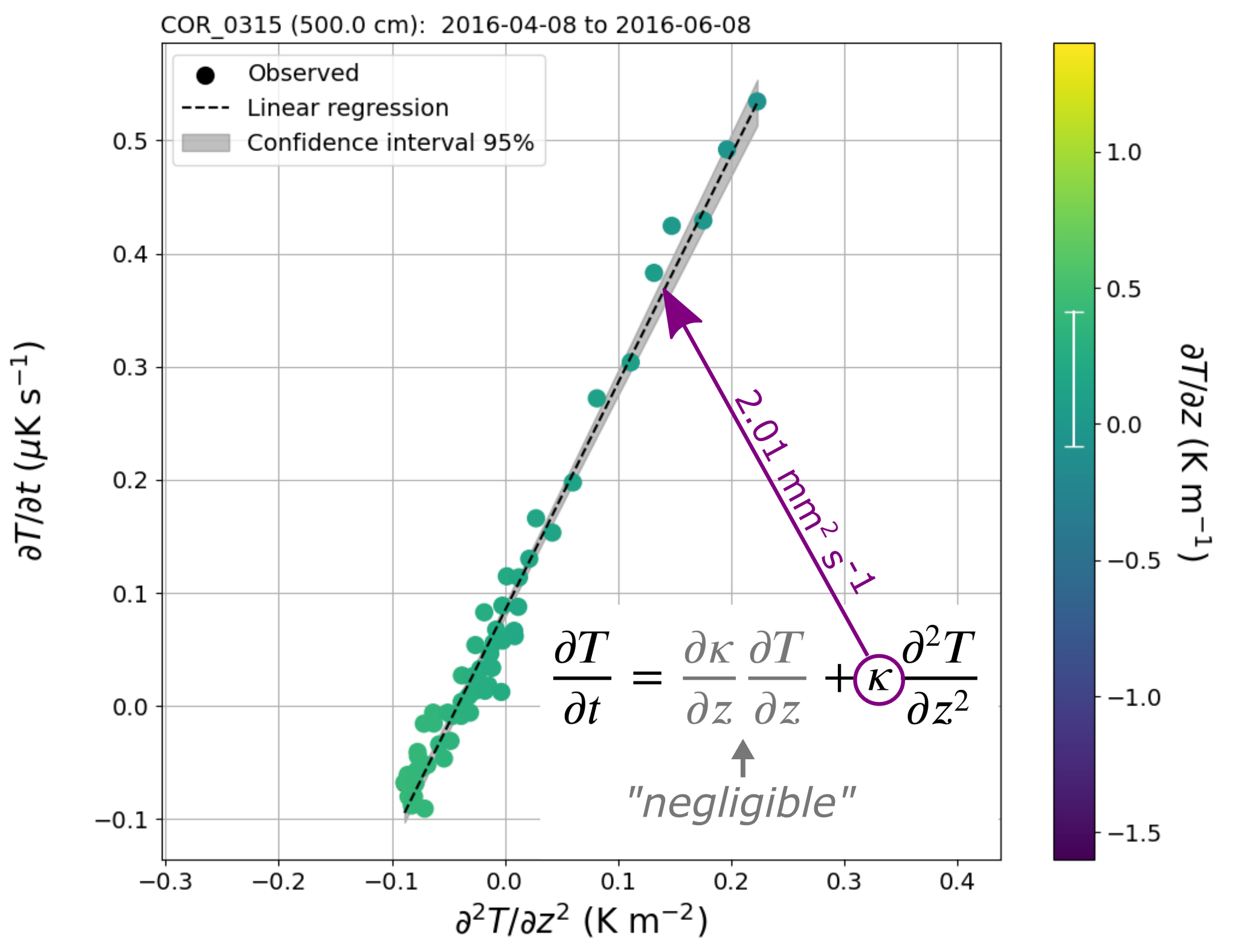
Murtèl-Corvatsch borehole: drilled in 2015, 60 m deep



Invert and validate thermal diffusivity through joint statistical and numerical modeling using three consecutive thermistors

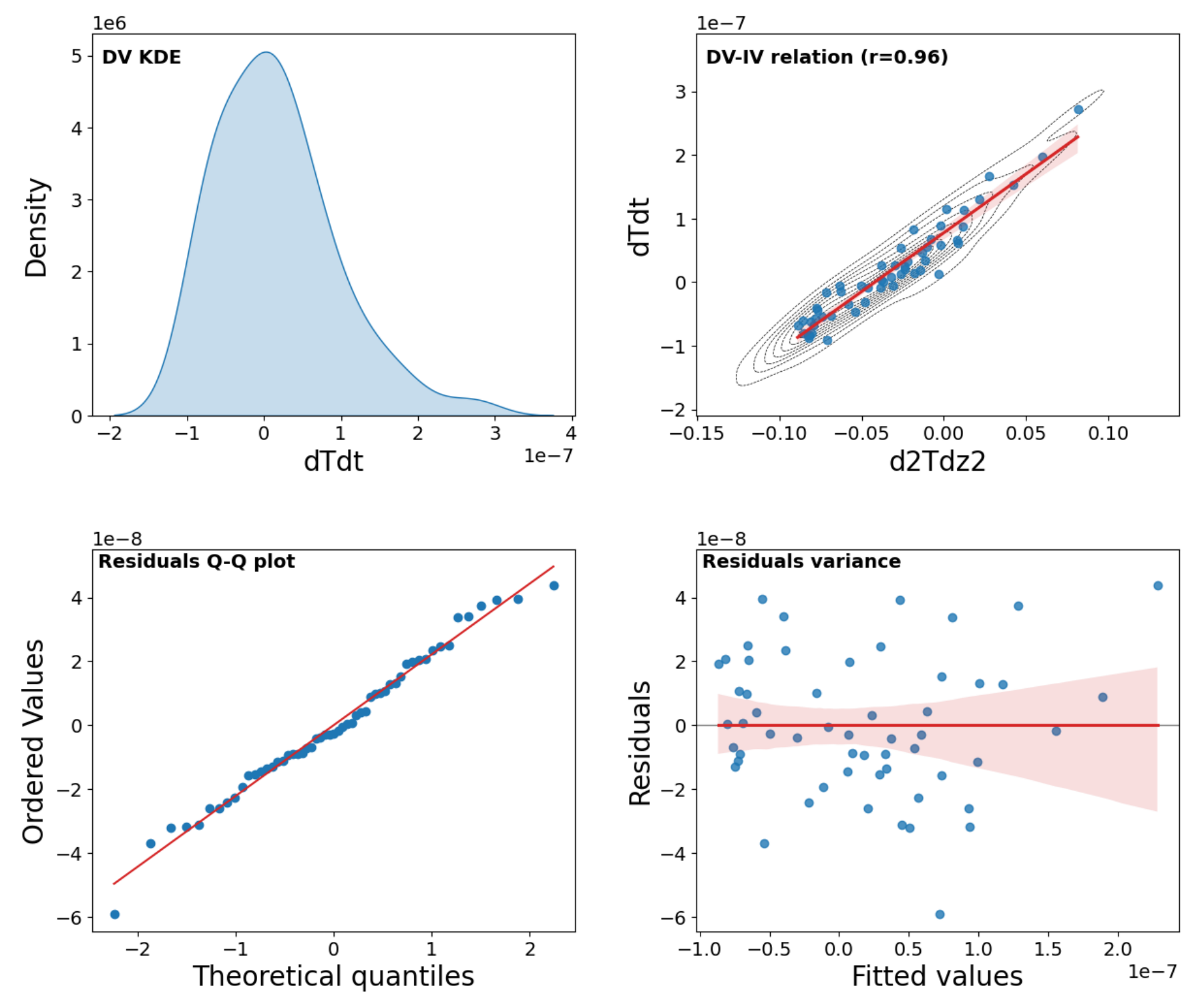
Statistical modeling

- ❯ Single linear regression model (LRM) on dT/dt vs d2T/dz2
- ❯ Sliding 2-month time window with daily iteration



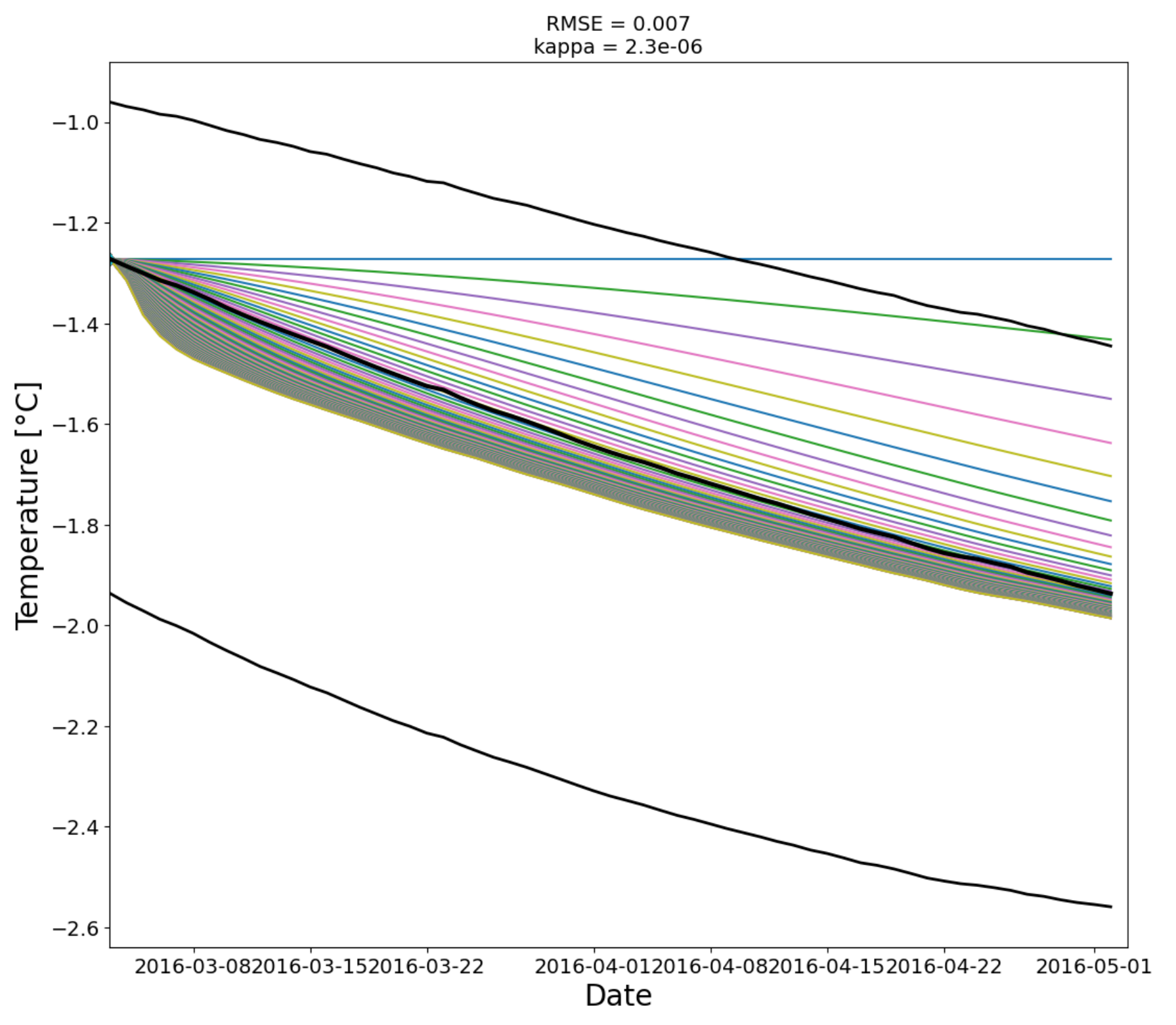
$$\frac{\partial T}{\partial t} = \underbrace{\frac{\partial \kappa}{\partial z}\frac{\partial T}{\partial z}}_{\text{"negligible"}} + \kappa \frac{\partial^2 T}{\partial z^2}$$

- ❯ Proof the LRM assumption
- ❯ Select the valid time windows



Numerical modeling

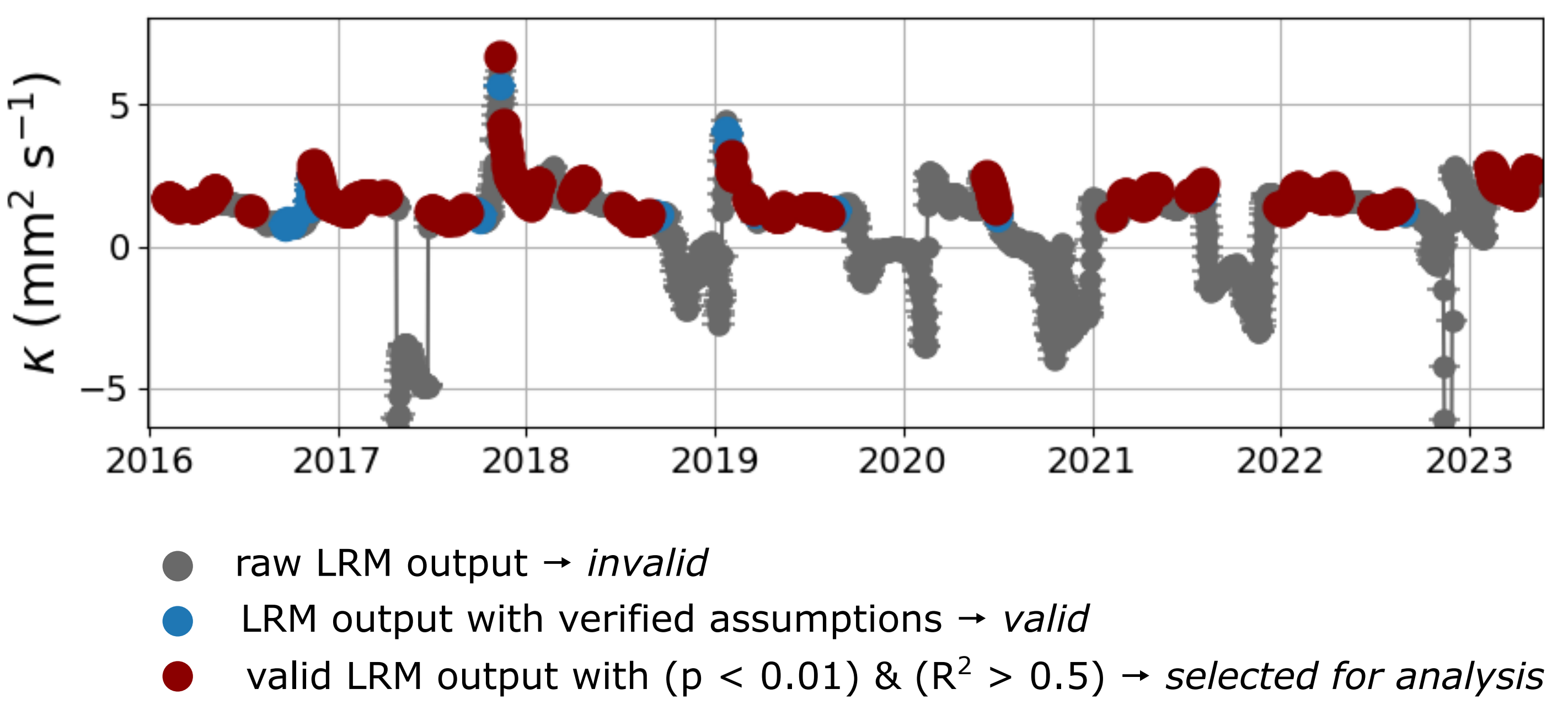
- ❯ Finite difference method for 1D heat conduction
- ❯ Minimize RMSE to optimize thermal diffusivity



Temporal evolution of thermal diffusivity

Murtèl-Corvatsch borehole

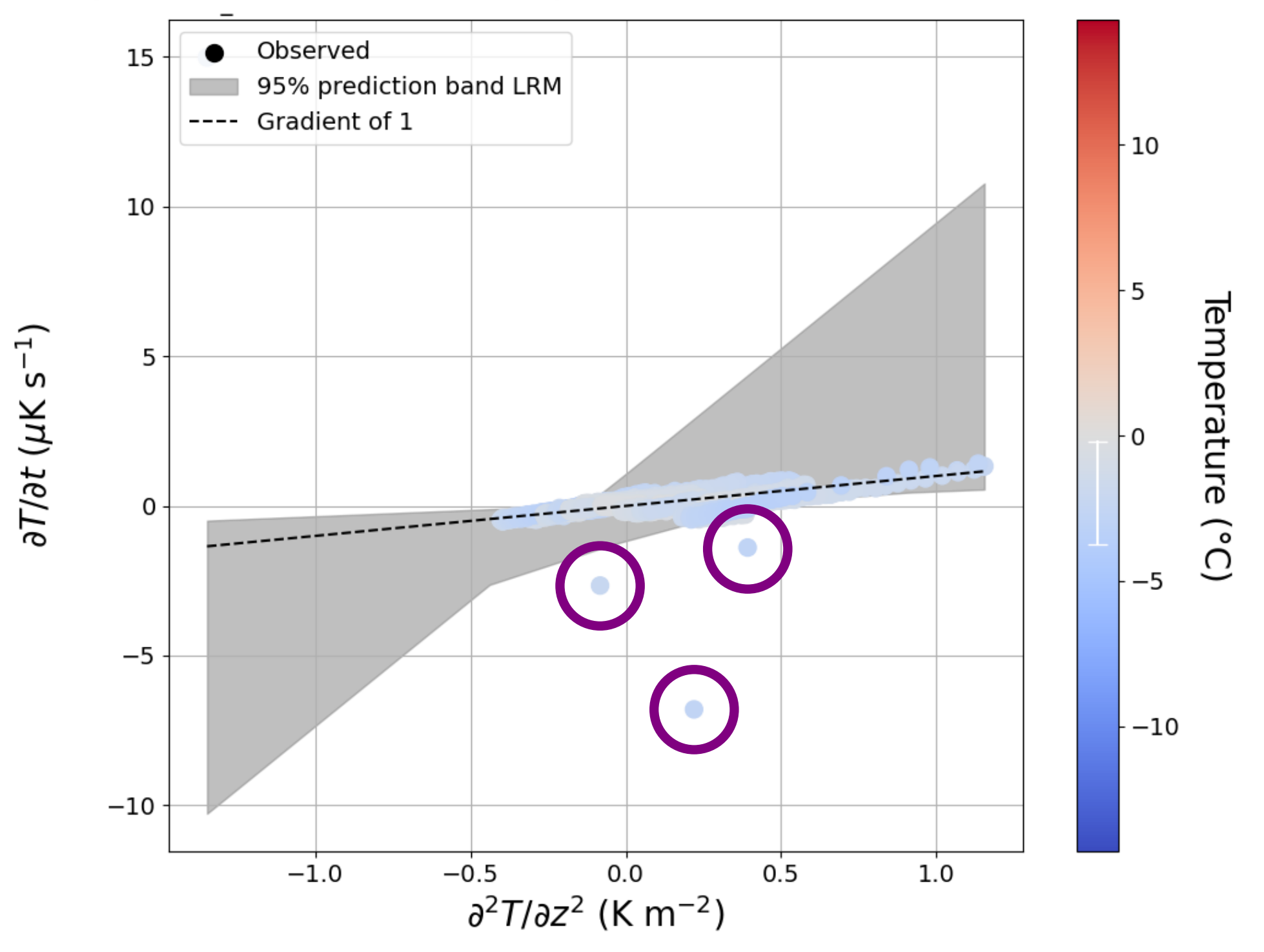
- ❯ Thermal diffusivity estimated with LRM approach
- ❯ Seasonal variations of thermal diffusivity at 5m depth



- ● raw LRM output → *invalid*
- ● LRM output with verified assumptions → *valid*
- ● valid LRM output with ($p < 0.01$) & ($R^2 > 0.5$) → *selected for analysis*

Identify periods with non-conductive heat flux

❯ *Non-conductive heat flux* can be isolated, when the LRM prediction can not explain the observations.

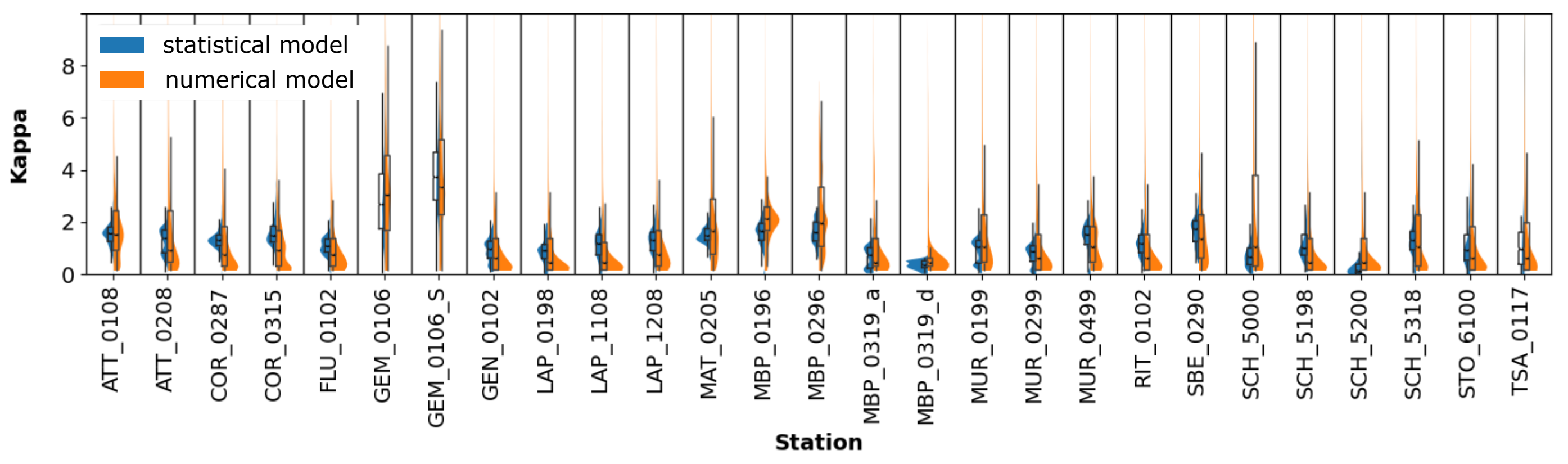


Thermal diffusivity at different sites and with various landforms

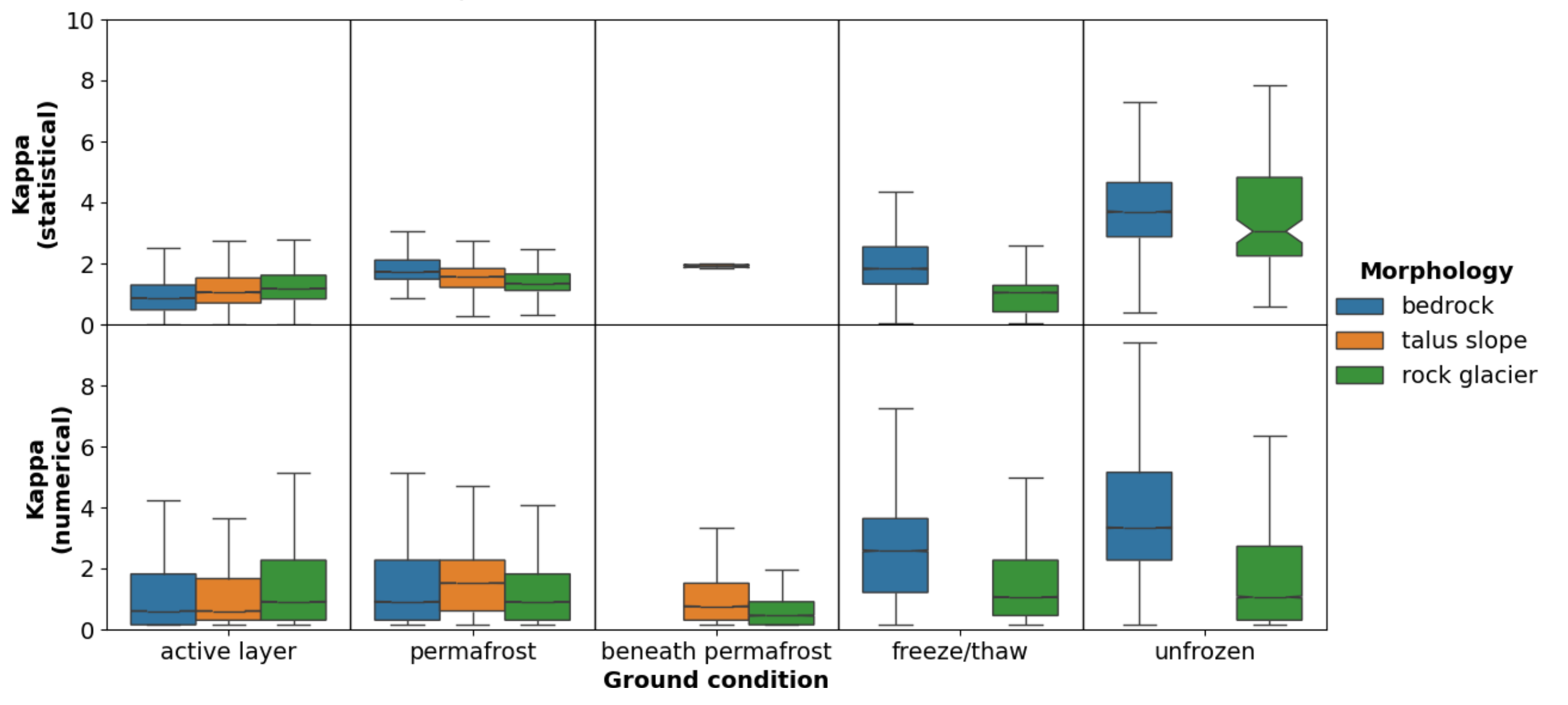
Combination of all PERMOS borehole temperature timeseries

- ❯ Morphology classification according PERMOS documentation
- ❯ Ground condition classification according site/depth specific thermal conditions

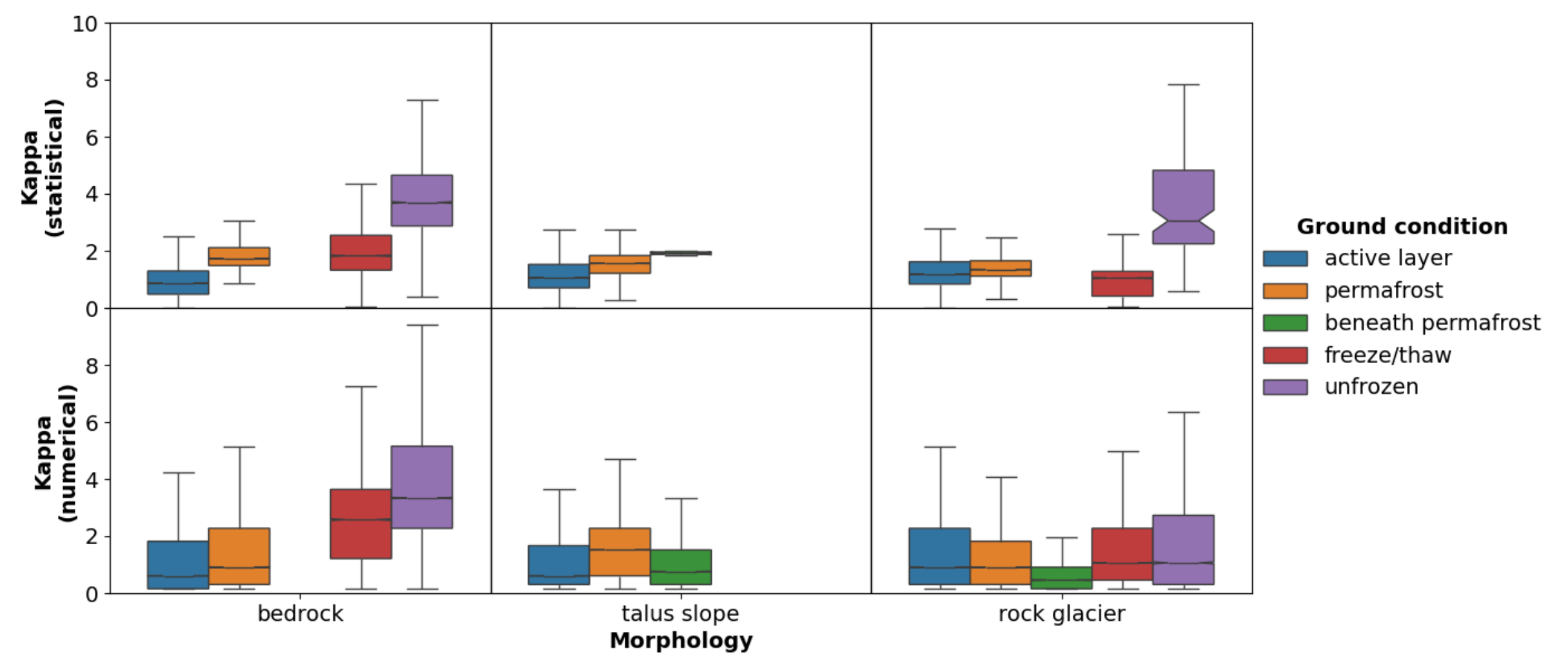
❯ Thermal diffusivity for each station illustrated with violin and box plots



❯ Thermal diffusivity grouped by thermal conditions and classified by morphology



❯ Thermal diffusivity grouped by morphology and classified by thermal conditions



Reference
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Contact
Samuel Weber - @Rock_n_Ice
samuel.weber@slf.ch *or* http://www.samuelweber.ch
WSL Institute for Snow and Avalanche Research SLF