VIA University College, Horsens

Evaluation of the potential for geological heat storage in Denmark

Modelling of heat storage
- temperatures, efficiency and environmental impact

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Outline

- Modelling tool and capabilities (FEFLOW)
- BTES
- BTES-PTES hybrid storage
- ATES
- 3D temperature model for Denmark (boundary conditions)

Equations of state (FEFLOW)

$$S_s \frac{\partial h}{\partial t} + \nabla \cdot \mathbf{q} = Q$$

$$\mathbf{q} = -\mathbf{K} f_\mu \left(\nabla h + \frac{\rho_f - \rho_0}{\rho_0} \mathbf{e} \right)$$

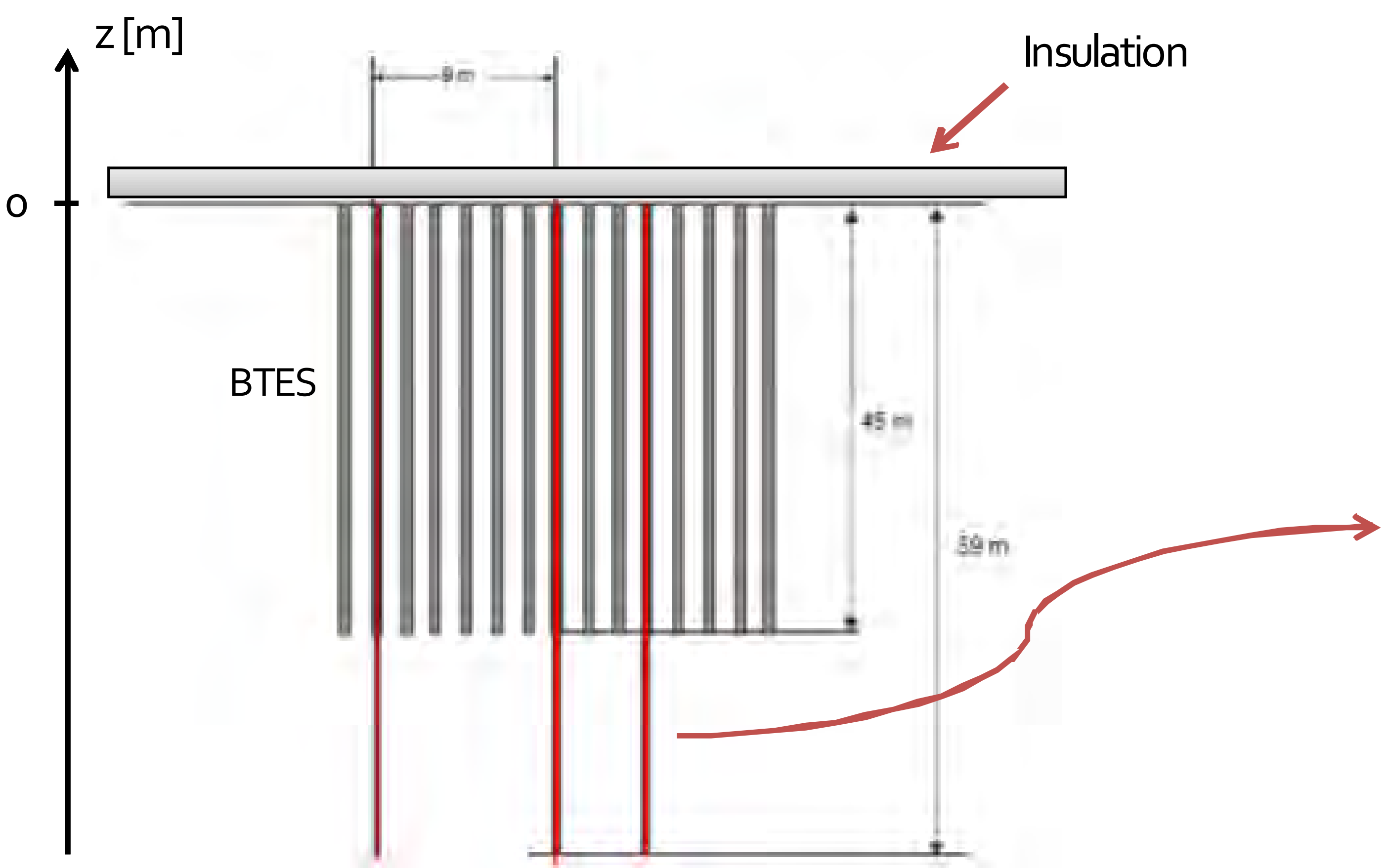
$$(\rho c)_b \frac{\partial T}{\partial t} = \nabla \cdot \left[\left(\lambda_\mathrm{b} \mathbf{I} + (\rho c)_b \mathbf{D} \right) \cdot \nabla T \right] - (\rho c)_f \, \mathbf{q} \cdot \nabla T + A$$

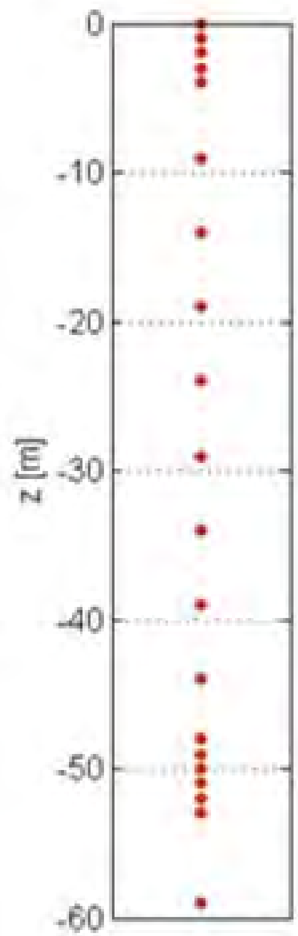
Special features

- Discrete feature elements
  - Fractures (e.g. chalk aquifers)
  - Water wells
- Separate BHE models
- Subdomain energy/fluid/solute budgets
- Model calibration (PEST)
- Application Programming Interface (API)

BTES

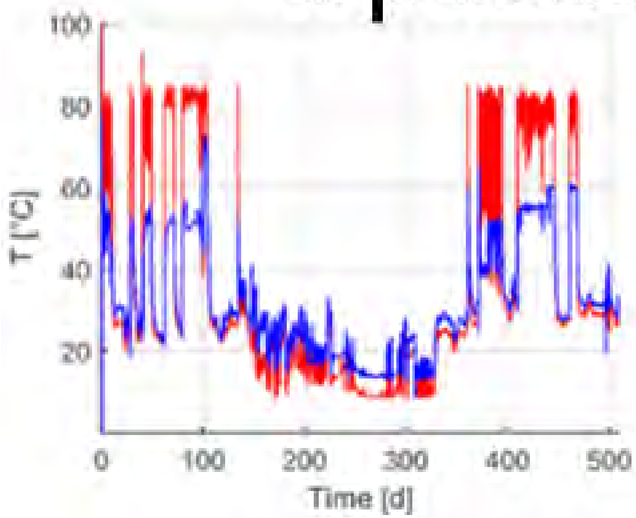
Temperature measurements Brædstrup

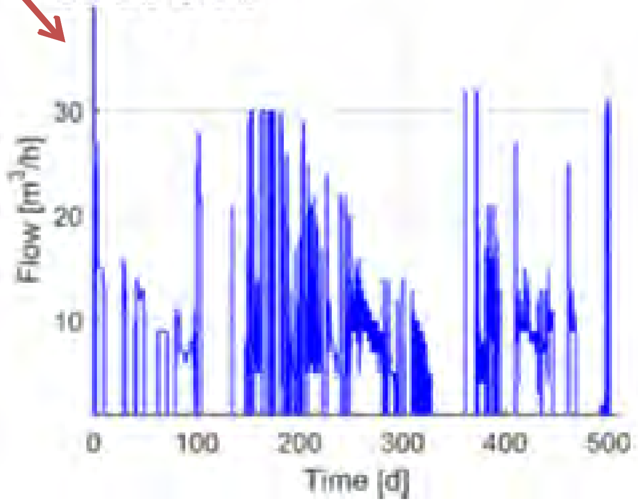


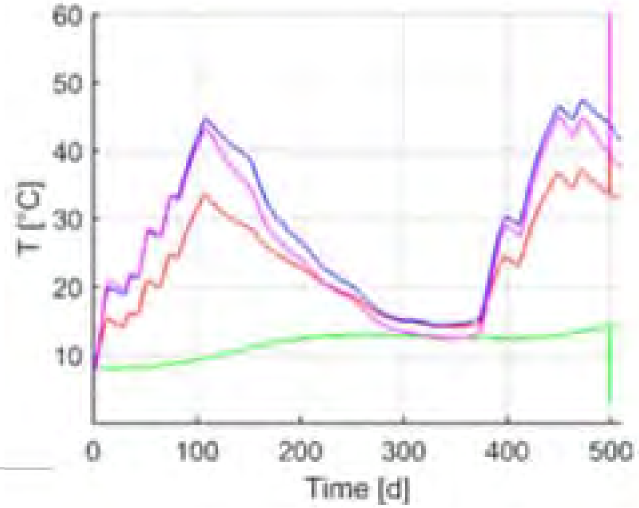


Manifold temperatures

Operational data

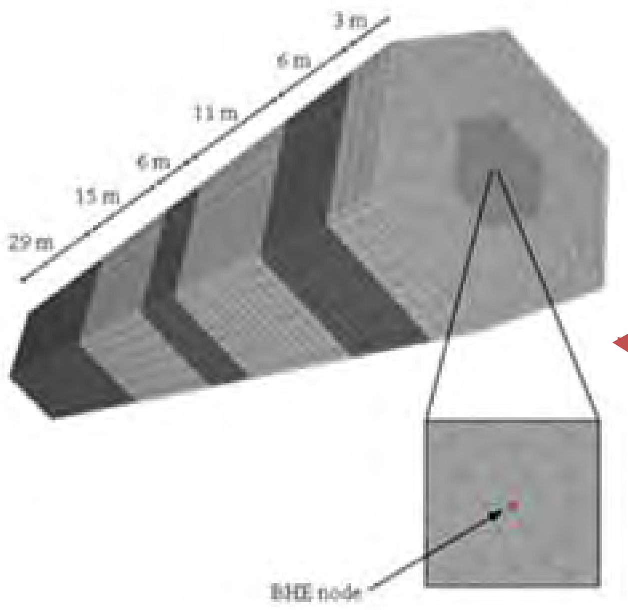






Soil temperatures at z = 1 m (purple), 14, m (blue), 44 m (red), og 51 m (green)

BTES FEM-model



TRT estimate
λ = 1.42 W/m/K
ρc = 1.9 $MJ/m^3/K$

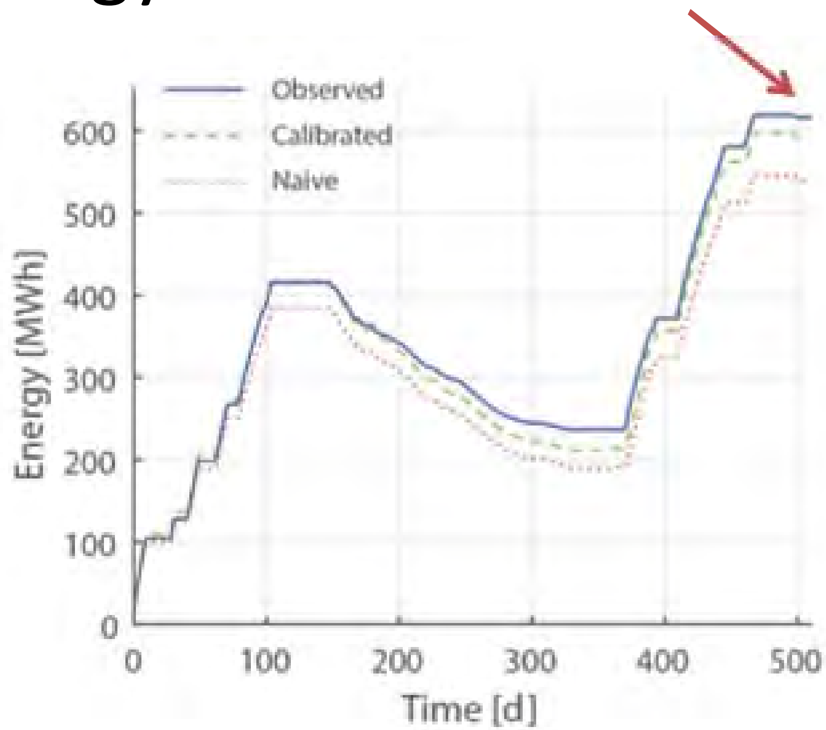
Estimate λ and ρc for each layer

Model validation

Predicted and observed energy balance

Reduces energy balance error from 12.5% til 4.0%

Lag	λ [W/m/K]	ρc [MJ/m³/K]
0 – 3m	2.27	2.03
3m – 9m	1.39	2.27
9m – 20m	1.63	1.75
20m – 26m	1.48	2.15
26m – 41m	1.75	1.94
41m – 70m	2.44	1.86

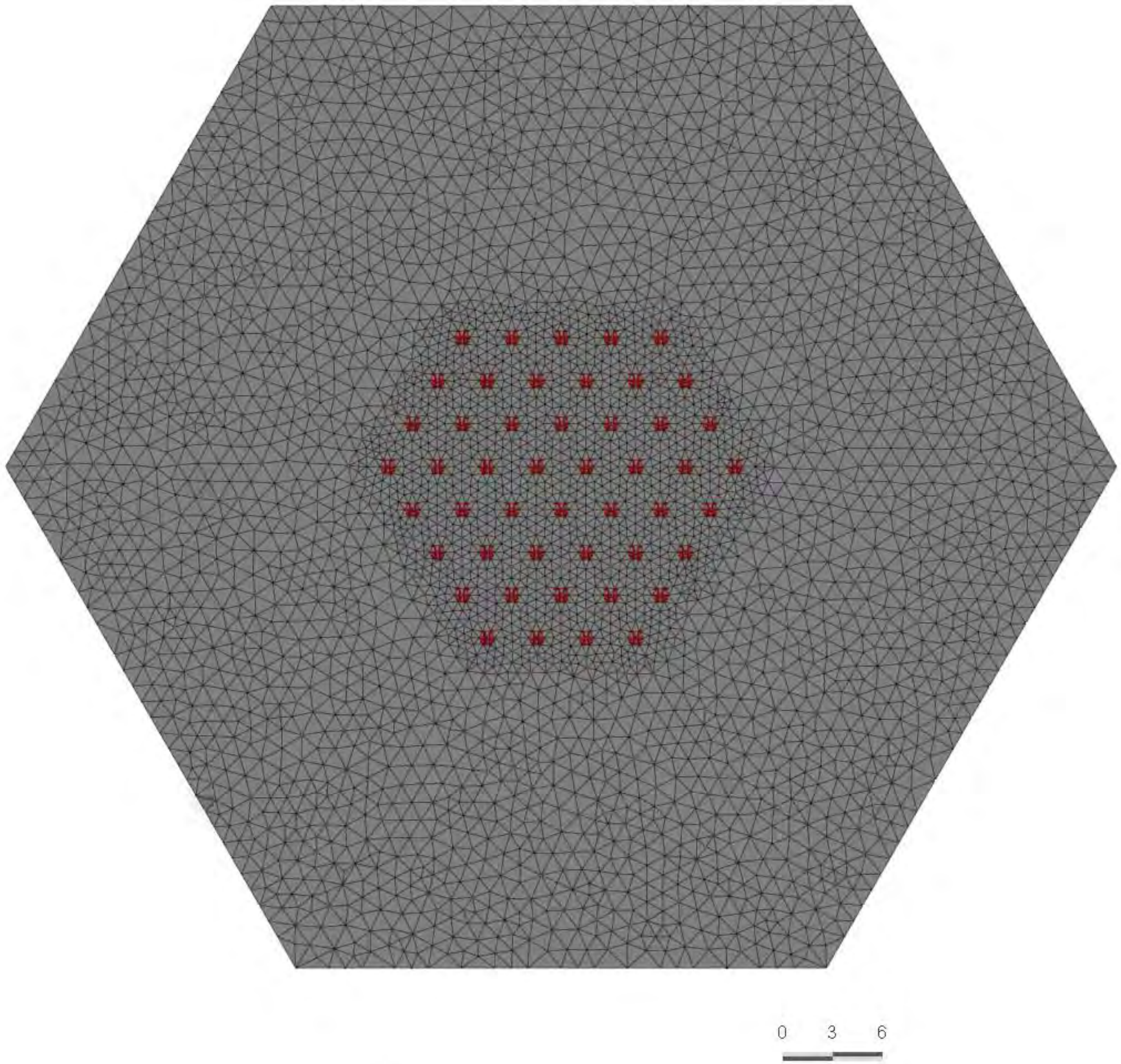


Scale effect! TRT scale -> pilot scale -> full scale(?)

Geophysical mapping to investigate scale effect?

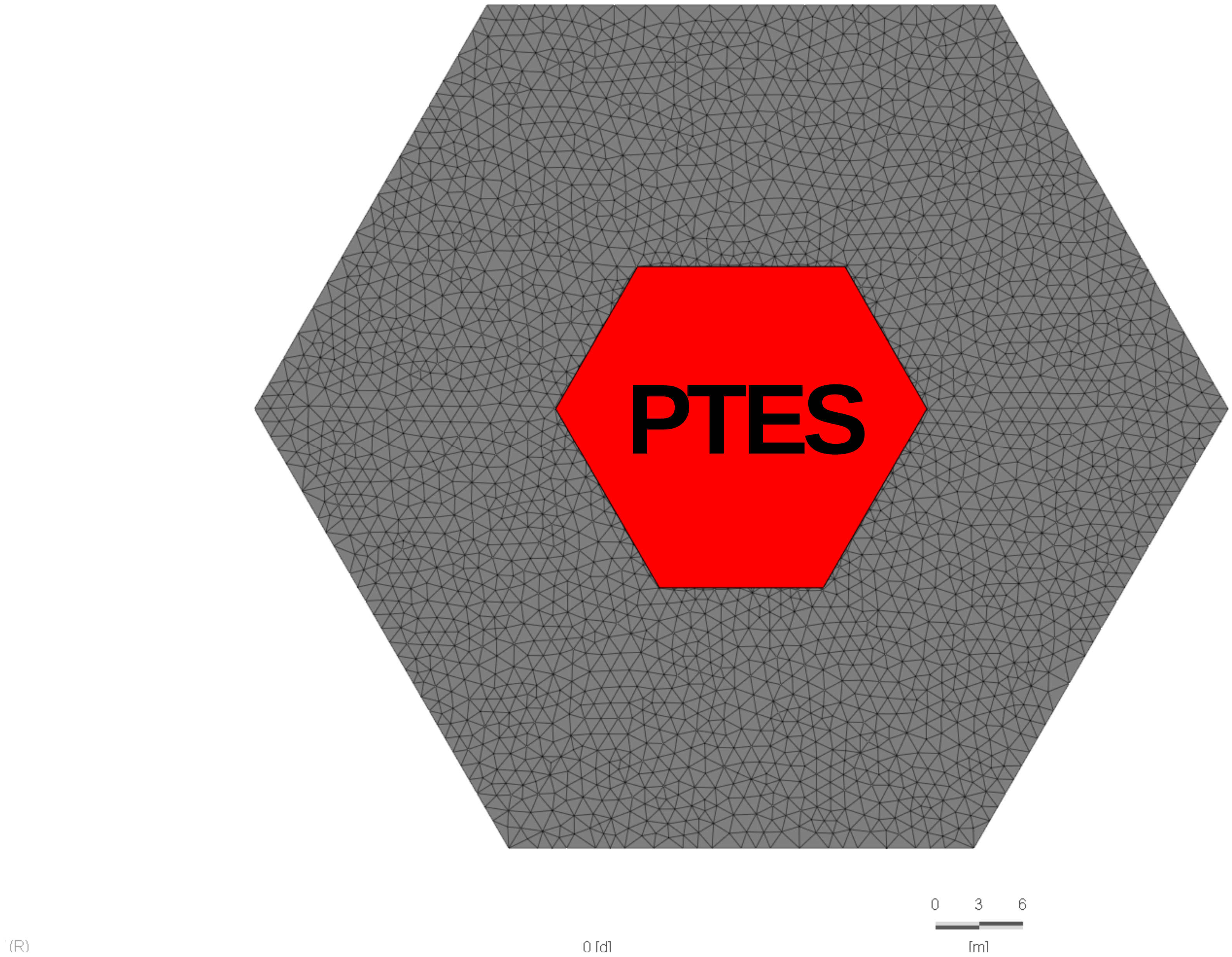
Tordrup, K. W., Poulsen, S. E., Bjørn, H., 2016. *Model analysis of operational data from pilot borehole thermal energy storage in Brædstrup, Denmark: calibration, validation and upscaling*, Renewable Energy (review).

PTES-BTES hybrid storage

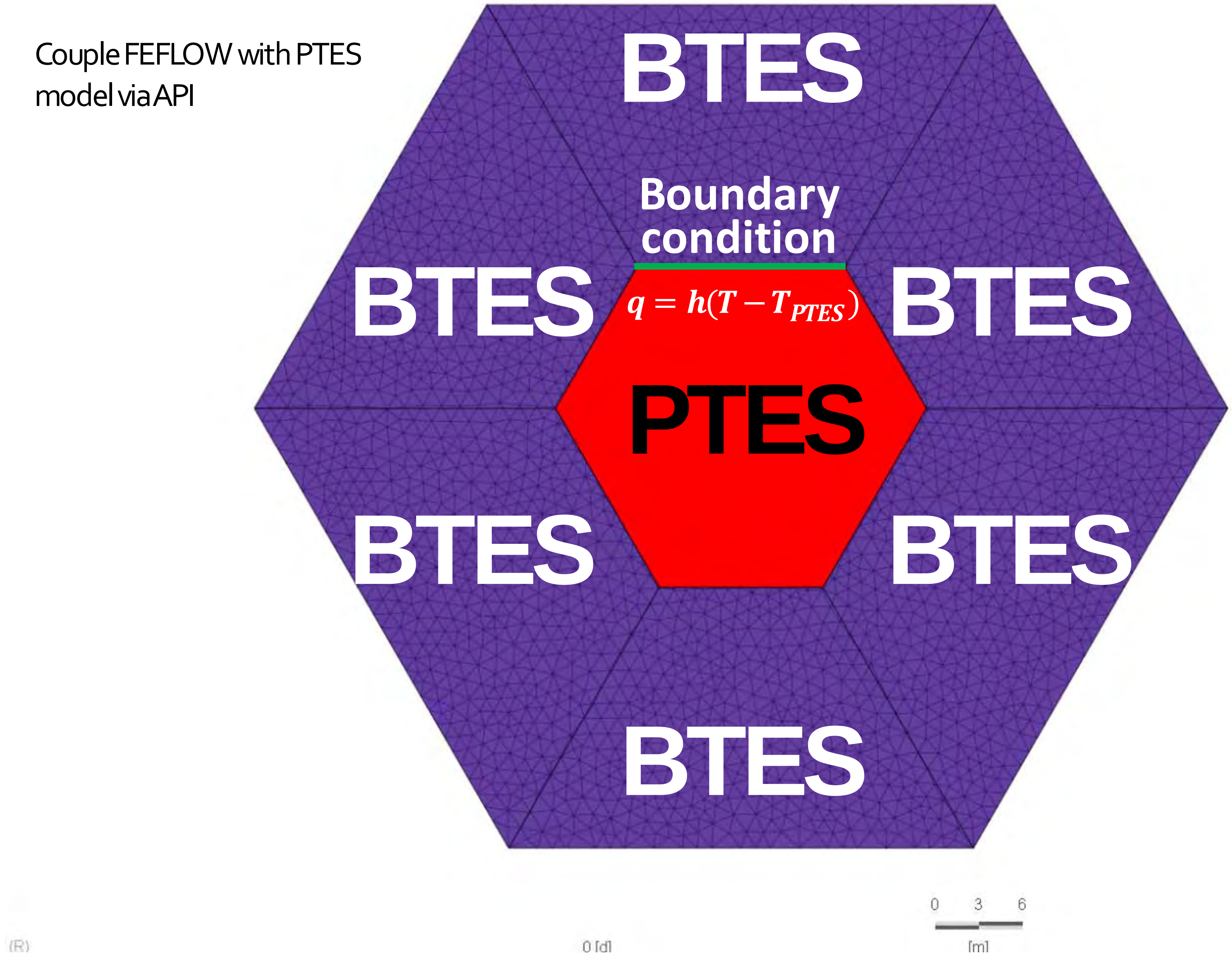


(R)

0 [d]


PTES
0
3
6
[m]
0 [d]
(R)

Couple FEFLOW with PTES model via API



ATES

A case study of urban Aquifer Thermal Energy Storage (ATES): geotechnical, ecological and environmental risks

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Geological setting and model

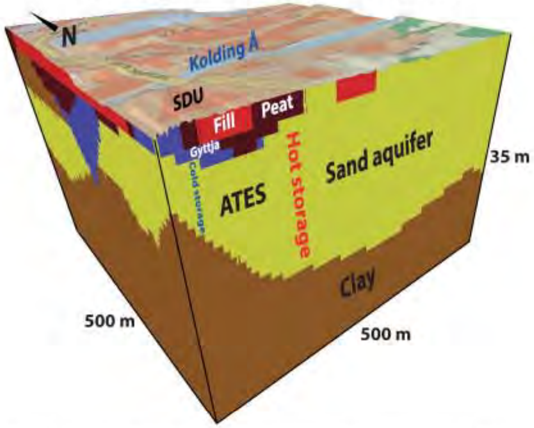


Figure 2: The hydrogeological setting and the voxel representation in the advection-dispersion heat transport FEM model utilized in the risk assesment. The ATES wells are screened in a large sand aquifer bounded by fill material, gyttja and peat on top and clay in the bottom.

Structural risk to the Design School building?

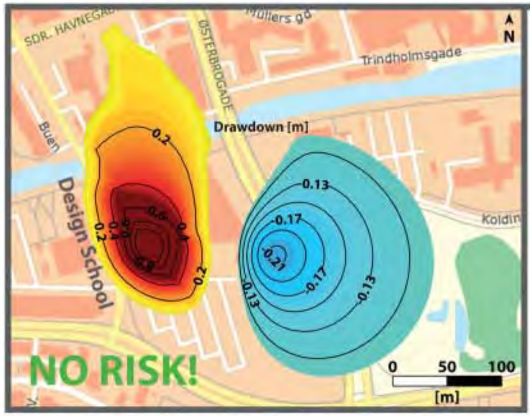


Figure 3: The foundation of the Design School building is threatened by subsidence from the cone of depression at the cold storage during summer. Maximum drawdown at the foundation of the building is approximately 20 cm and the associated geotechnical risks are deemed insignificant by the authorities.

Field site (city of Kolding, Denmark)

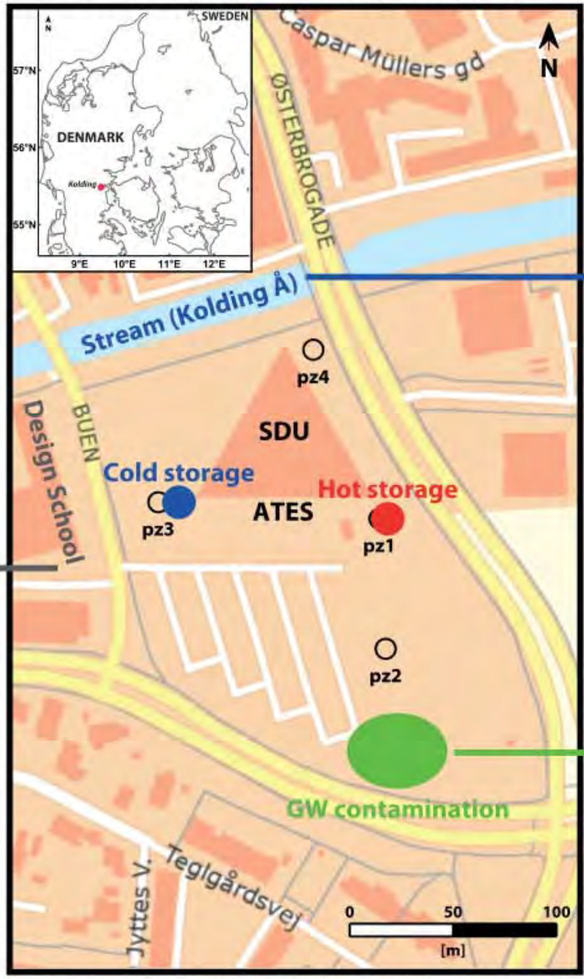


*Figure 1: The heating and cooling of the SDU building (University of Southern Denmark) near Kolding Å (stream) is supplemented by an ATES system. Four piezometers (**pz1-pz4**) are installed in close proximity of the ATES system. The Design School building is situated just 50 m west of the cold storage ATES well. An existing groundwater (GW) contamination is located ca. 100 m south of the ATES wells. The ATES system is expected to deliver 340 and 353 MWh/yr of heating and cooling, respectively.*

Ecological impact from perturbed GW temperatures?

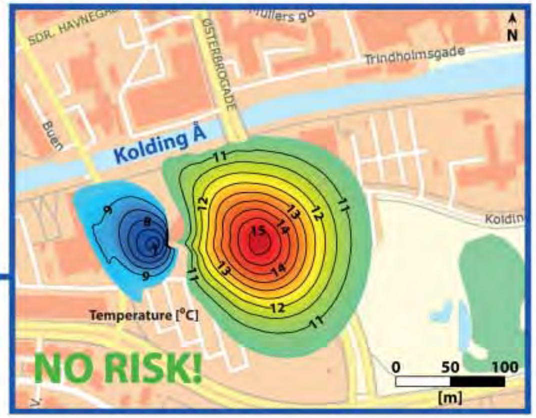


Figure 4: Groundwater temperatures in the sand aquifer following 10 years of operation. The temperature of the groundwater that discharges to Kolding Å is within the natural variations in the temperature of the stream water. As such, ATES operation poses no threat to the ecological conditon of Kolding Å.

Further mobilization of GW contamination?

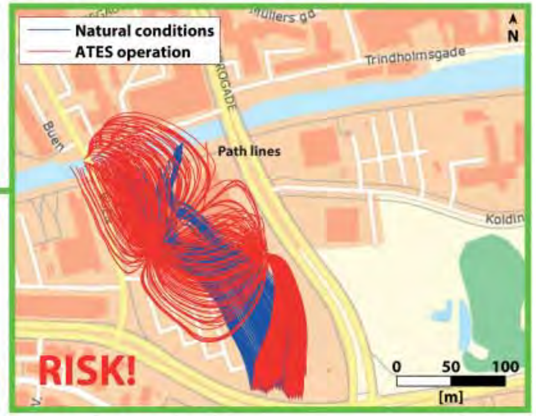
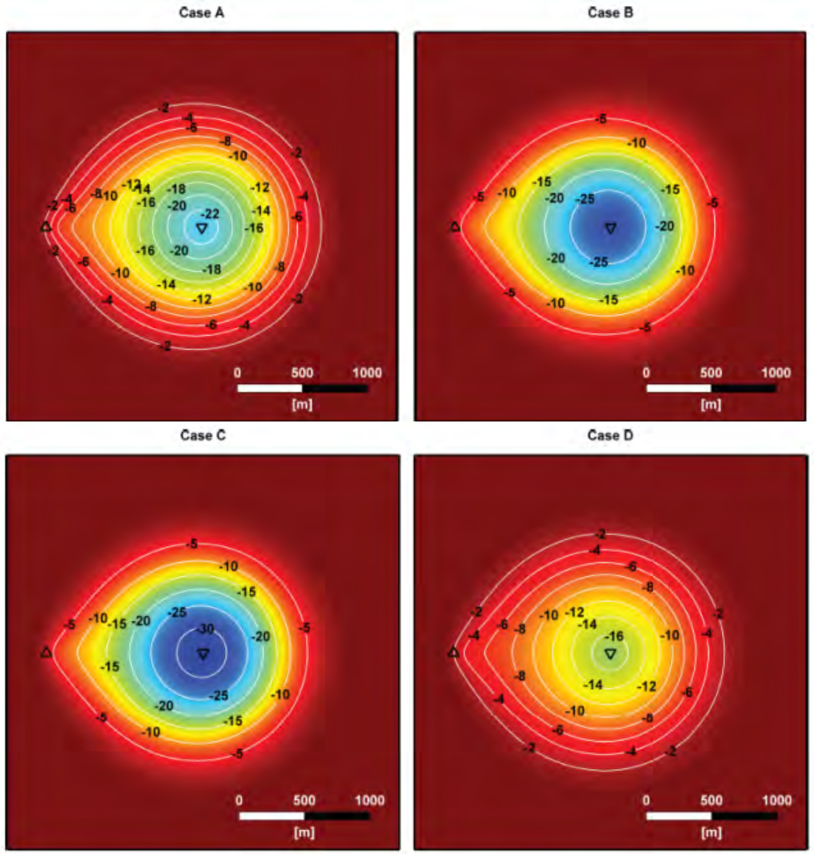
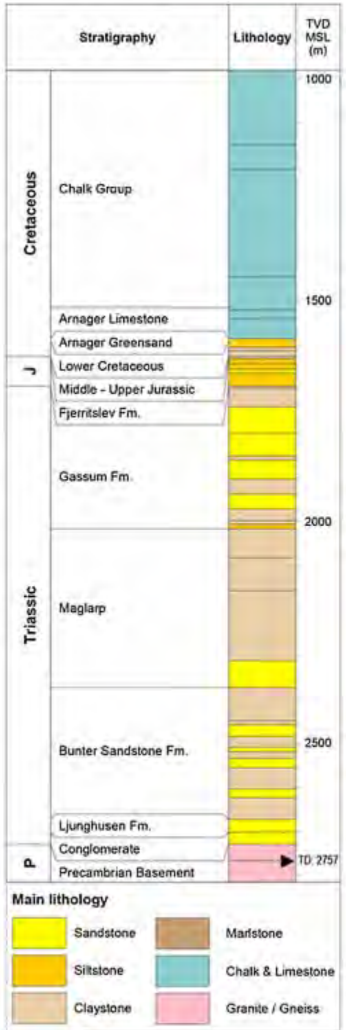


Figure 5: Steady-state particle paths for the existing GW contamination given that water is pumped from the hot storage at the maximum monthly average abstration rate (12.5 m^3/h). The contamination reaches the pumping well and is injected back into the aquifer at the cold storage well. Contamination discharges to Kolding Å and to the pumping well at the hot storage, respectively. ATES operation causes significant dispersion of the contamination. Implementation of active remediation in the ATES system should be considered.

Deep low-enthalpy reservoirs

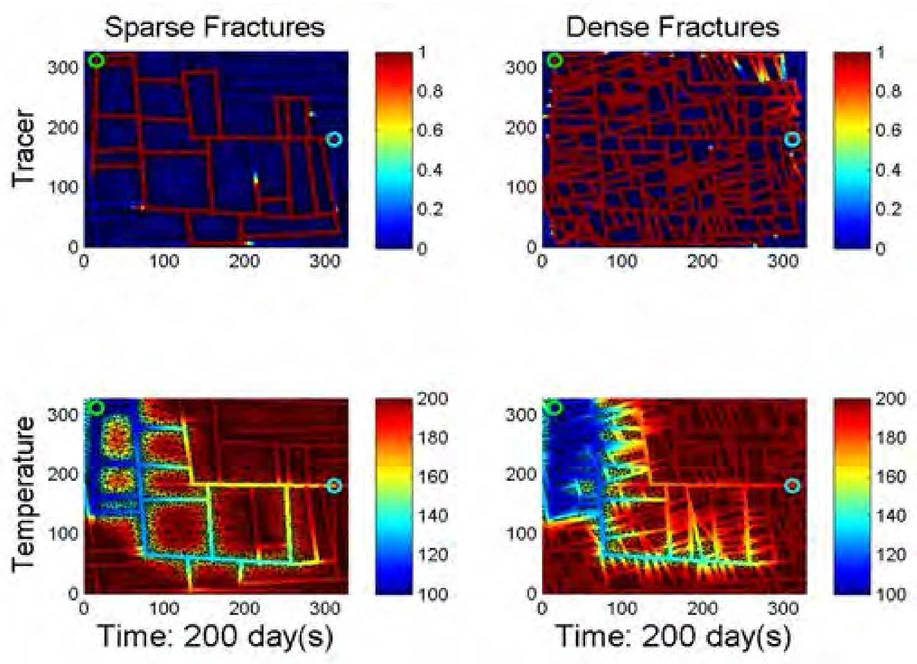
Reservoir simulations

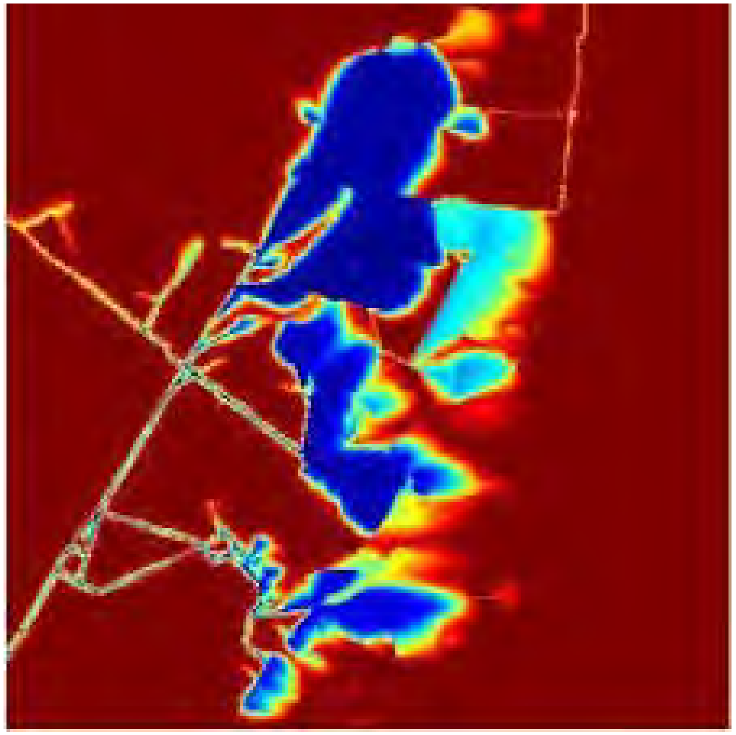




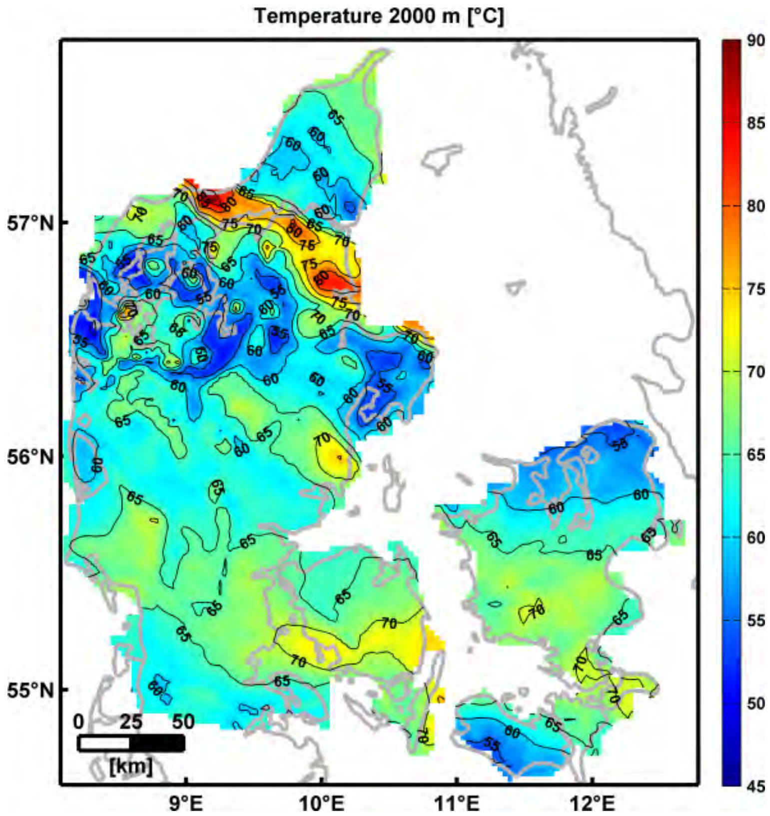
Poulsen, S. E., Balling, N., Nielsen, S. B., 2015. *A parametric study of thermal recharge of low enthalpy geothermal reservoirs*, Geothermics, 53, pp. 464–478.

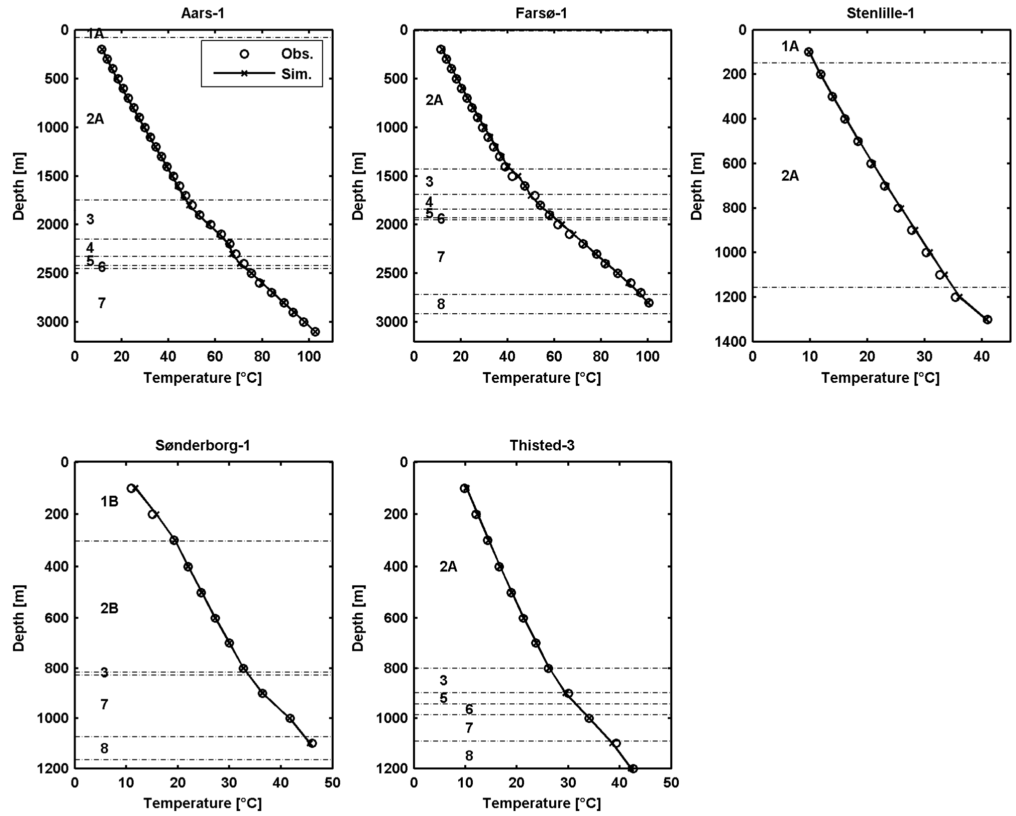
Heat transport in fractured chalk





3D temperature model for Denmark (boundary conditions)





Poulsen, S. E., Balling N., Bording, T. S., Mathiesen, A., Nielsen, S. B., 2016. *Regional-scale subsurface temperature modelling with inverse calibration methodology: application to Danish sedimentary basins*, Geothermics (submitted).

Use of modelling

- Parameter studies
- Storage efficiency estimation
- Long-term predictions
- The impact of storage temperatures and geology/lithology on the subsurface temperature distribution
- Measurement strategy (where and when?)