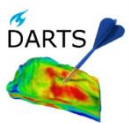


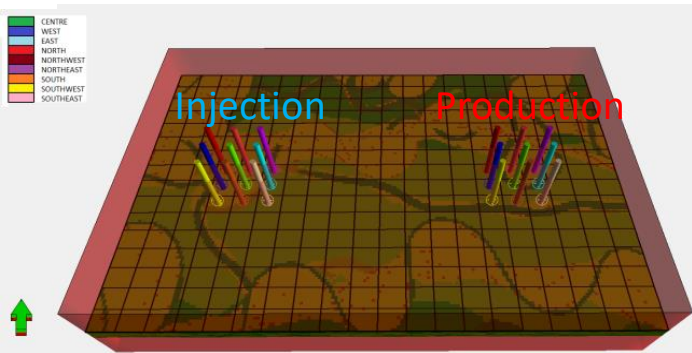
The Impact of Heterogeneity on Geothermal Production: Simulation Benchmarks and Applications

Presenter : Yang Wang

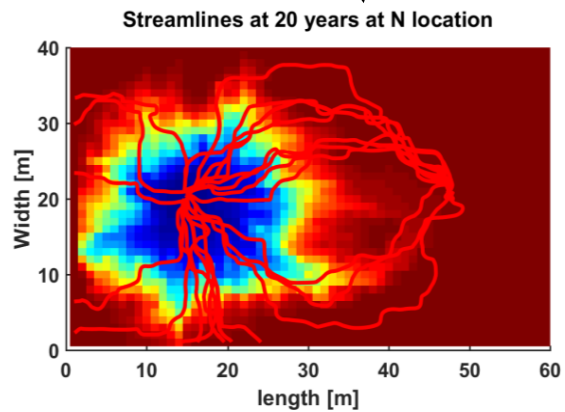
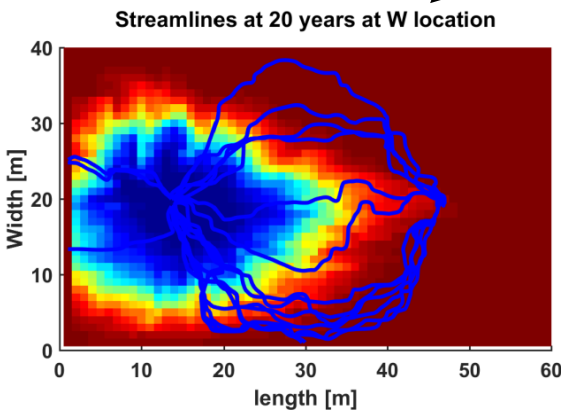
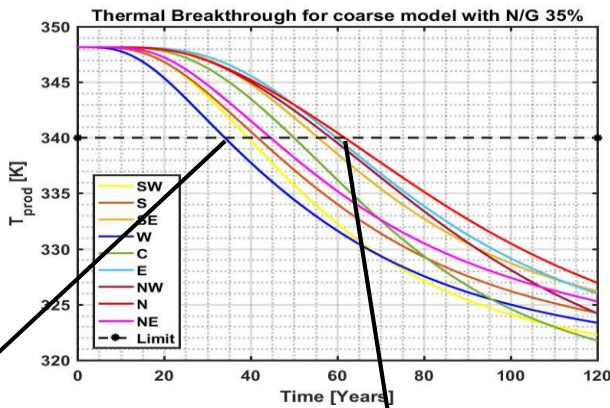
Introduction : Subsurface heterogeneity



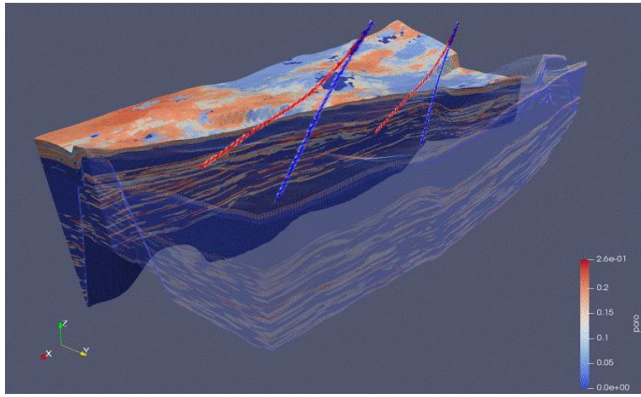
Synthetic model



Process-based analog for DAP well

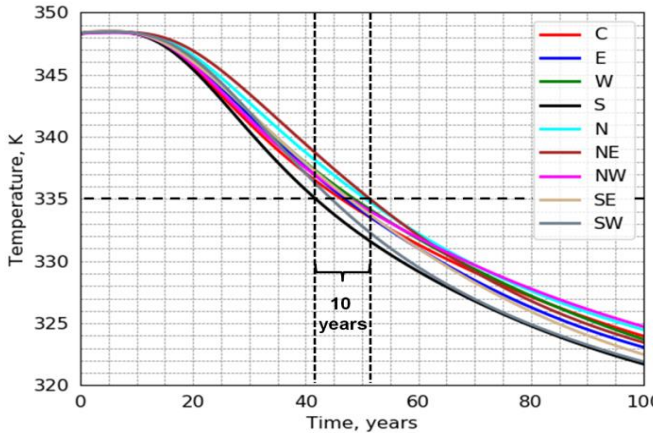


Realistic model



shale:
2.4M grid blocks
sandstone:
0.8M grid blocks
highly heterogeneous

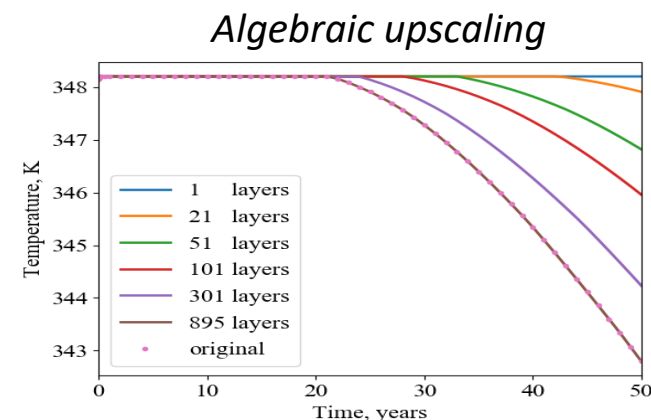
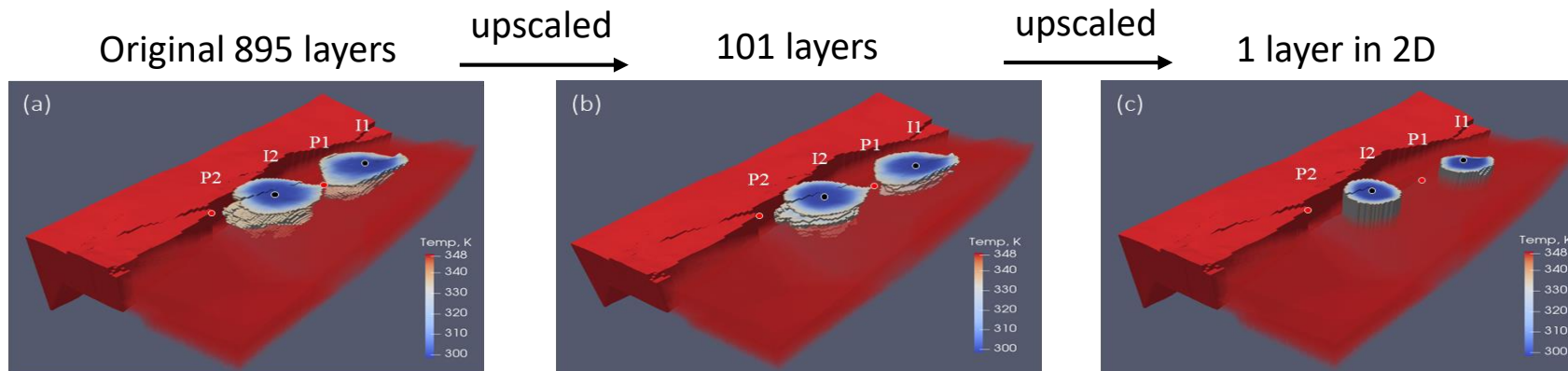
West Netherlands Basin



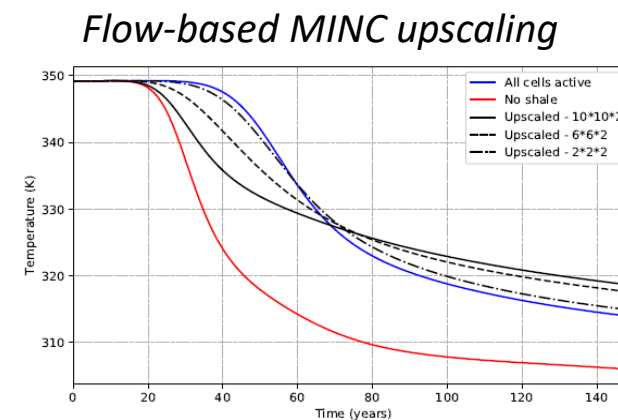
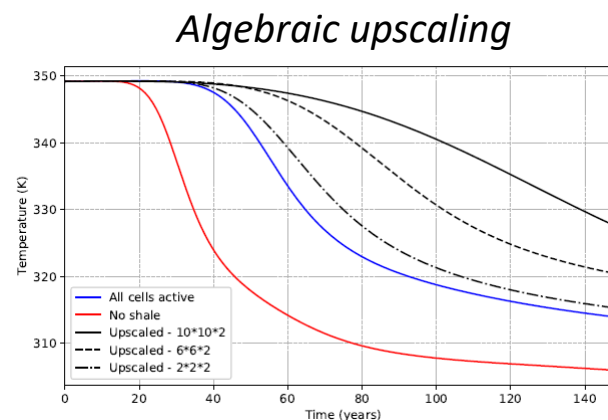
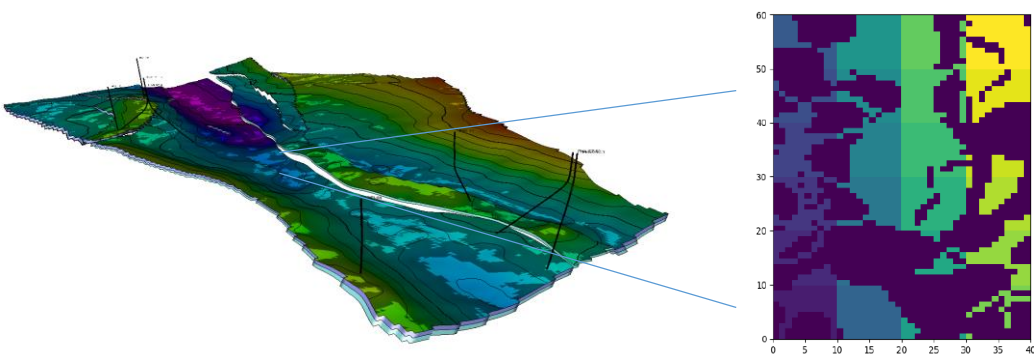
Heterogeneity can largely alter the fluid flow path under different well placements.

Introduction : Model representation

Realistic case (vertical upscaling)



Test case



Perkins, 2019

- *Conventional method of upscaling doesn't work for geothermal simulation.*
- *2D simulation can hardly be representative for a 3D model.*

Introduction : What is our tool?

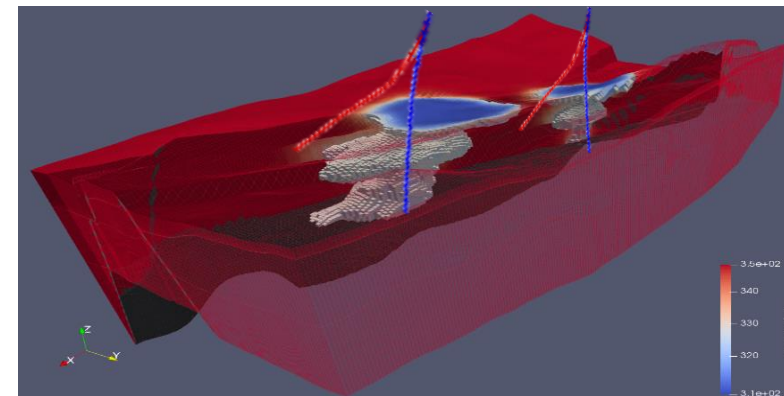
Delft Advanced Research Terra Simulator

<https://darts.citg.tudelft.nl/>

- accuracy
- efficiency
- robustness
- ✓ benchmarked (vs TOUGH2 for geothermal)
- ✓ support CPU (OpenMP) and GPU architectures
- ✓ handle intricate structures
- ✓ deal with multiple complex physical processes

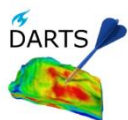
Geothermal model:

- 3.2M active reservoir blocks
- 50-years development
- 2 unknowns per block
- CPU: **40 min**, CPU*: **16 min**, GPU: **3.5 min**

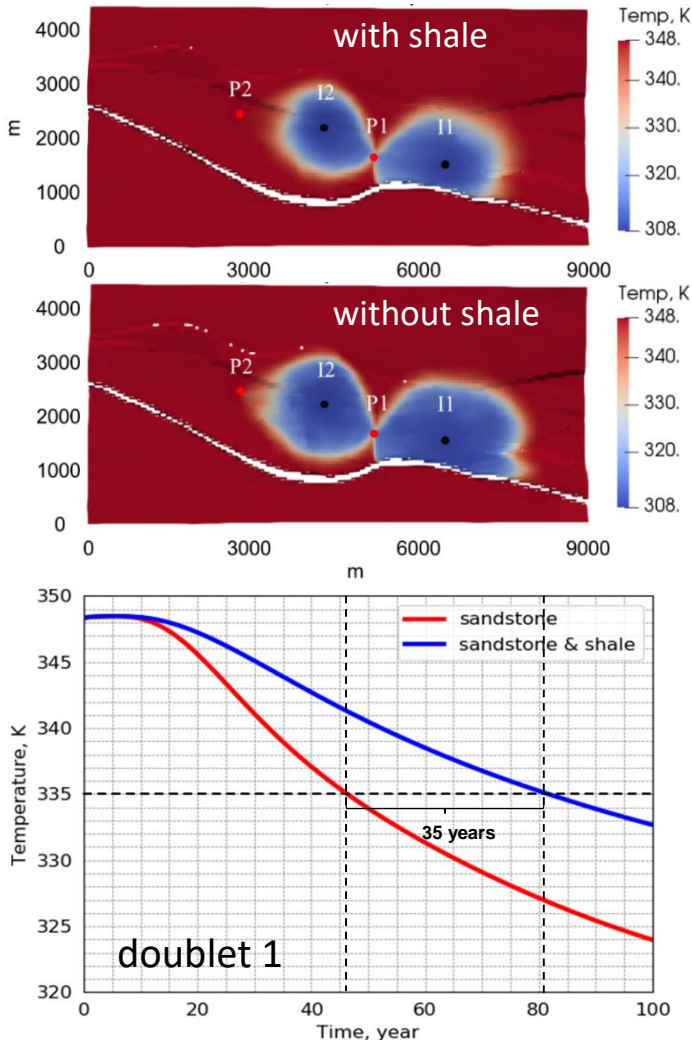


DARTS: A powerful geothermal simulator

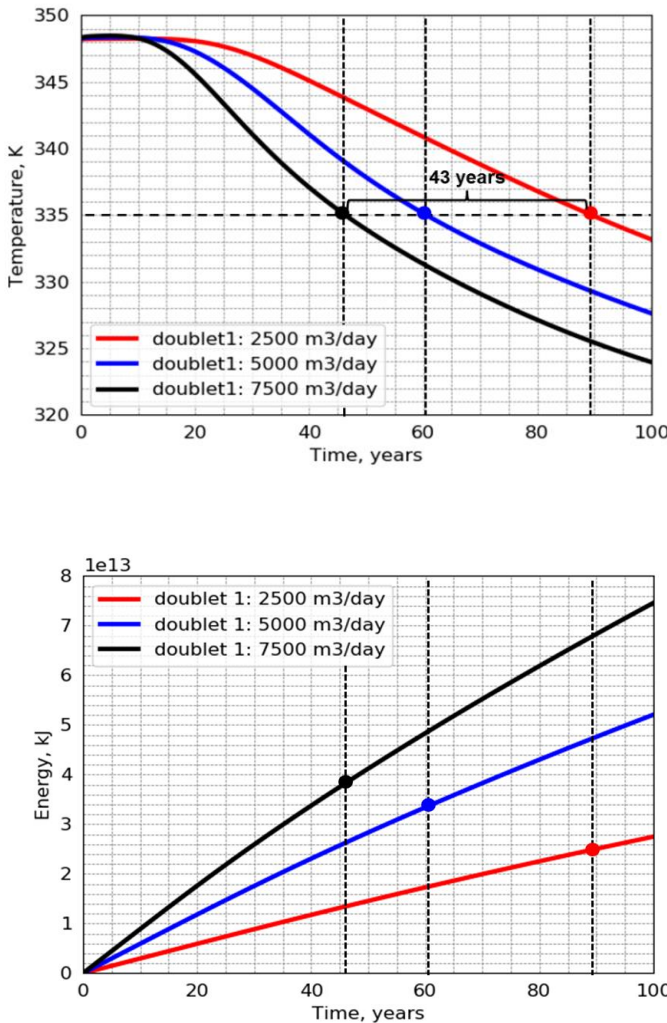
Sensitivity Analysis



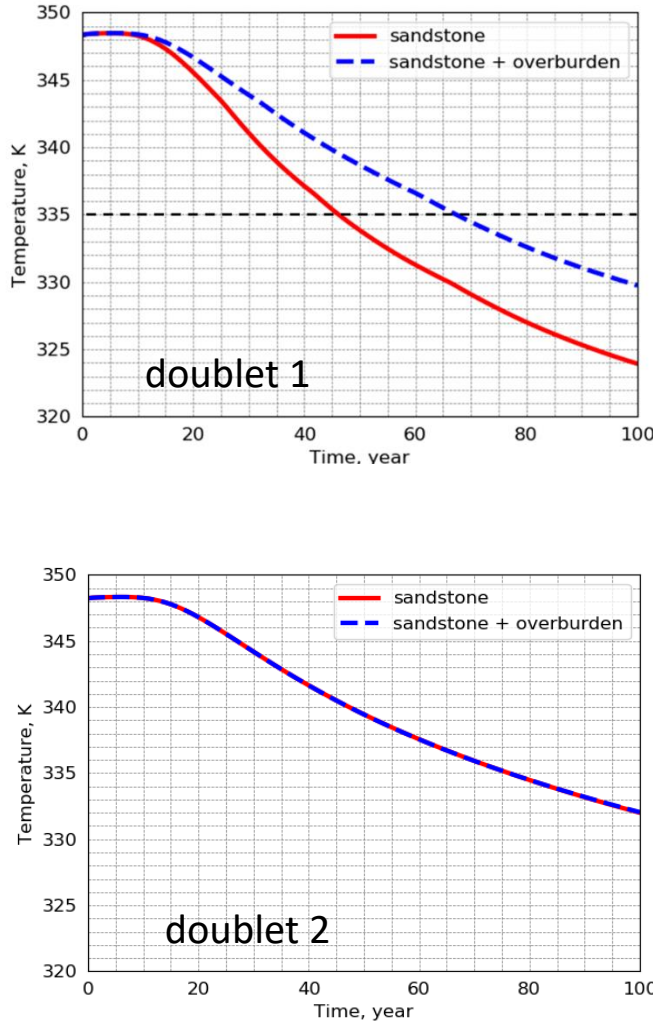
Shale facies



Flow rate



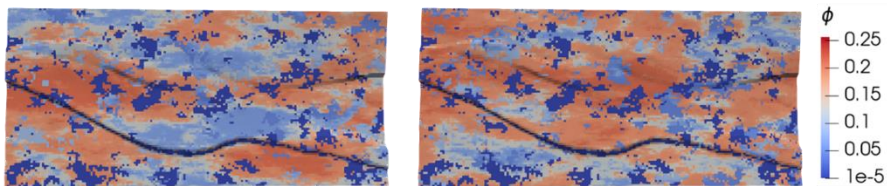
Overburden



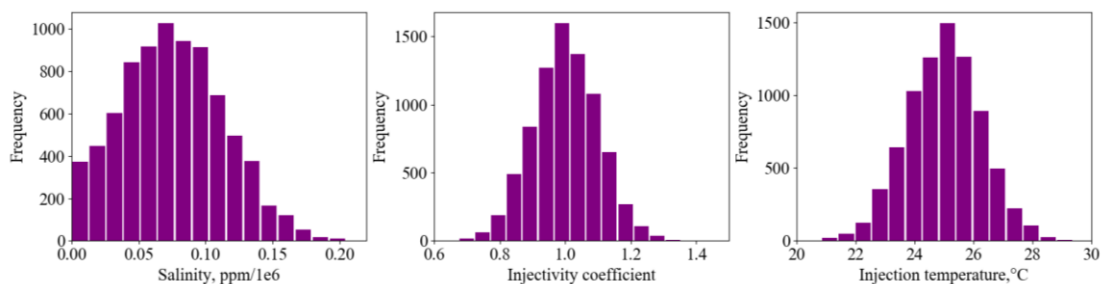
Uncertainty quantification

- Geological parameters

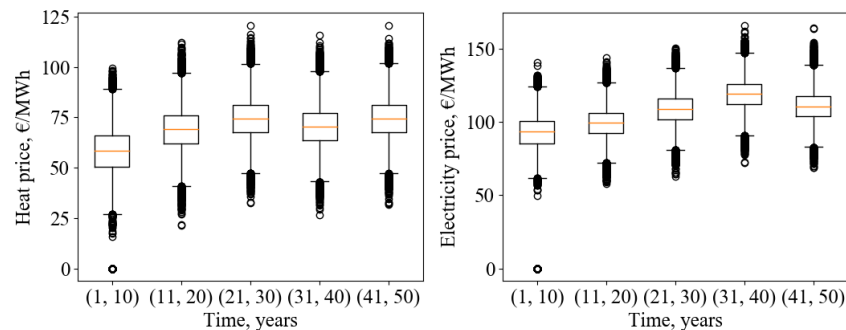
different $\phi - k$ distribution



- Physical parameters

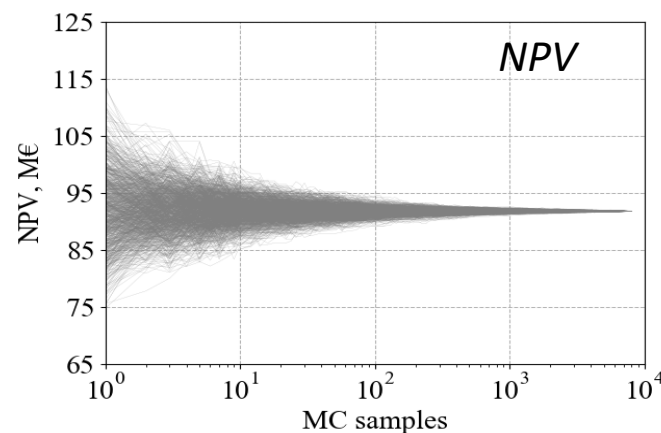


- Economical parameters

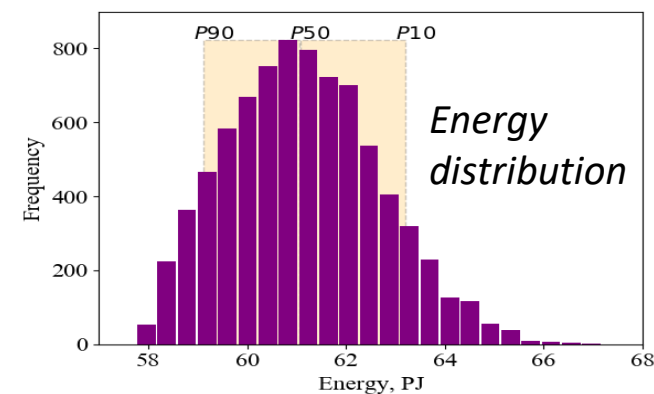
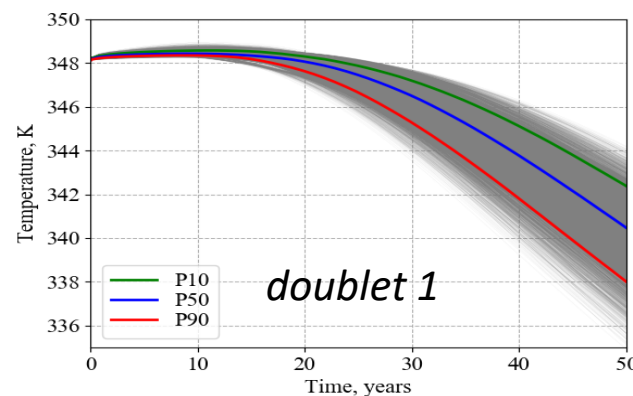
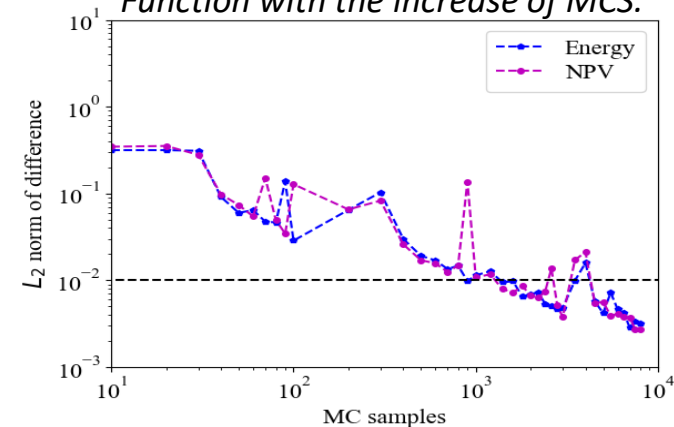


Totally 8000 Monte Carlo Simulations of 50-years development

- GPU version of DARTS
- 16 GPU cards running in parallel
- Totally <30 hours! (On average 3.47 min/simulation)



The variation of Probability Density Function with the increase of MCS.

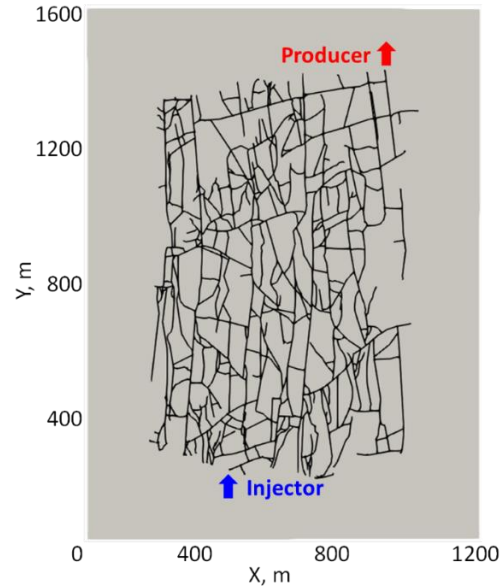


Large uncertainty exists in the system output.

Realistic fracture network

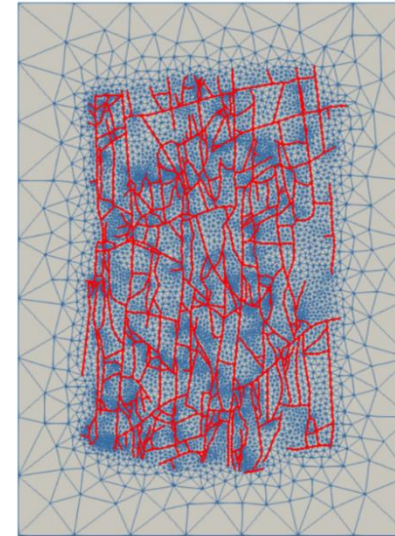
High-enthalpy reservoirs contain large heat potentials.

- The Geysers, USA
- California well, Netherlands

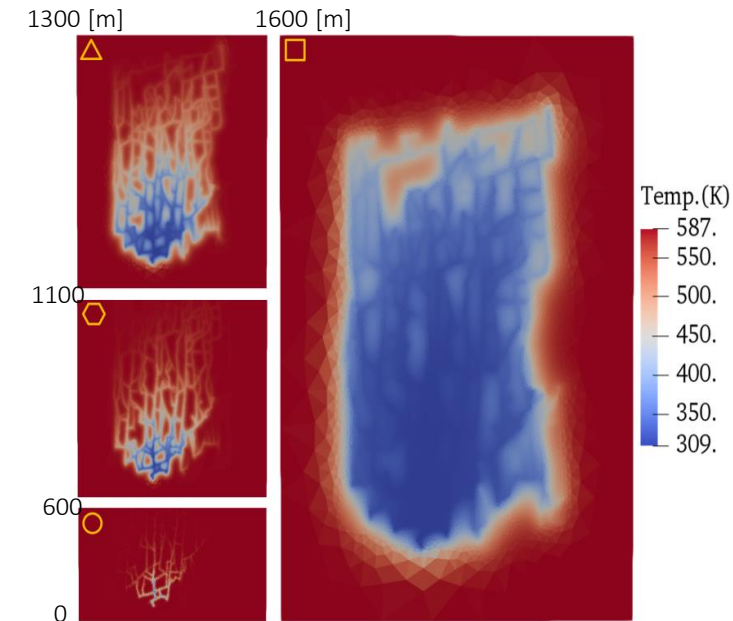


Generated from outcrop
(2148 fracture segments)

Boersma et al., 2015



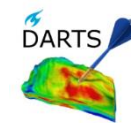
Mesh discretization



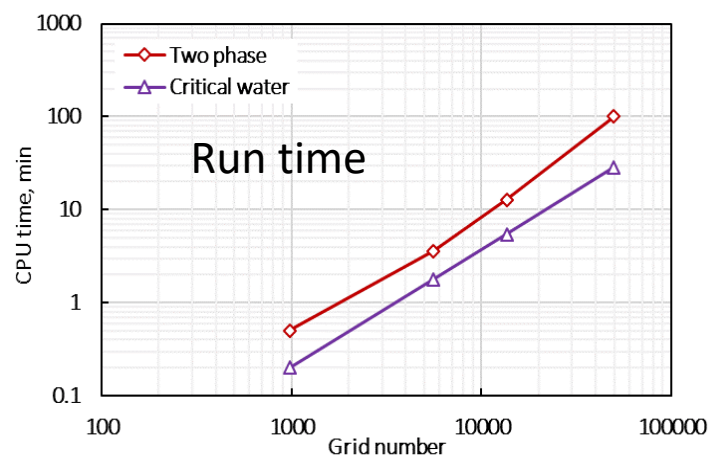
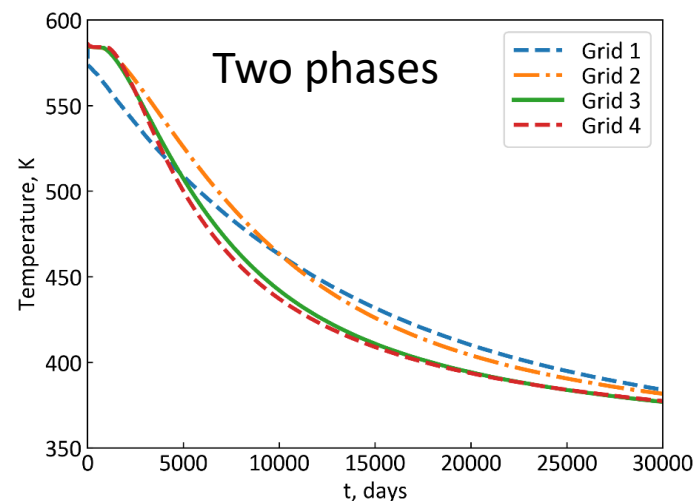
Evolution of the temperature plume

- High-enthalpy thermal flow
- Fractured reservoir
- Discrete Fracture Model (DFM)
- Dynamic heat transfer

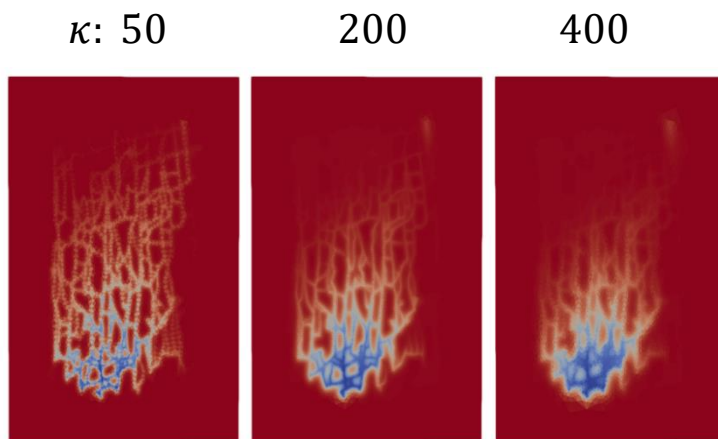
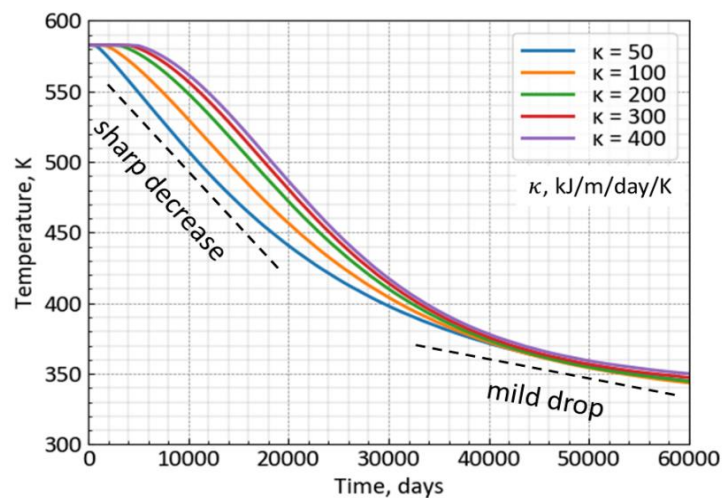
Heat transfer dynamics



Mesh convergence

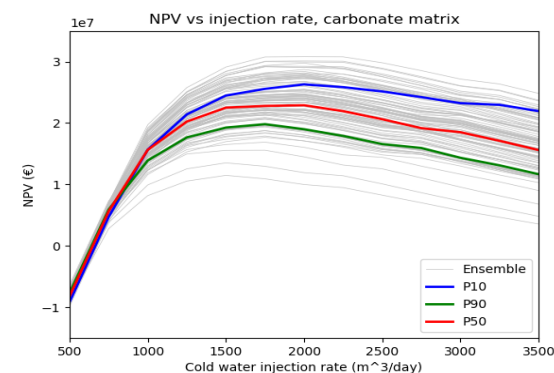
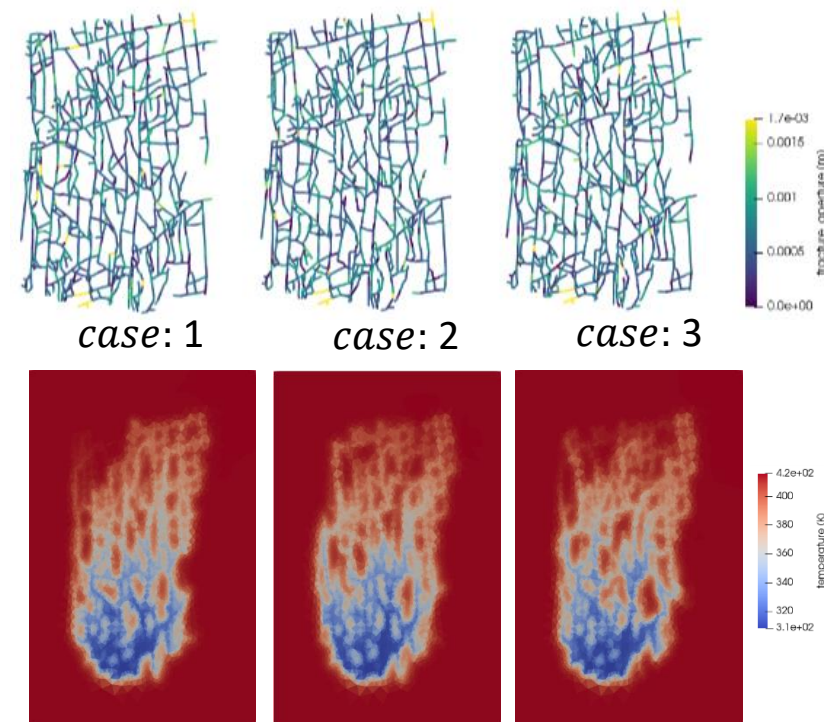


Rock heat conductivity

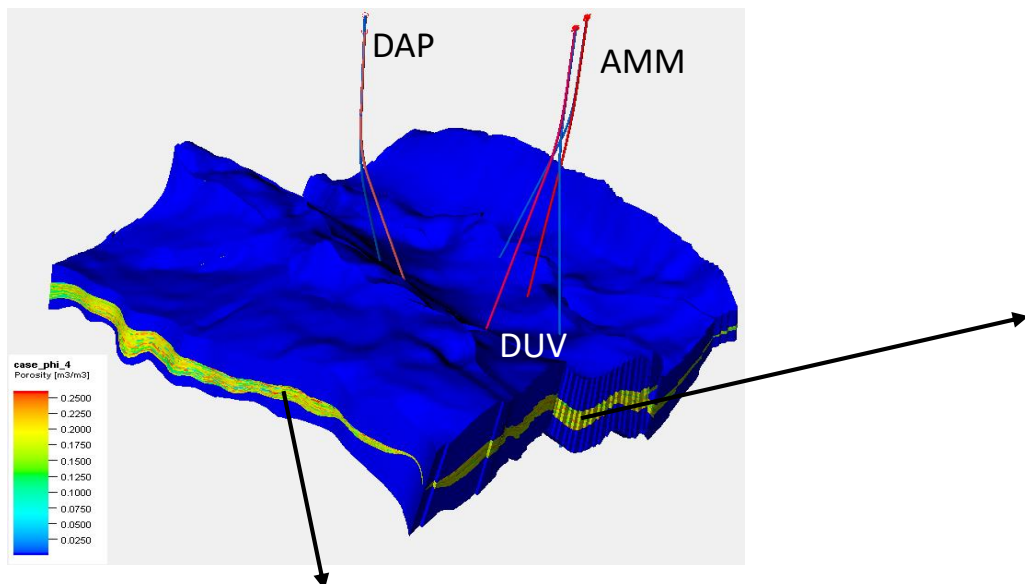
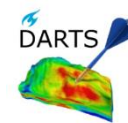


Fracture aperture distribution

van der Kooij, 2020



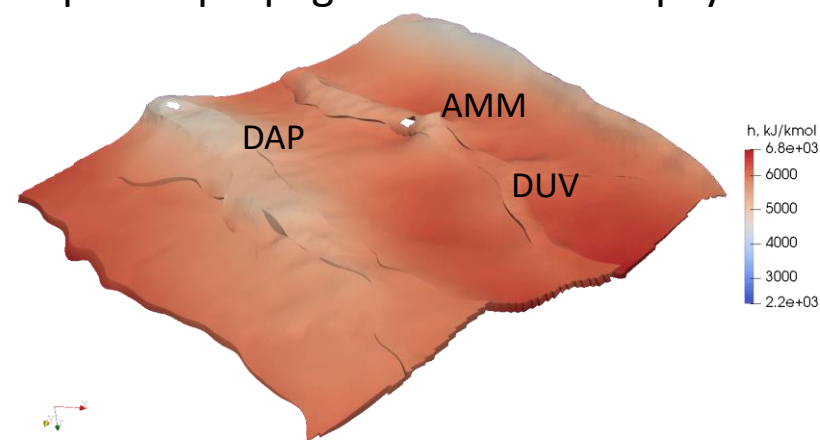
Delft Aardwarmte Project (DAP)



Permeability distribution of one realization

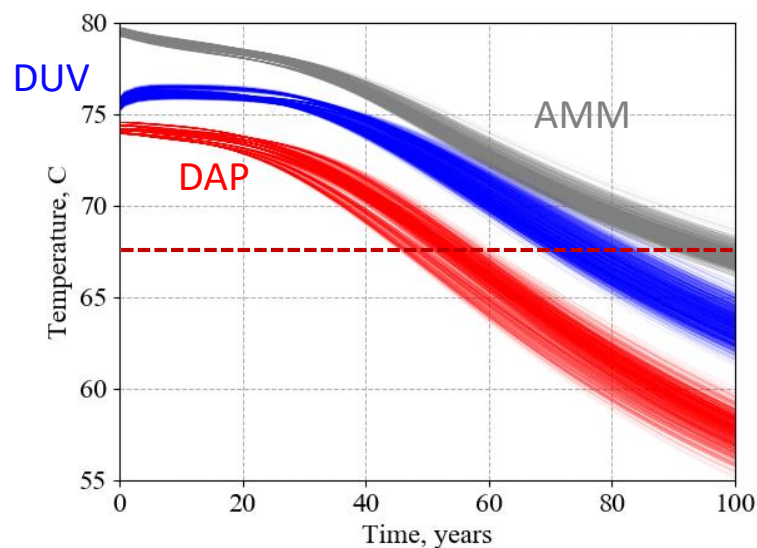


Cold plume propagation within the payzone

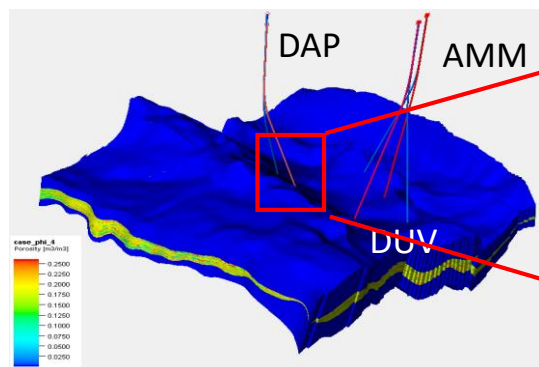


Total simulation time: 100 years

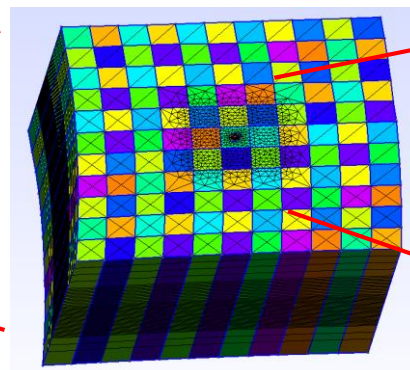
Production temperature of the 3 doublets



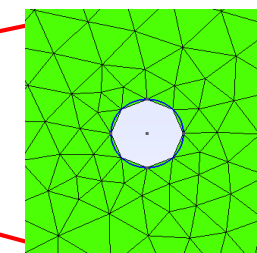
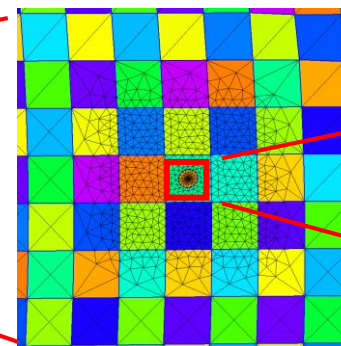
Transient analysis and monitoring



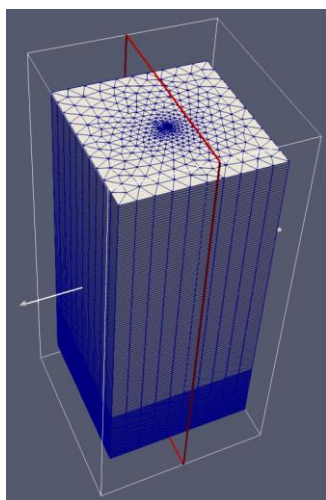
Petrel model



Gmsh model

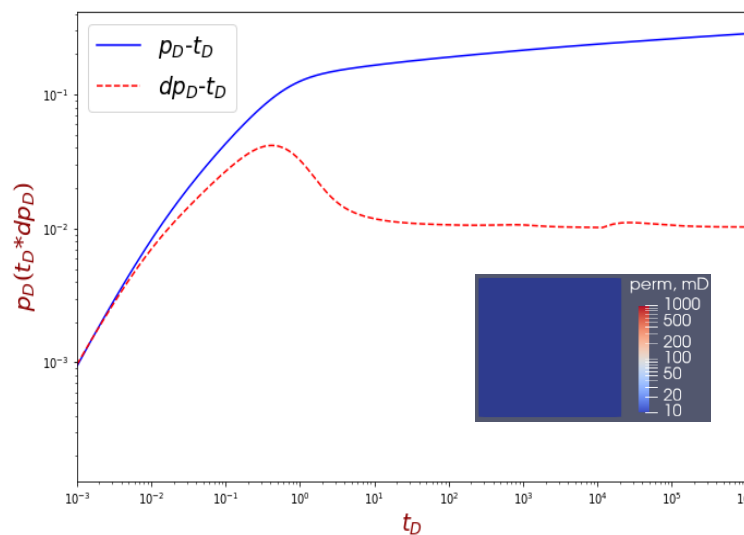


Mesh size surrounding the wellbore equalizes to the well radius (0.1 meter).

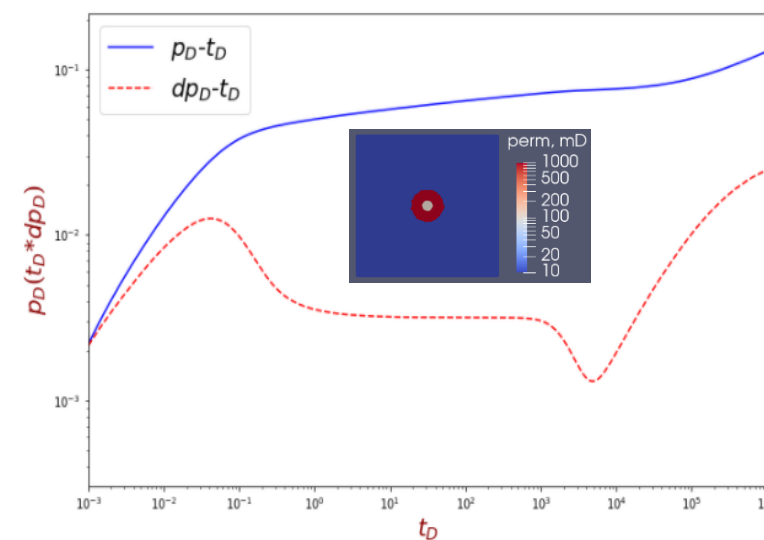


Model size(x*y*z, meter): 500*500*1000

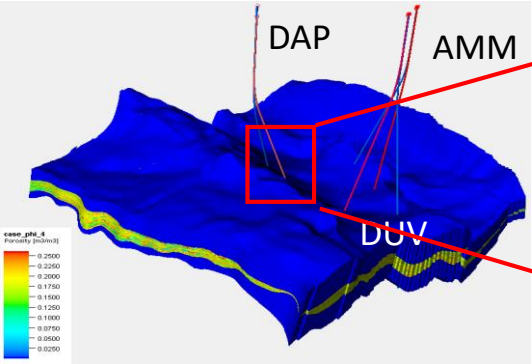
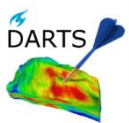
Homogeneous



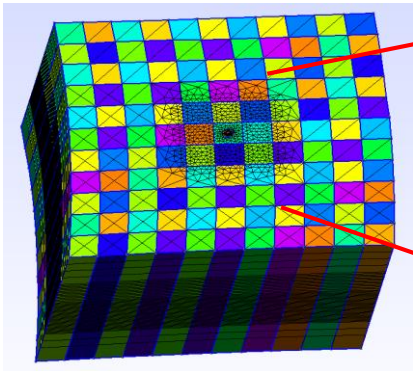
Heterogeneous



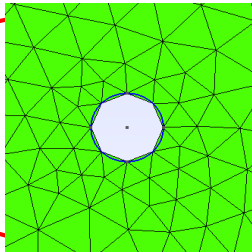
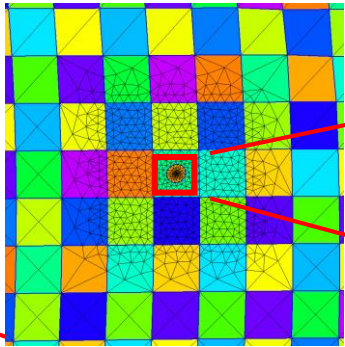
Wellbore Heat Loss



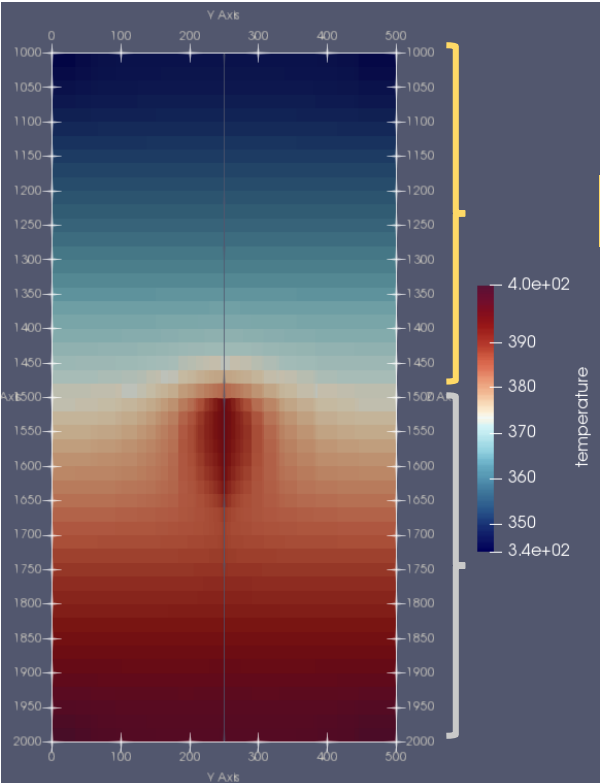
Petrel model



Gmsh model

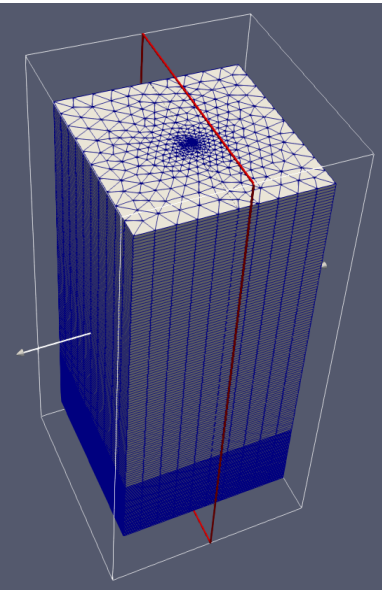


Mesh size surrounding the wellbore equalizes to the well radius (0.1 meter).



Upper part of the wellbore is insulated.

Bottom part of the wellbore is non-insulated.

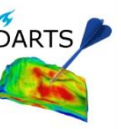


Model size(x*y*z, meter): 500*500*1000

Conclusions

- Heterogeneity matters to heat production /propagation in normal and fractured geothermal reservoirs.
- 2D representation can poorly reflect the characteristics and heat transfer in 3D models.
- Full uncertainty quantification helps to recognize the uncertainty of the system output.
- Multiphase thermal dynamics in fractured reservoirs can be impacted by various aspects.
- Detailed well model can help to calculate heat losses and interpret well measurements.

Acknowledgement



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- <https://darts.citg.tudelft.nl/>
- S. Shetty, D. Voskov, and D. F. Bruhn, Numerical strategy for uncertainty quantification in low enthalpy geothermal projects, in Workshop on Geothermal Reservoir Engineering (2018).
- Khait, M., Voskov, D., Zaydullin, R., 2020. High performance framework for modelling of complex subsurface flow and transport applications, ECMOR.
- Boersma et al., Fracture-fault network characterization of pavement imagery of the Whitby Mudstone, Yorkshire, (2015).
- D. Perkins, Reservoir Simulation for Play-based Development of Low Enthalpy Geothermal Resources: Application to the Delft Sandstone, Master thesis, TU Delft, (2019).
- R. van der Kooij, Performance of a deep, high temperature fractured geothermal system, Bachelor thesis, TU Delft, (2020).

Thank you!
Q & A