GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

RWTH AACHEN UNIVERSITY

Using thermal springs to quantify deep fluid flow and its thermal footprint in the Alps

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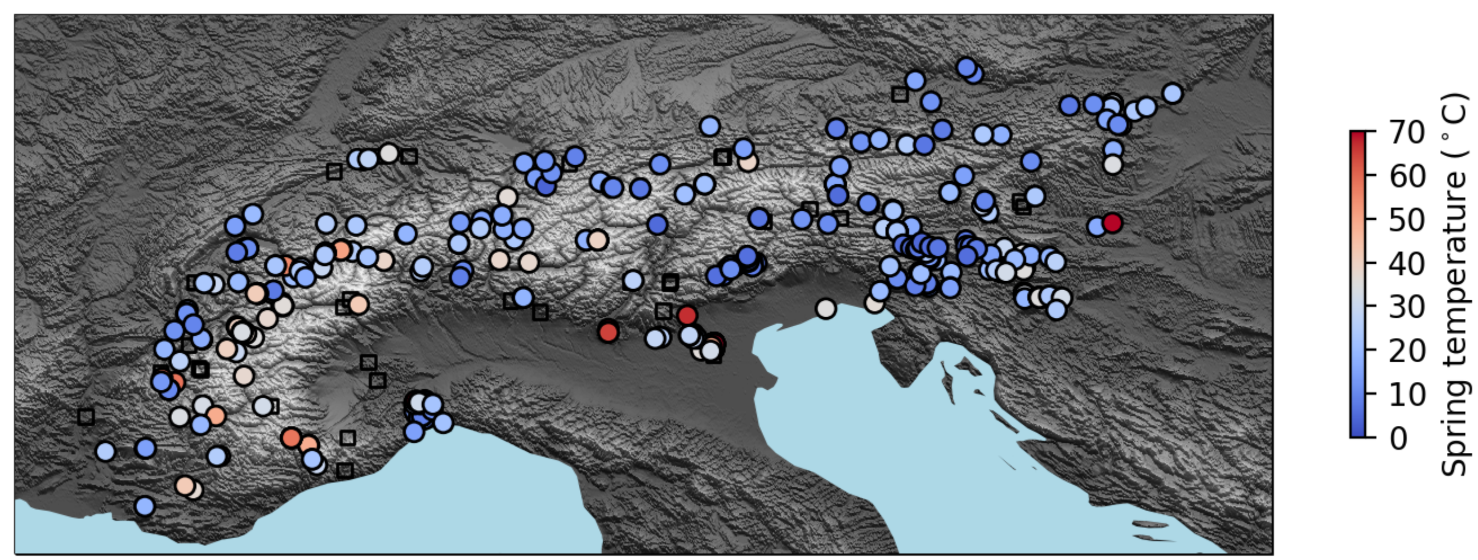

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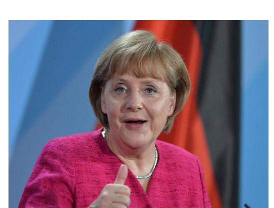


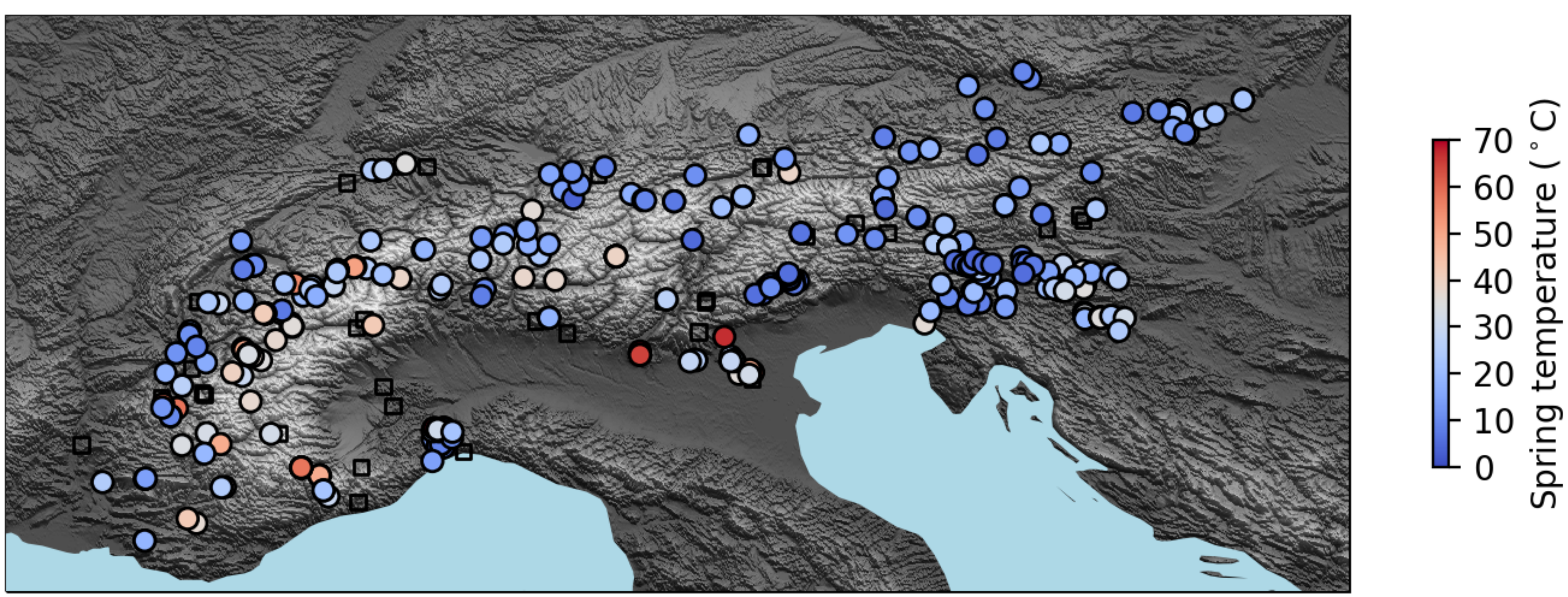
Mountain Building Processes in 4D

Introduction

- Deep fluid flow can affect subsurface temperatures in orogens, may play a role in fault activity, and plays a role in the formation of ore deposits
- However, the extent of deep fluid in orogens is largely unknown
- Thermal springs are the most obvious outcrop of deep fluid flow and may offer a window into deep fluid flow in orogens
- Can we use data from thermal springs to quantify deep fluid flow and its thermal effects in the Alps?

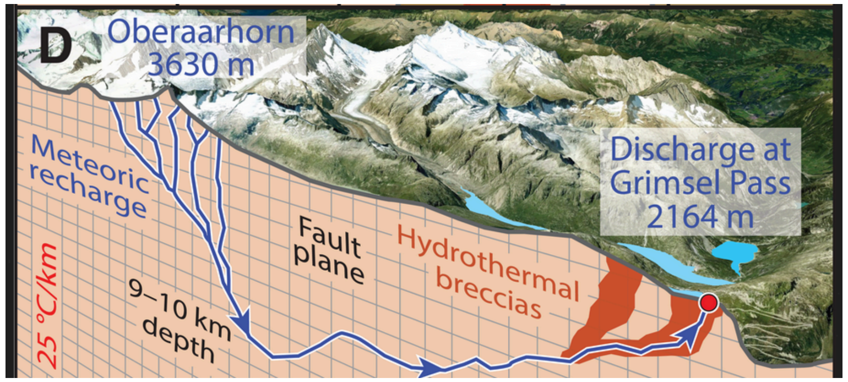
New database of thermal springs in the Alps

- Compilation of data on thermal springs from published literature, geological survey data, existing national databases (thanks Switzerland / Sonney & Vuataz 2008)
- Results: 448 springs, 211 with temperature & discharge data, ~150 with fluid chemistry and/or isotope data
- Data publication and online repository planned in summer 2019

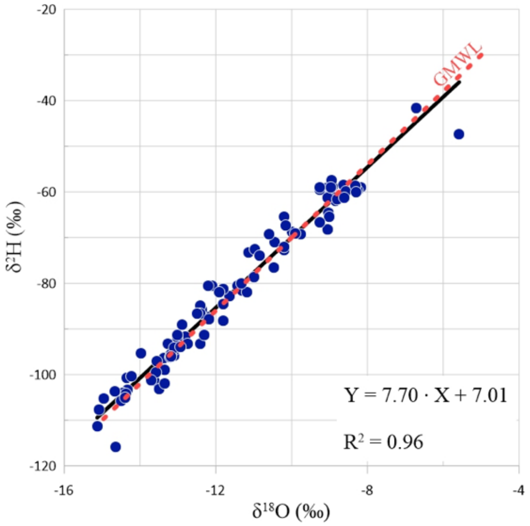


Quantifying heat flux of thermal springs in the Alps

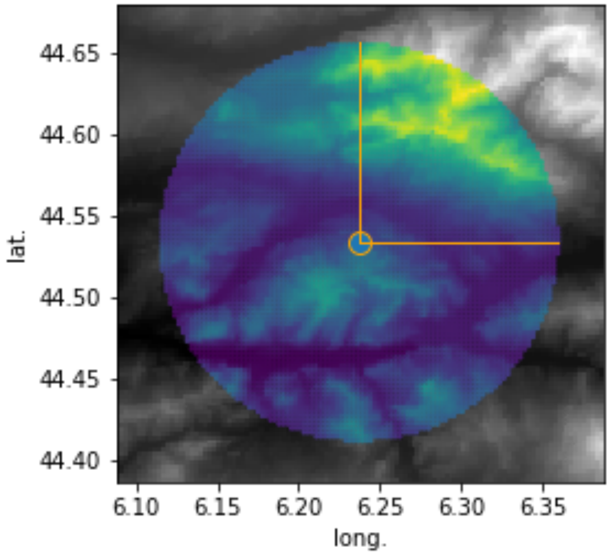
- First estimate of the heat flux of thermal springs based on the difference between recharge and discharge temperature (ie, the heat gained or lost along the entire flow path up to the spring):
  - $HF = \rho\ c\ (T_{disch} - T_{rch})\ Q$
- Temperature and discharge known for 211 of 448 springs
- Spring plot along the meteoric water line
- Area contributing recharge to each spring calculated using existing recharge estimates (de Graaf et al. 2015) and spring discharge data
- Recharge temperature somewhere between avg. temperature at elevation of the spring and max. elevation in the contributing area



Conceptual model of a meteorically driven hot spring system in the Alps
Diamond et al. (2018) Geology

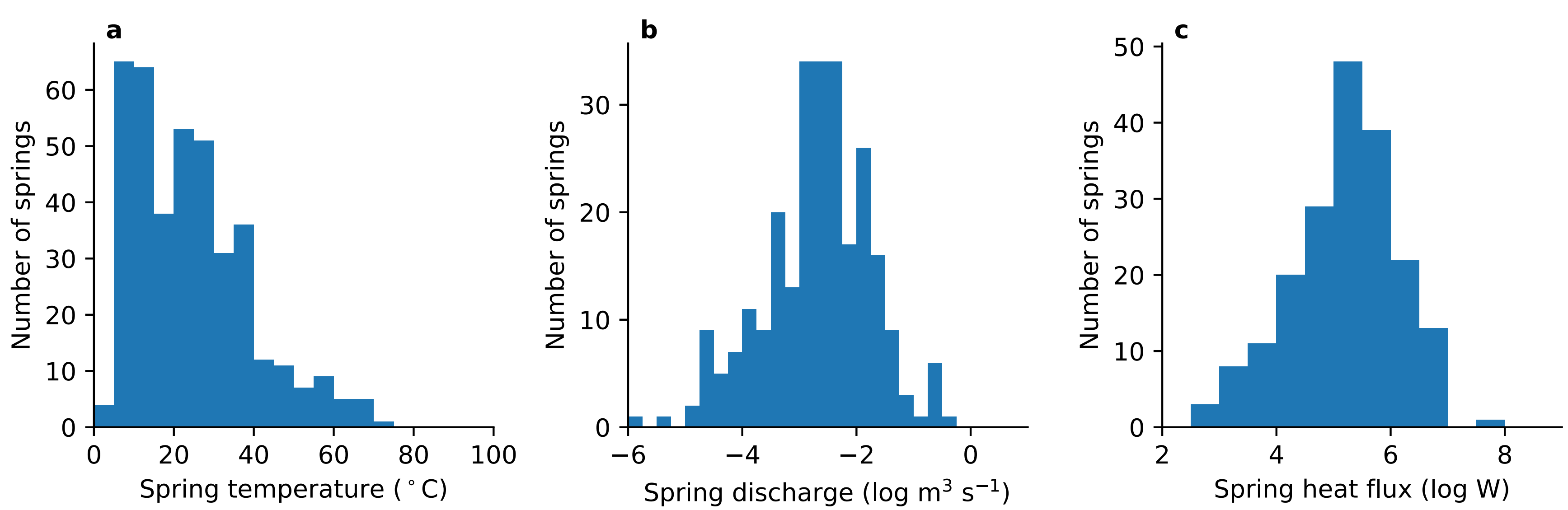


Stable isotopes of spring discharge plot along the meteoric water line.
MSc. thesis Theis Winter



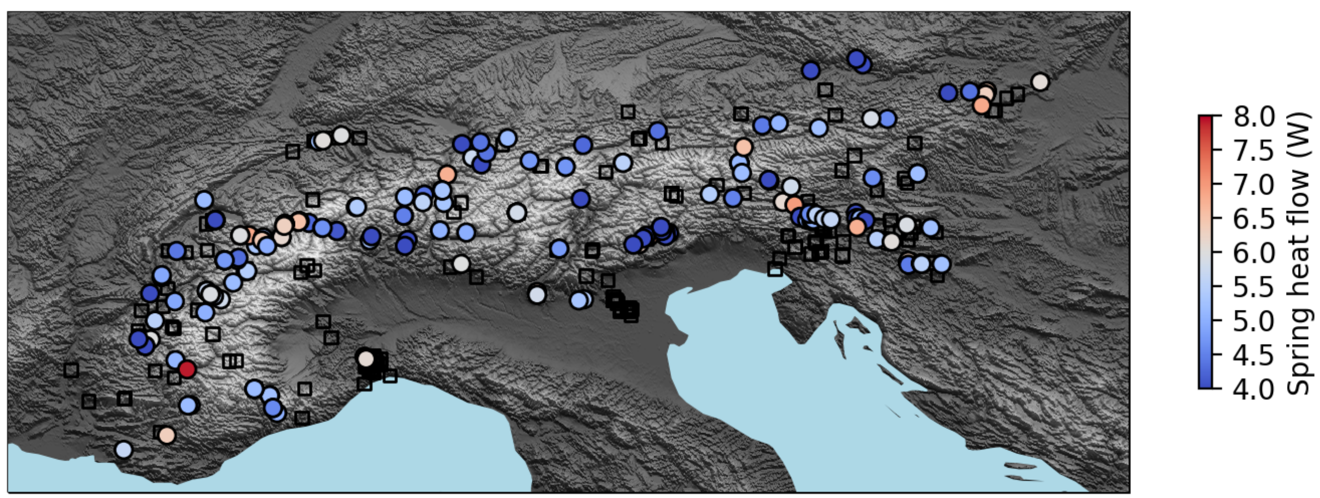
Quantifying heat flux of thermal springs

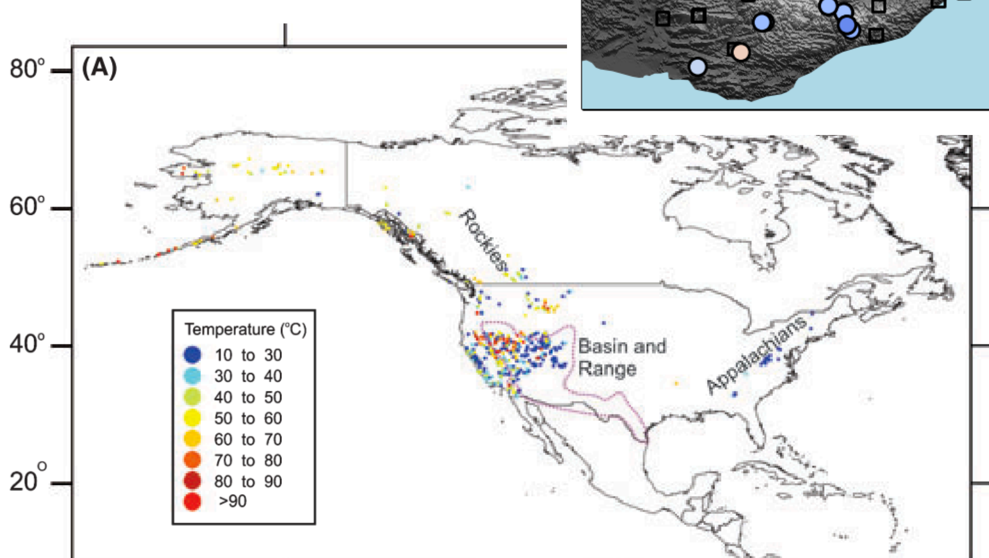
- Results: Heat flux of all springs with temperature and discharge data in the Alps = 160 to 230 MW
- Which is 1-2% of the total heat flow of the Alps of 14000 MW
- This may be an underestimate for the total heat flux by deep fluid flow because
  - Only 211 of the total of 448 springs have temperature and discharge data
  - Not all deep fluid flow discharged in springs, diffuse discharge may be more common
  - Mixing of shallow topography-driven flow may affect spring temperature and heat flow



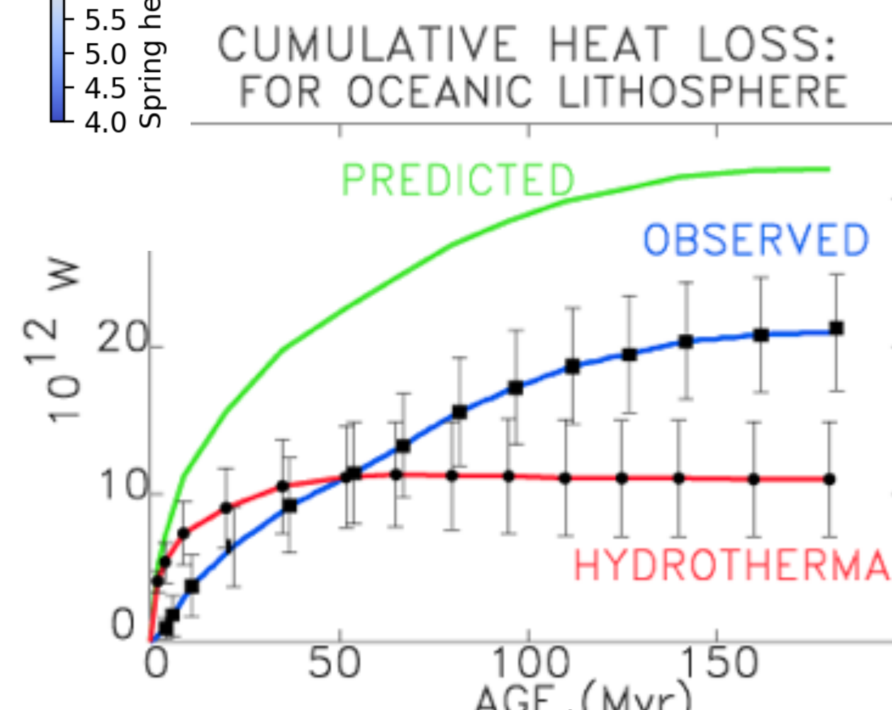
Quantifying heat flux of thermal springs

- Comparison with the relatively few settings where there is data on the heat flux of thermal springs:
  - Similar calculation for the Basin and Range Province: contribution of thermal springs = 2% of total heat flow (data from Ferguson and Grasby 2011)
  - Hydrothermal circulation in young ocean crust: 30% of total heat flow



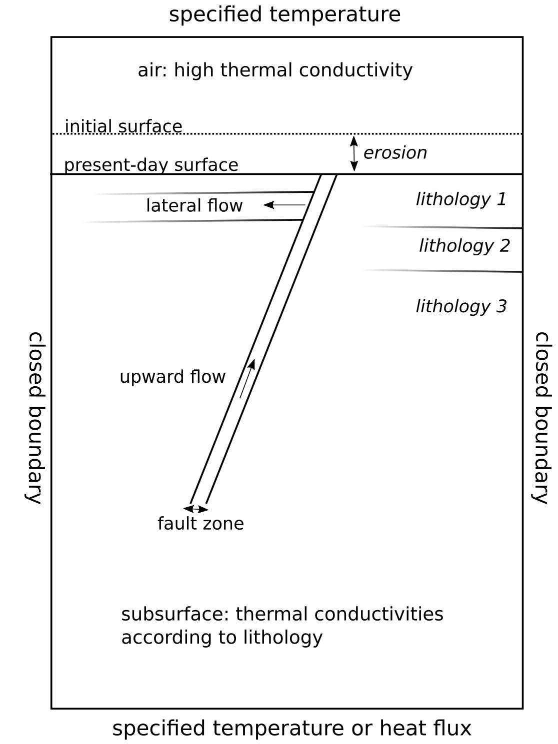


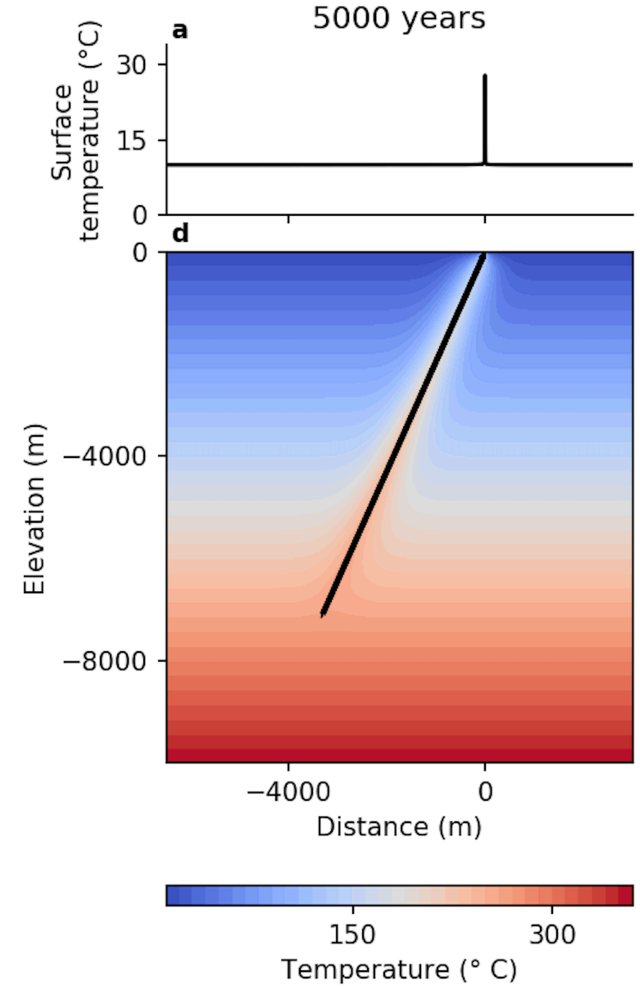
Thermal springs in North America (Ferguson & Grasby 2009)



Estimated contribution hydrothermal heat flux ocean crust. Stein & Stein, 1994, JGR

Modelling heat flow around thermal springs





- Model sensitivity analysis & comparison with spring temperatures, discharge to quantify depth of flowpaths and thermal footprint at depth

- New model code Beo: Numerical model of advective and conductive heat flow around hydrothermal systems.

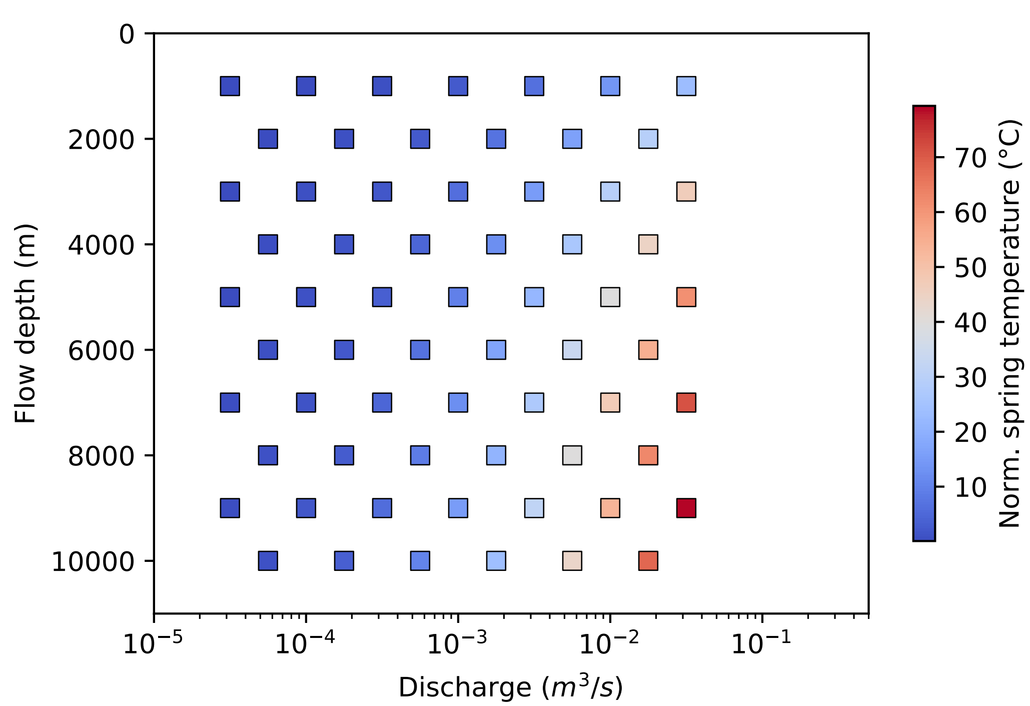
  - GitHub: https://github.com/ElcoLuijendijk/beo

  - Publication in Geosc. Model Develop. Discussions (https://www.geosci-model-dev-discuss.net/gmd-2018-341) -> Feel free to add comments online

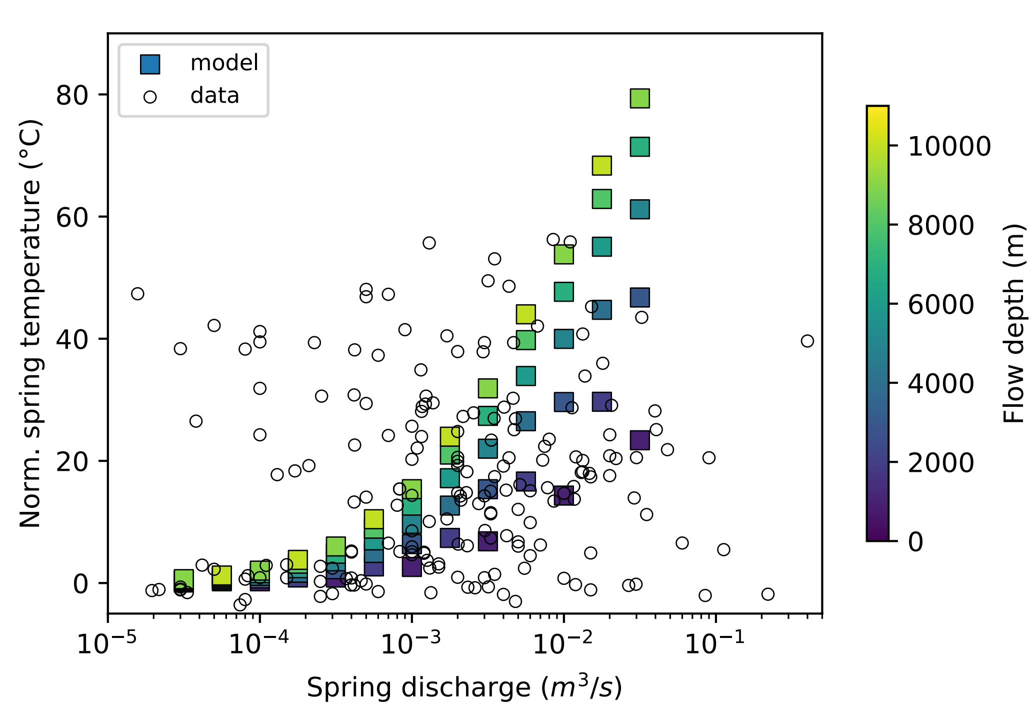
- Incorporates latent and sensible heat flux at the land surface to simulate realistic surface heat flow & spring temperatures

Modelling heat flow around thermal springs

- First order control on spring temperature: the depth & temperatures at which upward flow originates and the discharge rate
- Comparison with spring discharge & temperature data may allows first order estimate of flow depth for thermal springs



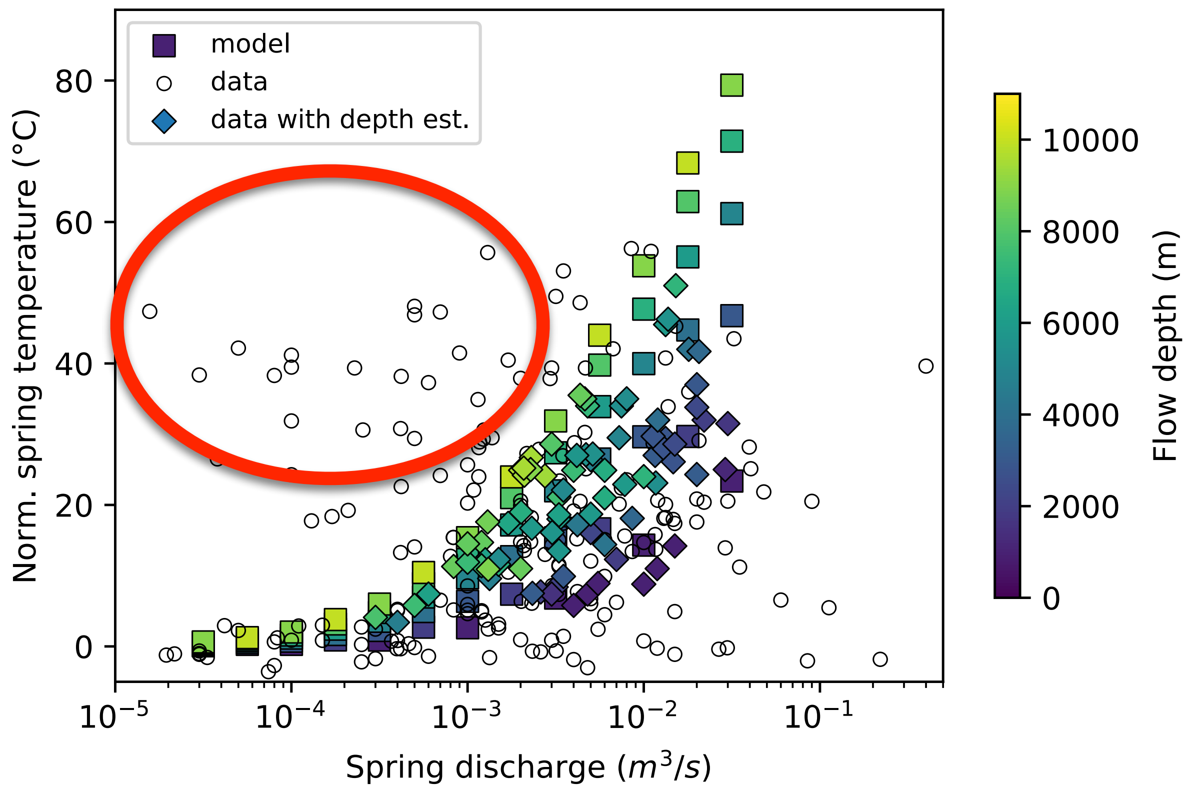
Modelled spring temperatures as a function of discharge & flow depth after 10000 years (ie ~ since last glacial)



Comparison of modelled and observed spring temperatures

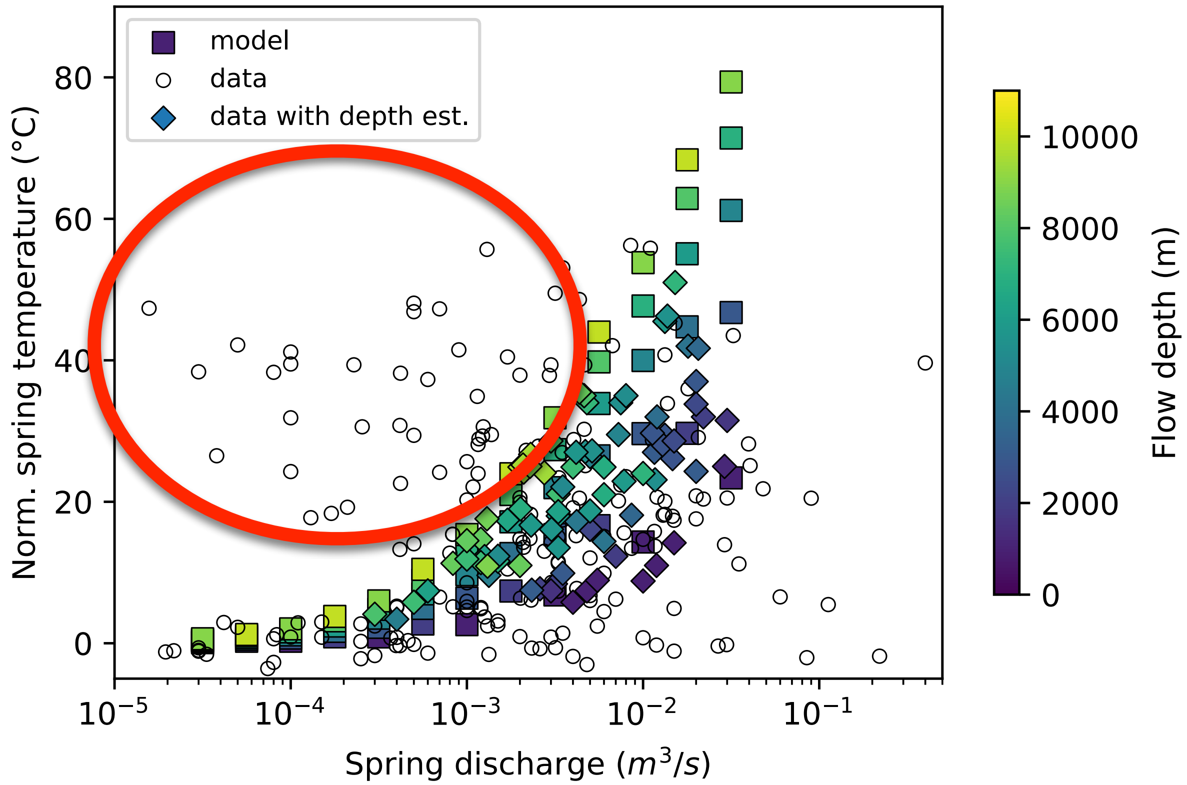
Modelling heat flow around thermal springs

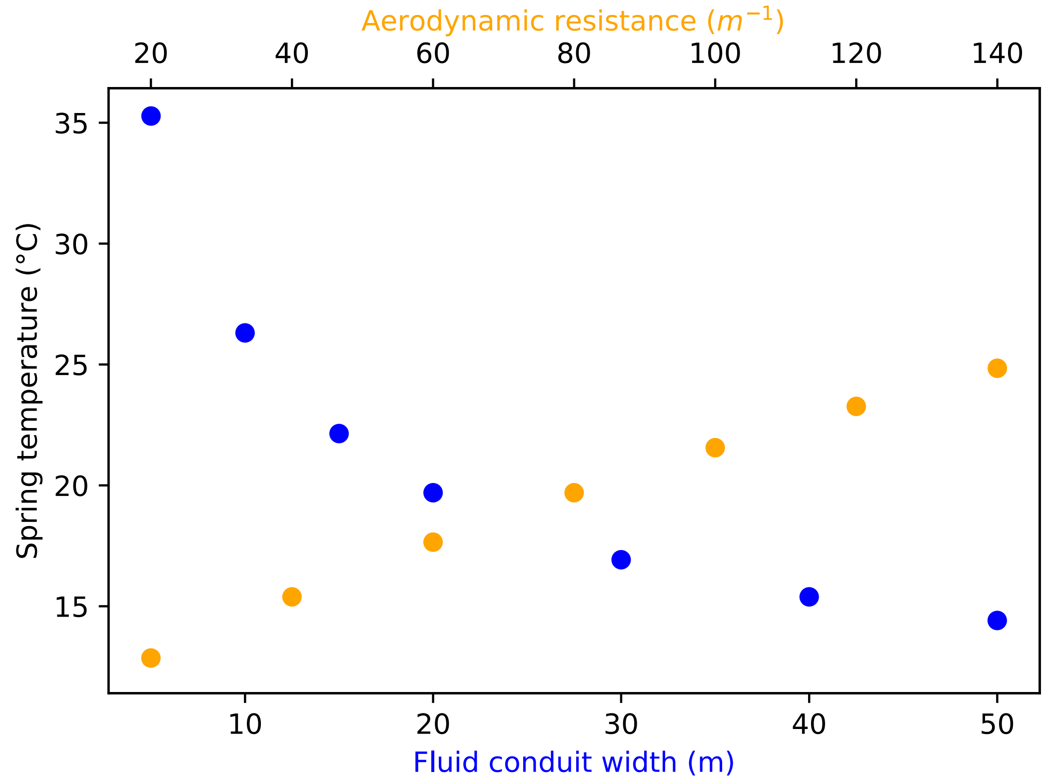
- First order control on spring temperature: At what depth does upward flow originate, and what is the discharge rate?
- Comparison with spring discharge & temperature data allows first order estimate of flow depth for thermal springs
- Difficult to model low-discharge and high temperature springs



Estimating flow depth

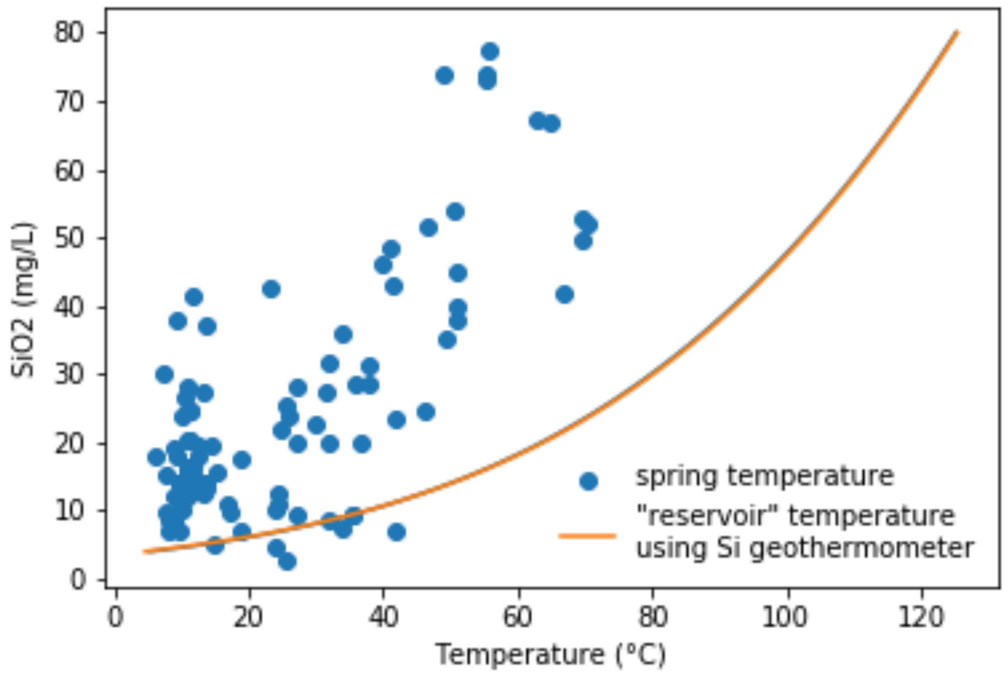
- Potential explanation for low-discharge high temperature springs:
    - fluid conduits often much narrower than the 10 m radius assumed in our first model experiments
    - surface heat flux may be overestimated, is dependent on relatively uncertain parameters such as aerodynamic resistance

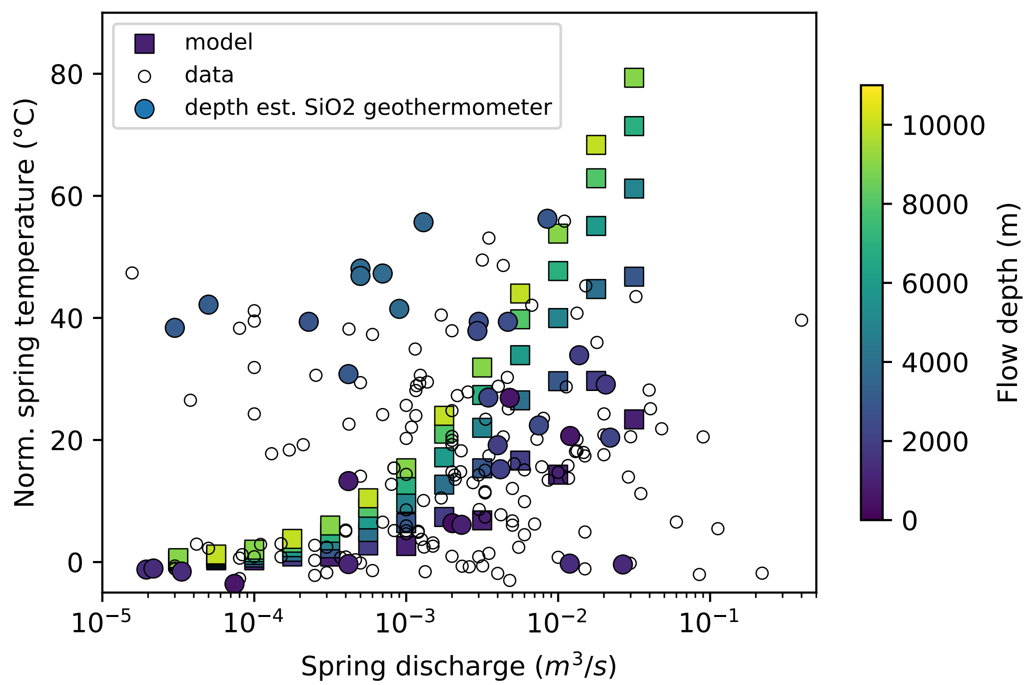




Estimating flow depth

- Solutions for estimating flow depth and resolving the dependence on fluid conduit size:
    - comparison with depth/temperature estimates from the Si geothermometer
    - first order estimates of minimum conduit size based on permeability and max. estimated hydraulic potential -> what is the maximum 1D flux that can be generated? How does that compare the the measured discharge?

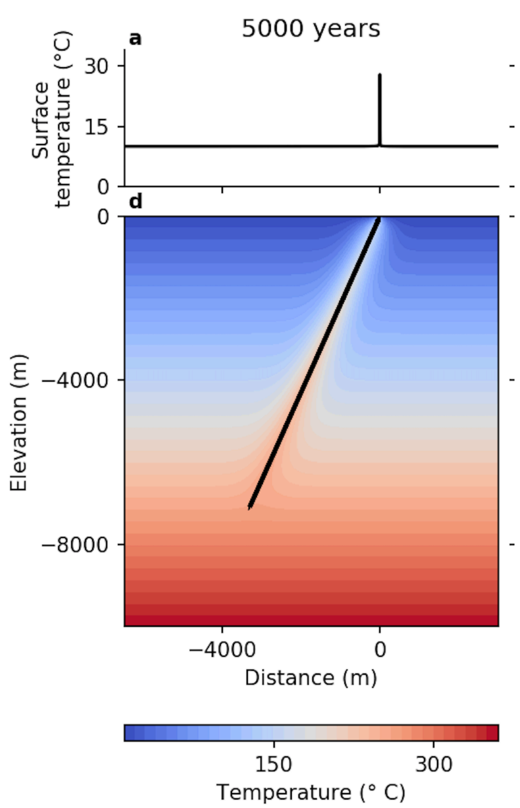


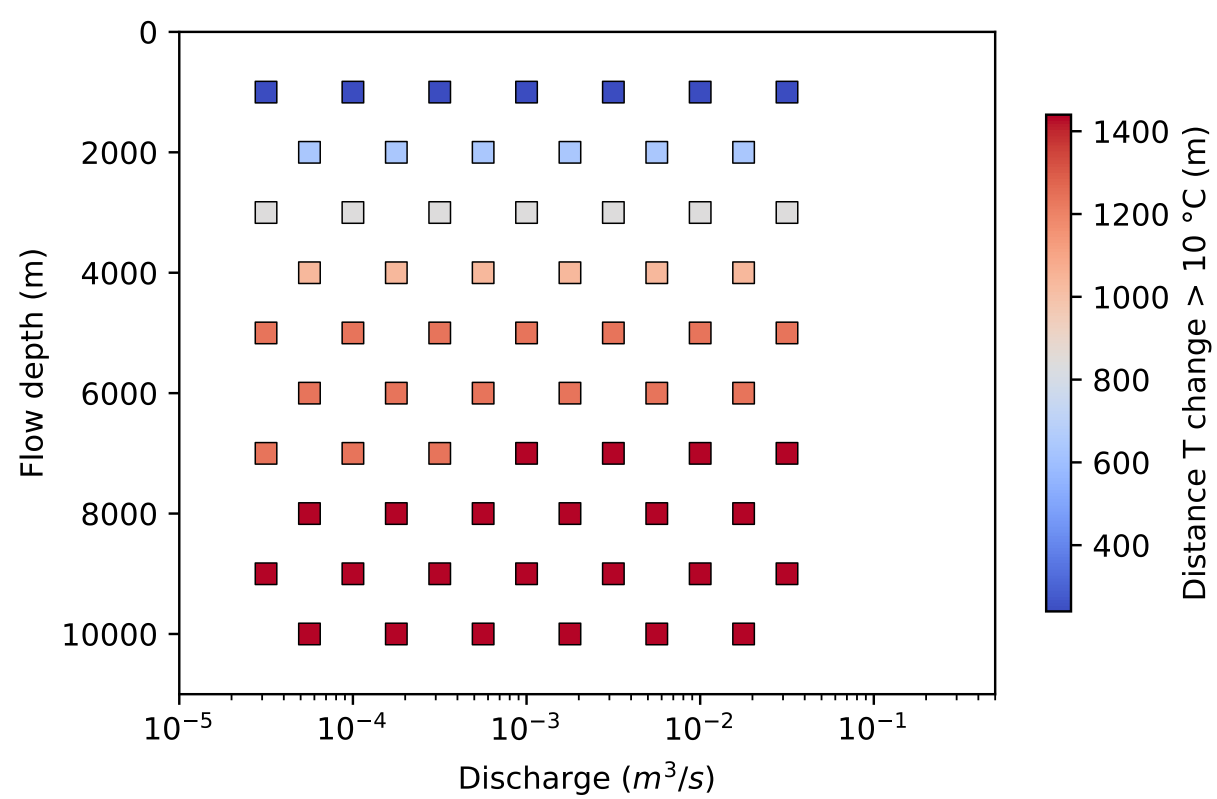


Thermal footprint of fluid flow

- First order estimate of thermal footprint model experiments suggests it is predominantly a function of the depth / temperature where upward fluid flow originates

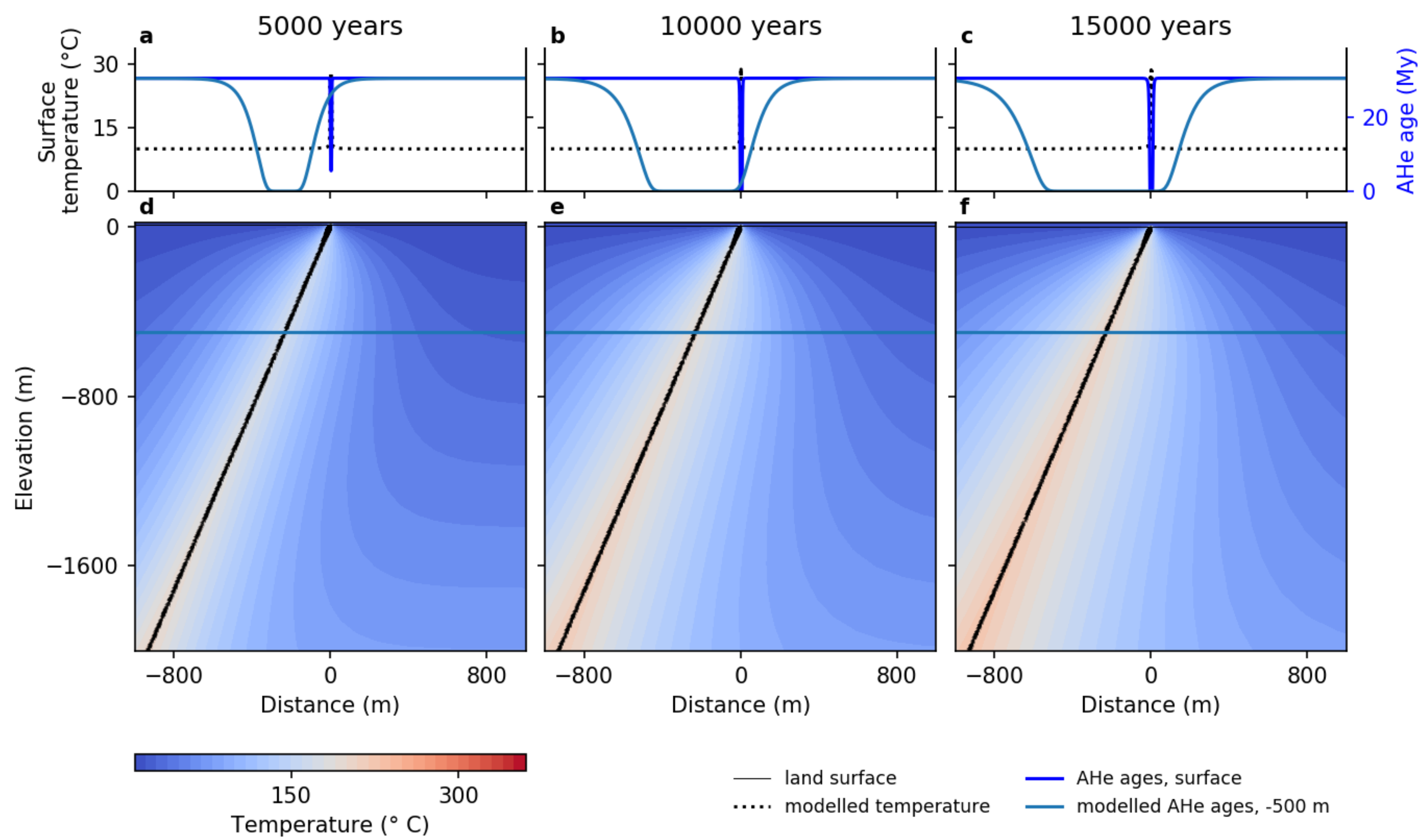
- Preliminary results: For the majority of springs subsurface temperatures are >10 ˚C higher than the background temperature at a distance up to 500 to 1500 m from the fluid conduit





Implications for thermochronology

- Effects on low-temperature thermochronometers around hydrothermal systems may be pronounced:



Modelled effects of hydrothermal activity on apatite (U-Th)/He data
(Luijendijk 2019, Geosc. Model Develop. Discussions)

Conclusions

- Thermal springs contribute 1-2% to the total heat flow of the Alps. This is probably an underestimate of the contribution of deep fluid flow to the overall heat budget
- First estimate of depth of fluid flow suggests that flow depths of up to 7 km may be needed to explain observed spring temperatures
- However, model estimates of spring temperatures and thermal footprint depend strongly on the assumed size of fluid conduits -> ongoing work to run models with smaller fluid conduits and use independent estimates using hydrochemistry of springs / Si geothermometers
- Model experiments indicate that the thermal footprint of springs depends almost exclusively on the maximum flow depth and temperature, and ranges up to 1.5 km for the springs with the highest temperatures and heat flux