# Towards robust uncertainty quantification for low enthalpy geothermal projects

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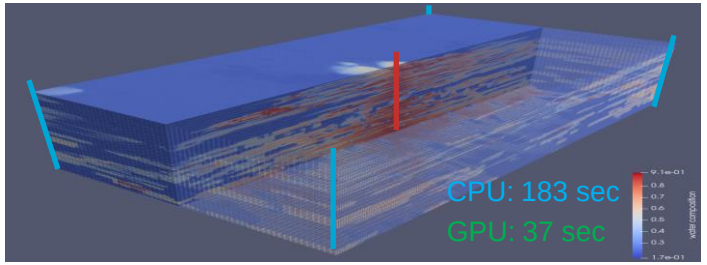
# Delft Advanced Research Terra Simulator (DARTS) platform

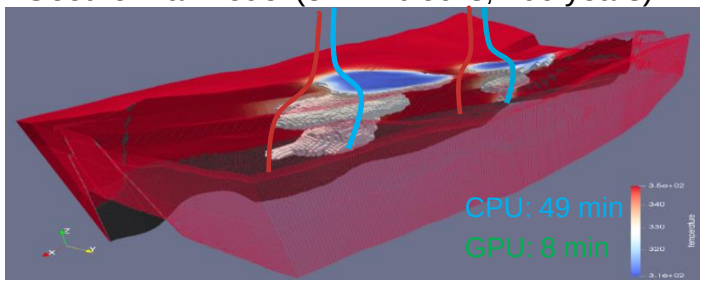
**Novel platform for modeling of Energy Transition applications**

- Wide range of physics supported
  - Multi-phase multi-component reactive formulation
  - Generic energy equation with advanced thermodynamics
  - Momentum conservation for stress approximation
- Highly robust and performant forward simulation capabilities
  - Advanced Operator-Based Linearization technique
  - Fully-implicit fully-coupled THCM formulation
  - Comparable with fastest commercial simulators (e.g. ECHELON)
- Advanced inverse capabilities
  - Adjoint formulation for data assimilation
  - Physics-based data-driven proxy modeling

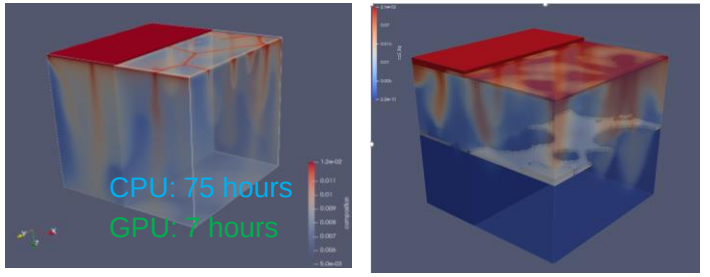
SPE10 model (1.1 M blocks, 5.5 years)




Geothermal model (3.2 M blocks, 100 years)




CO2 sequestration (1.0 M blocks, 3000 years)

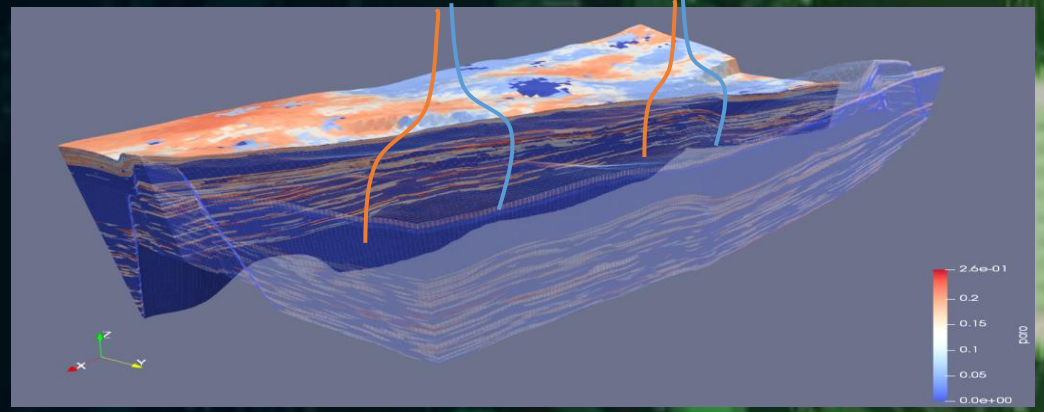


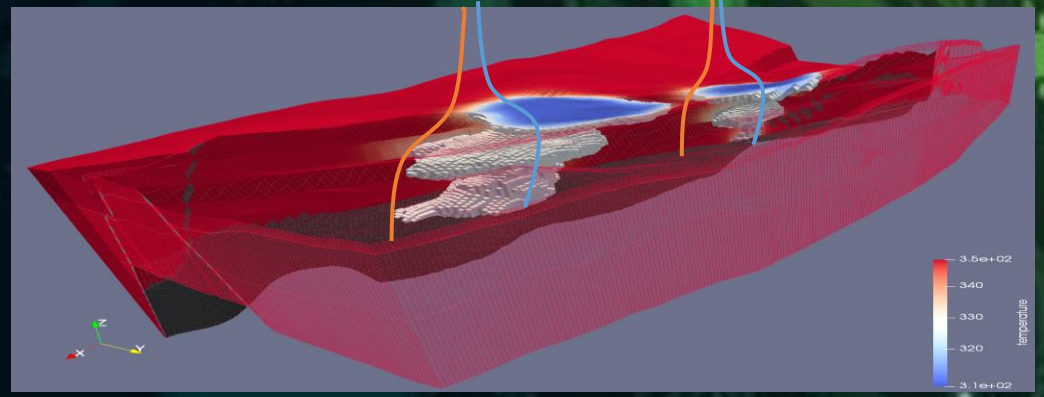

Khait and Voskov, SPE, 2021; Wang et al., 2021; Lyu et al., IJGGC, 2021

# How much energy does your geothermal field produce?

Converged Monte-Carlo simulation: 10,000 forward runs using geological model takes less than 23 hours on 16 Titan RTX GPU cards*

*3.2 M grid blocks, 100 years of simulation*



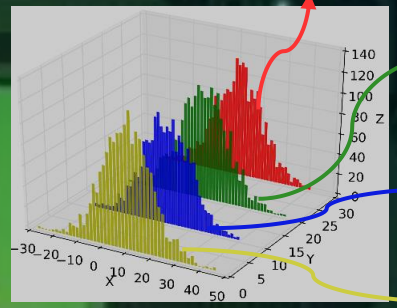



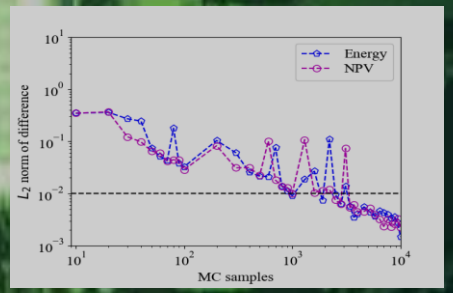

Geological parameters

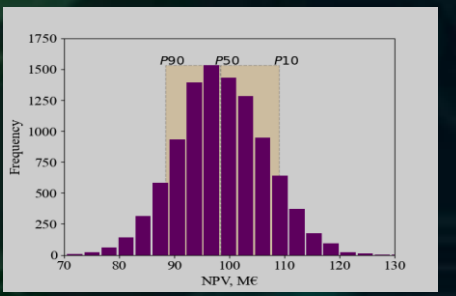
Physical parameters

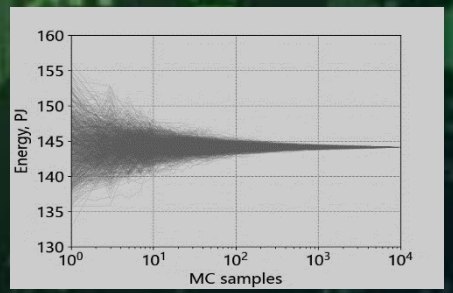
Economical parameters

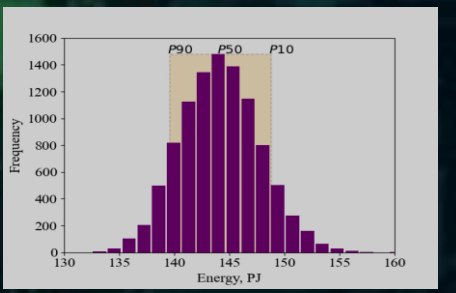
Technological parameters





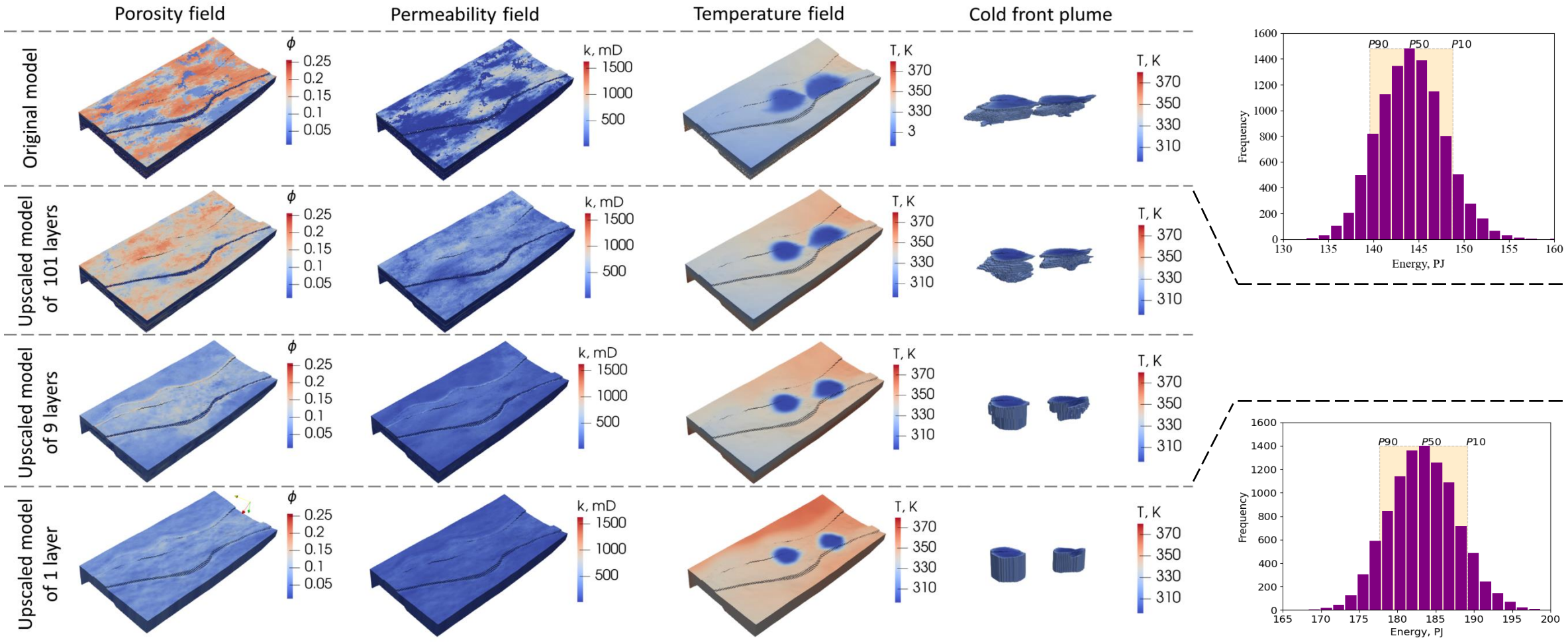



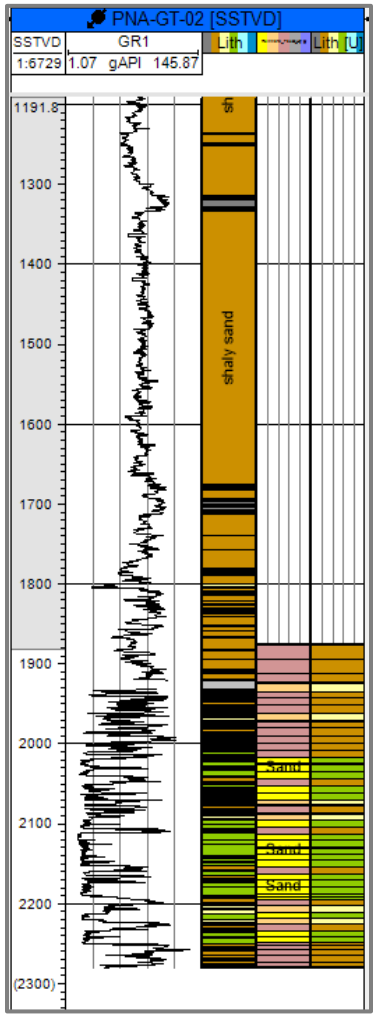

*Thanks to SURFsara for the access to the Lisa GPU cluster and TotalEnergies for sponsoring DARTS-GPU

# Effect of upscaling (single realization)

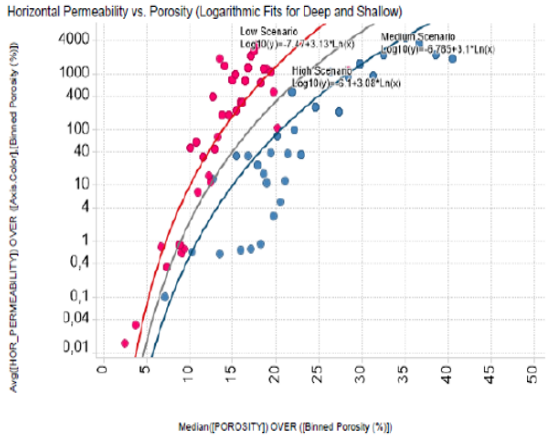


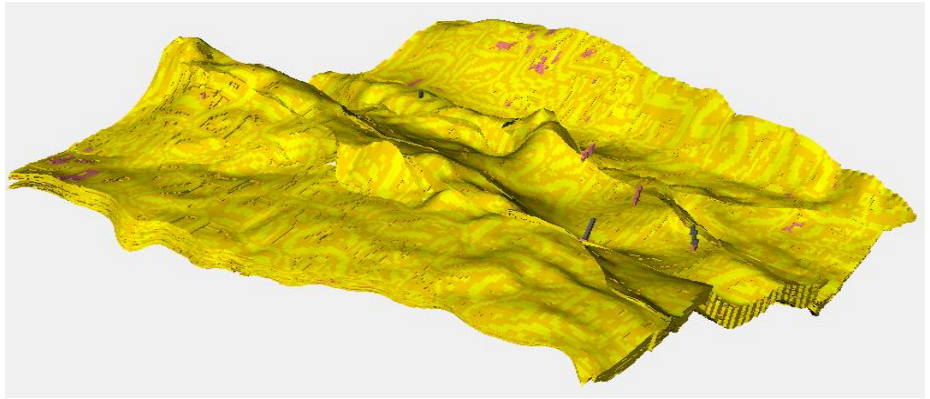

Wang et al., in review, 2022

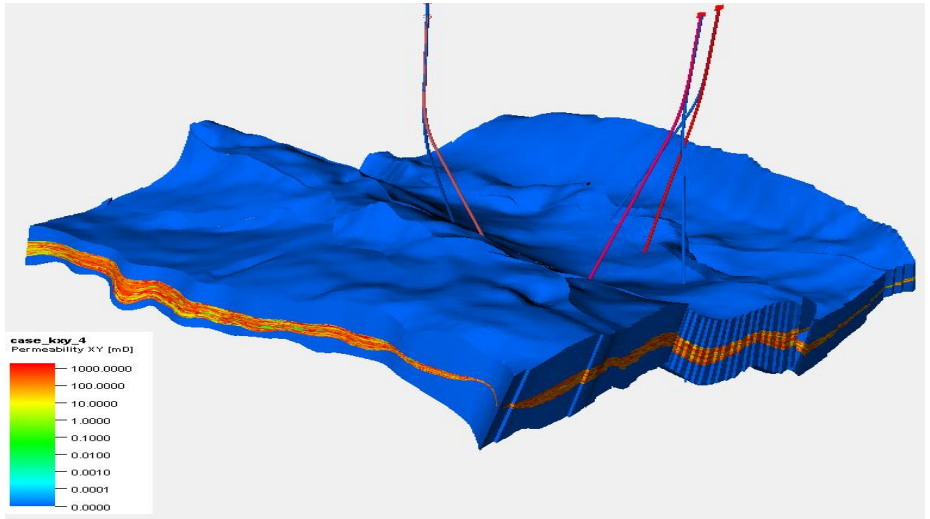
# Geological model for DAP project




| Lithology | GR Range |
|---|---|
| Coarse Sand | GR<30 |
| Fine Sand | 30<GR<60 |
| Shaly Sand | 60<GR<100 |
| Shale | GR>100 |



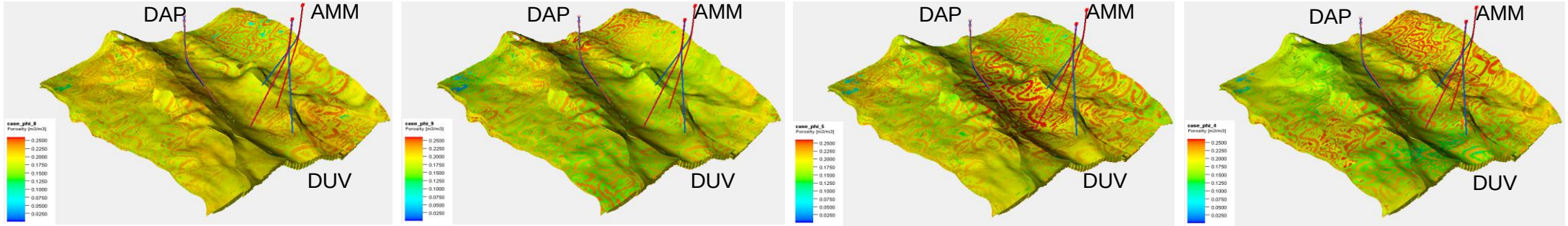





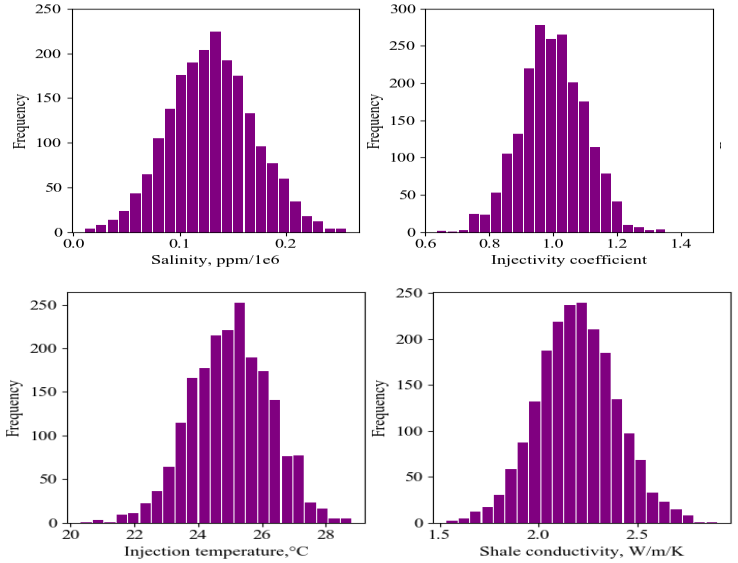

Reinhard, MSc, 2019

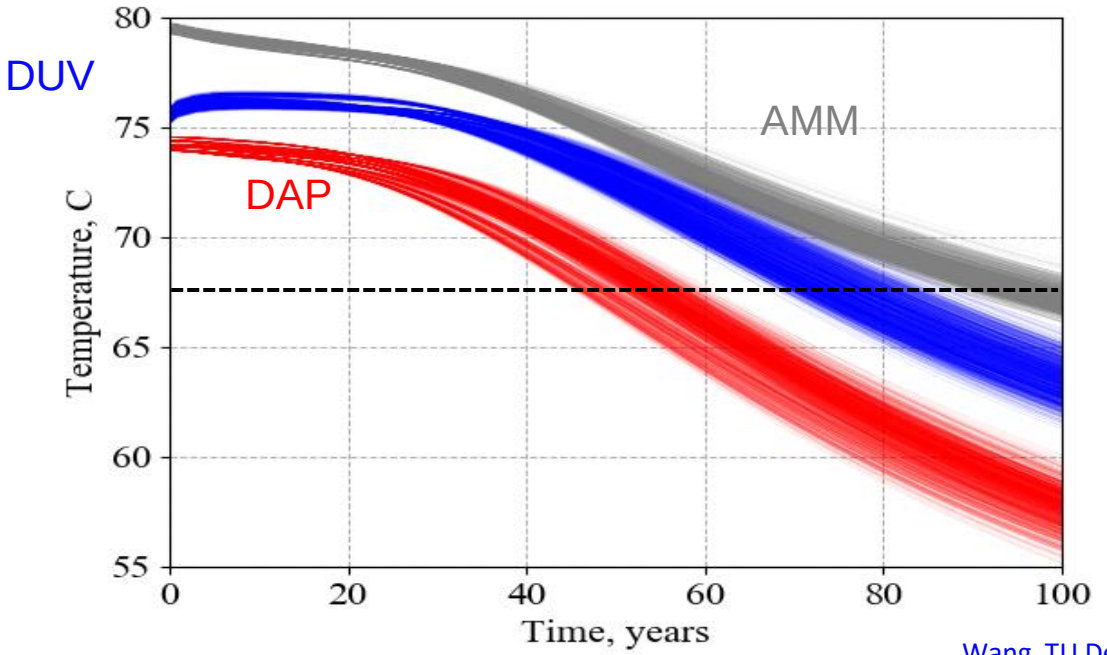
# Sensitivity study for DAPwell project

Porosity distributions of 4 (out of 10) cases




Distribution of other parameters



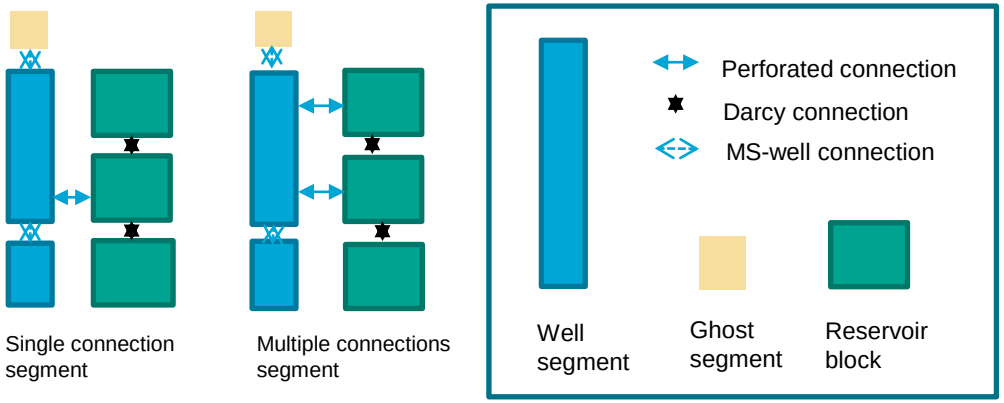

Wang, TU Delft, 2021

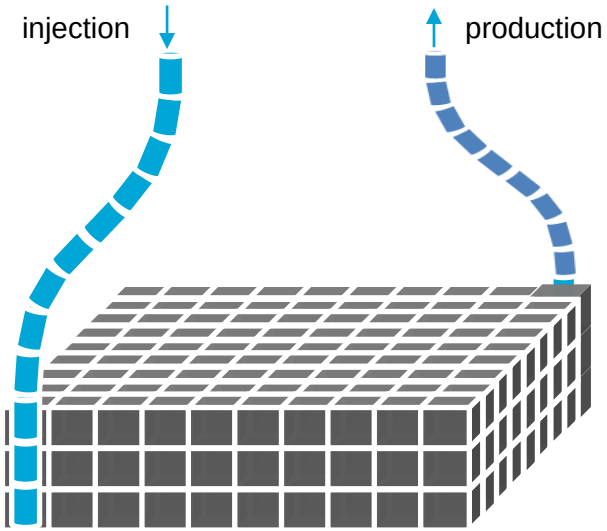
# Multi-segmented well model

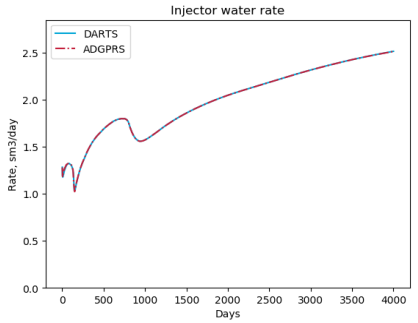
- Multi-physics in wellbore (thermal multiphase multi-component reactive flow and transport with heat loses)
- Complex well network (deviated, multilateral, annulus, etc.)

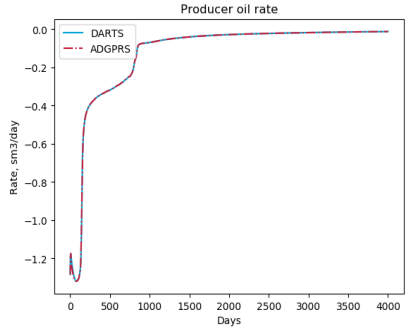
$$\frac{\phi_0 V}{\Delta t}[\boldsymbol{\alpha}(\boldsymbol{\omega}) - \boldsymbol{\alpha}(\boldsymbol{\omega}_n)] + \sum_l v_t^l(\boldsymbol{\xi}, \boldsymbol{\omega})\boldsymbol{\beta}\,(\boldsymbol{\omega}) = \boldsymbol{g}(\boldsymbol{\omega})$$

$$\Delta p - \underbrace{\theta_h(\boldsymbol{\omega}, \boldsymbol{\xi})}_{\text{Hydrostatic losses}} - \underbrace{\theta_f(\boldsymbol{\omega}, \boldsymbol{\xi}, v_t)}_{\text{Friction losses}} - \underbrace{\theta_a(\boldsymbol{\omega}, \boldsymbol{\xi}, v_t)}_{\text{Acceleration losses}} = \boldsymbol{g}^{\boldsymbol{w}}(\boldsymbol{\omega})$$



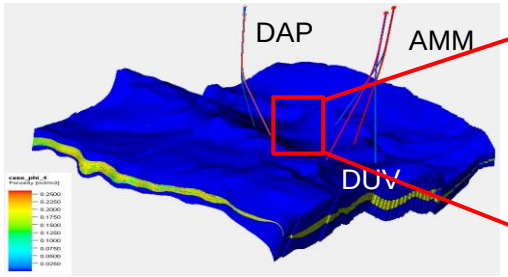



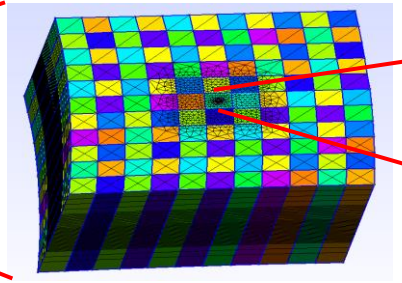

Pour et al., WGC, 2021

# Near-well modeling

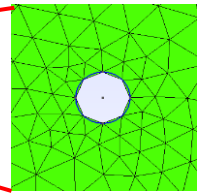
Petrel model



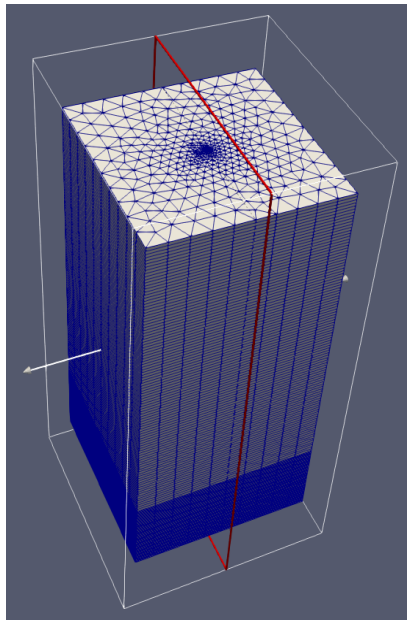

Gmsh gridding



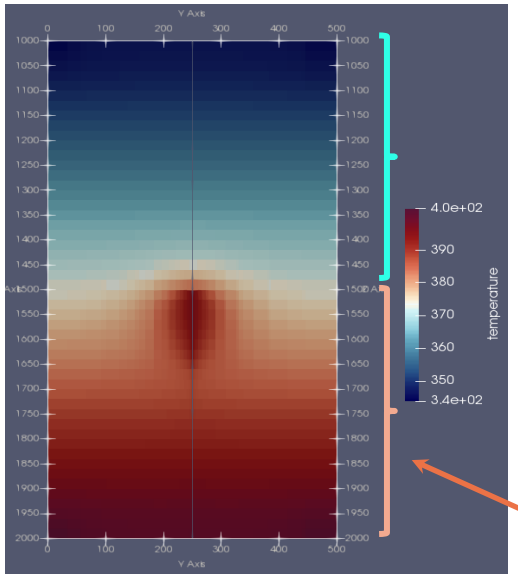
Well model



*Wellbore discretization down to* $r_w = 0.1\ m$

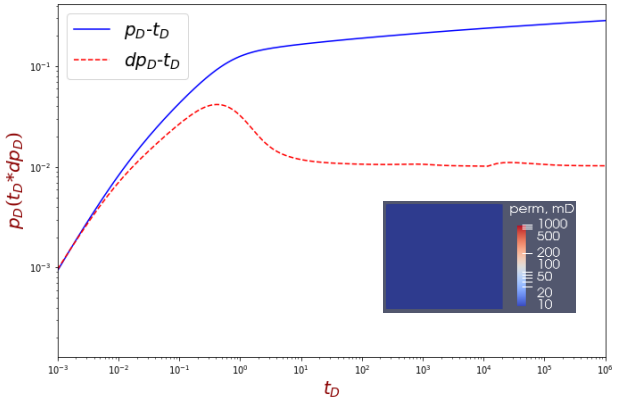


Effect of insulation

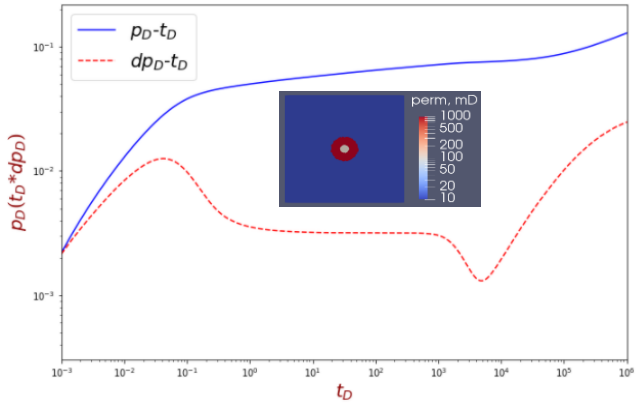



Non-insulated interval

Homogeneous




Heterogeneous

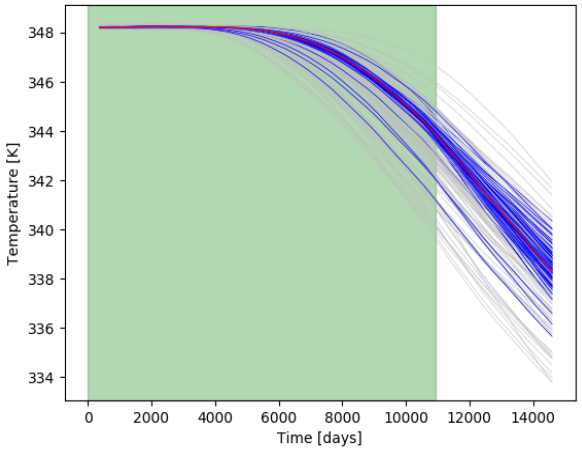



Wang, TU Delft, 2021

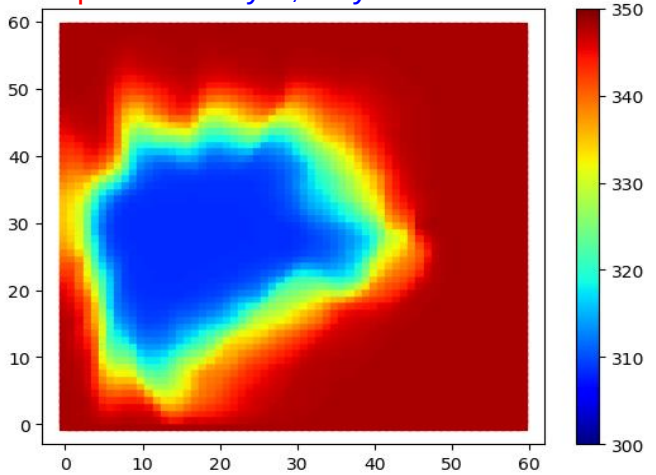
# History Matching in DARTS using Electro-Magnetic observations

The green area is the training period (30 years). The white area is the forecasting period (10 years)

Well temperature



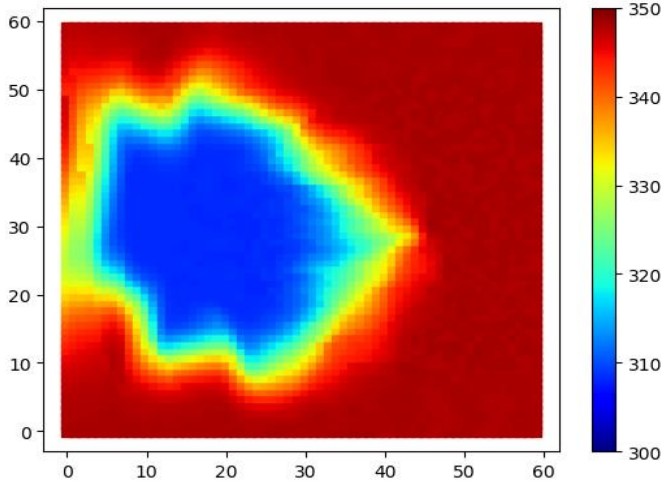

T prior – 4th layer, 30 years



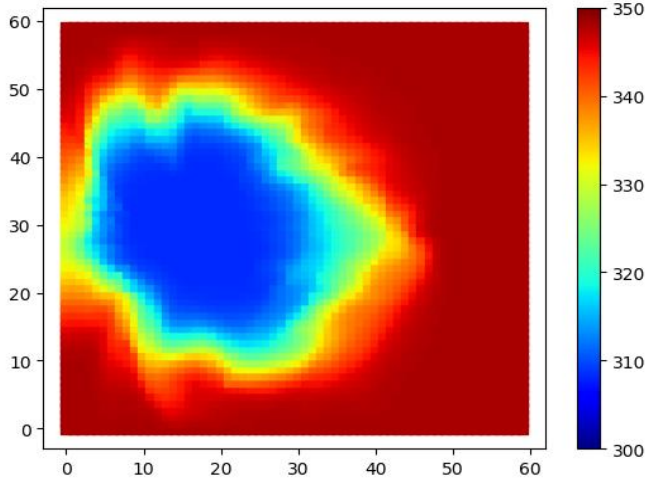
The temperature model respone before history matching

EM is taken as one of the observations to do the history matching. Other observations include well temperature and well BHP.

True EM – 4th layer, 30 years



T posterior – 4th layer, 30 years



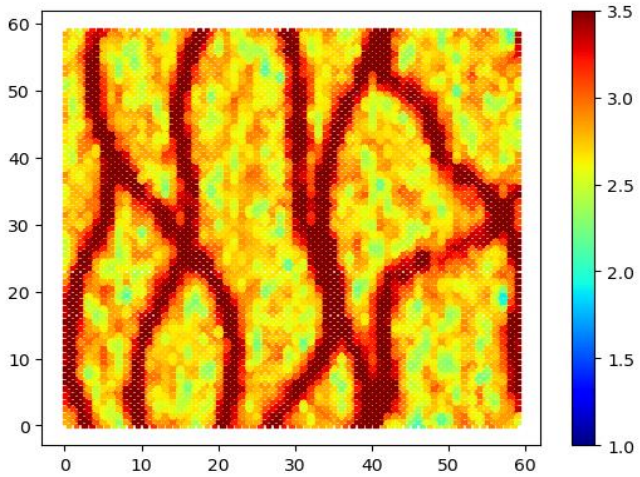
The temperature model respone after history matching

Tian et al., in preparation

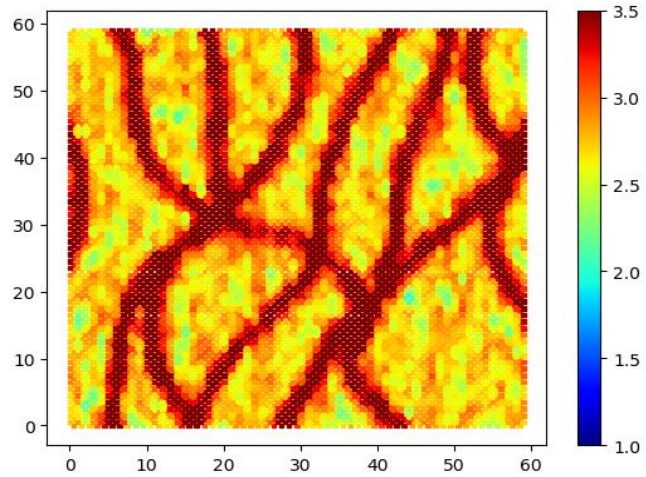
# Results of History Matching using RML

True permeability map

True log(perm) – 4th layer



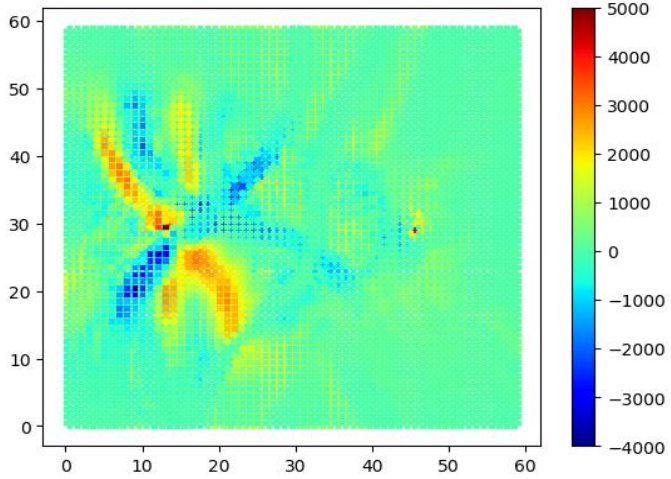

Prior log(perm) – 4th layer



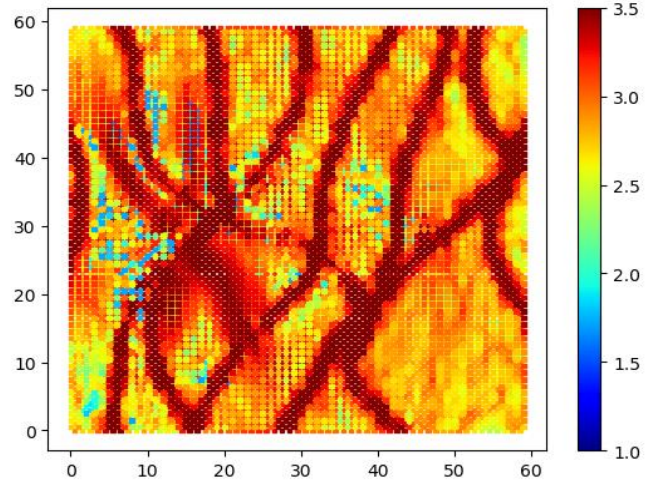

The permeability map before history matching

The optimizer trying to block the prior channel, while re-constructing the “true” channel

diff = Posterior - Prior




Posterior log(perm) – 4th layer




The permeability map after history matching

Tian et al., in preparation

# Conclusion

- DARTS is a fully integrated numerical framework that combines unique flexibility and performance for forward simulation in energy transition applications
- To optimize the performance and mitigate risks in geothermal projects, extended uncertainty quantification and risk analysis are required
- Current status and ongoing developments in the DARTS framework will allow creating a true digital twin for the DAP project

# Acknowledgments


- DARTS team: Xiaocong Lyu, Mark Khait, Michiel Wapperom, Yang Wang, Aleks Novikov, Stephan de Hoop, Xiaoming Tian, Kiarash Mansour Pour
- Colleagues: Alex Daniilidis, Phil Vardon, Evert Slob, Oleg Volkov, David Bruhn

For more details on DARTS, check: https://darts.citg.tudelft.nl/

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