Simulation of Borehole Heat Exchanger Fields based on an integrated model approach

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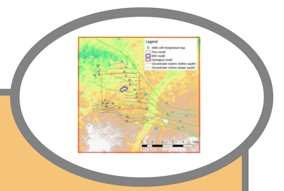
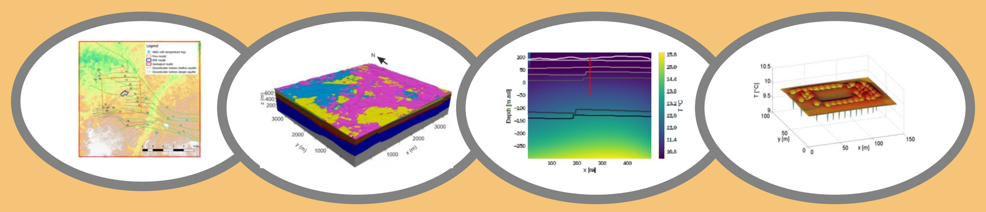
EoCoE

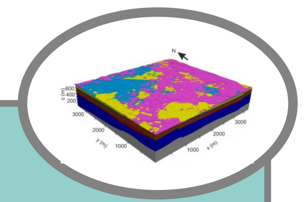
Motivation



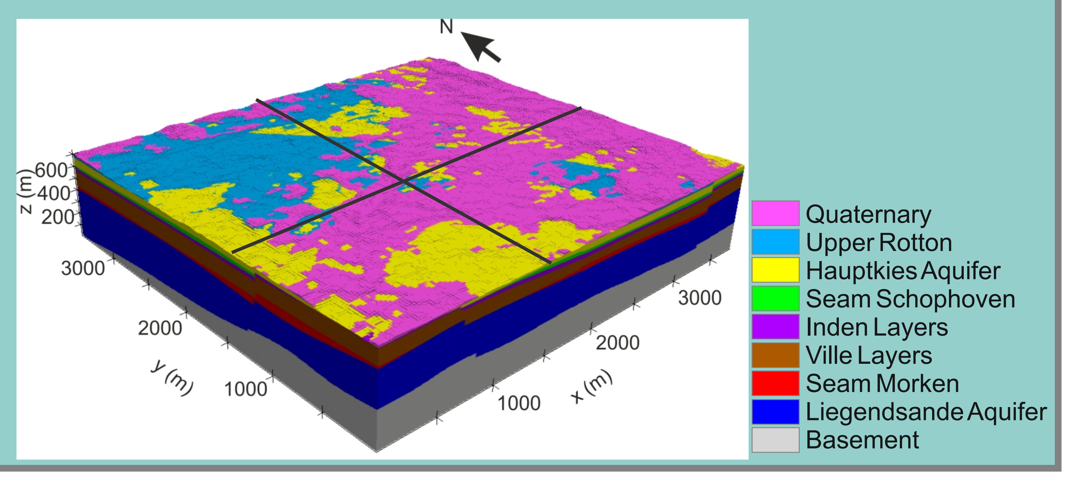
27 % of the annual energy consumption in Germany are used for space heating. Direct heat geothermal energy use provides a ecologic possibility to provide energy for space temperature regulation.
The aim of this project is to assess the geothermal energy potential for a city quarter situated in the Lower Rhine Embayment (Neu-Teveren near Geilenkirchen).
This is done in a 4 step workflow from data acq. to a final borehole heat exchanger model.
Computational demand of the model simulations makes this project perfectly suited for EoCoE.



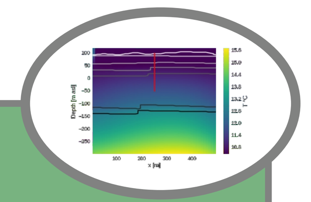
Geological Model



The study area is located in the Lower Rhine Embayment. The upper 500 m consist of Tertiary sediments, consisting of marine and continental deposits. Maximum model depth is 3 km, but for modelling a Borehole Heat Exchanger (BHE) field, a geological model of the upper 700 m is generated.
The final model covers an area of 16 km^2 comprising all Aquifers and Aquitards



Numerical Model

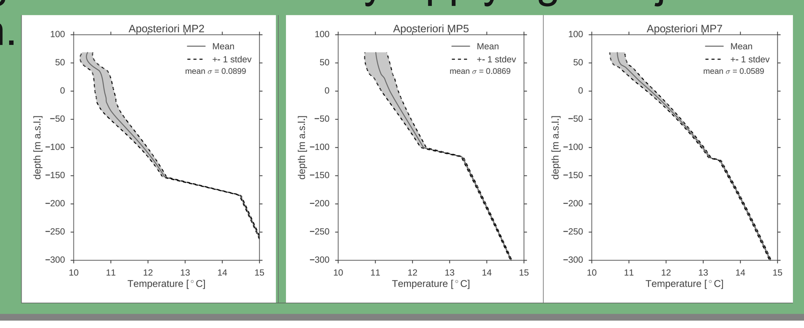


The geological model is discretised in a numerical model comprising about 8 million cells. The model is calibrated using temperature data from boreholes.
Balance equations:

$$S_s \frac{\partial h}{\partial t} = \nabla\left[\frac{\rho_f g \mathbf{k}}{\mu_f}(\nabla h_0 + \rho_r \nabla z)\right] + W$$

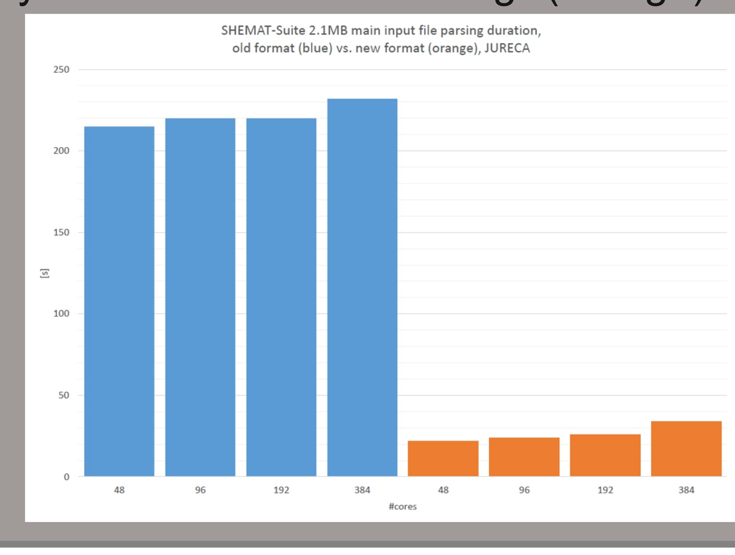
$$(\rho c)_e \frac{\partial T}{\partial t} = \nabla\left[\boldsymbol{\lambda}_e \nabla T\right] + (\rho c)_f \boldsymbol{v} \nabla T + H$$

Adressing spatial heterogeneity of permeability, we simulated an ensemble comprising multiple hundret members of equally likely permeability fields on JURECA. The ensemble was then conditioned against groundwater data by applying a rejection algorithm.

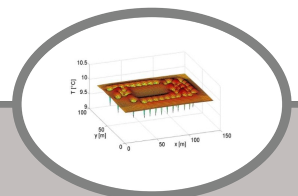


Code optimization in EoCoE

In cooperation with WP1 of EoCoE, the input format of SHEMAT has been changed to a binary HDF5. This conversion yields a significant performance increase in the input parsing process for large models. Parsing time of an input file is measured with different number of cores on the JURECA system. Conversion process time is already included in the new timings (orange).

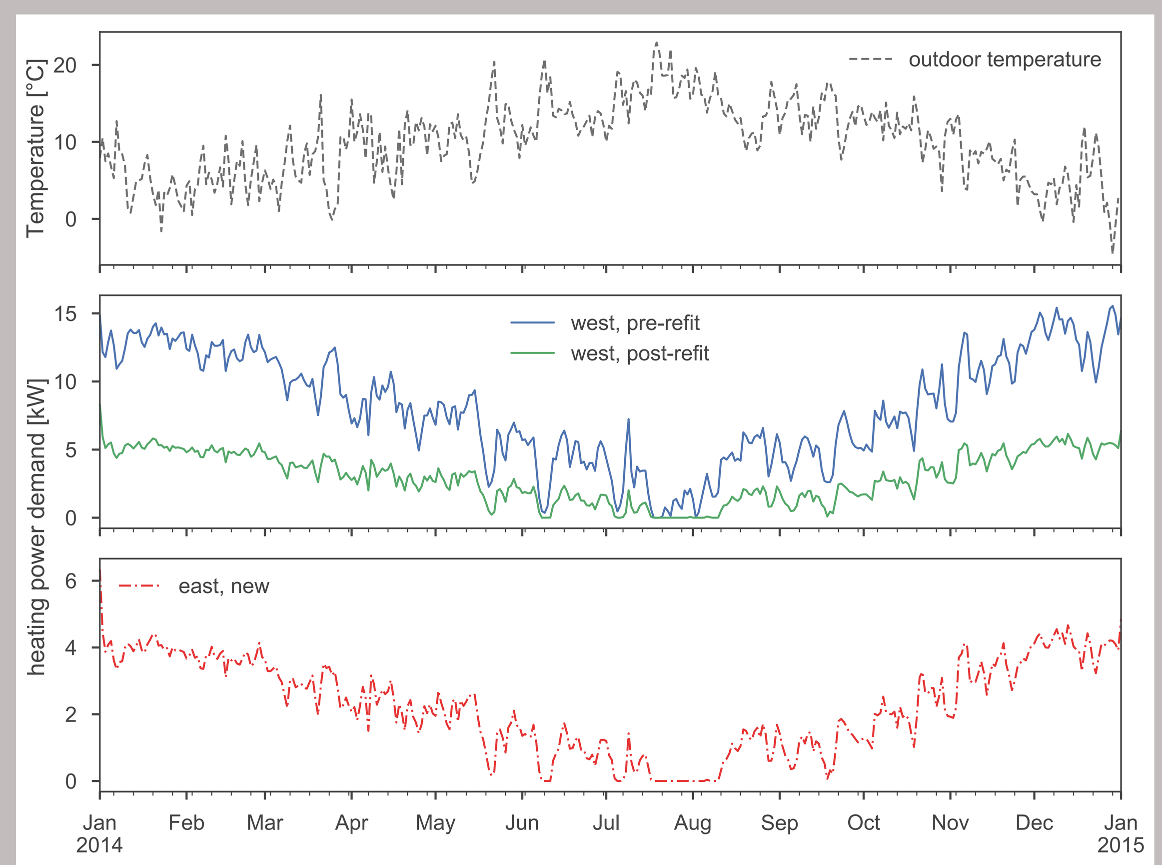


BHE Model

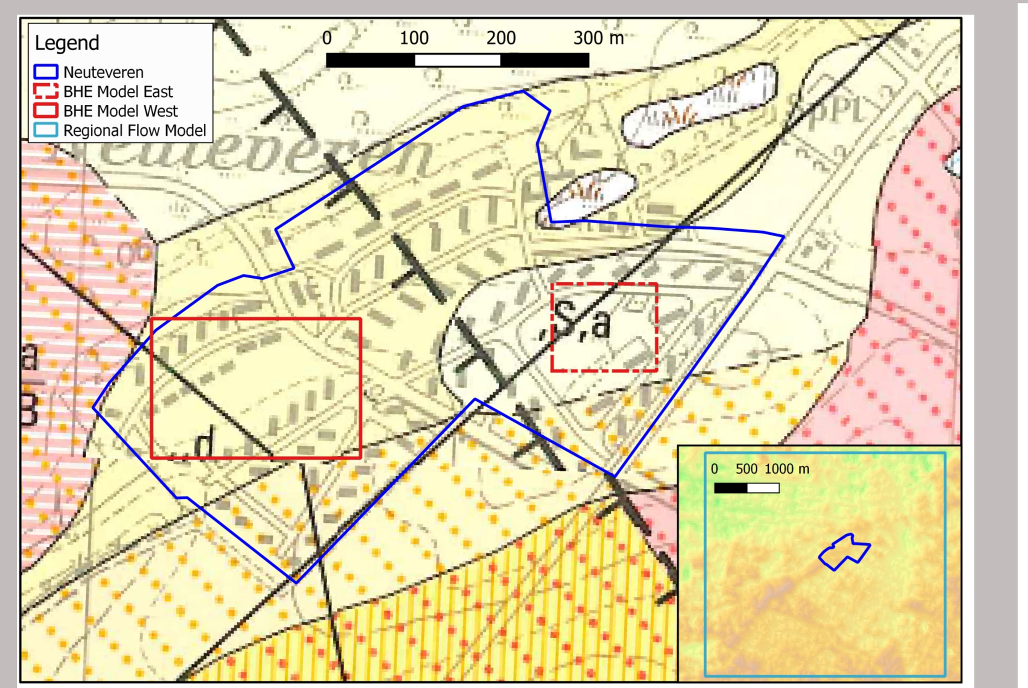


Several Borehole Heat Exchanger (BHE) models are run in order to conclude several statements:

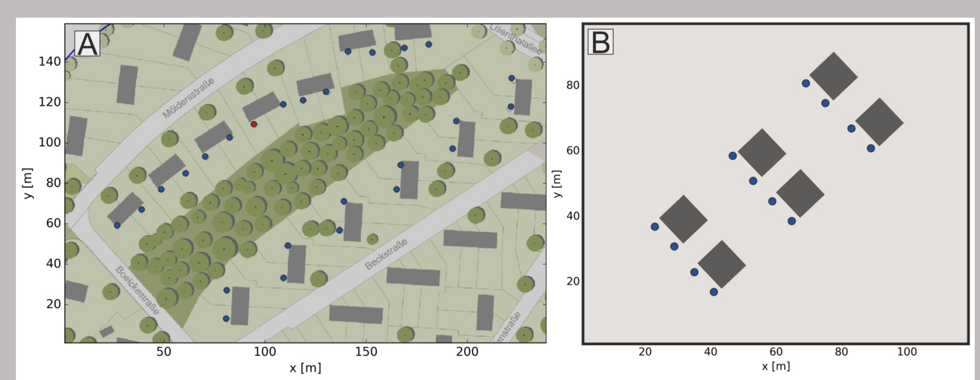
- How do renovated buildings with a lower heating demand perform compared to buildings in original state?
- How does the BHE-Field perform over a certain time frame of multiple years?
- How does the layout of the BHE field influence performance in presence of groundwater flow?



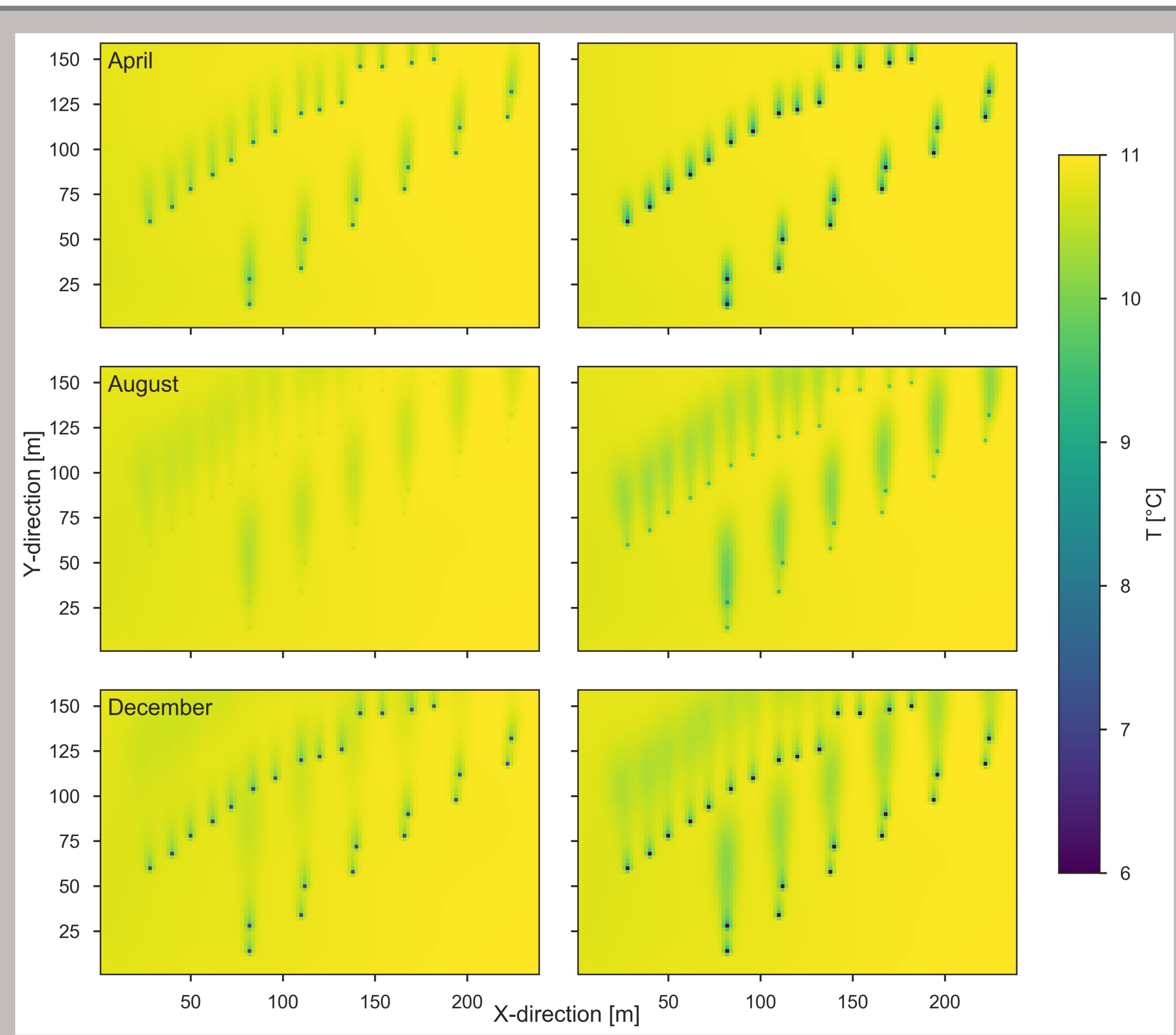
Based on outdoor air temperatures, we dimulated the heating demand for a building with the same key parameters as the buildings in the study area. Resulting demand curves for the western model and eastern model are used as input for the BHE simulations.



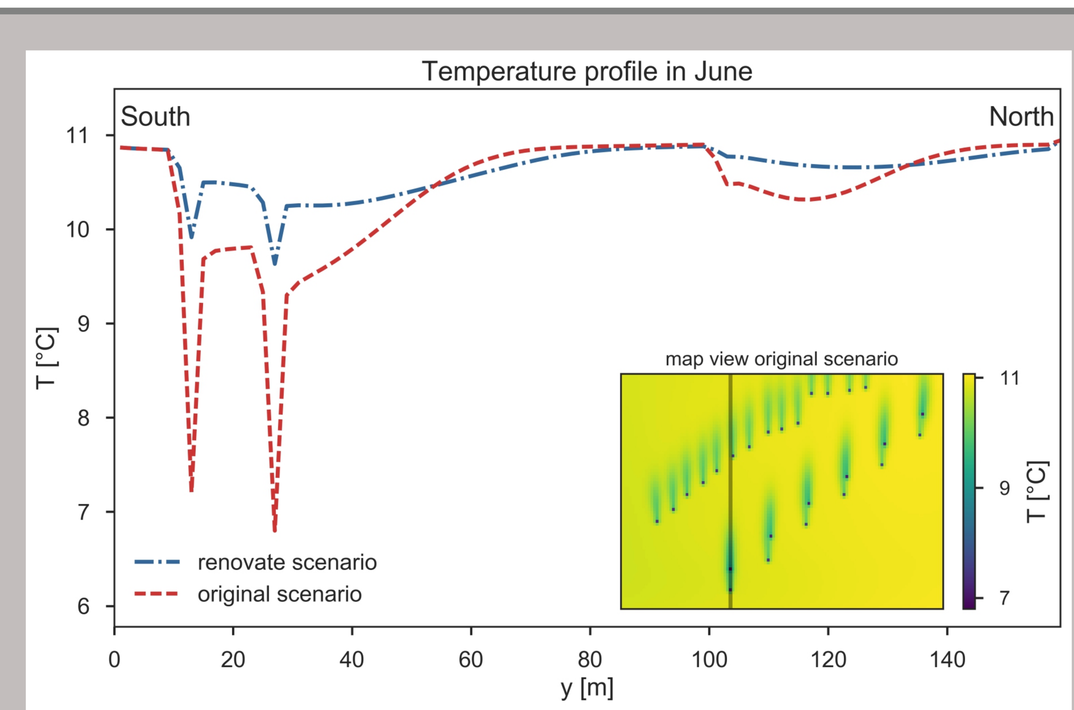
Due to a relative homogeneous subsurface structure in the study area (blue polygon above), we generated two representative submodels (red squares) for simulating the performance of the BHE fields associated to different housing conditions (plot below).

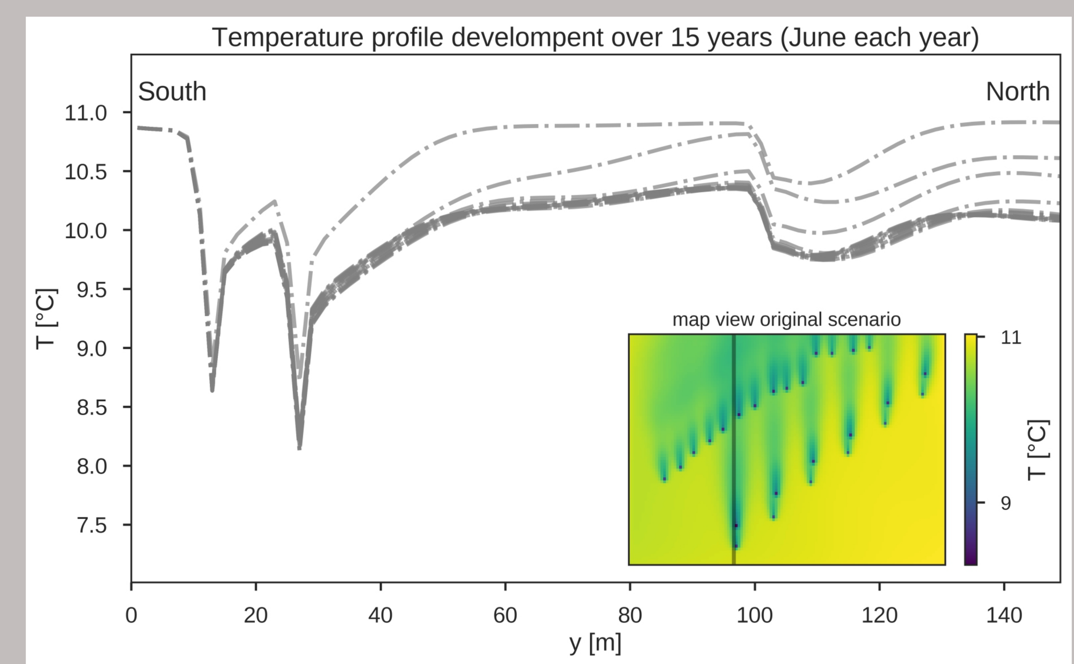


In the western part (A), existing buildings will be reconstructed. In the eastern part (B), new buildings will be constructed. Blue dots represent BHE installations for the buildings (gray rectangles).



Comparison of annual behaviour of BHEs in the western model shows a strong influence of the building type (left renovated, right original state) on temperatures in the subsurface. In case of buildings in original state, temperatures around the BHE installations are significantly lower. Further, due to northward groundwater flow, thermal plumes develop at each BHE with reduced temperatures compared to the undisturbed subsurface temperatures. In a NS-cross section, we assess the layout influence of the BHEs, i.e. how strong do southern BHEs affect northern BHEs.





TOP: NS cross sections of temperature in June of one year comparing renovated to original building state. An influence of southern BHEs on its northern neighbours is visible and in the range of around 1.5 K.
BOTTOM: Long term evaluation of temperatures in the renovated scenario. Temperatures decrease over time, but stabilize after 4 to 5 years.

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