Creating digital twin for DAPwell project: challenges and solutions

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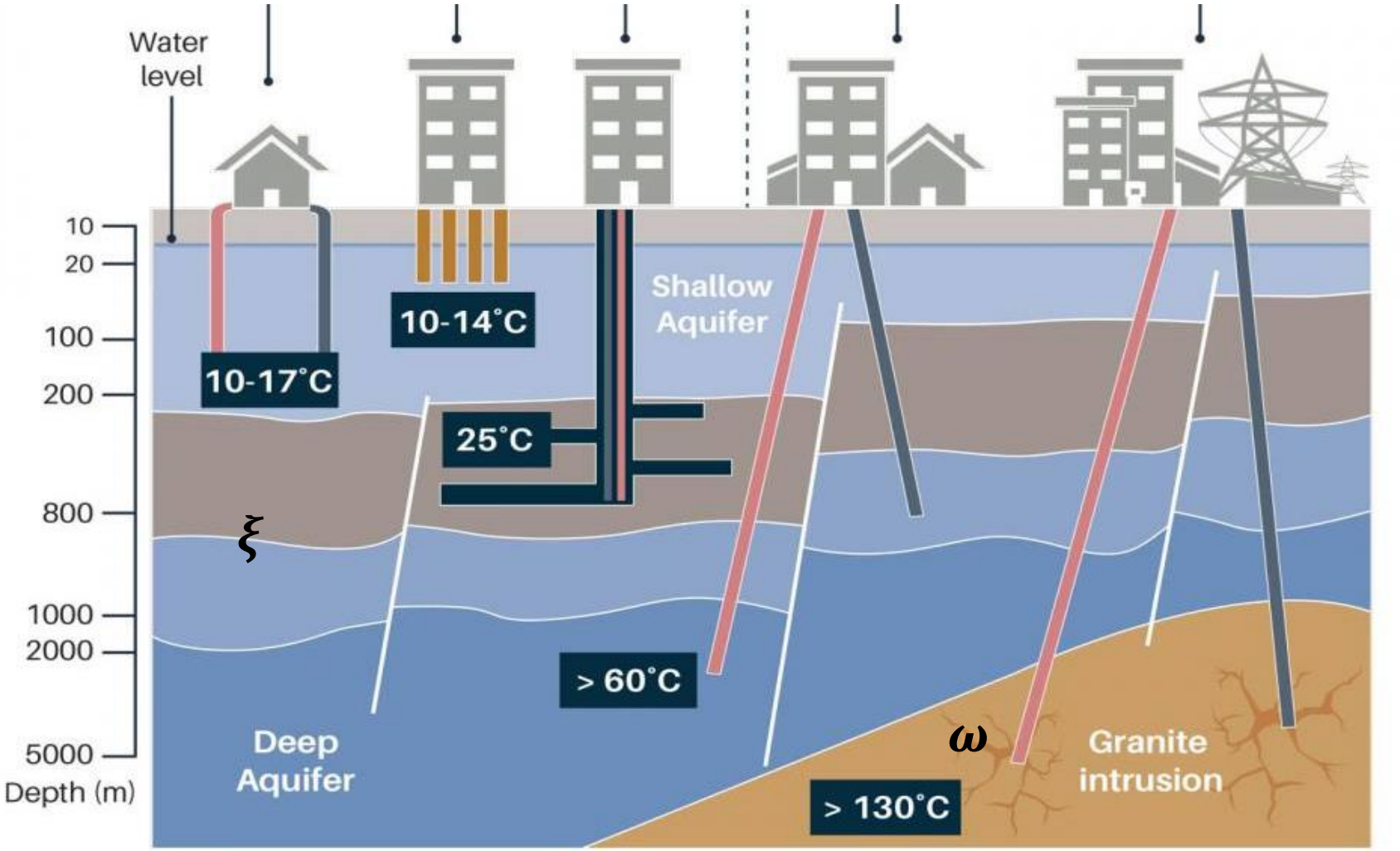
Geoscience & Engineering, TU Delft

Geothermal energy

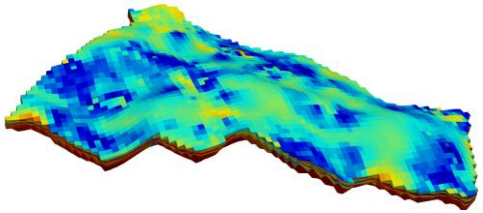


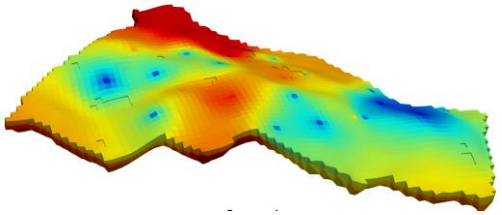
Source: BGS

PDE for Energy Transition applications

$$\boldsymbol{g(\omega) = a_t(\omega,\xi) + \nabla \cdot b(\omega,\xi) + \Delta c(\omega,\xi) + d(\omega,\xi) = 0}$$

FIM approach: Finite Volume discretization in space and backward Euler in time

$\boldsymbol{\xi = \{G, \phi, K\}}$ 

$\boldsymbol{\omega = \{p, T\}}$ 

$$\boldsymbol{g(\omega) = \frac{\phi_0 V}{\Delta t}[\alpha(\omega) - \alpha(\omega_n)] + \sum_l v_t^l \beta(\omega) + V\delta(\omega) = 0}$$

$$g_e(\omega) = \frac{\phi_0 V}{\Delta t}[\alpha_e(\omega) - \alpha_e(\omega_n)] + \sum_l v_t^l \beta_e(\omega) + \sum_l \Theta^l (T^l - T)\gamma(\omega) + V\delta(\omega) = 0$$

$$\alpha_c(\omega) = c(p) \sum_{j=1}^{n_p} x_{cj}\rho_j s_j, \qquad \beta_c(\omega) = \frac{1}{\Lambda}\sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\gamma(\omega) = c(p) \sum_{j=1}^{n_p} s_j \rho_j \kappa_j, \qquad \delta(\omega) = \sum_{k=1}^{n_k} \nu_{ck} r_k$$

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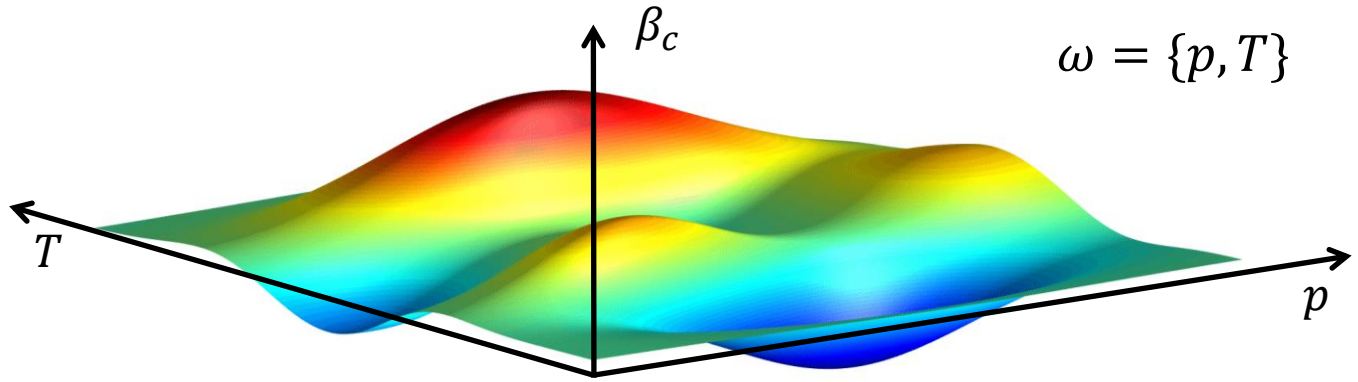
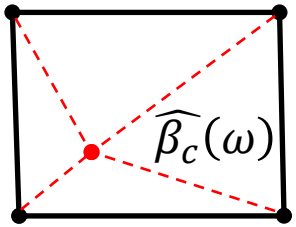
Operator-Based Linearization



$$\beta_c(\omega^1) = \frac{1}{\Lambda}\sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\beta_c(\omega^2) = \frac{1}{\Lambda}\sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$



$$\beta_c(\omega^3) = \frac{1}{\Lambda}\sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

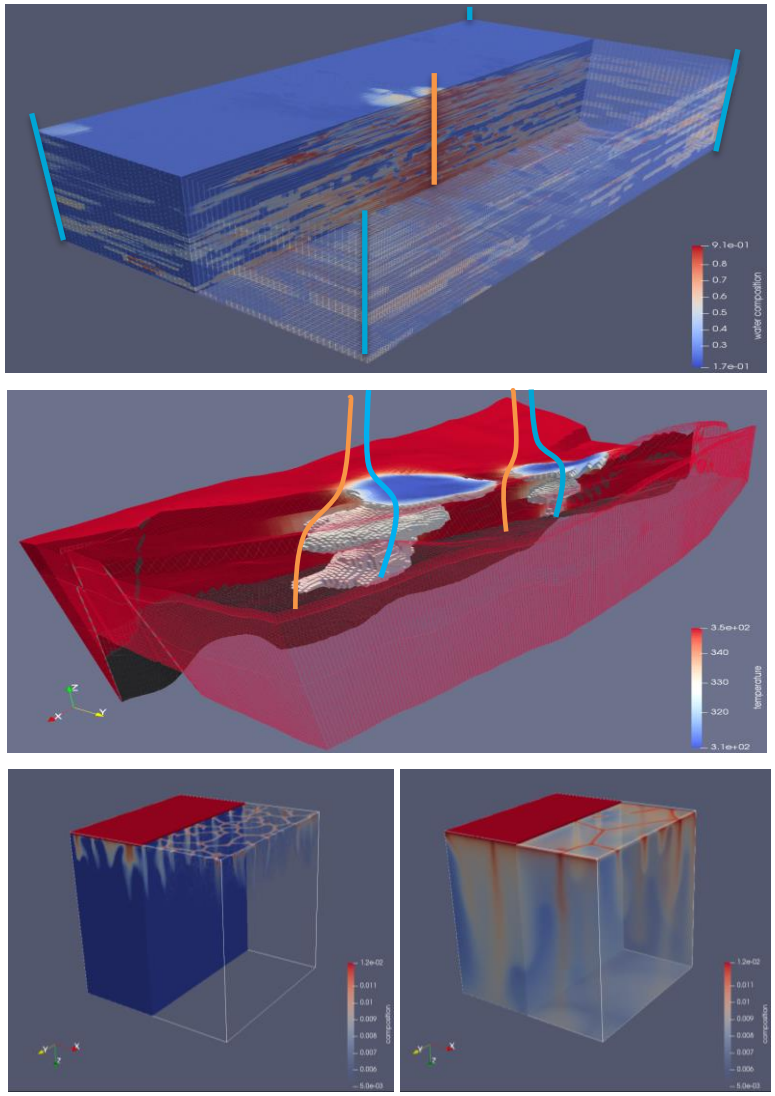
$$\beta_c(\omega^4) = \frac{1}{\Lambda}\sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\left|\widehat{\beta_c} - \beta_c\right| \leq cA^2 \sup_{\omega} |\nabla^2 \beta_c|$$

Voskov, JCP 2017

Delft Advanced Research Terra Simulator

- CO_2 injection for EOR
  - 1.1M active blocks, 5.5 years
  - 4 unknowns per block
  - CPU*: 20 min, GPU: 3.5 min
- Geothermal model
  - 3.2M active blocks, 100 years
  - 2 unknowns per block
  - CPU*: 49 min, GPU: 8 min
- CO_2 sequestration
  - 1.0M active blocks, 3000 years
  - 2 unknowns per block
  - CPU*: 3.8 hours, GPU: 55 min



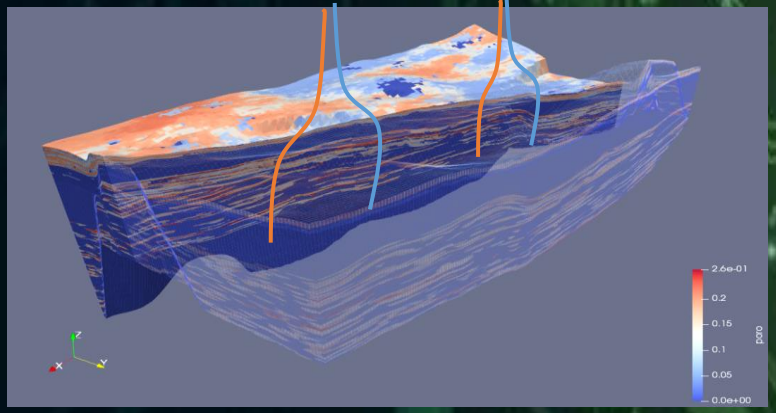
*OpenMP on 20 physical cores

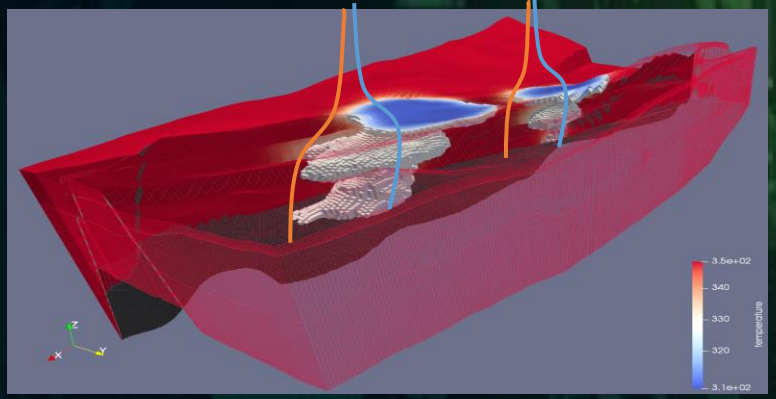
Khait and Voskov, SPE, 2021

How much energy does your geothermal field produce?

Converged Monte-Carlo simulation: 4000 forward runs using geological model takes less than 15 hours on 16 Titan RTX GPU cards*

- 3.2 M grid blocks, 50 years of simulation



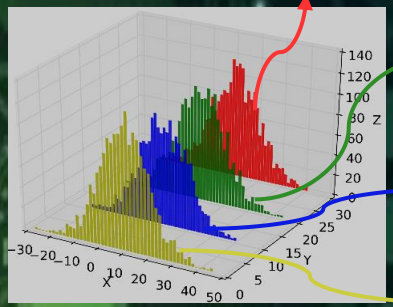


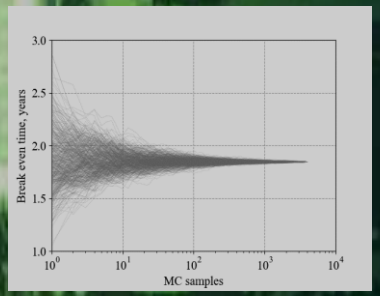
Geological parameters

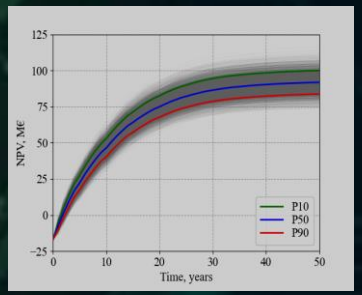
Physical parameters

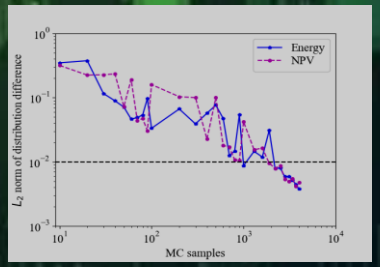
Economical parameters

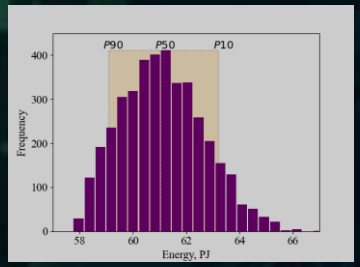
Technological parameters





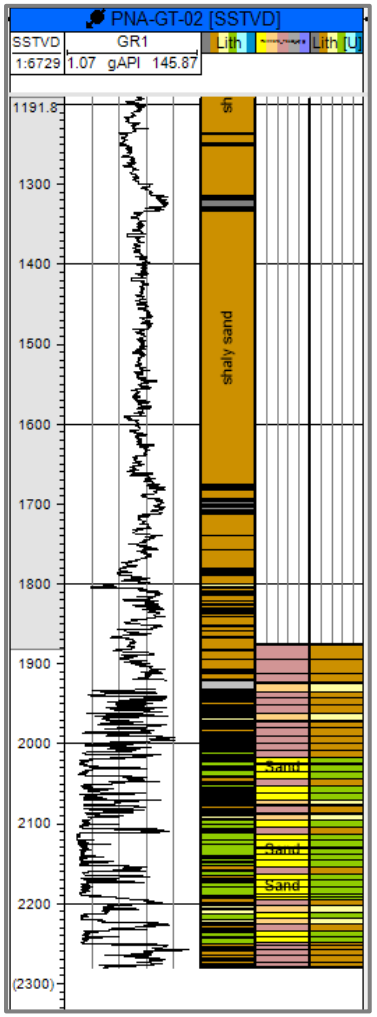




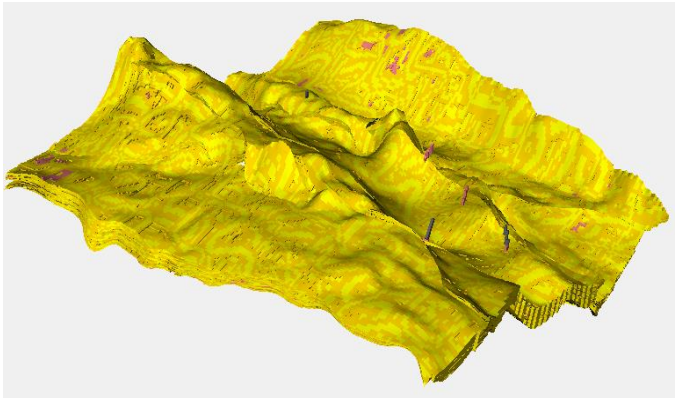


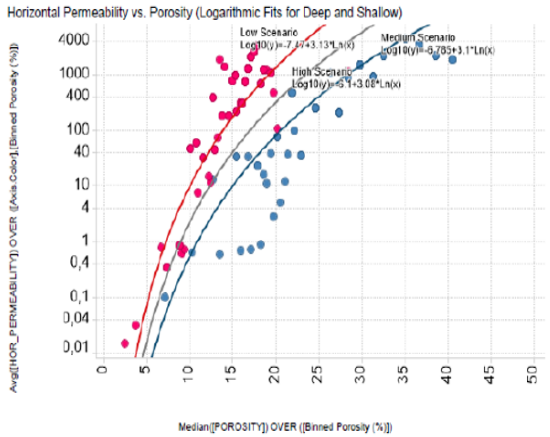
*Thanks to SURFsara for the access to the Lisa GPU cluster and TotalEnergies for sponsoring DARTS-GPU

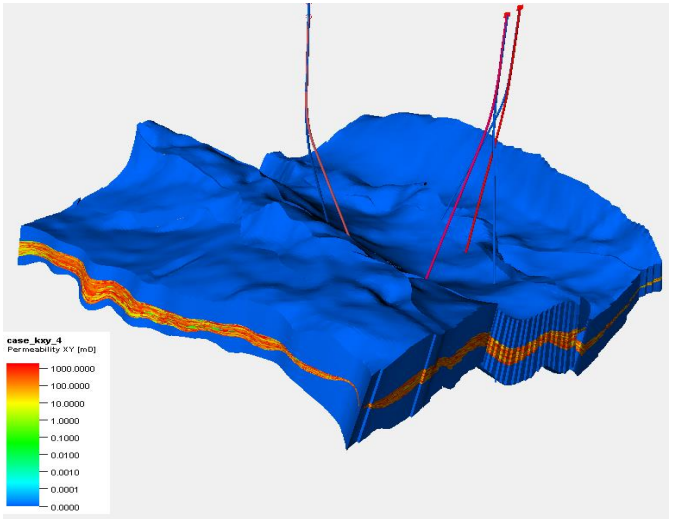
Geological model for DAP project



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



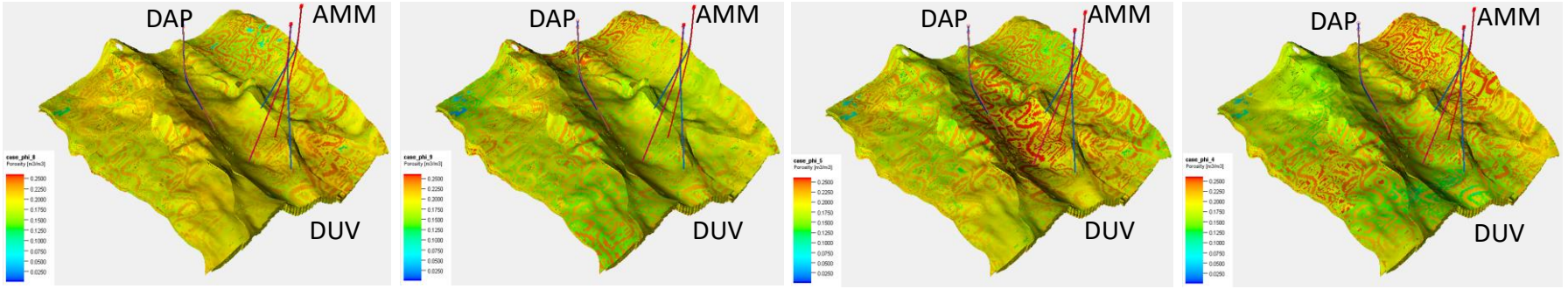




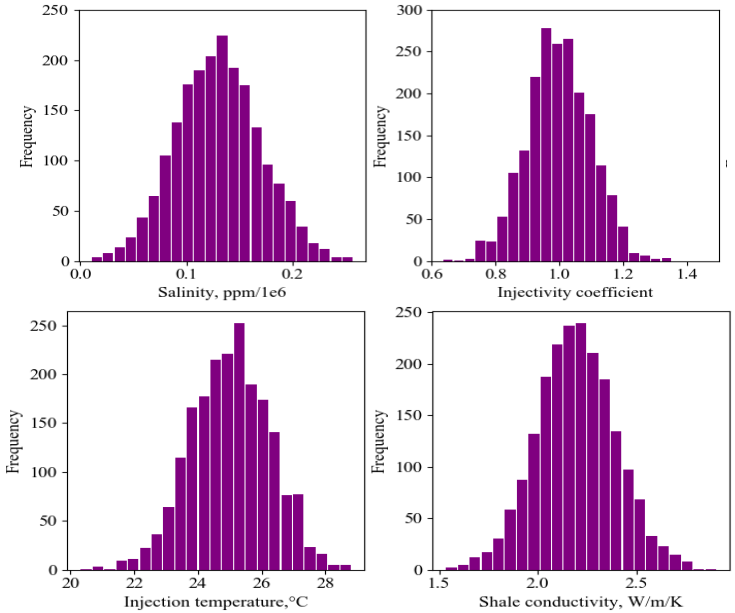
Reinhard, MSc, 2019

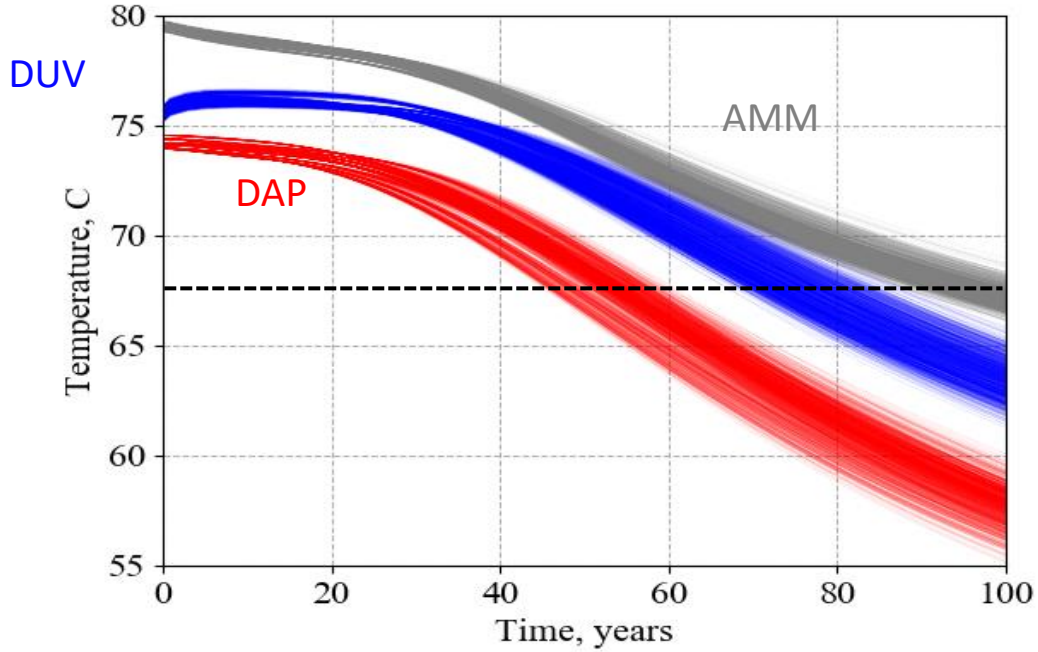
Sensitivity study for DAP project

Porosity distributions of 4 (out of 10) cases



Distribution of other parameters





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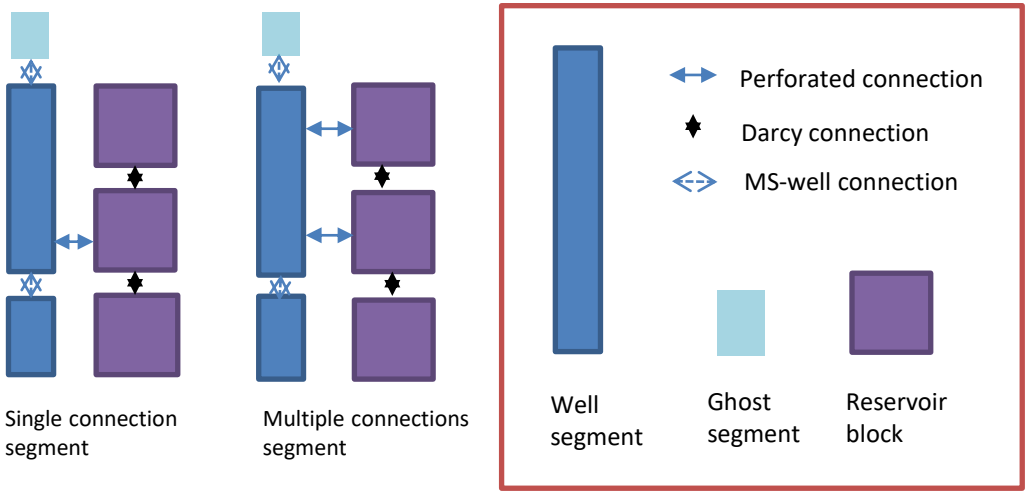
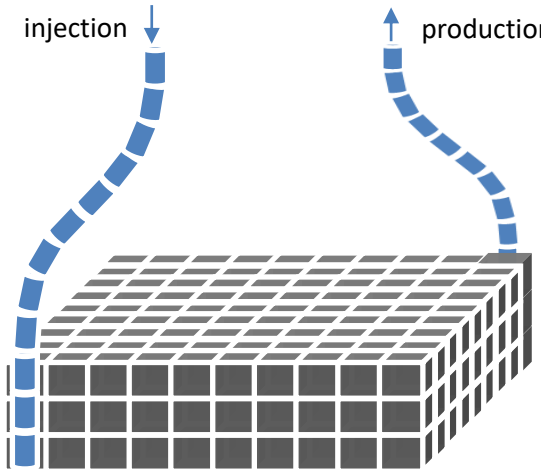
Multi-segmented well model

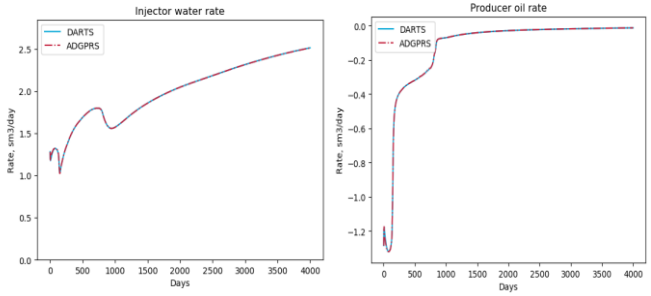
- Multi-physics in wellbore (thermal multiphase multi-component reactive flow and transport with heat loses)
- Complex well network (deviated, multilateral, annulus, etc.)

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

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

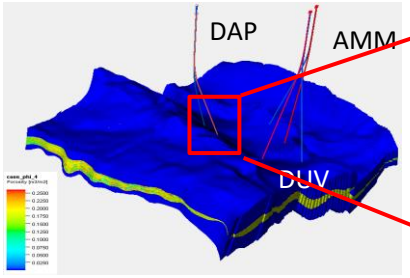




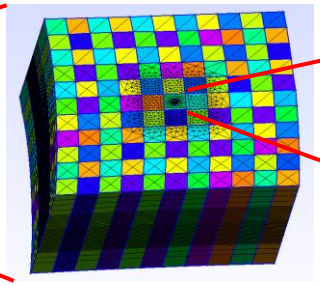


Near-well modeling

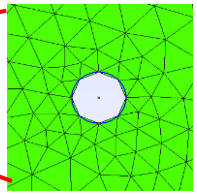
Petrel model



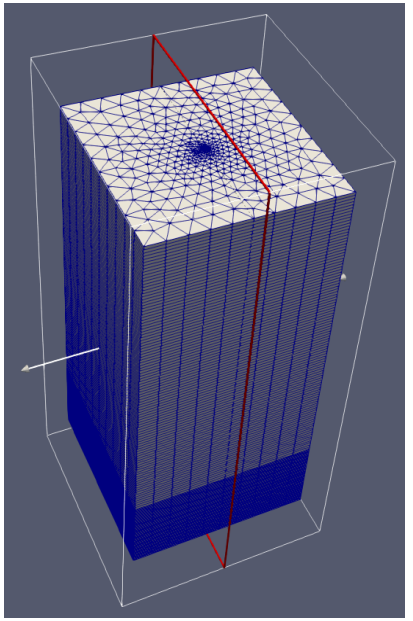
Gmsh model



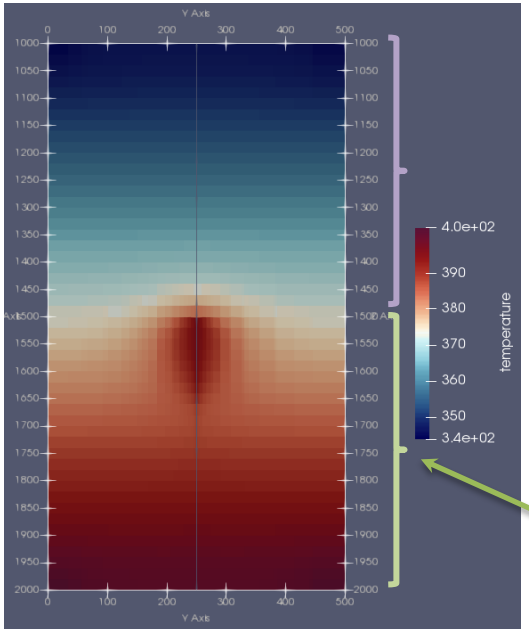
Well model



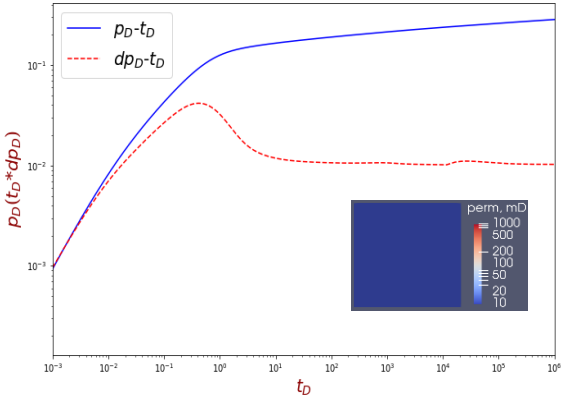
Wellbore discretization down to $r_w = 0.1\ m$



Effect of insulation

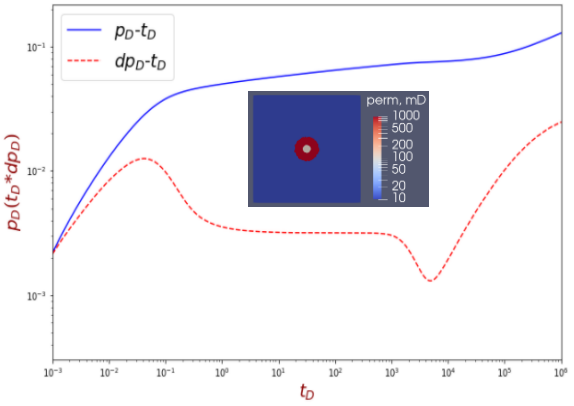


Homogeneous



Non-insulated interval

Heterogeneous



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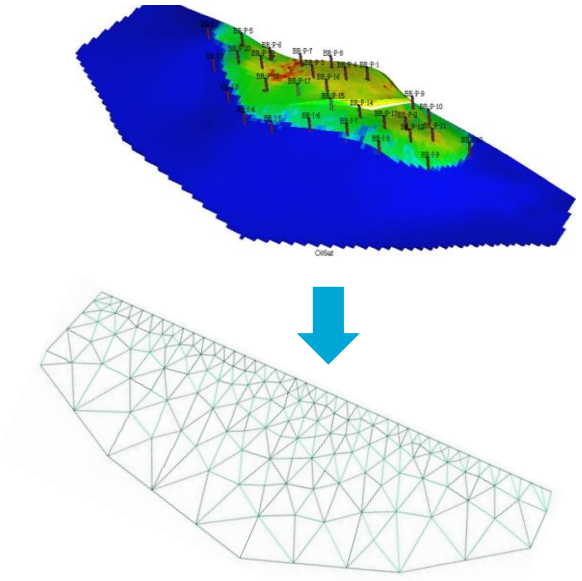
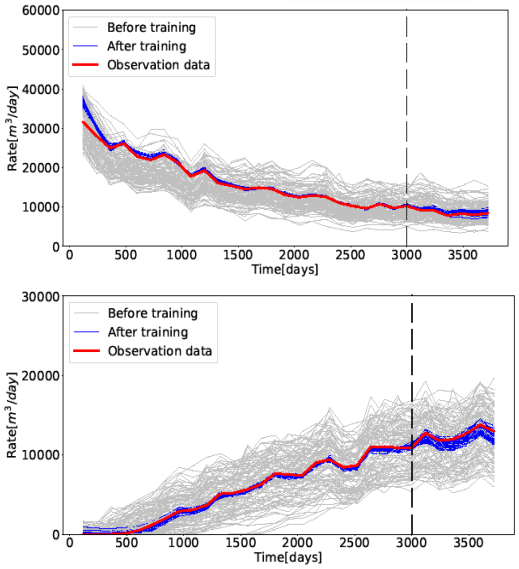
Physics-based proxy

	High fidelity model	DiWA proxy
Control volumes	43,846	283
Control variables	124,169	394
Production data	24*30 days	24*30 days
Single forward run	175 seconds	0.8 seconds



Numerical Gradients	Adjoint Gradients
$J(\omega, u)$	$\bar{\mathcal{J}}(\omega, u, \lambda) = J(\omega, u) + \lambda^{\mathrm{T}} g(\omega, u)$
$\frac{\partial J}{\partial u_1} = \frac{J(\mathbf{u} + \delta_k \varepsilon) - J(\mathbf{u})}{\varepsilon} + O(\varepsilon)$	$\bar{\mathcal{J}}_\lambda = g(\omega, u) = 0$
$\frac{\partial J}{\partial u_2} = \frac{J(\mathbf{u} + \delta_k \varepsilon) - J(\mathbf{u})}{\varepsilon} + O(\varepsilon)$	$\bar{\mathcal{J}}_\omega = \lambda^{\mathrm{T}} g_\omega(\omega, u) + J_\omega(\omega, u) = 0$
$\vdots$	$\bar{\mathcal{J}}_u = \lambda^{\mathrm{T}} g_u(\omega, u) + J_u(\omega, u) = 0$



348 sec vs. **1.5** sec for one gradient evaluation

Tian et al., SPEJ, 2021

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