Oscillatory Thermal Response Tests

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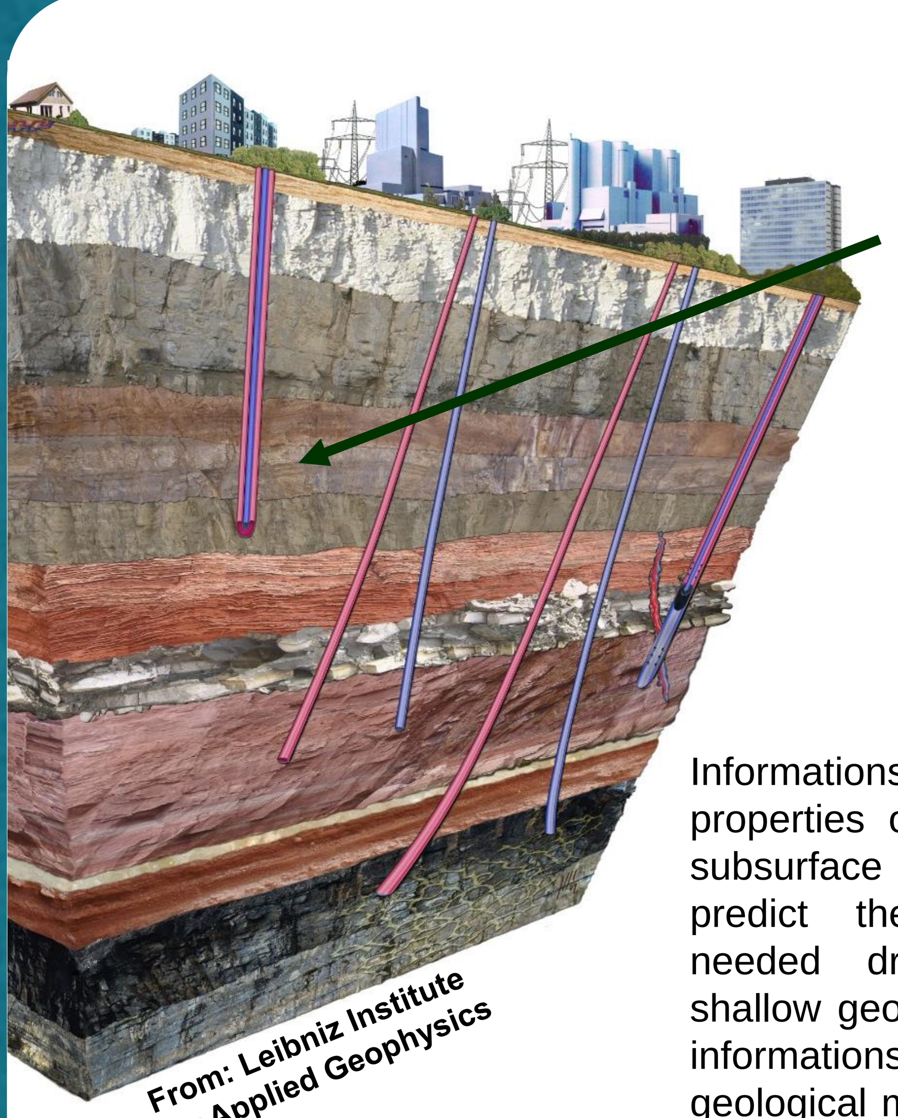
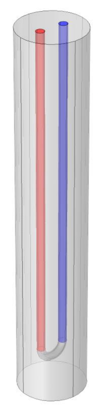
An advanced method for shallow geothermal applications, developed with COMSOL®



Geothermal Energy is a growing branch of sustainable energies. We focus on **shallow geothermal applications**. A common setup is a **Borehole Heat Exchanger (BHE)** of typical depth between 20m and 300m with a single or double u-pipe inside. The subsurface is used as thermal source or sink, the heat exchange is done by a working fluid that transports heat between the subsurface and a heat pump.



Informations about the thermal properties of the BHE and the subsurface are important to predict the productivity and needed drilling depth of a shallow geothermal system. The informations are gained from geological maps and from in-situ tests at the local site.

Thermal response tests (TRTs) provide the effective thermal resistivity of a BHE system. The test and the standard evaluation are simple but the conclusions of the tests are somehow limited.

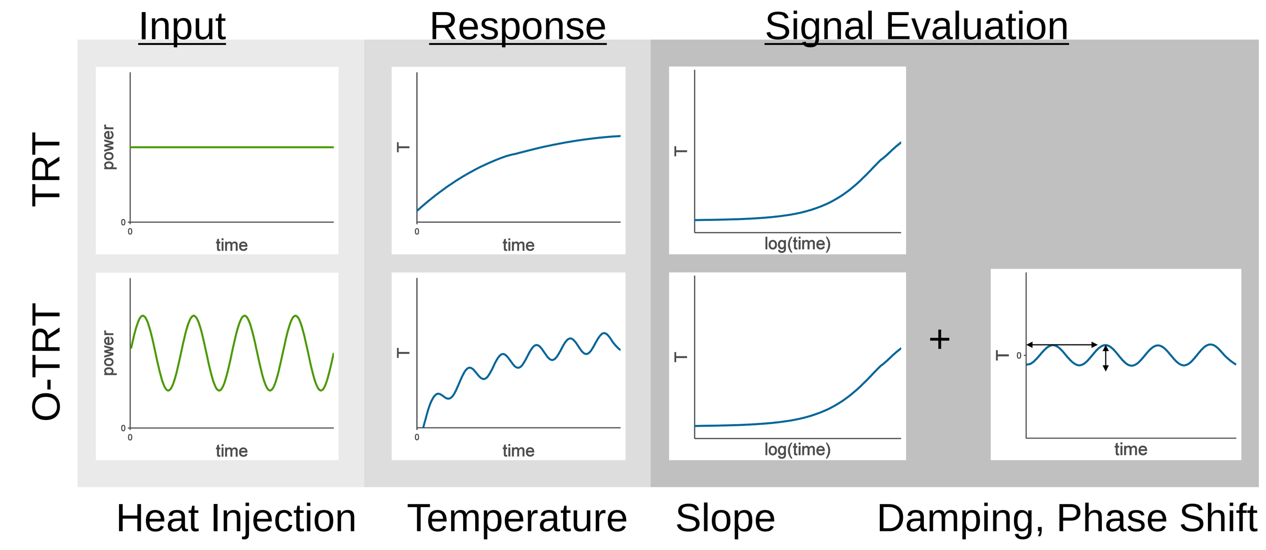
How can the state-of-the-art TRT design be enhanced

?

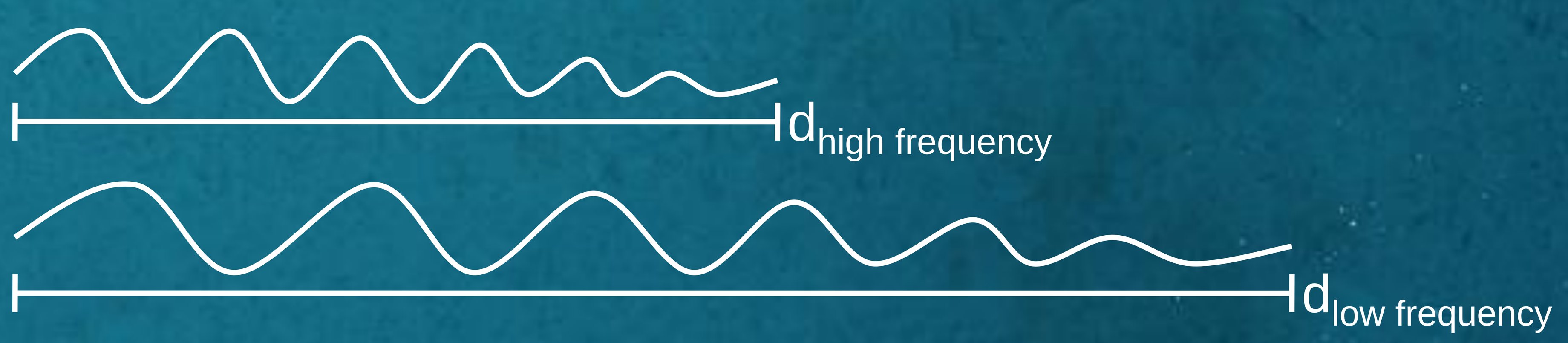
to gain further information about the BHE quality and the subsurface?

Idea: Oscillatory Heat Injection

Conventional TRTs in shallow geothermal applications are carried out by injecting a constant thermal power into the subsurface and evaluating the temperature response of the system. After some hours, the slope of a Temperature – log(t) plot becomes (nearly) constant. According to Kelvin's line source theory, the thermal resistivity of the system is proportional to the slope that can be easily evaluated. Unfortunately, no information about heat capacities or filling quality of the borehole can be gained with this method.

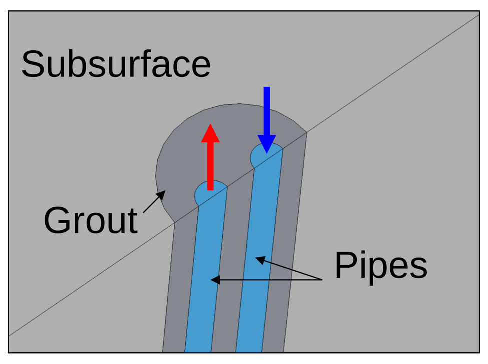


The idea is to add an oscillatory part to the constant heat injection. The system response is a superposition of constant and oscillating heating. **The constant part can be evaluated conventionally, the oscillation contains further information about thermal properties.** The amplitude and phase shift are functions of thermal conductivity and heat capacity. The **penetration depth** depends on the frequency of the signal and can thus be adjusted to expand only into certain regions.



COMSOL® Model

The numerical simulation of oscillatory TRTs requires a 3D model of a BHE that is able to represent the vertical and horizontal heat fluxes within the system. The fluid flow in the pipes is not explicitly calculated, we rather assume a mean velocity and calculate the heat transfer coefficients for the heat exchange between working fluid and filling grout. For the pipes, **heat transfer in fluids** mode is used, the grout is represented by **heat transfer in solids** and for the subsurface, we use **heat transfer in porous media**. The simulation area is reduced by utilizing the symmetry of the problem, a mirror plane shrinks the geometry to one-half.

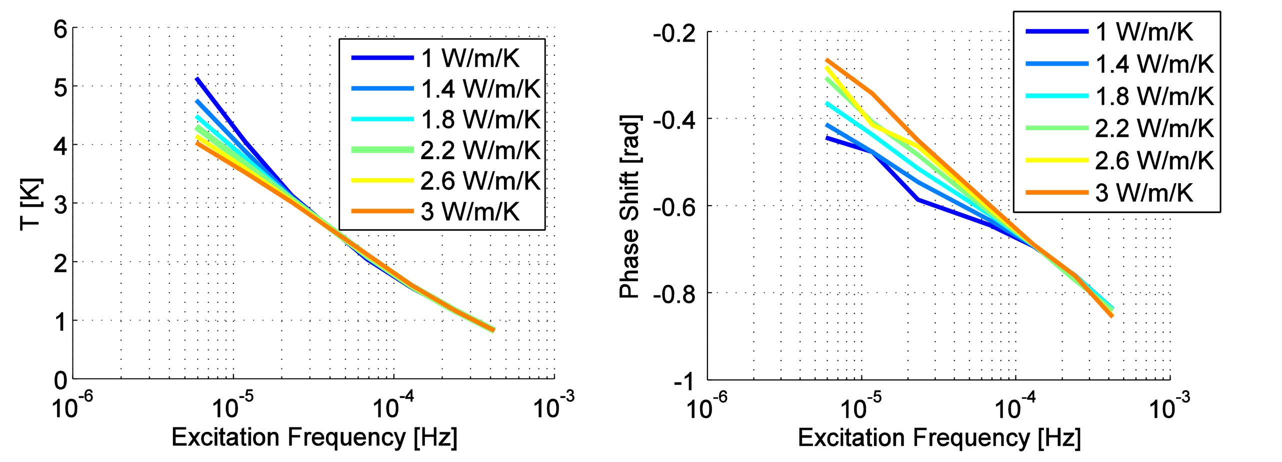


The model was validated with experimental data to assure that it works properly and represents the physical processes in a BHE. Since we are interested in oscillatory signals, we need to evaluate the solutions in terms of phase shift, frequency and amplitude. Therefore, **LiveLink™ *for* MATLAB®** is used to perform parametric studies and for post-processing the thermal response of the BHE system.

Parametric Studies

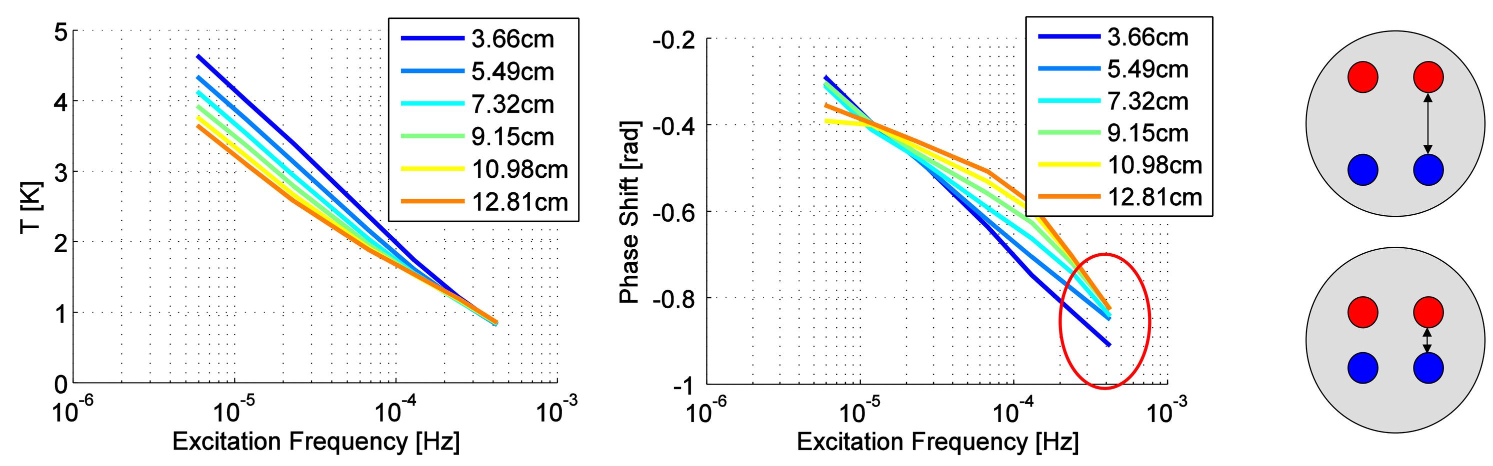
Variation of Subsurface Thermal Conductivity

The (mean) **thermal conductivity of the subsurface** is important for the long time behavior of the system. The effect of thermal conductivity only affects at low frequencies. Thus, **high frequency responses are only affected by borehole characteristics and not by the borehole ambient**.



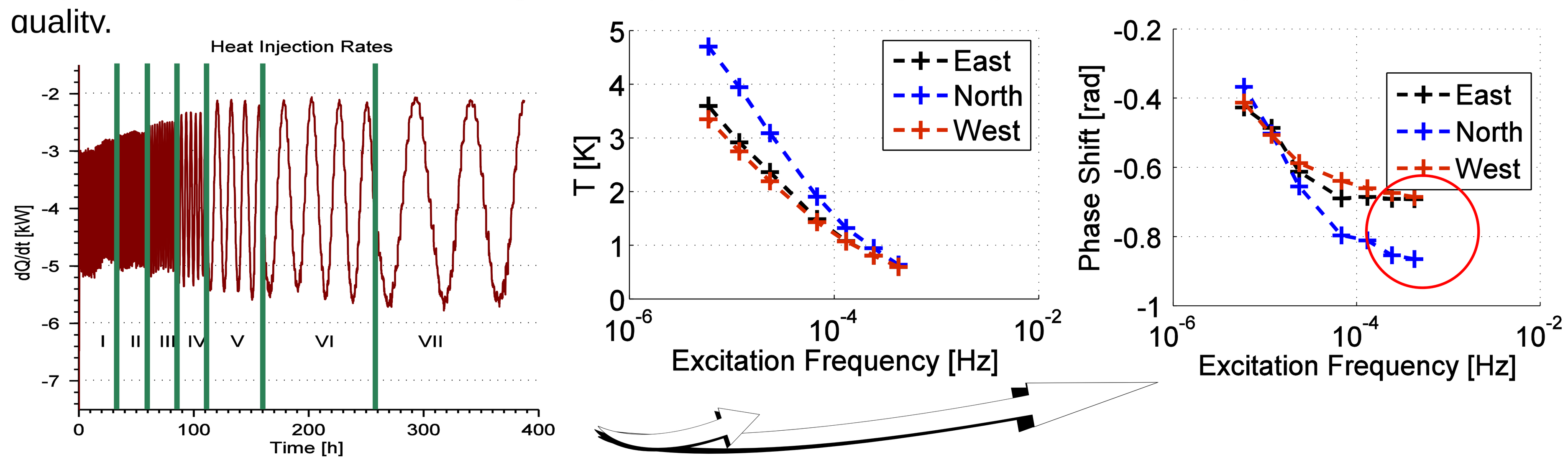
Pipe Distance Variation

The **pipe distance** is a factor of uncertainty at BHEs. They may be closer or more apart then expected. If the pipes are too close, a thermal short cut occurs. **This effect can be detected in the phase shift at high frequencies**.



Experimental Results

Within the EFRE project Geo-Solar-WP, three BHEs were put down at a test site in Hameln / Germany. A long-time oscillatory thermal response test was conducted, running through 7 different excitation frequencies. BHE North shows significant phase shift at high frequencies that may indicate a low BHE quality.



Conclusion

We could show that the thermal response test can be improved by adding oscillatory heat injection to the constant injection. The evaluation of the amplitude and phase of the resulting system response provides additional information about the thermal properties of the system. Numerical parametric studies were used to derive the dependence of the signal response on the involved thermal parameters.
The results of the COMSOL models permit to understand the thermal responses of in-situ geothermal setup and will be used for the further development of the new method in the future.

Any question or comments?

Please Contact me!

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