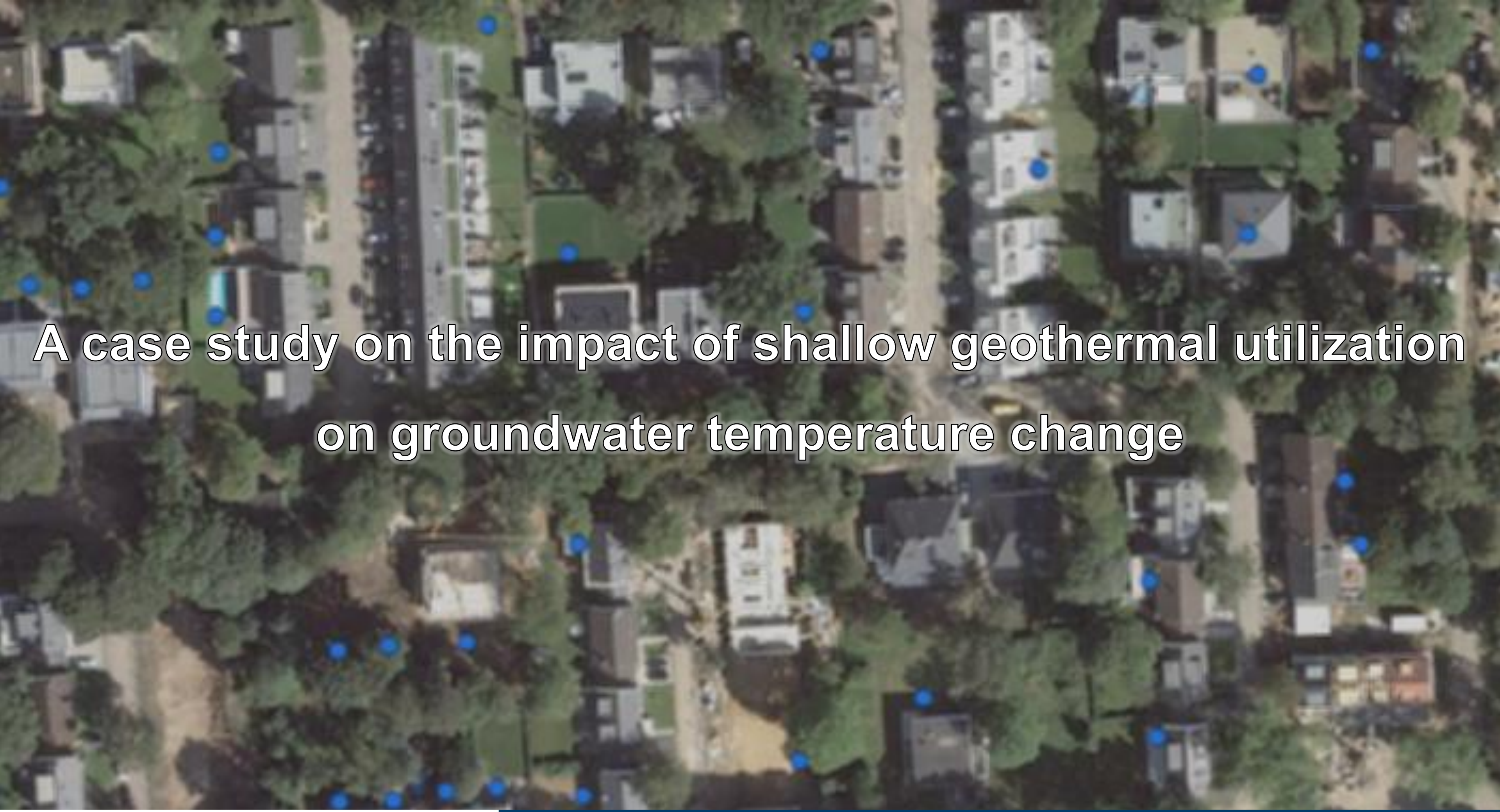


A case study on the impact of shallow geothermal utilization on groundwater temperature change

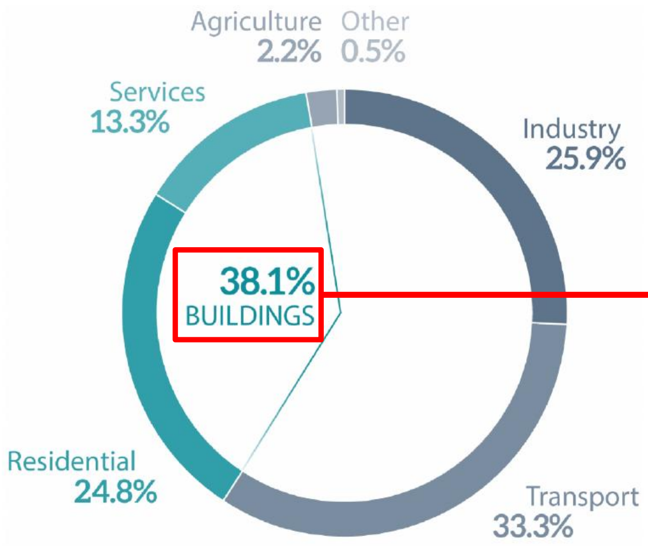
Haibing Shao, Boyan Meng, Thomas Vienken, and Olaf Kolditz

DGK 2018 | 28.11.2018 | Essen

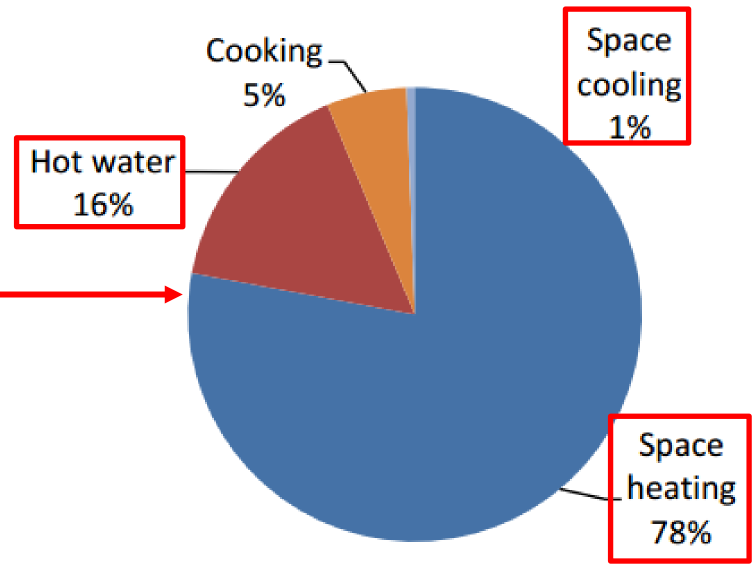
HELMHOLTZ
CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Heating and cooling (H&C) for buildings

- Energy consumption in the EU



source: Eurostat, 2014



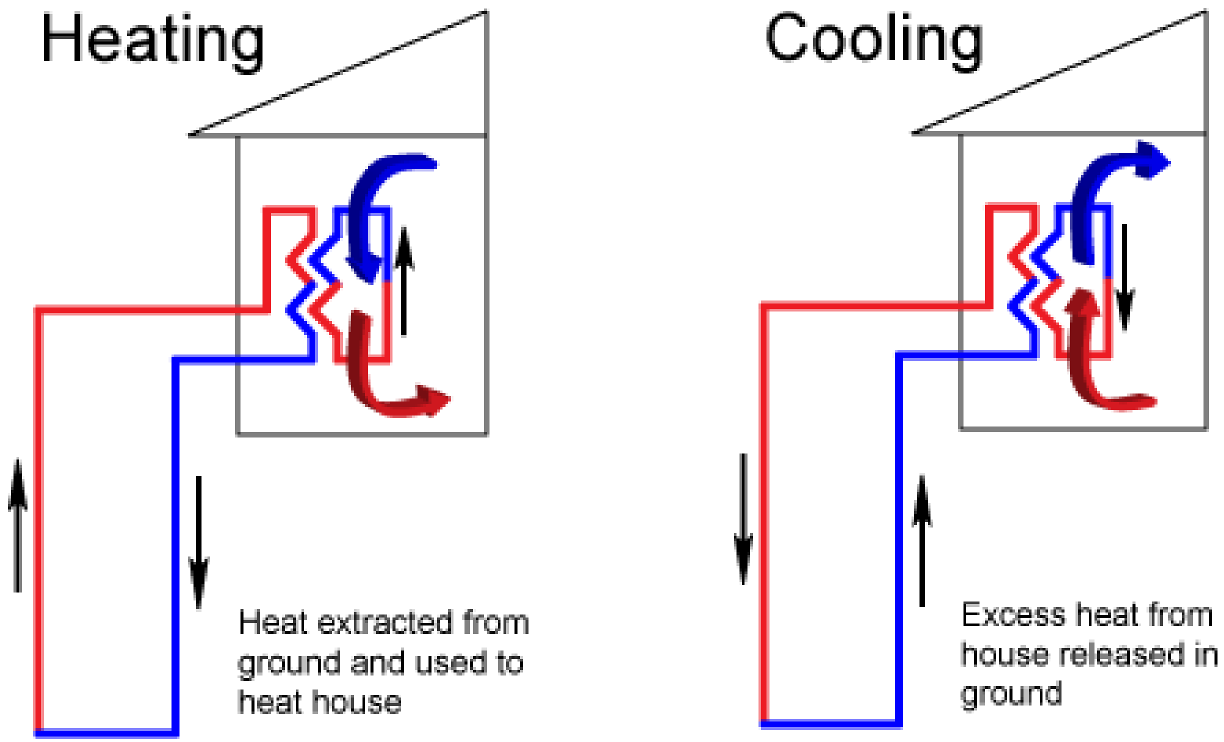
source: European Commission, 2016

- 84% of H&C is still generated from fossil fuels
- EU <u>carbon reduction</u> target: 80% by 2050

  EU <u>renewable energy</u> target: 12% of heat from renewable energy by 2020
- Using shallow geothermal energy for H&C is a viable option.

  ✓ *local, clean and efficient!*

Ground source heat pumps (GSHPs)



$$\dot{Q}_{building} = \dot{Q}_{ground} + W$$

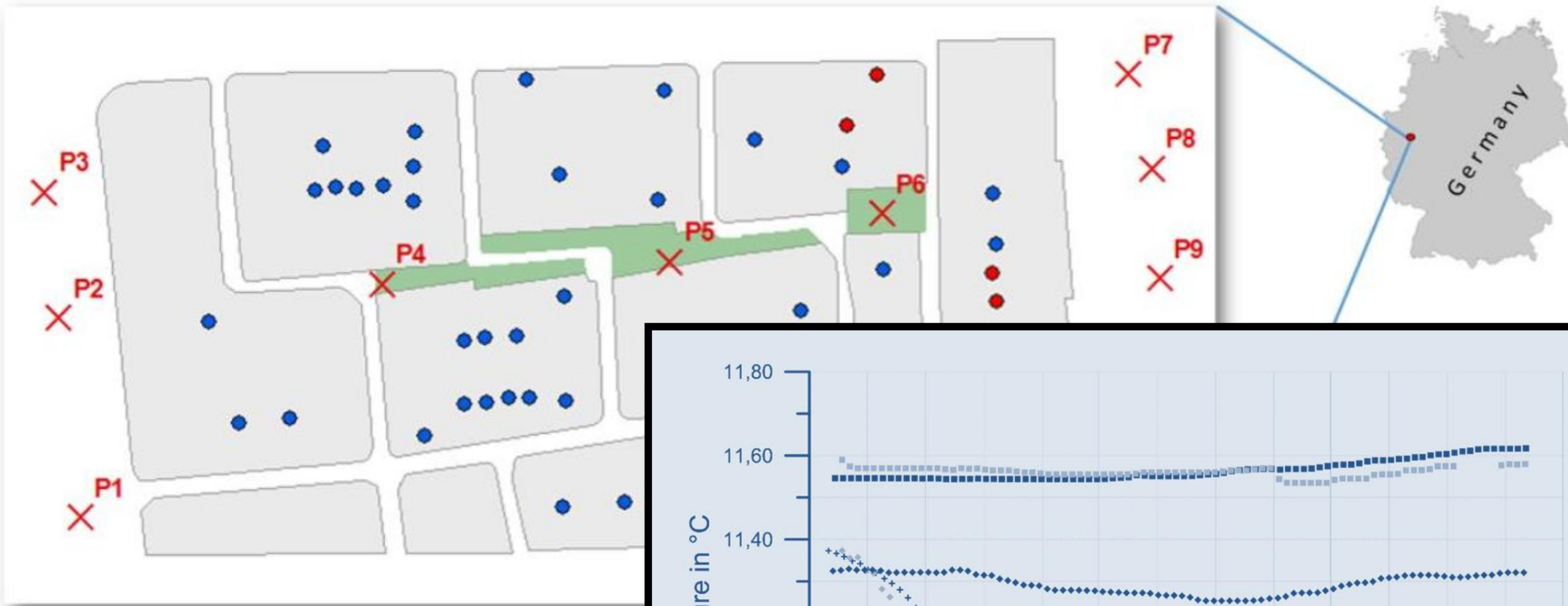
$$\dot{Q}_{building} = \dot{Q}_{ground} - W$$

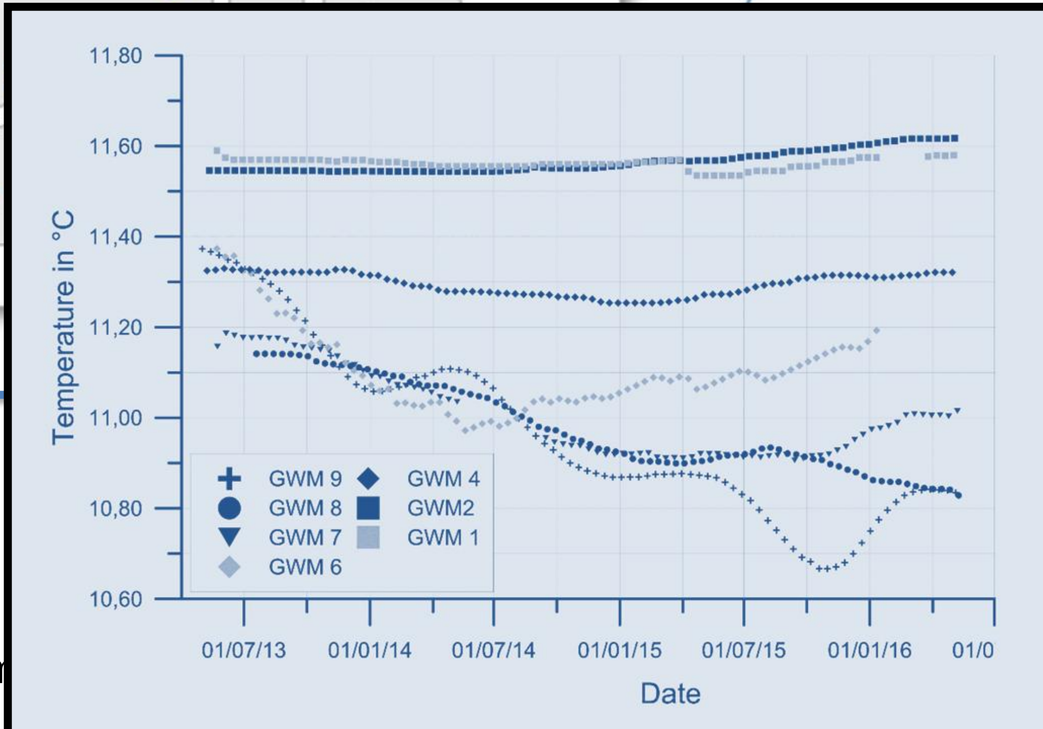
http://www.geothermalheatingandcoolingreview.com/geothermal-heat-pump/

GSHP-induced subsurface temperature changes

- Form as a result of heat injection / extraction
- May influence
  - ✓ groundwater quality and ecological functions
  - ✓ heat pump efficiency (in case of extreme local heating or cooling)
- Regularized in some countries (e.g. $\Delta T < 6$ K for open loop systems in Germany)
- Depends on a wide range of factors in practical applications, in particular
  - ➢ site hydrogeological and thermal conditions (heat advection vs. conduction)
  - ➢ arrangement (e.g. spacing, pattern) of compact GSHP arrays (thermal interference)

A real-case application of dense GSHP systems

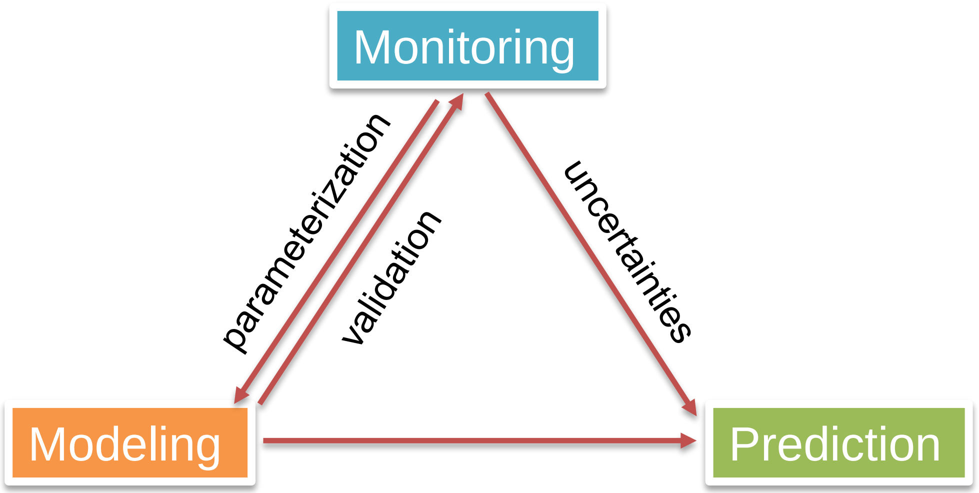




- 47x closed systems (borehole heat
  closest distance < 10 m
- Measurement of GW levels and tem
- Unsaturated flow, hydraulic gradient: 6×10^{-4} (±35%)

Main research questions

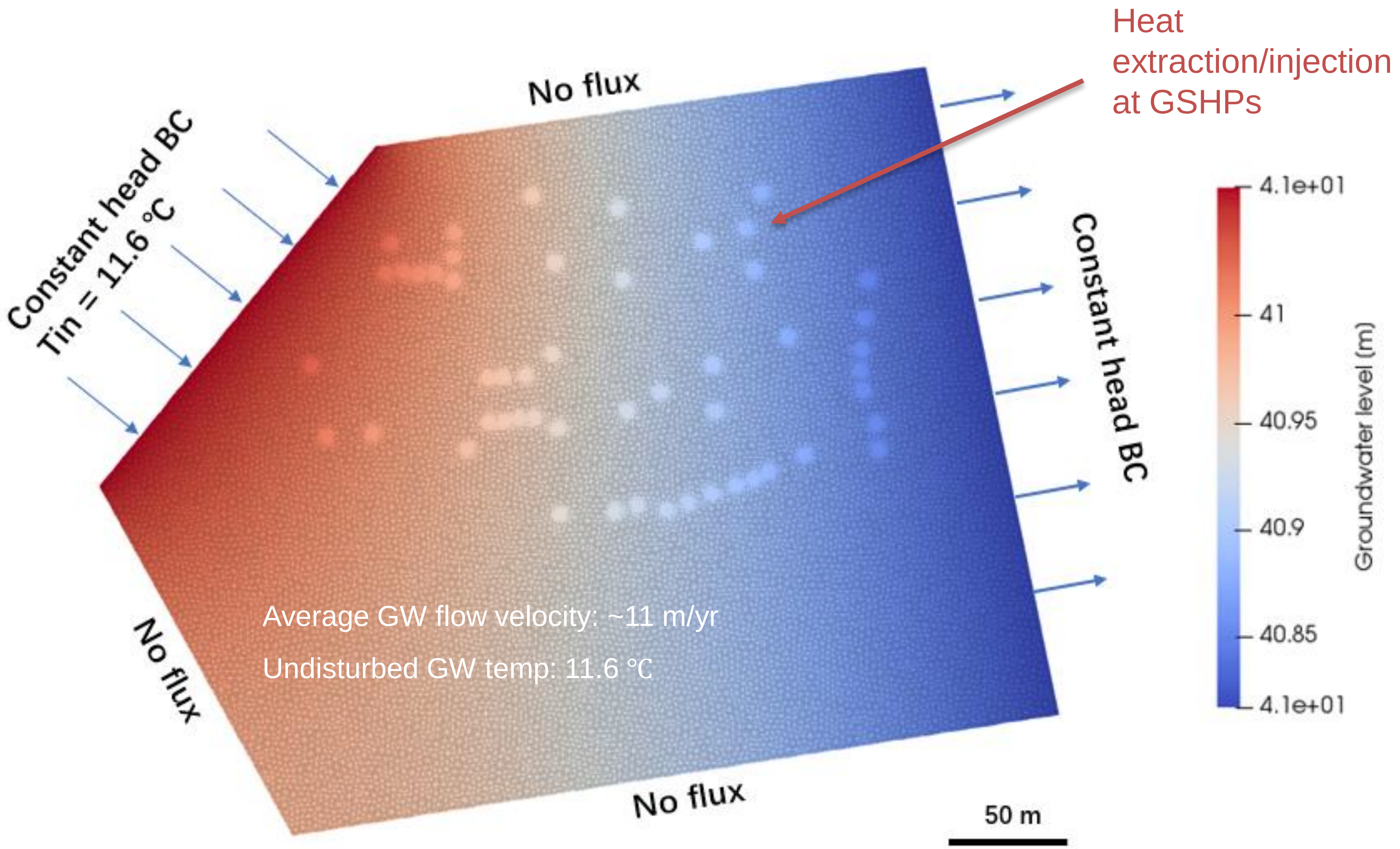
- ✓ How much heat is extracted in one year on average?
- ✓ Will the subsurface temperature continue to drop in the future? If yes, how much?
- ✓ What implications does it have on the GW quality and GSHP efficiency? What can be done to reduce such effects ahead of time?



"Monitoring – modeling – prediction" concept

2D GW flow and heat transport model constructed with *OpenGeoSys*

- assuming fully-saturated flow → depth-averaged model
- finite element mesh, refined around GSHP nodes



steady state GW flow field

GSHP operation specifications

- Heating season: 11/27 to 3/6 (2400 h)

  Cooling season: 7/16 to 8/9 (600 h)

- Energy demand per household per year

  - for closed systems: 23098 kWh → (divided by 2400 h) 9624 W → (divided by 37 m) 260 W/m

    (on average 6 BHEs)

  - for open systems: 414 W/m

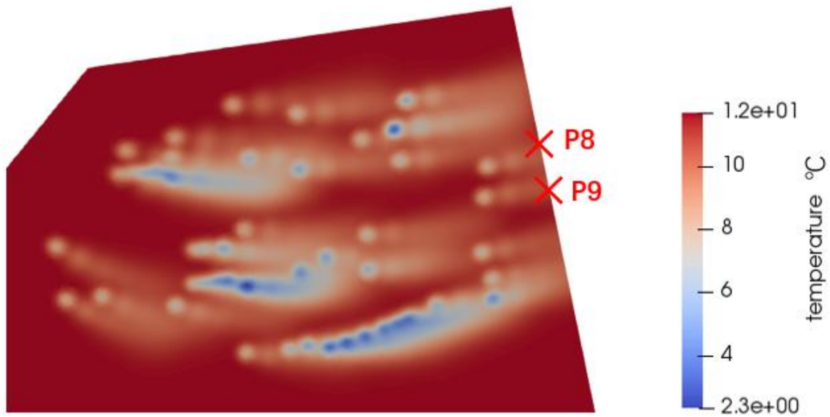
  - *how much is coming from the subsurface?*

- Maximum cooling ratio: 40%

  - cooling ratio = $\frac{Q_{inj}}{Q_{ext}}$

Estimation of heat pump efficiency (short-term)

- assuming average flow velocity
- only heating is considered in the short-term (based or

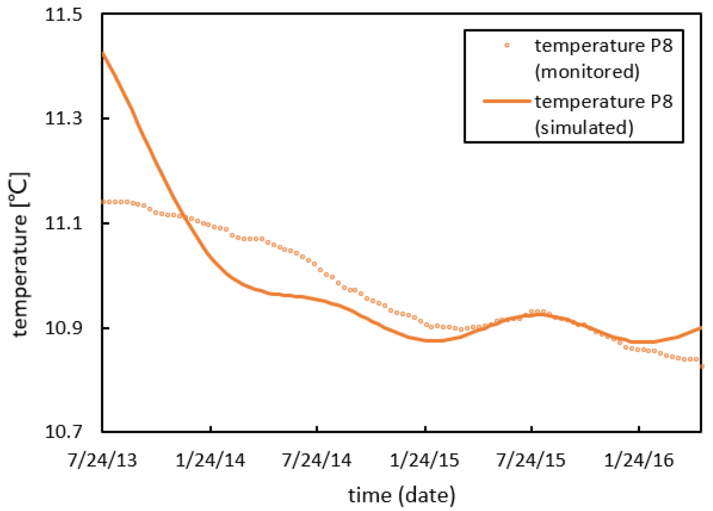


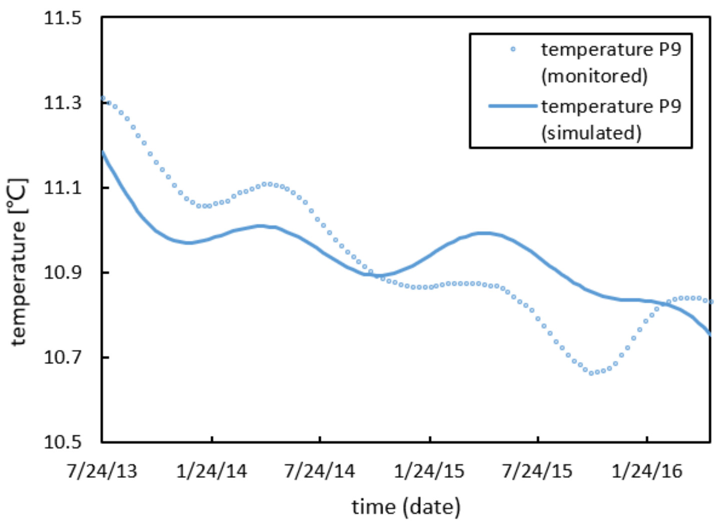
Temperature distribution after six years

Extracted heat = 65% energy demand

➢ coefficient of performance (COP)

$$\text{COP} = \frac{\dot{Q}_{building}}{W} \approx 3$$





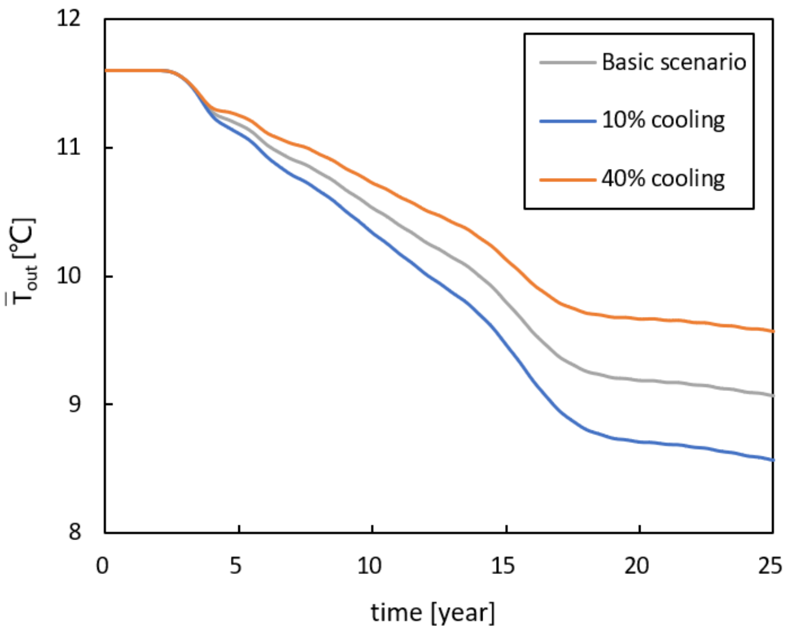
Estimated thermal conductivity: 1.0 W/m/K

Effect of uncertainties (long-term)

- Basic scenario: 25% cooling, mean flow velocity

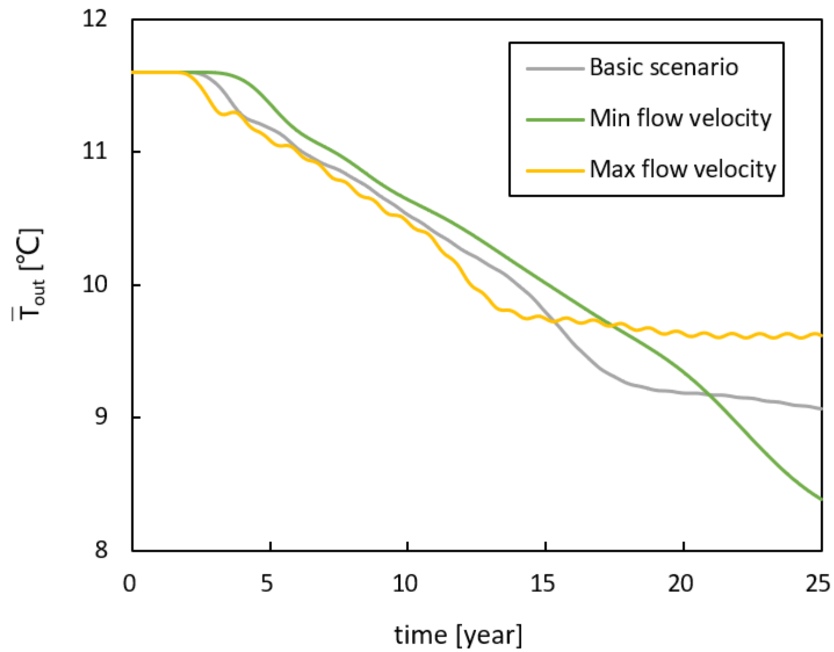
- temporal evolution of the mean effluent temperature

1. Cooling ratio



A high cooling ratio is good for GW temperature recovery

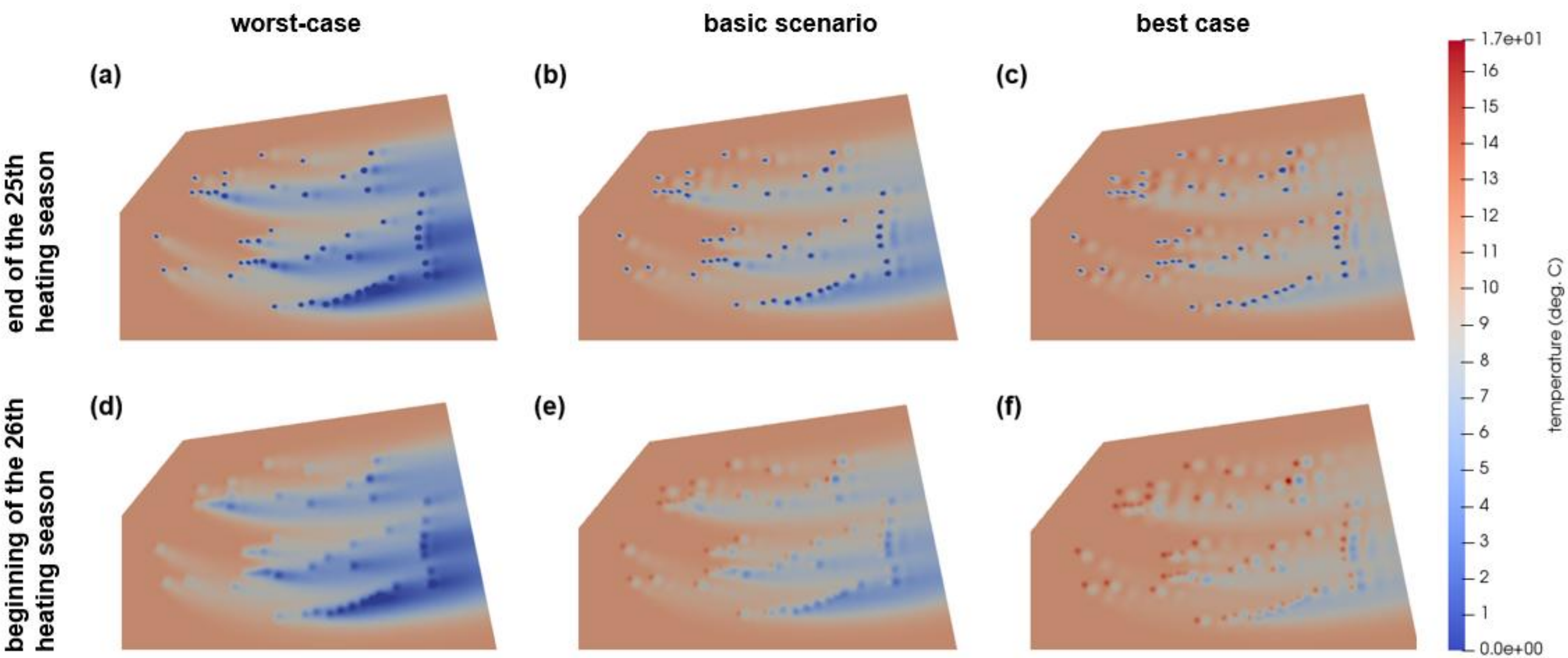
2. GW flow velocity



Less ground cooling for higher flow velocity (in the long term)!

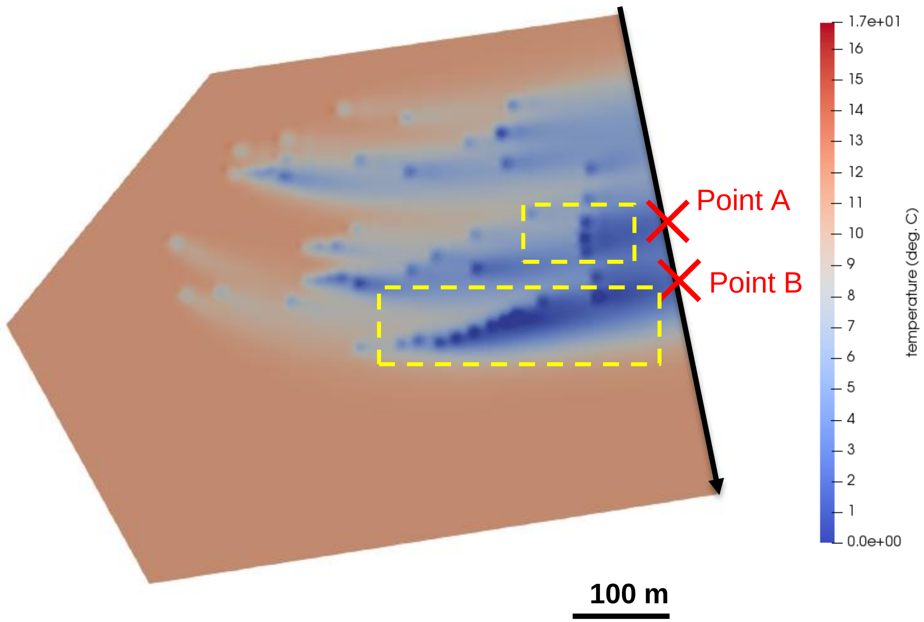
Prediction of long-term GW temperature

- basic scenario: 25% cooling, mean GW flow
- best-case: 40% cooling, max GW flow;
- worst-case: 10% cooling, min GW flow

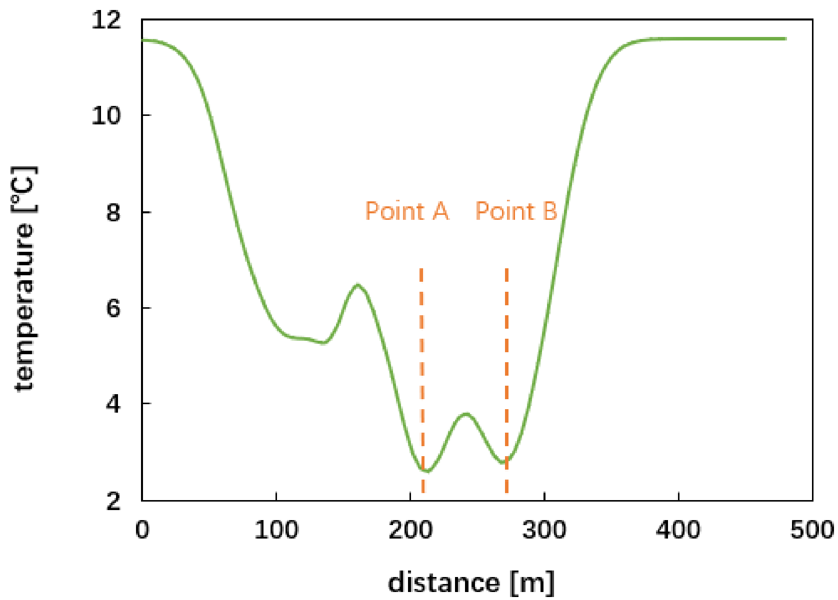


Prediction of long-term GW temperature

- temperature profile along the outflow boundary



temperature distribution of the worst-case scenario at the beginning of the 26th heating season



two points with the lowest temperature on the outflow boundary

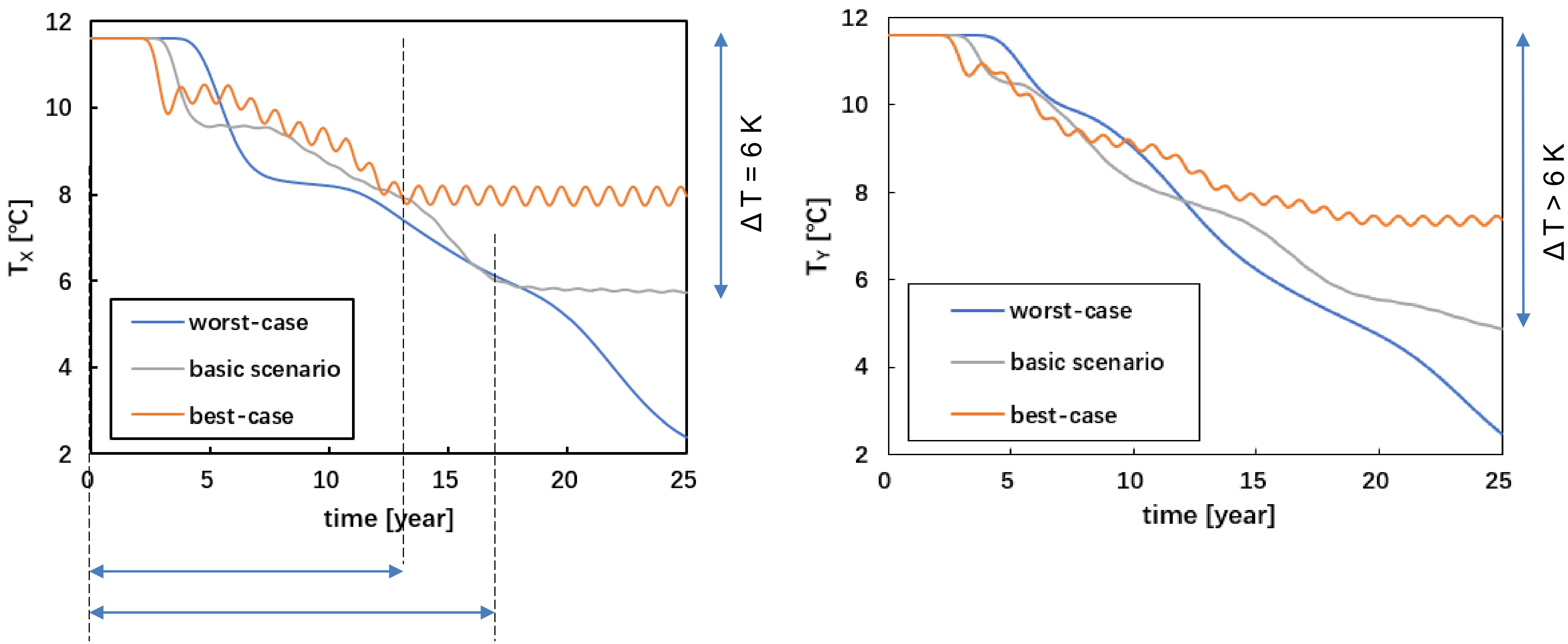
A series of GSHPs along the flow direction adds to downstream cooling!

Prediction of long-term GW temperature

- temperature evolution at:

Point A (downstream of open system)

Point B (downstream of BHE array)



Δx = 190 m (distance from farthest installation)

Not sustainable for worst-case scenario!

Not sustainable for basic and worst-case scenarios!

Summary and outlook

- Thermal impacts of GSHP systems need to be considered when used for domestic H&C
- Site investigations, particularly hydrogeological measurements, are important for the planning and design of dense GSHP systems
- Tips to mitigate cooling of subsurface due to GSHP operation
  - ✓ increase the cooling load in summer
  - ✓ avoid in general the alignment of GSHPs along the GW flow direction
  - ✓ use different depth intervals for different installations
- In the case of extreme ground cooling, are GSHPs still preferable compared to gas boilers? (electricity, CO_2 emission...)
- How sensitive are the results to different parameters? (necessity for site monitoring)

Thank you for your attention!