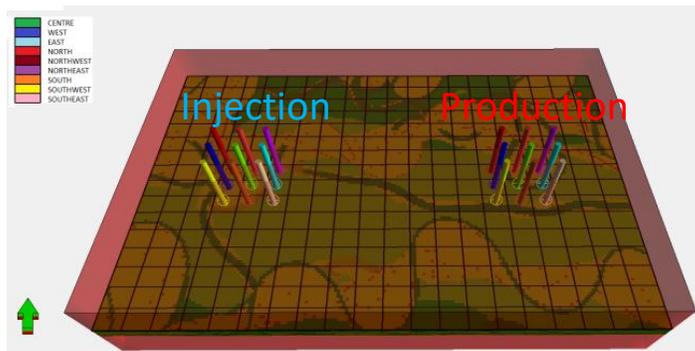


The Impact of Heterogeneity on Geothermal Production: Simulation Benchmarks and Applications

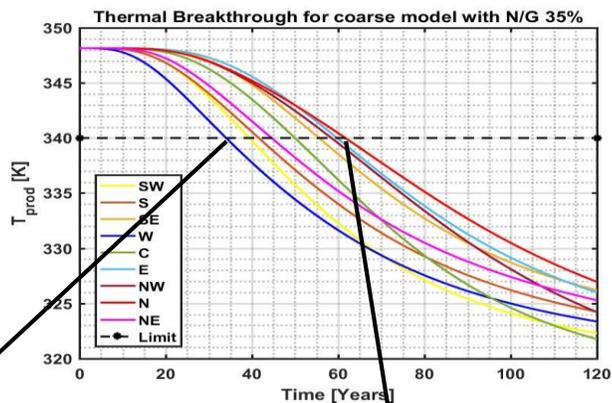
Presenter : Yang Wang

Introduction : Subsurface heterogeneity

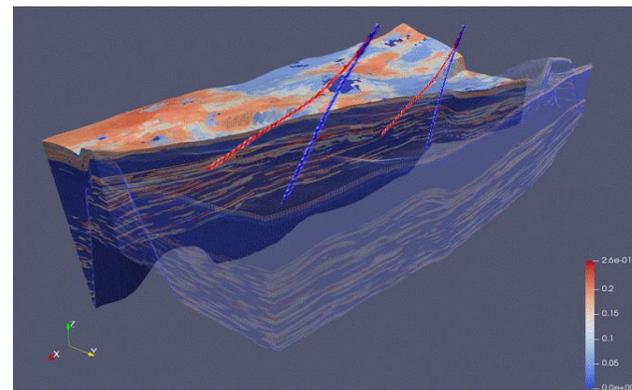
Synthetic model



Process-based analog for DAP well

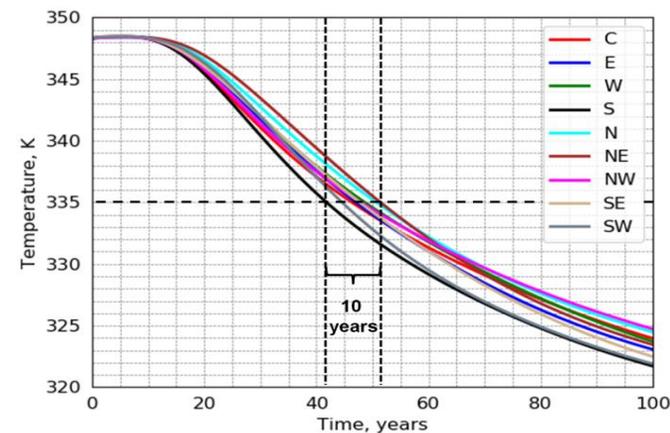


Realistic model

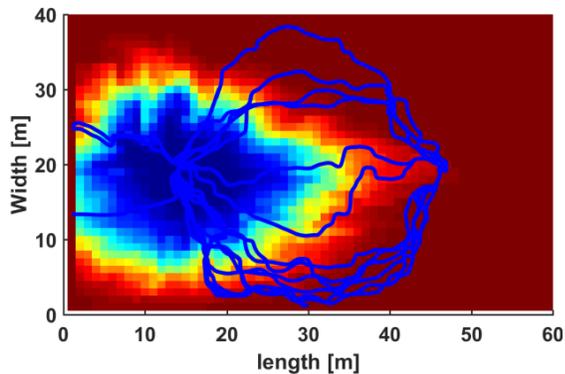


shale:
2.4M grid blocks
sandstone:
0.8M grid blocks
highly heterogeneous

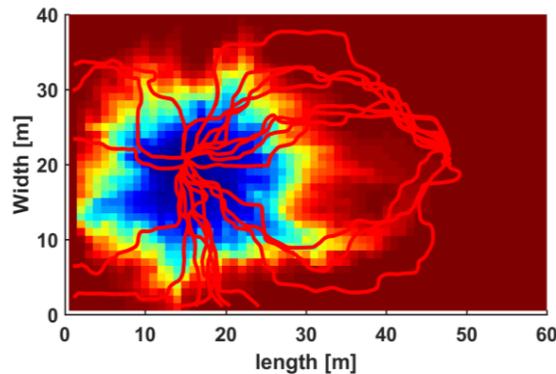
West Netherlands Basin



Streamlines at 20 years at W location



Streamlines at 20 years at N location

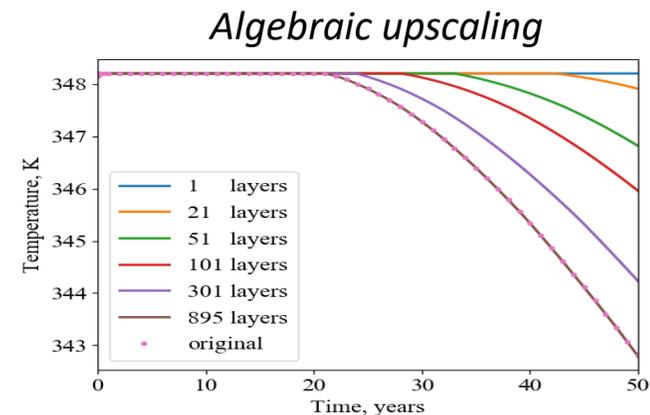
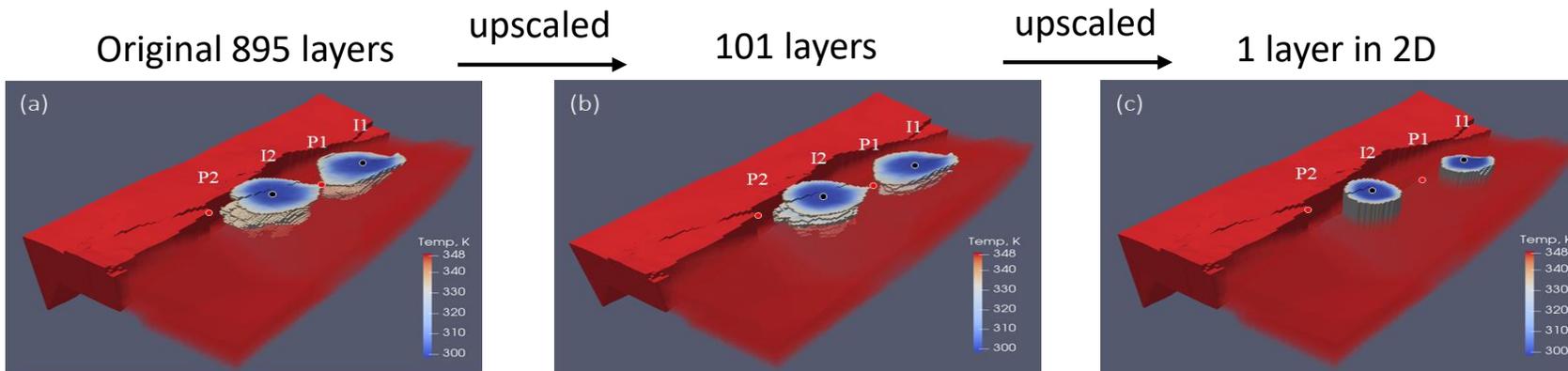


Shetty et al, 2018

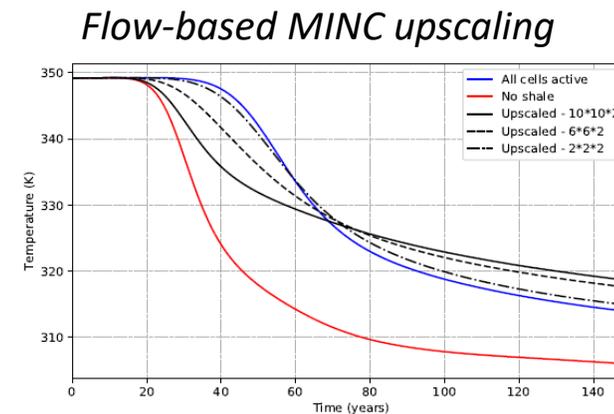
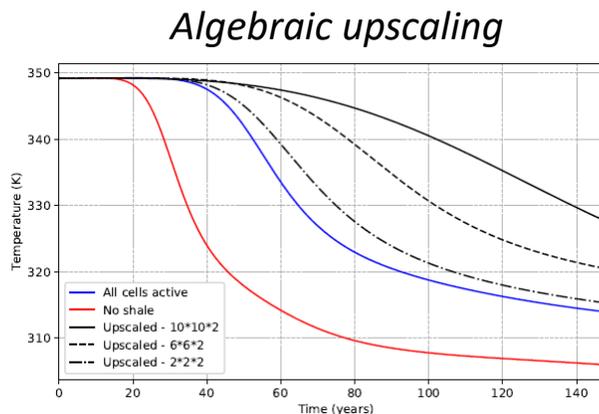
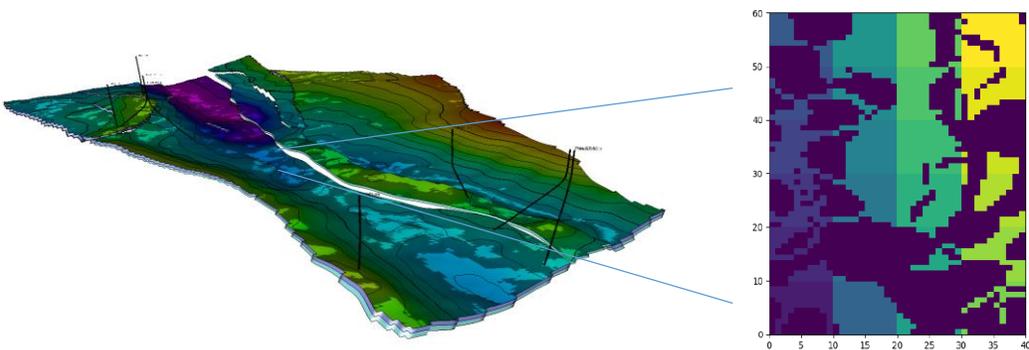
Heterogeneity can largely alter the fluid flow path under different well placements.

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?

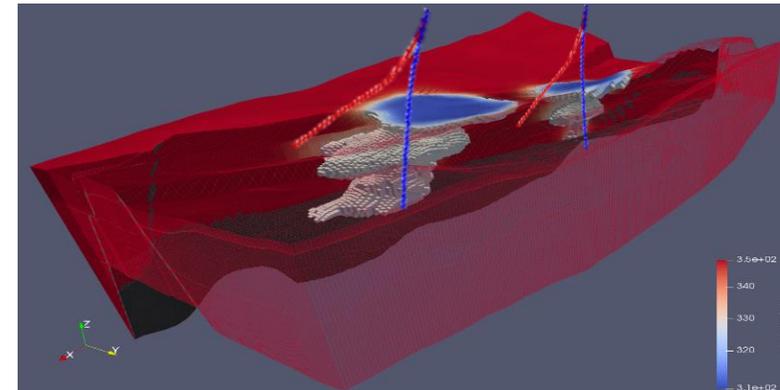
Delft Advanced Research Terra Simulator

<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:

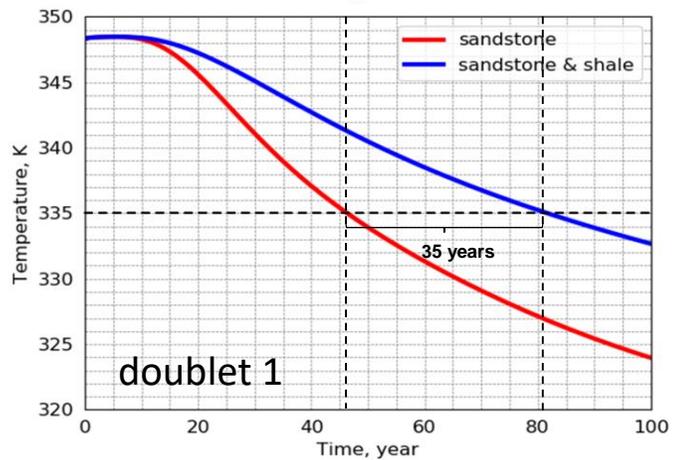
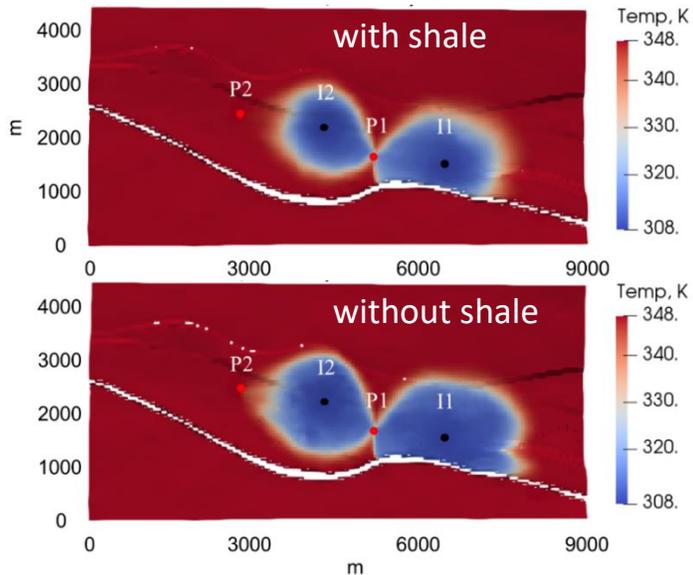
- 3.2M active reservoir blocks
- 50-years development
- 2 unknowns per block
- CPU: **40 min**, CPU*: **16 min**, GPU: **3.5 min**



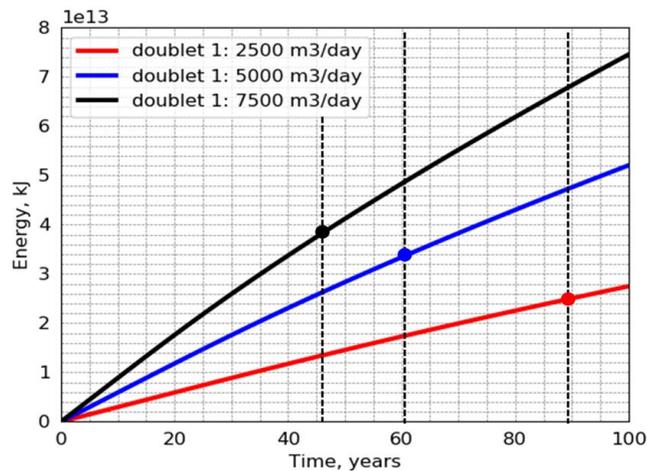
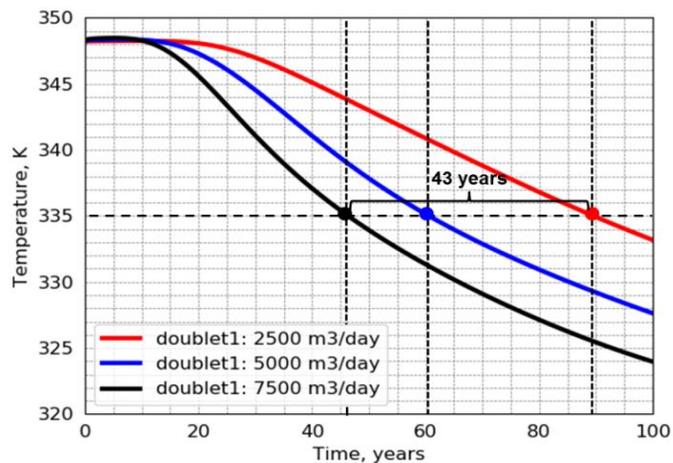
DARTS: A powerful geothermal simulator

Sensitivity Analysis

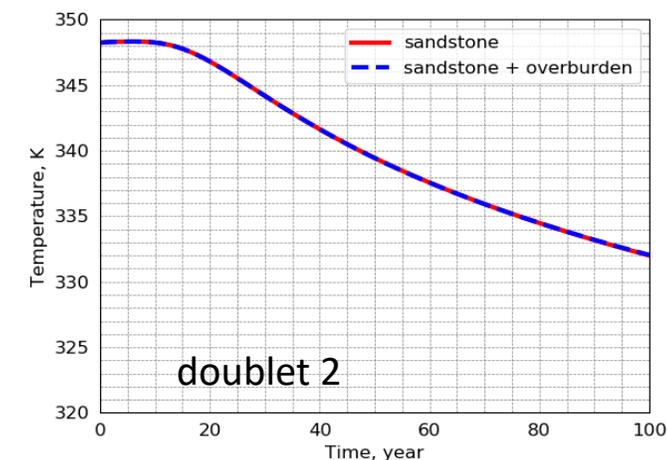
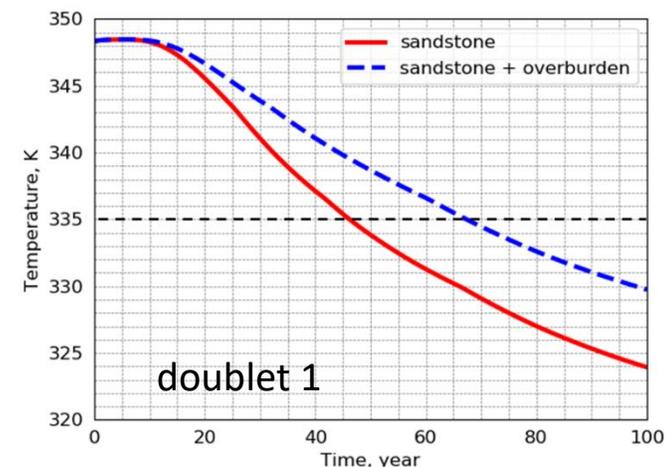
Shale facies



Flow rate



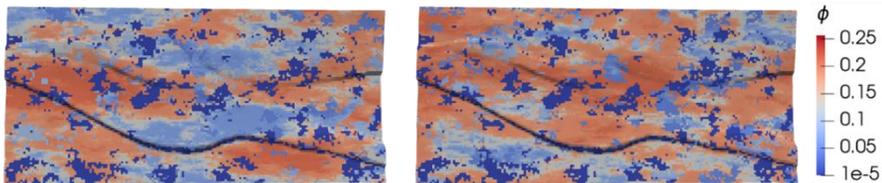
Overburden



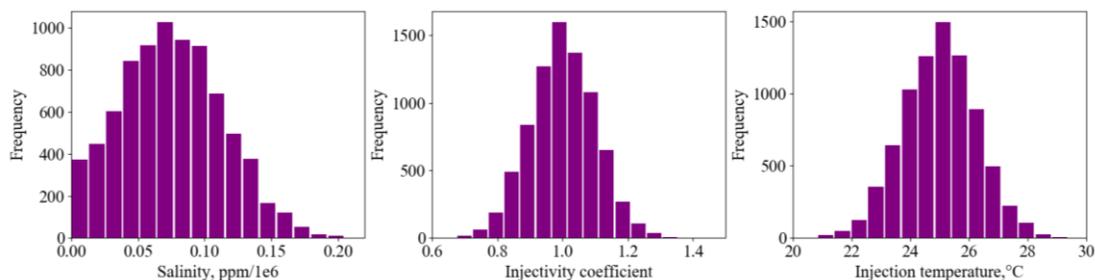
Uncertainty quantification

- Geological parameters

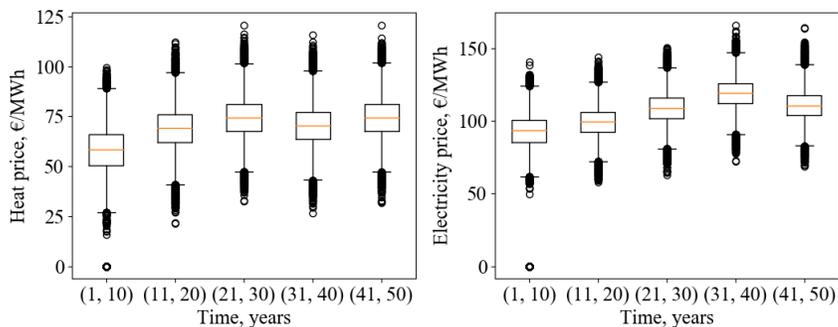
different $\phi - k$ distribution



- Physical parameters

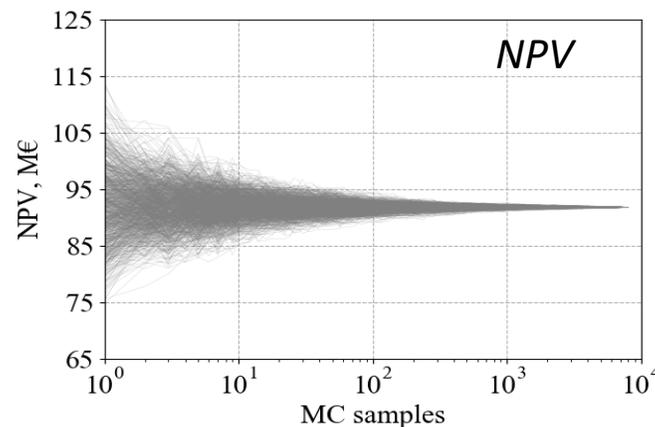


- Economical parameters

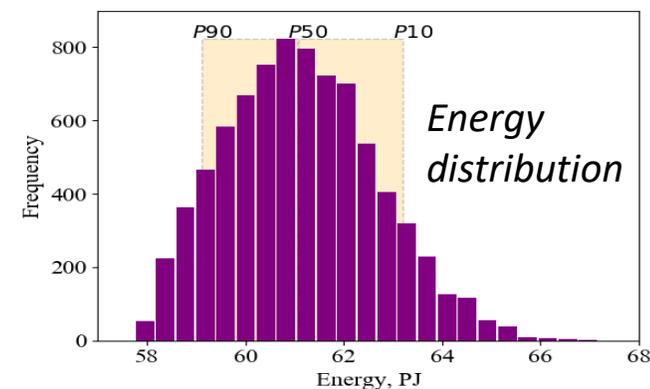
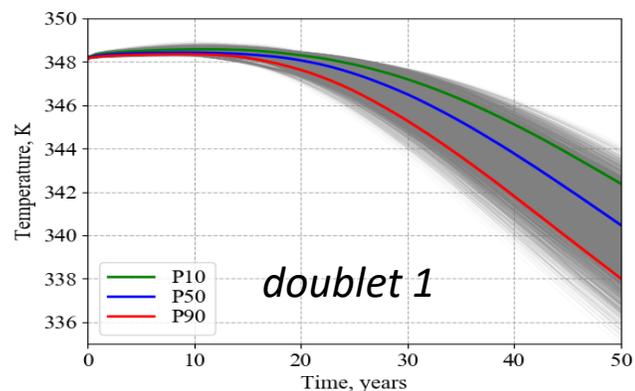
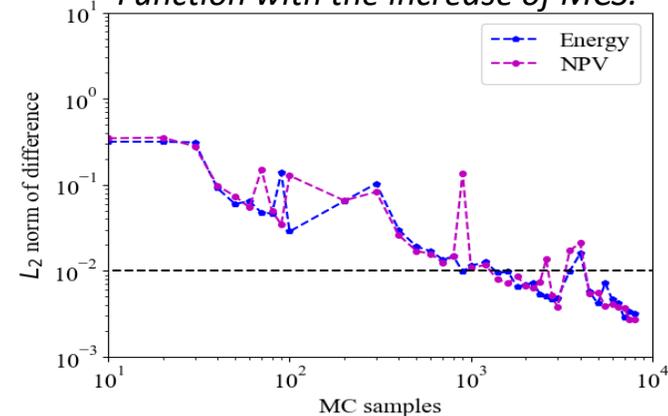


Totally 8000 Monte Carlo Simulations of 50-years development

- 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.

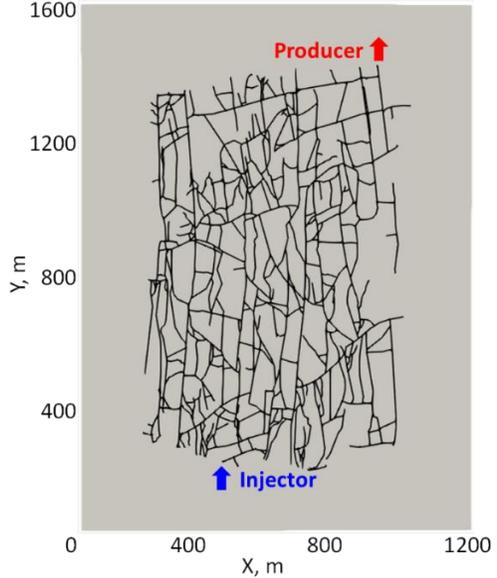
Realistic fracture network

High-enthalpy reservoirs contain large heat potentials.

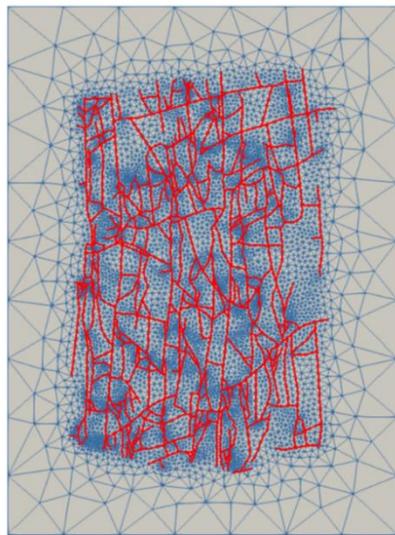
- The Geysers, USA
- California well, Netherlands



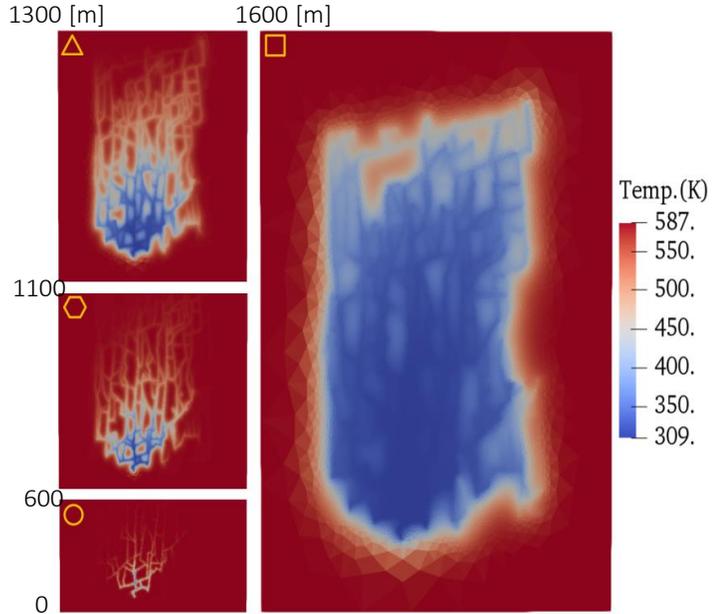
- High-enthalpy thermal flow
- Fractured reservoir
- Discrete Fracture Model (DFM)
- Dynamic heat transfer



Generated from outcrop
(2148 fracture segments)
Boersma et al., 2015



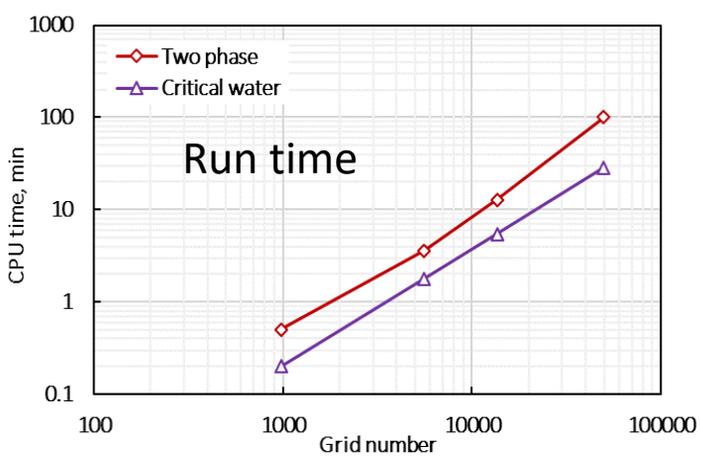
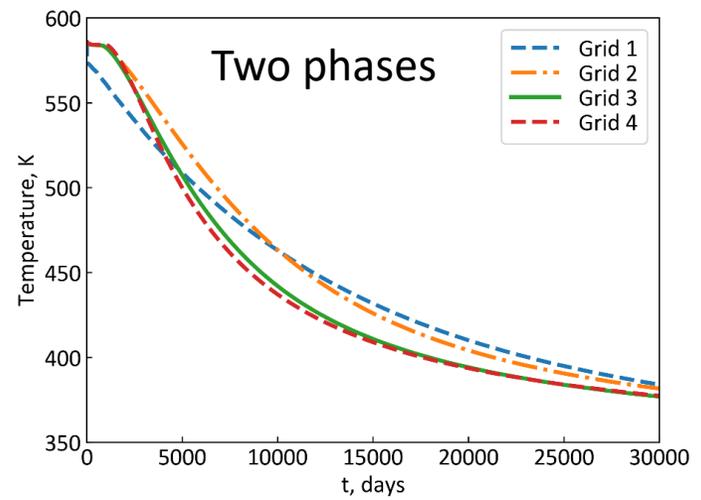
Mesh discretization



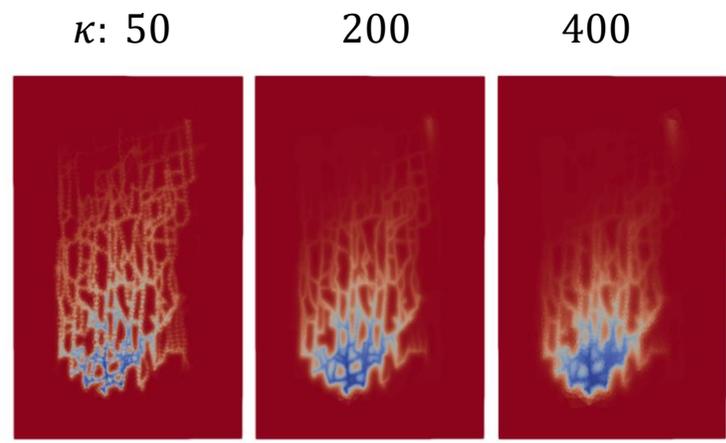
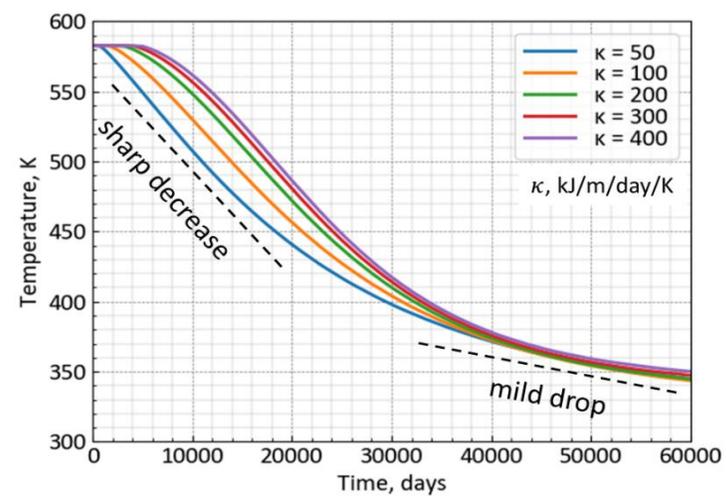
Evolution of the temperature plume

Heat transfer dynamics

Mesh convergence

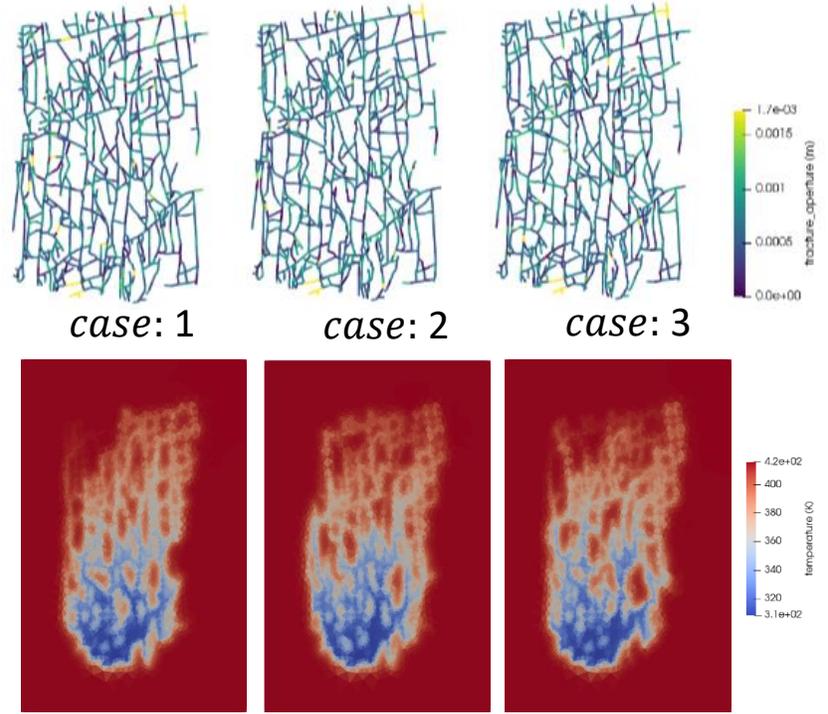


Rock heat conductivity

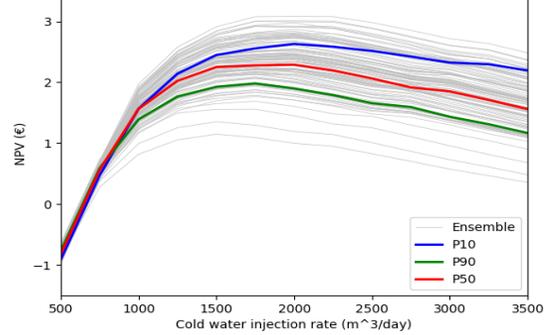


Fracture aperture distribution

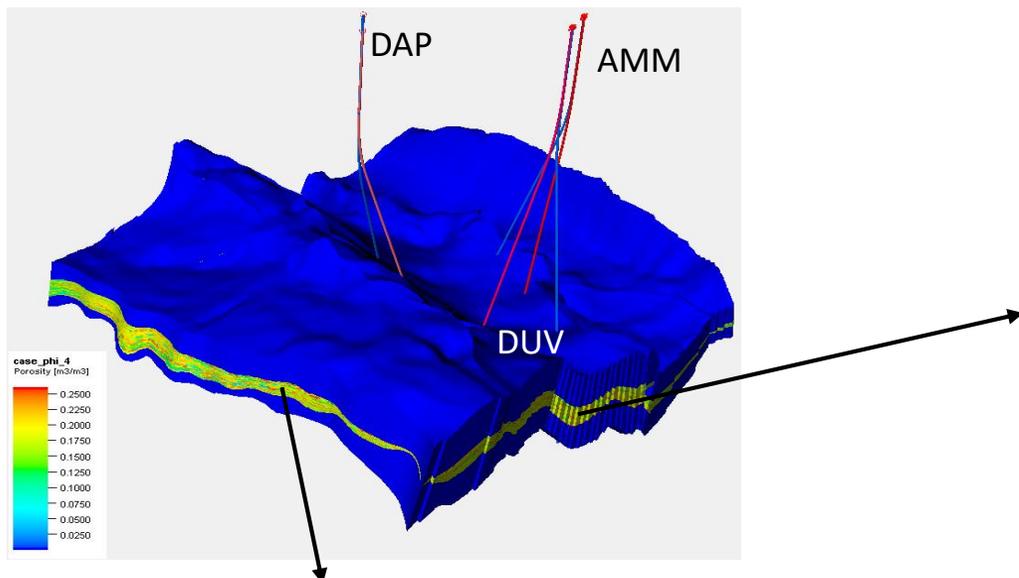
van der Kooij, 2020



NPV vs injection rate, carbonate matrix



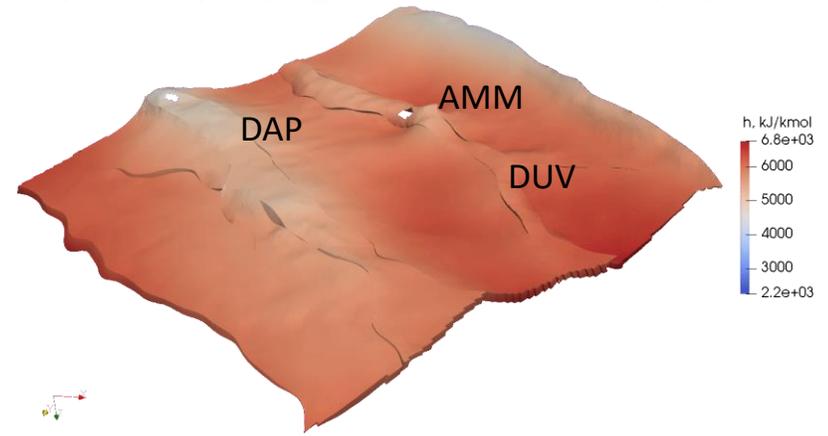
Delft Aardwarmte Project (DAP)



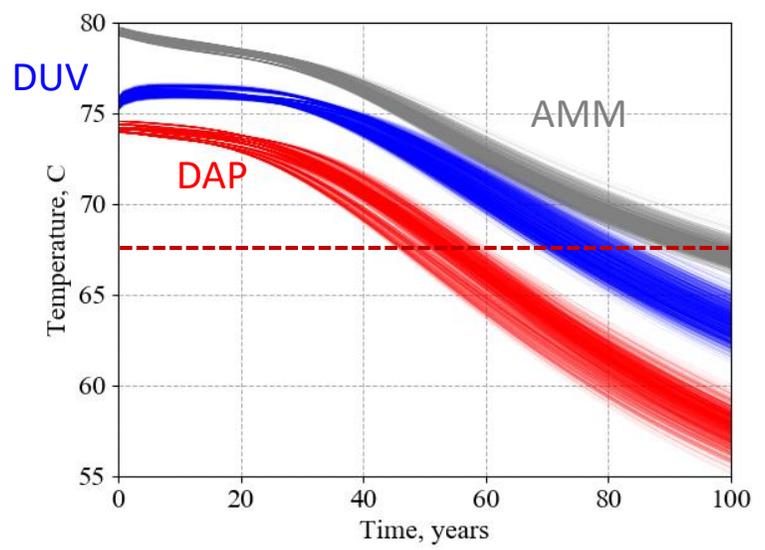
Permeability distribution of one realization



Cold plume propagation within the payzone

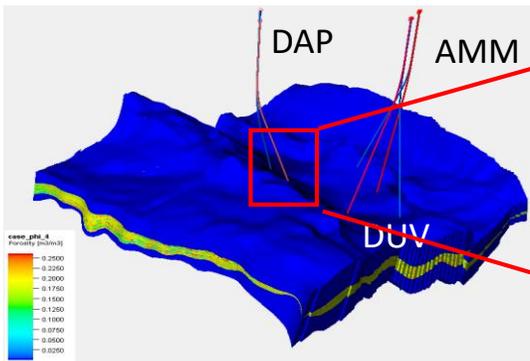


Production temperature of the 3 doublets

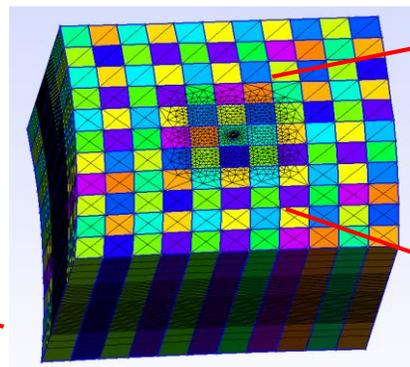


Total simulation time: 100 years

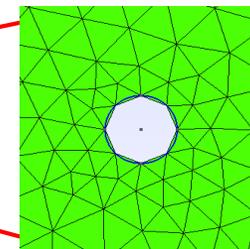
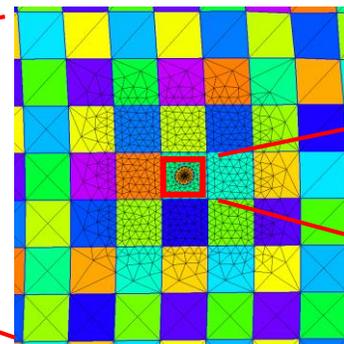
Transient analysis and monitoring



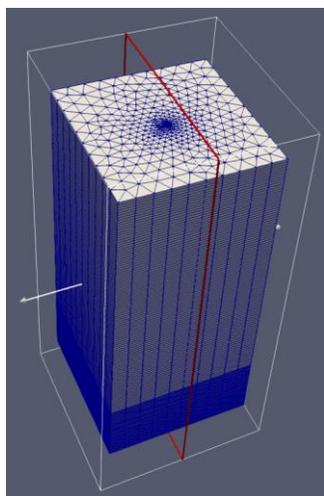
Petrel model



Gmsh model

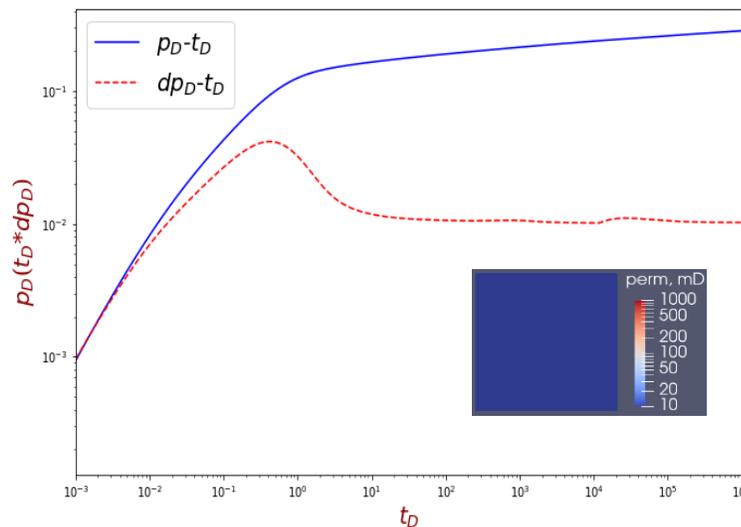


Mesh size surrounding the wellbore equalizes to the well radius (0.1 meter).

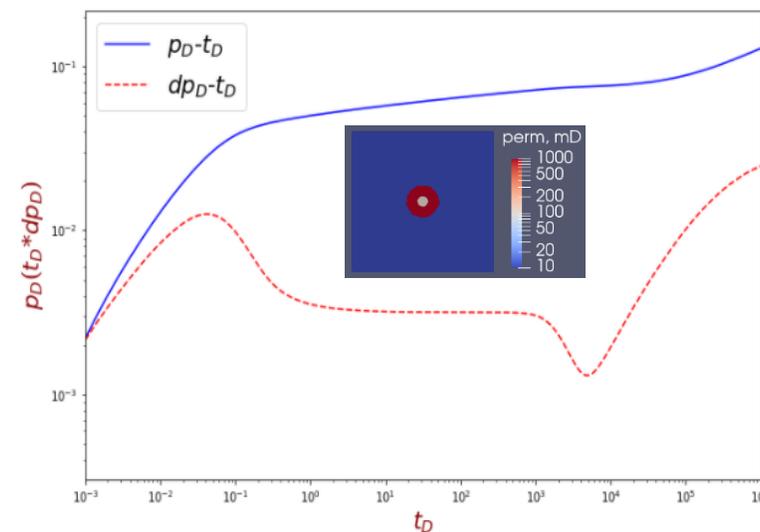


Model size(x*y*z, meter): 500*500*1000

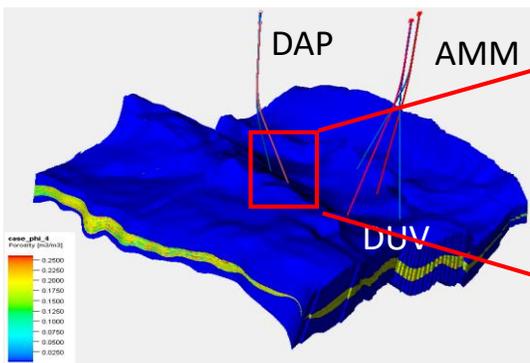
Homogeneous



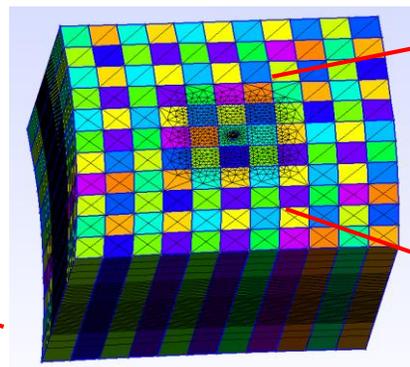
Heterogeneous



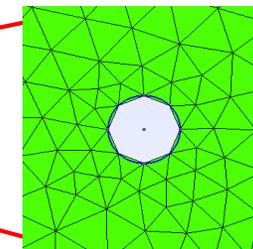
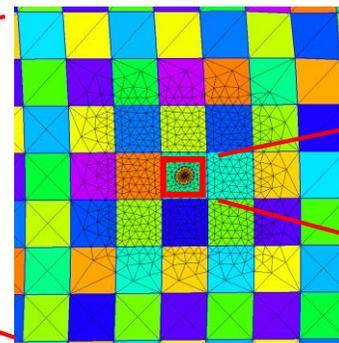
Wellbore Heat Loss



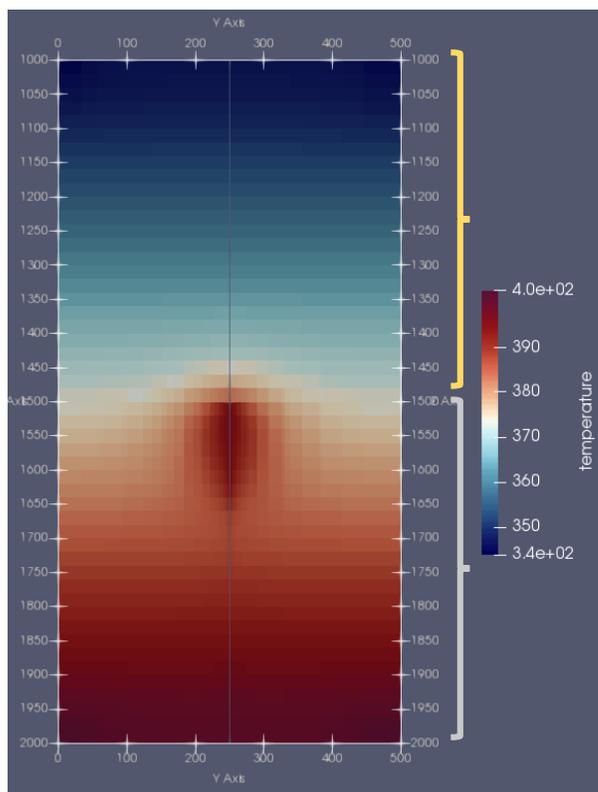
Petrel model



Gmsh model

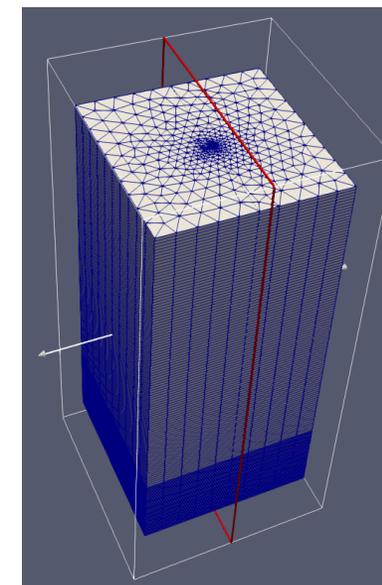


Mesh size surrounding the wellbore equalizes to the well radius (0.1 meter).



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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Stephan de Hoop

References

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