A Digital Toolbox for Modeling and Optimization of Geothermal Energy Systems

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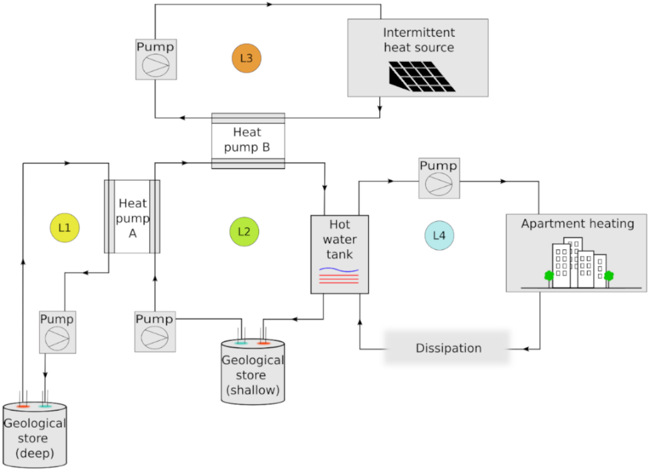
CGER Matchmaking Event, Jan. 26, 2023



Introduction

- Innovation Project with SINTEF Digital and Ruden AS (2020-2023)
- Main objective: develop a *Digital Platform* to optimize design and management of complex geothermal systems for production and seasonal storage of heat.

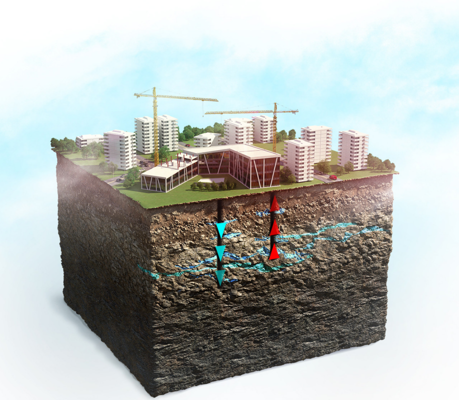


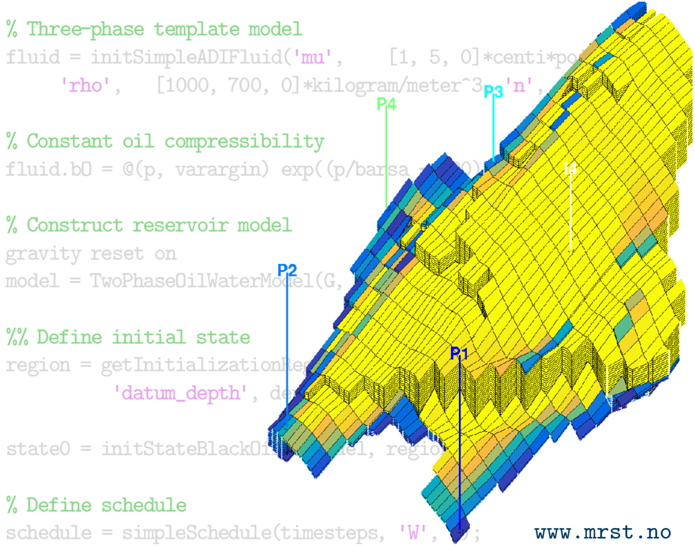
image credit: Ruden AS

MATLAB Reservoir Simulation Toolbox (MRST)

Transforming research on reservoir modelling

Unique prototyping platform:

- Standard data formats
- Data structures/library routines
- Fully unstructured grids
- Rapid prototyping:
  - Differentiation operators
  - Automatic differentiation
  - Object-oriented framework
  - State functions
- Industry-standard simulation



MATLAB Reservoir Simulation Toolbox (MRST)

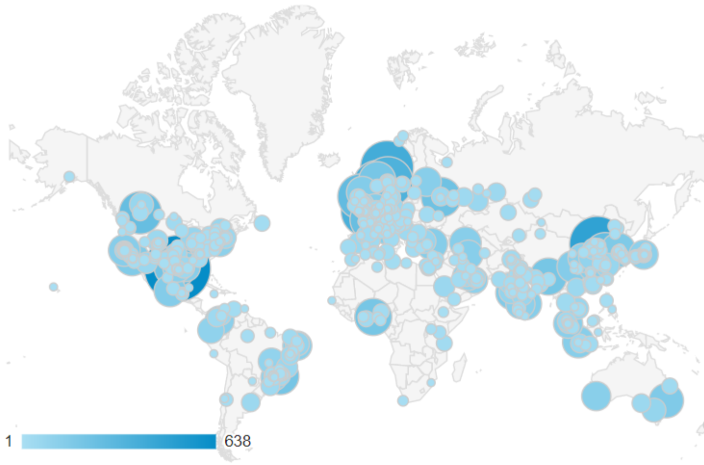
Transforming research on reservoir modelling

Large international user base:

- downloads from the whole world
- 124 master theses
- 56 PhD theses
- 400 journal papers (not by us)
- 144 proceedings papers

Numbers are from Google Scholar notifications

Used both by academia and industry



Google Analytics: access pattern for `www.mrst.no`
Period: 1 July 2018 to 31 December 2019
Unique downloads: 5 516 (103 countries and 838 cities)

Modules for optimization and geothermal simulation

Geothermal simulation module

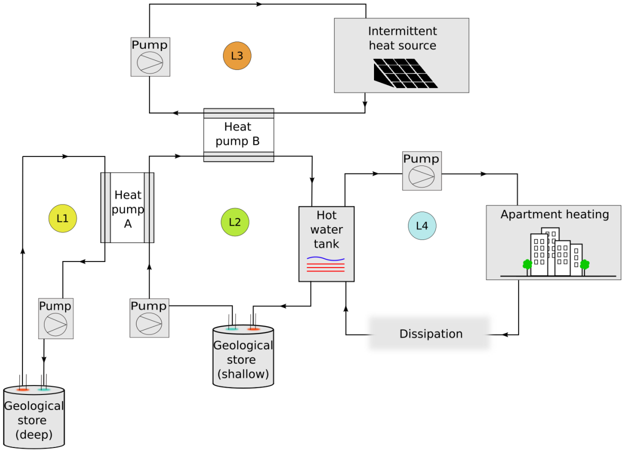
- 1ph fluid flow in porous/fractured medium
- Energy conservation (temperature or enthalpy formulation)
- Complex, unstructured grids
- Temperature/pressure dependent rock properties
- Well group controls
- Multisegment wells

Nonlinear optimization module

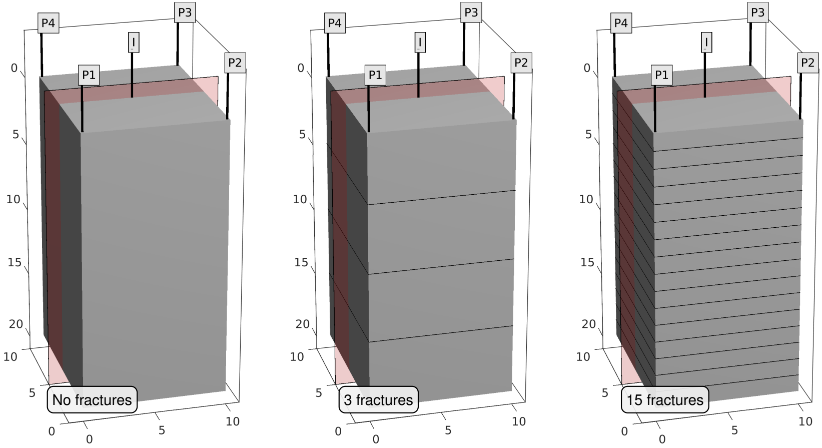
- Adjoint-based nonlinear optimization
- Calibrate model parameters
- Compute optimal operational parameters (e.g. maximising profits)
- Ensemble optimization

Digital Platform modular concept

- The geological reservoir is only one component in a larger system that includes:
  - wells and well groups
  - water pumps and heaters
  - heat pumps and heat exchangers
  - (time-dependent) heat sources and consumers
  - system losses
- Optimal use requires taking the whole system into account, while considering:
  - supply and demand
  - energy prices



The importance of fracture and well modeling

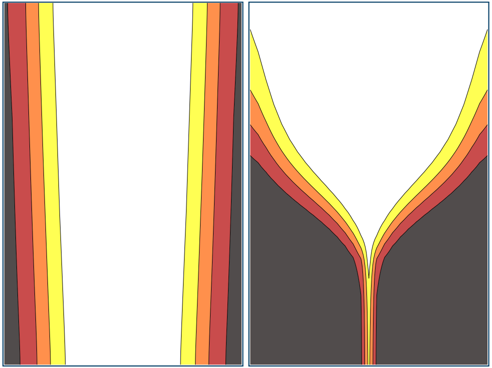


The importance of fracture and well modeling

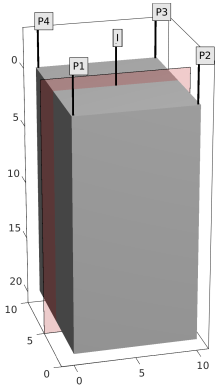
1 mm aperture

3 mm aperture

Upscaled, homogeneous perm/poro



3 fractures



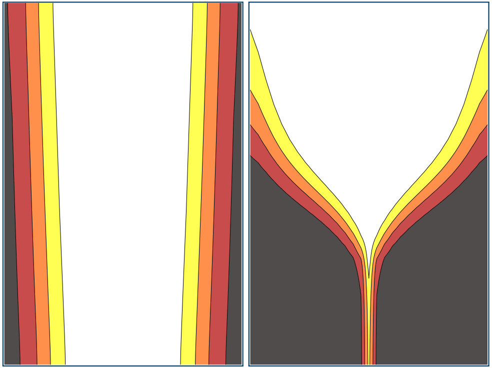
Temperature at red cross-section

The importance of fracture and well modeling

1 mm aperture

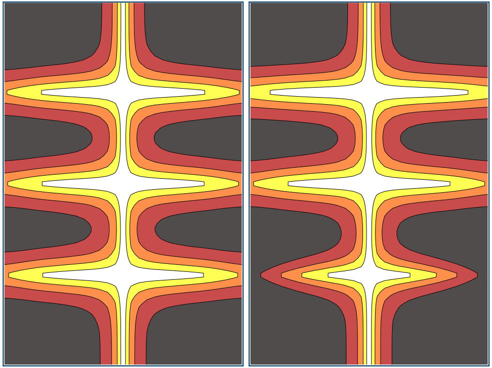
3 mm aperture

Upscaled, homogeneous perm/poro



3 fractures

Discrete fracture model

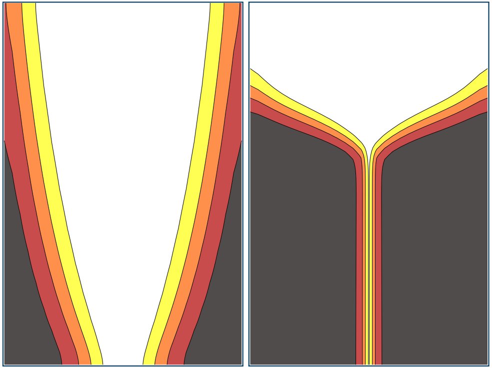


3 fractures

The importance of fracture and well modeling

1 mm aperture 3 mm aperture

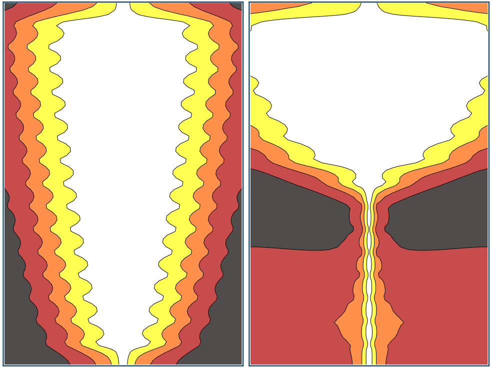
Upscaled, homogeoenous perm/poro



15 fractures

1 mm aperture 3 mm aperture

Discrete fracture model

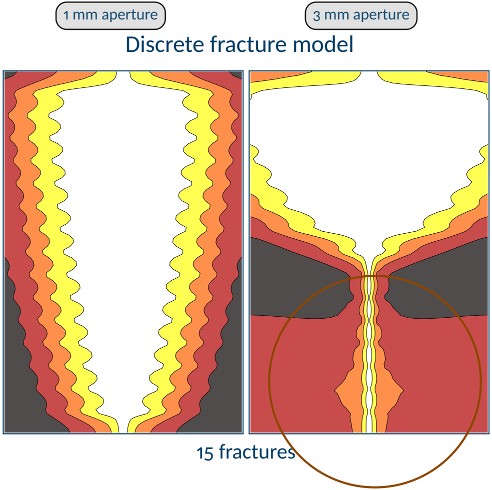


15 fractures

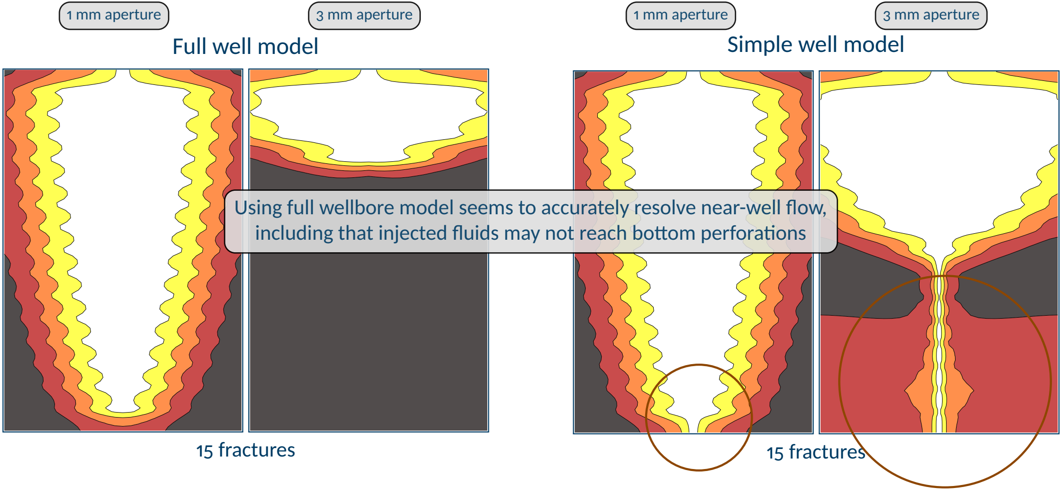
The importance of fracture and well modeling

Short inter-well distance, low pressure differences, significant buoyancy effects
$\rightarrow$ unresolved wellbore flow leads to non-physical flow pattern

Solution: full wellbore model with *conservation of mass/energy*

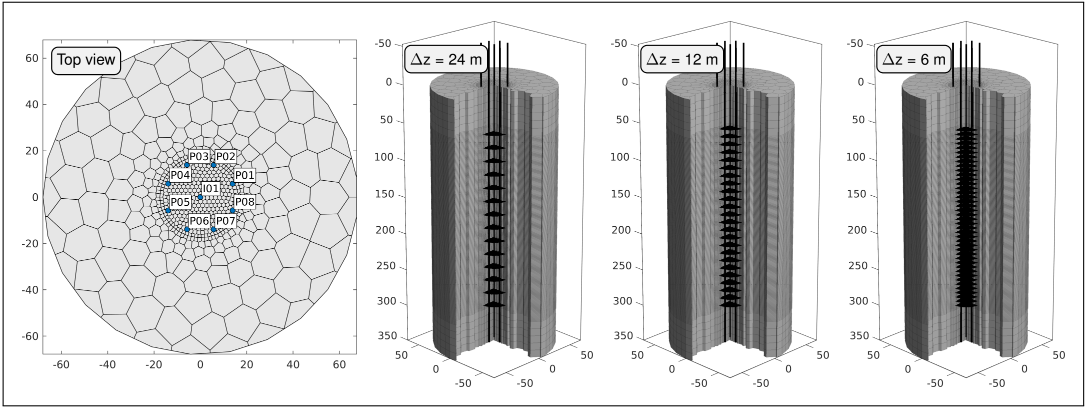


The importance of fracture and well modeling



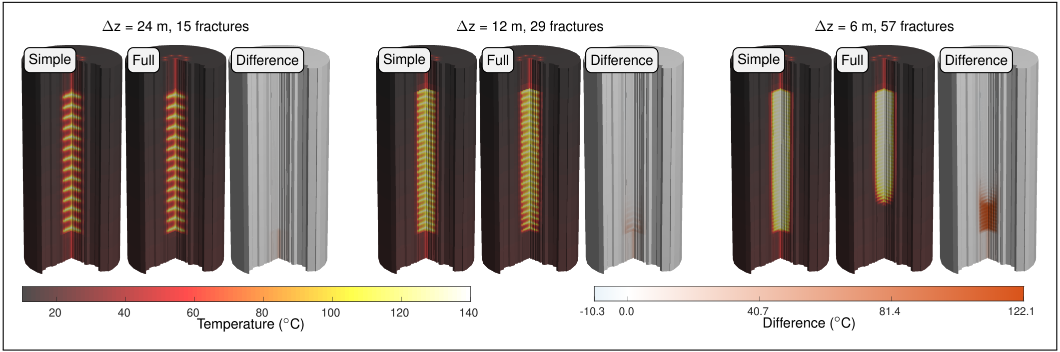
Example: Kvitebjørn (Tromsø)

Model construction: Conforming 2D Voronoi grid extruded vertically



Example: Kvitebjørn (Tromsø)

Simulation results: Matrix temperature after 6 months of charging



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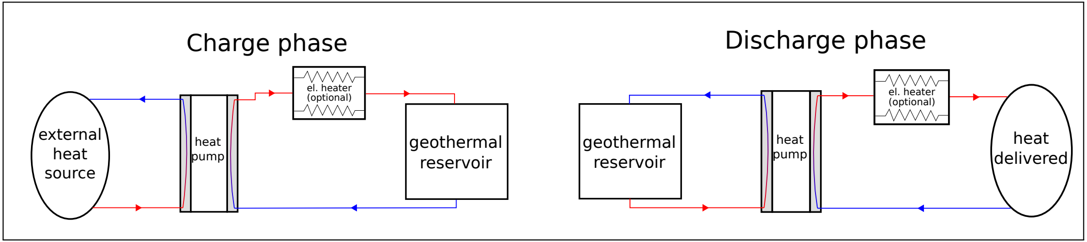
Optimal Control

- Setup: heat storage in 60 $\times$ 60 $\times$ 20 m box, homogeneous perm/poro of 2 md/0.04
- Charge for specific time, then discharge to provide peak load to external application
- Objective: find injection rate/temperature that minimizes associated energy costs



Optimal control

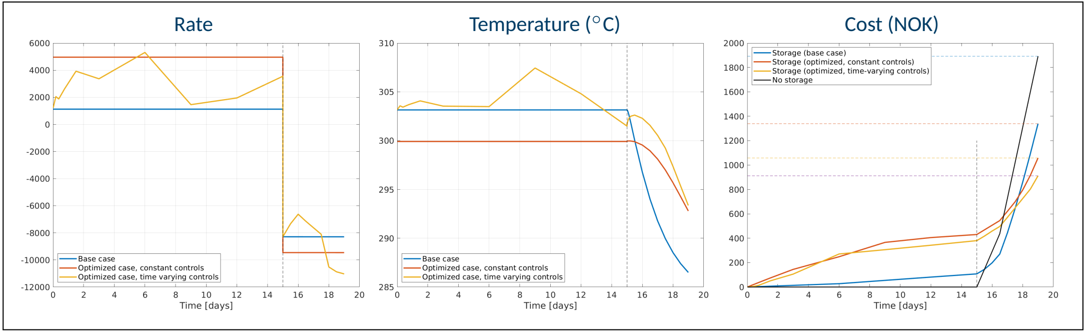
Optimal control – simple storage scenario

Parameter	Value
Charge period (days)	15
Discharge period (days)	4
Energy price (NOK/kWh) 5	0.75 - 1.5 - 3.0
Charge: max power from source (MW)	1
Discharge: power delivery required (MW)	8
Initial reservoir temperature, T_0 (°C)	10

Four strategies: no heat storage, base case storage, optimized storage with constant and varying temperature/rate

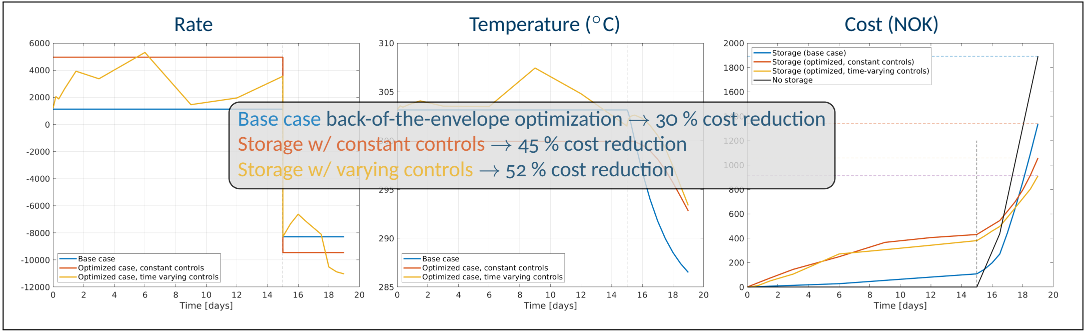
Optimal Control

Optimal control results

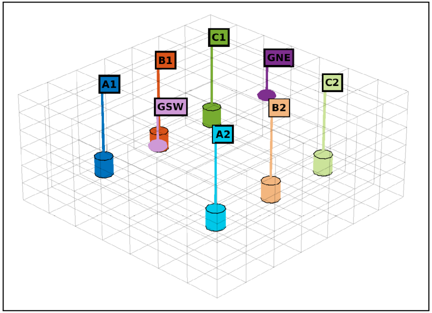


Optimal Control

Optimal control results



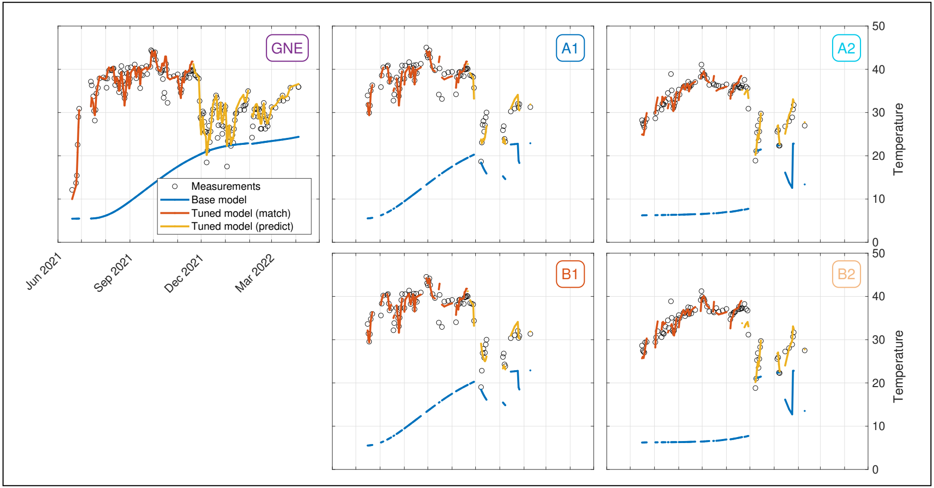
Calibration to data – model tuning



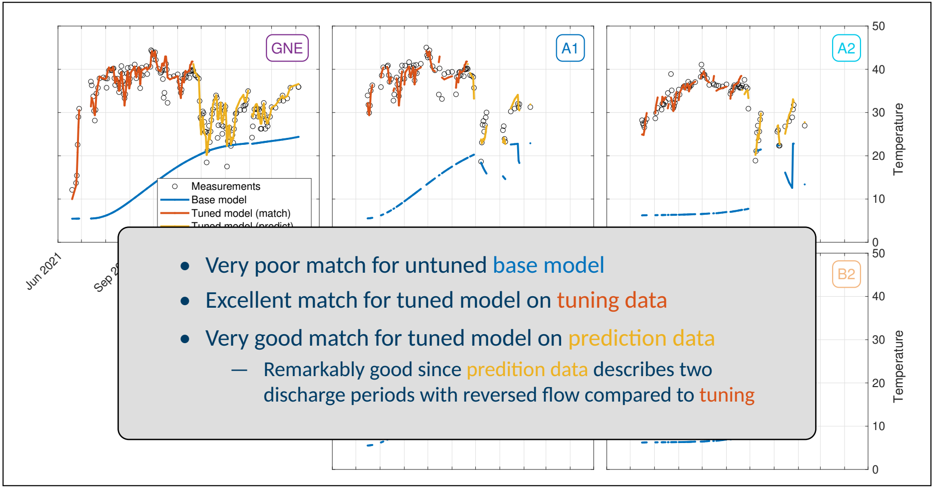
Coarse network model

- Use gradient-based optimization with manifold temperature mismatch as objective
  - Recast as nonlinear least-squares problem $\rightarrow$ use Levenberg Marquardt algorithm
- Tune *coarse-grid network model* with manifolds only instead of full model w/ 97 wells
- Parameters tuned: pore volumes, flow/thermal transmissibilities, heat capacities

Calibration to data – model tuning



Calibration to data – model tuning



- Very poor match for untuned base model
- Excellent match for tuned model on tuning data
- Very good match for tuned model on prediction data
  - Remarkably good since predition data describes two discharge periods with reversed flow compared to tuning

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Concluding remarks

Conclusions

- Integrated framework for modelling and optimization of geothermal heat storage
  - Based on methods from simulation of oil and gas reservoirs
  - Fracture mass and heat flow (DFM), accurate wellbore modelling
  - Gradient-based optimization capable of optimal control and parameter tuning
  - System simulated as a set of connected loops: “plug and play” with reservoirs, pumps, heaters, ...
- Simplified parameter study highlights important modelling aspects
  - Explicit fracture modelling is important when the rock is sparsely fractured
  - Densely fractured plants may be adequately modelled using upscaled rock parameters
  - Modelling mass/heat flow inside wellbore has significant effect on simulated performace

Acknowledgements

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