EAGE

27-31 OCTOBER 2025
ROTTERDAM, THE NETHERLANDS

GET2025

GEOTHERMAL ENERGY CONFERENCE

GEOTHERMAL FIELD DEVELOPMENT OPTIMIZATION

Optimizing well design in marginal reservoirs

Eduardo Barros

TNO innovation for life

CONTEXT

Geothermal field development

- Every geothermal project is unique, both from subsurface and surface infrastructure perspectives
- Wells are only drilled once. There is generally no second chance to develop a geothermal project, at least not without additional costs
- Narrow margins for project viability: marginal reservoirs in areas of confirmed heat demand put pressure on business case
- All above point to the need of optimizing geothermal wells and field development strategies

KEY INGREDIENTS

Computer-assisted decision support workflow

- EVEREST™ optimization framework
  - Flexible to be applied in different contexts
  - Robust in order to be reliable in real-life cases
  - Open-source in order to be accessible and transparent
- Techno-economic performance
  - OPM-Flow: high-fidelity 3D reservoir simulator supporting thermal effects
  - PyThermoNomics: dedicated economic calculation for geothermal projects
- Honoring constraints
  - Drilling constraints
  - Production constraints
  - Geomechanical constraints
- Accounting for uncertainties

EVEREST

transforming uncertainty into opportunity

https://www.everest.tools/

OPM OPEN POROUS MEDIA

https://opm-project.org/

PyThermoNomics

https://github.com/TNO/pythermonomics

EVEREST TECHNOLOGY

Typical decisions in subsurface management

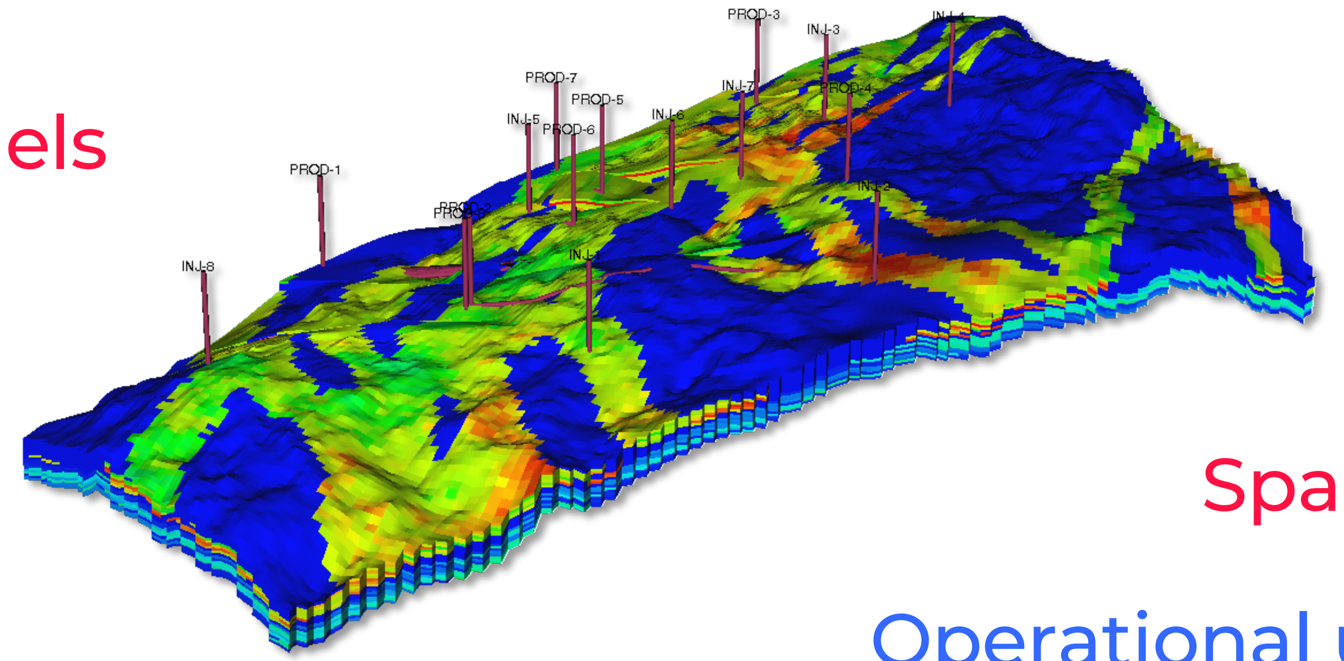
Geological uncertainties:
is the reservoir how we think it is?

Constraints

Economic uncertainties:
what will be the oil / CO_2 / heat price in the next 30 years?

Slow models

Safety



CO_2 footprint

Too many options

Sparse information

Measurement uncertainties:
how reliable is the acquired data?

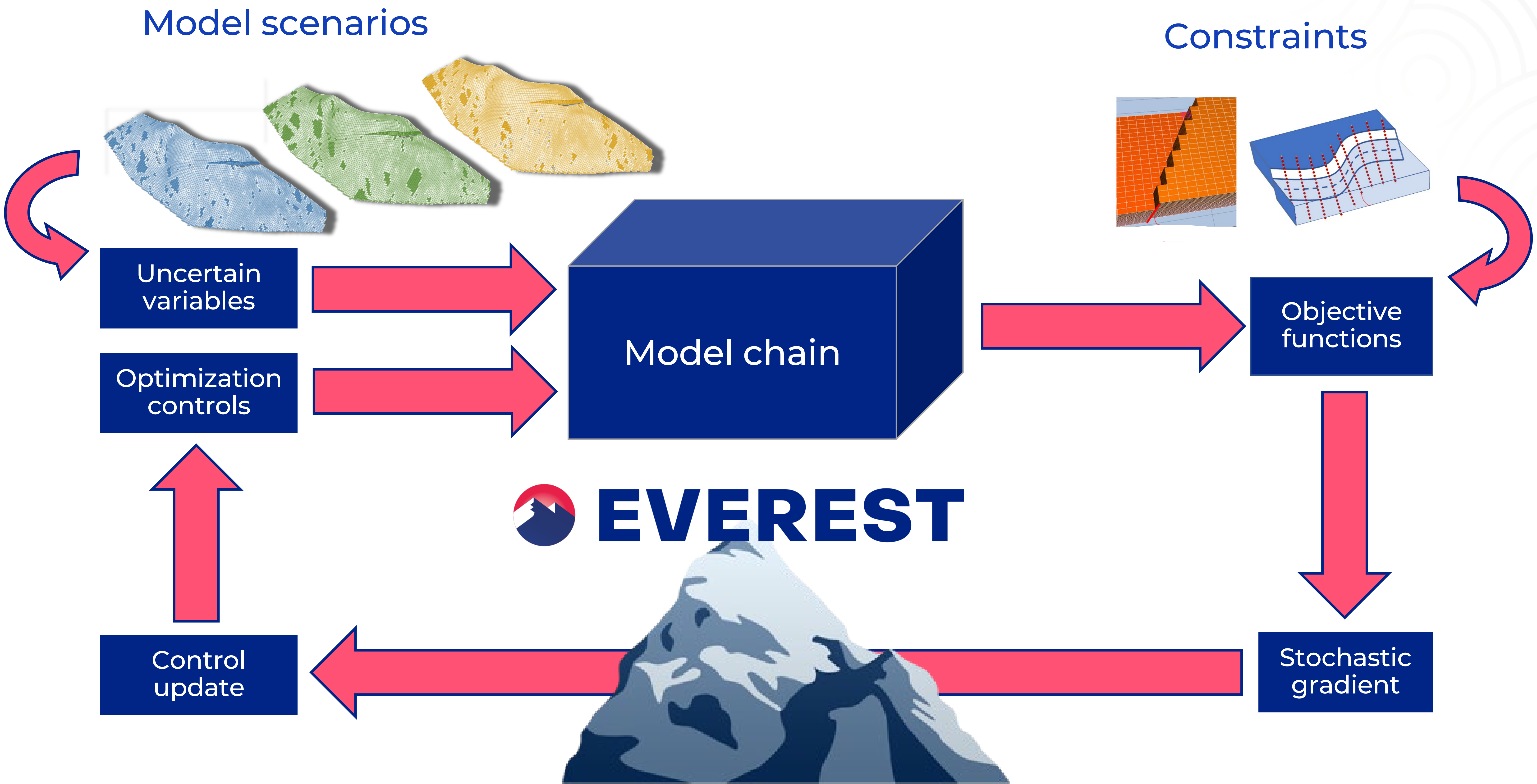
Operational uncertainties:
can the development strategy be executed as planned?

Multi-objective

- How many wells?
- Well trajectory: where to drill wells?
- Well type: production or injection?
- In which order to drill the wells?
- How to control the flow in the wells?
- Which additional data to acquire?

EVEREST TECHNOLOGY

Model-based optimization framework



RESULT PROJECT

Enhancing REServoirs in Urban deveLopmenT

- Confirmed heat demand + matching adjacent, prolific geothermal reservoir = successful geothermal projects
  - However, potential poor reservoir quality at locations of existing heat demand may result in poor business case
  - Advanced drilling solutions to improve the productivity of geothermal system do exist
- Main objective: investigate innovative approaches to guide well concept selection and engineering design of geothermal wells
  - Use of state-of-the-art modelling and optimization frameworks
  - Demonstration of scientific methodology in various case studies (Netherlands, Ireland, Iceland)
  - Practical drilling demonstration of innovative well designs

GEOTHERMICA

RESULT

Enhancing REServoirs in Urban deveLopmenT: smart wells and reservoir development
Geothermica Project Number 200317

TNO innovation for life · ebn · engie · Huisman · GDG Gavin & Doherty Geosolutions · ÍSOR · OR Orkuveita Reykjavíkur

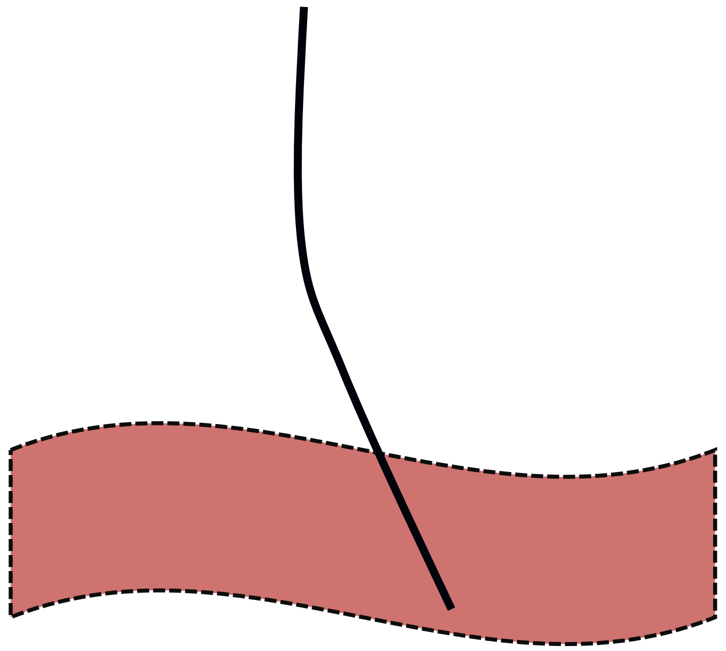
https://www.result-geothermica.eu/home.html

RESULT: OPTIMIZATION STUDY

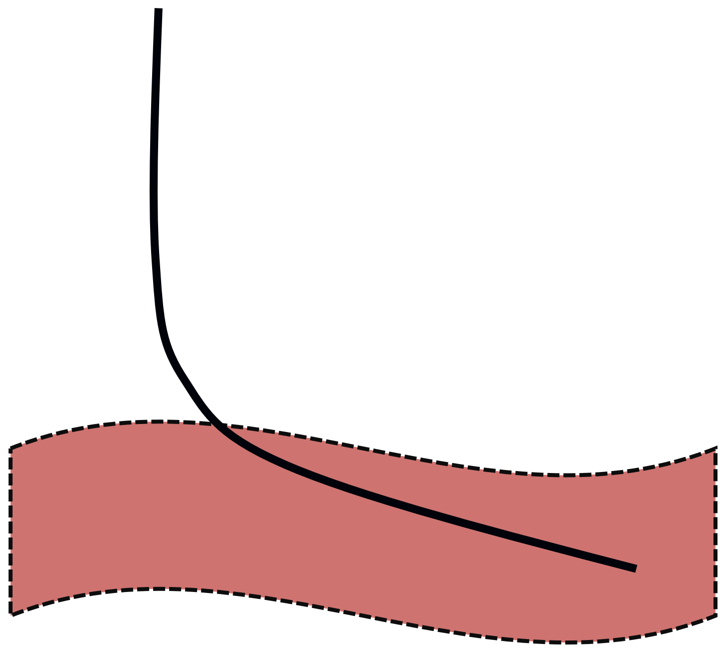
Assisting in well concept selection

- Numerical optimization approach is used to support the selection of the well concept for the Zwolle site by enabling the comparison of considered well concept designs
- Well trajectory optimization functionality from EVEReST allows for simultaneous optimization of well locations and well shapes
- 3 optimization experiments have been performed with different initial assumptions (and inclination constraints) regarding the shape of the wells, namely:

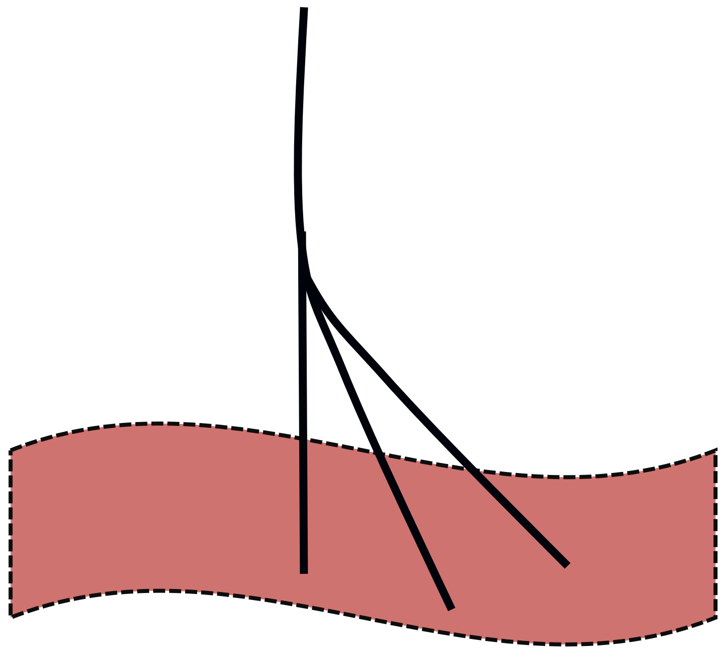
1. Slightly deviated wells
(i.e., quasi-vertical)



2.Strongly deviated wells
(i.e., sub-horizontal)



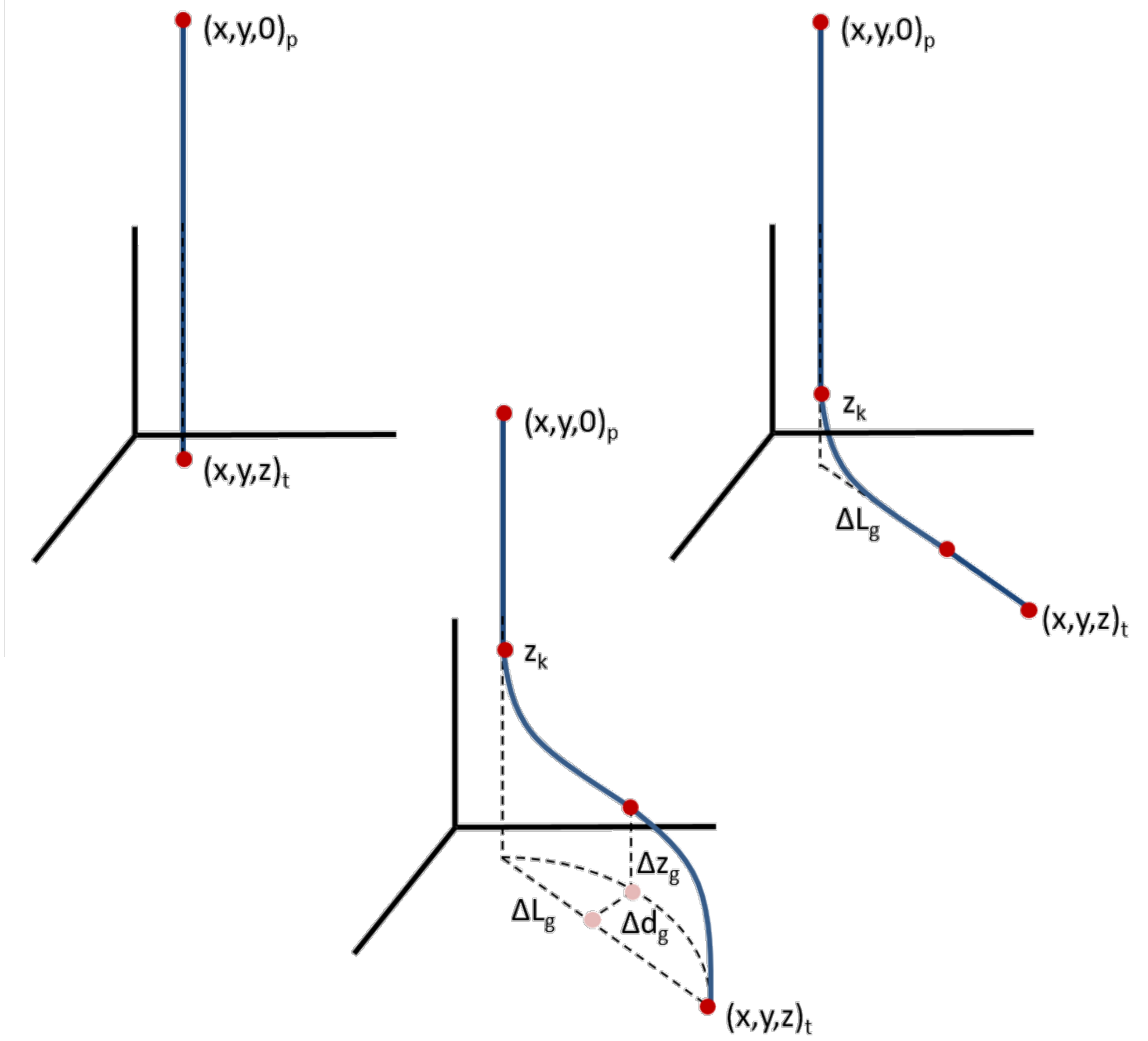
3.Multi-lateral wells
(3 quasi-vertical branches)



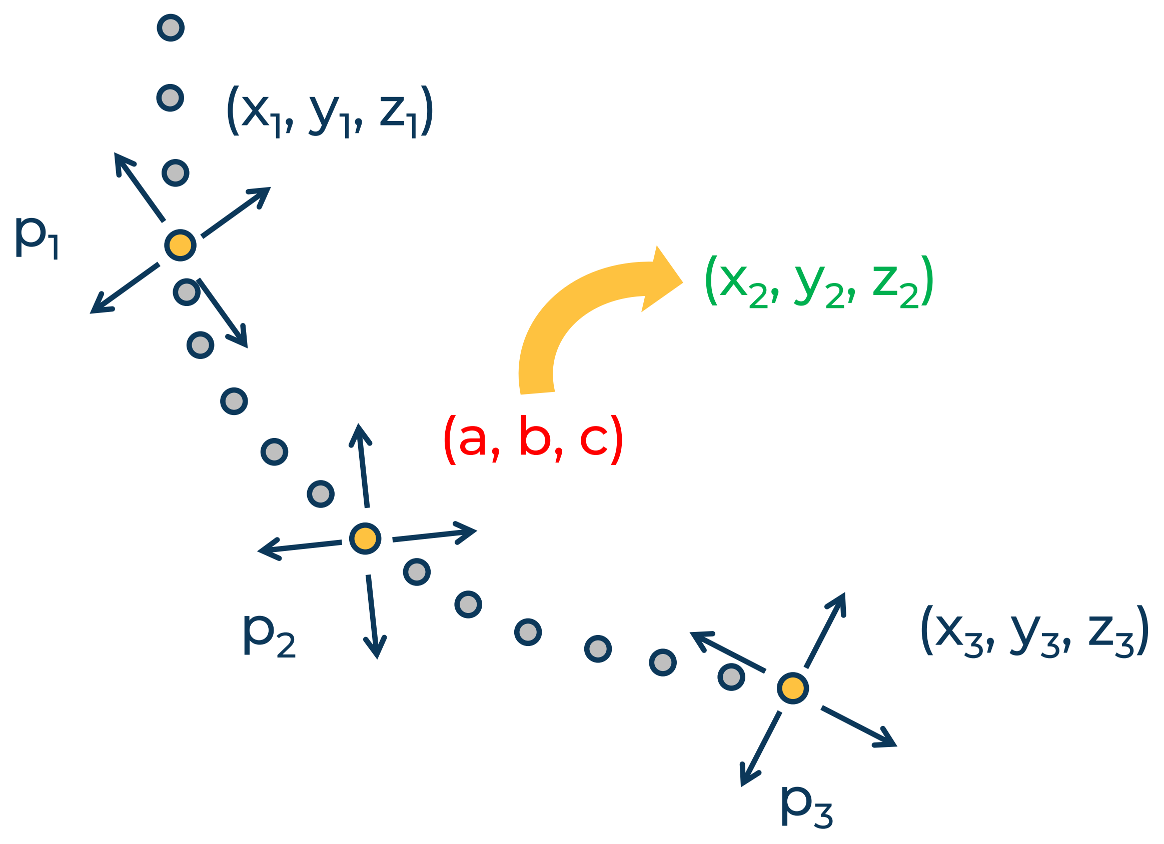
RESULT: OPTIMIZATION STUDY

Well trajectory parametrization

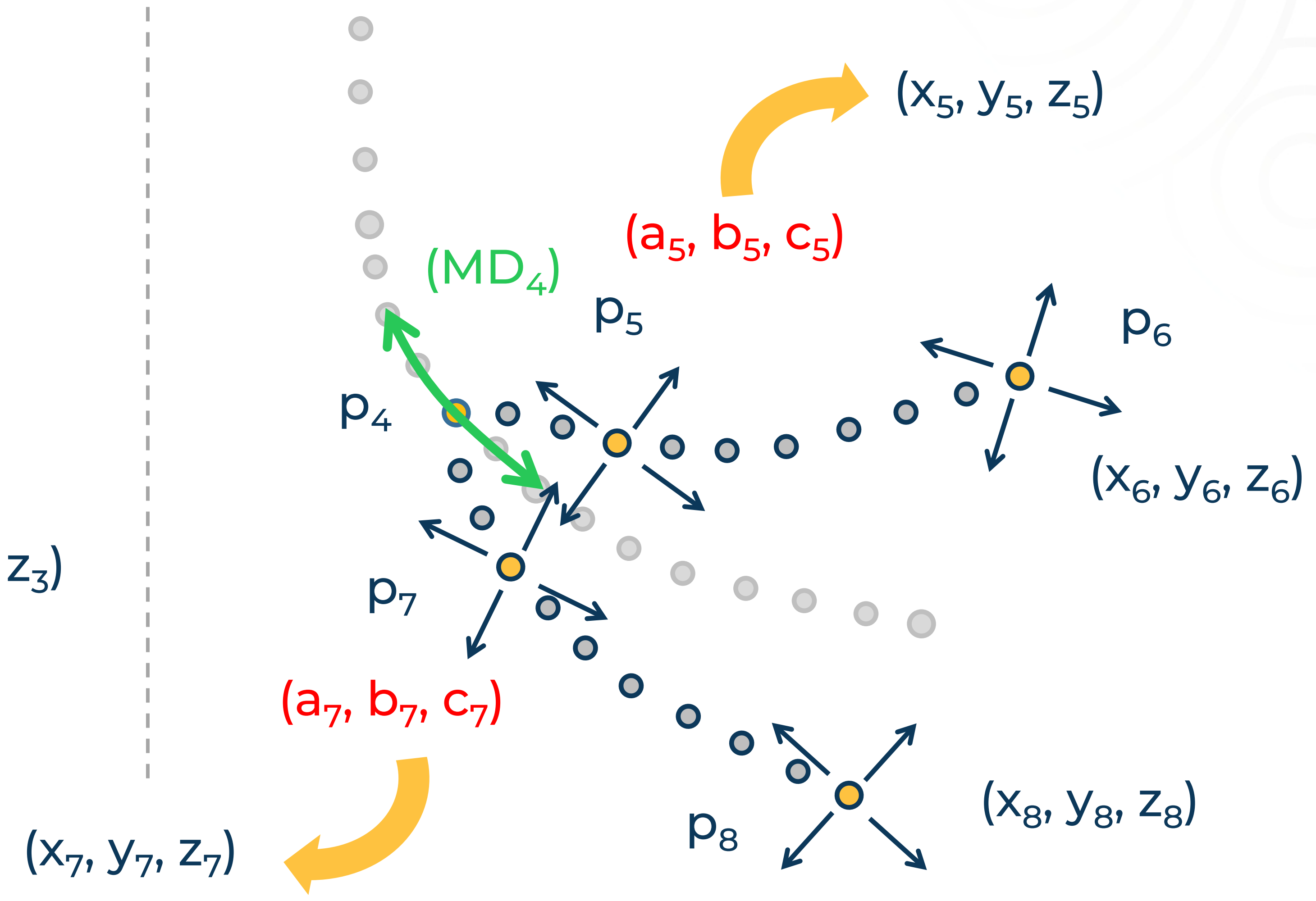
- Special parametrization defines complex well geometries with as little variables as possible
- Also constrains “target points” to move in coordinated manner: avoids un-drillable wells
- For multi-lateral wells: parametrization of main branch remains the same, and additional parameters are introduced to describe the multi-lateral legs



Main branch



Multi-lateral legs



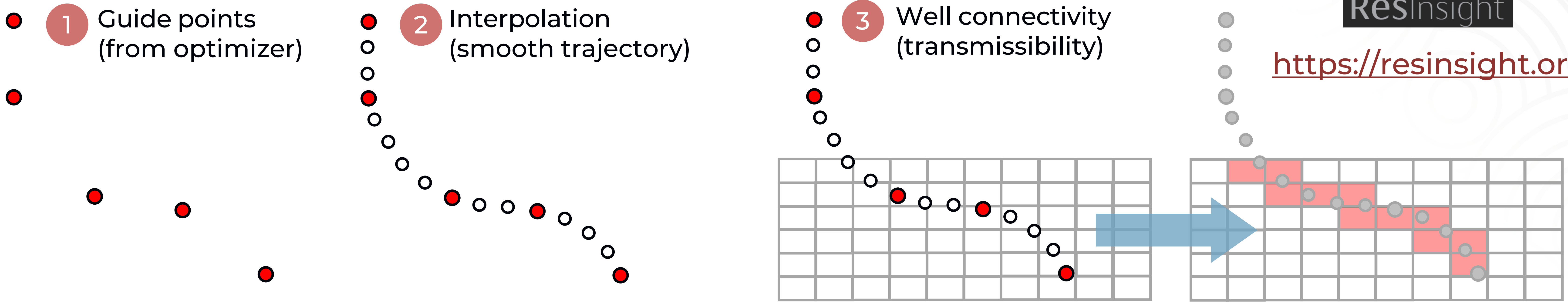
RESULT: OPTIMIZATION STUDY

Well trajectory workflow

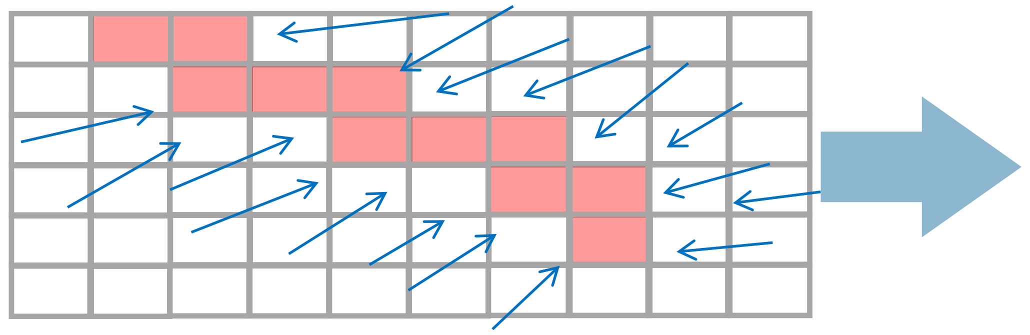
RESULT

ResInsight

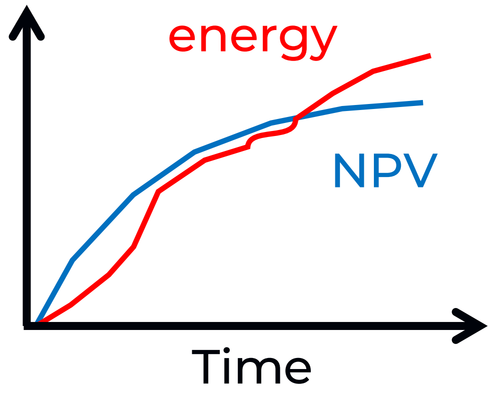
https://resinsight.org/



4 Production forecast
(from reservoir simulator)



5 Objectives
(energy, economics)



Well trajectories are grid-independent and need to be translated into trajectories for reservoir simulator, i.e. into grid well cells indices and connection factors

OPM OPEN POROUS MEDIA

https://opm-project.org/

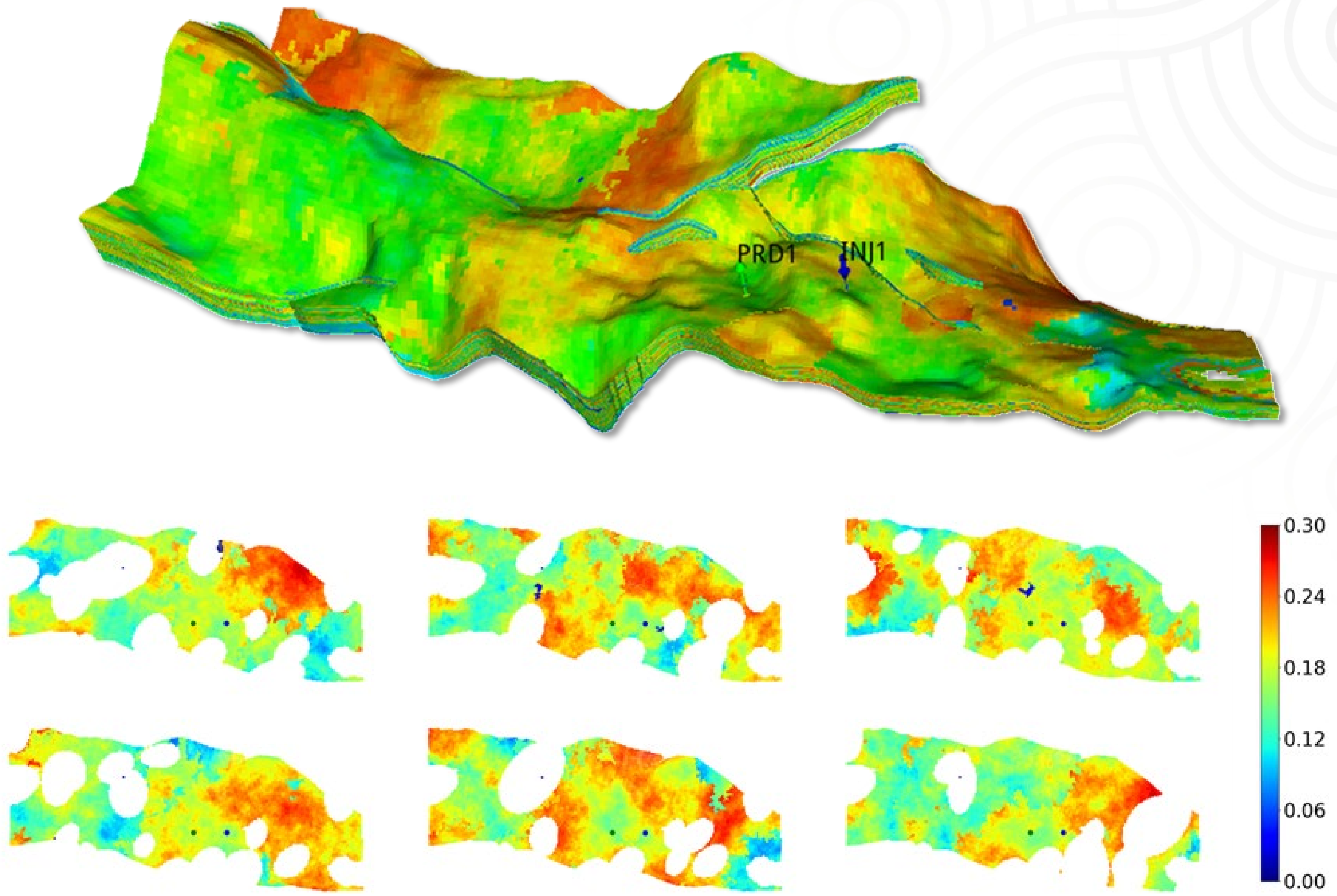
PyThermoNomics

https://github.com/TNO/pythermonomics

RESULT: OPTIMIZATION STUDY

Zwolle case study: reservoir model

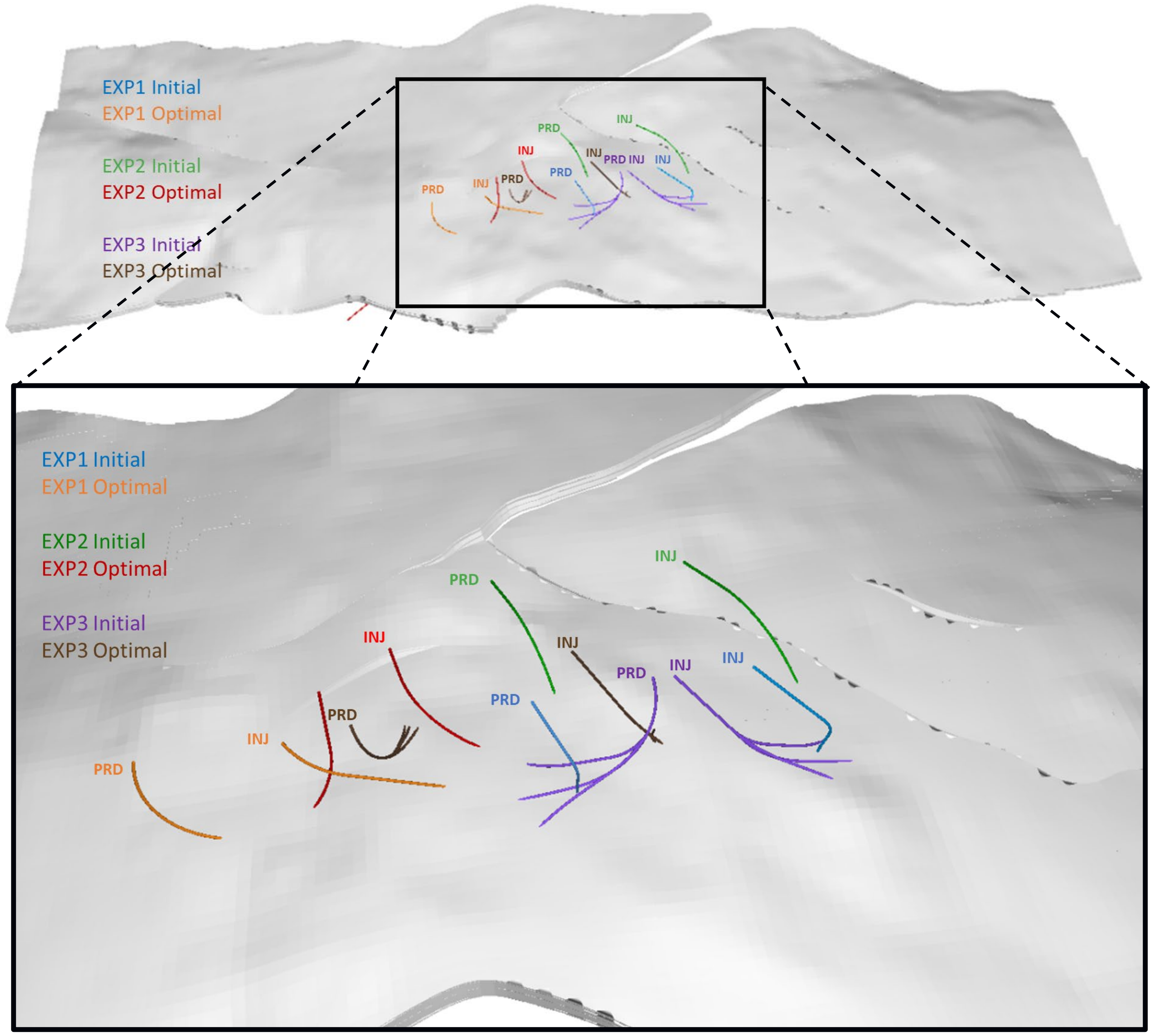
- The numerical model is a representation of reservoir at the Rotliegend formation
- The geological static model was generated by EBN based on geological knowledge
- Best-guess scenario concerning the cementation assumptions was used to create ensemble of 100 realizations
- Spatially heterogenous model with different static properties (i.e., porosity and permeability fields) to reflect the inherent geological uncertainties
- The model specifics:
    - Grid with 219 × 101 × 169 grid cells
    - Area of approximately 45 km² (= 11 km × 4 km)
    - Average depth: 2,400 m
    - Thickness from 50-80 m
    - Total of about 950,000 active cells
      (which varies slightly per model realization)

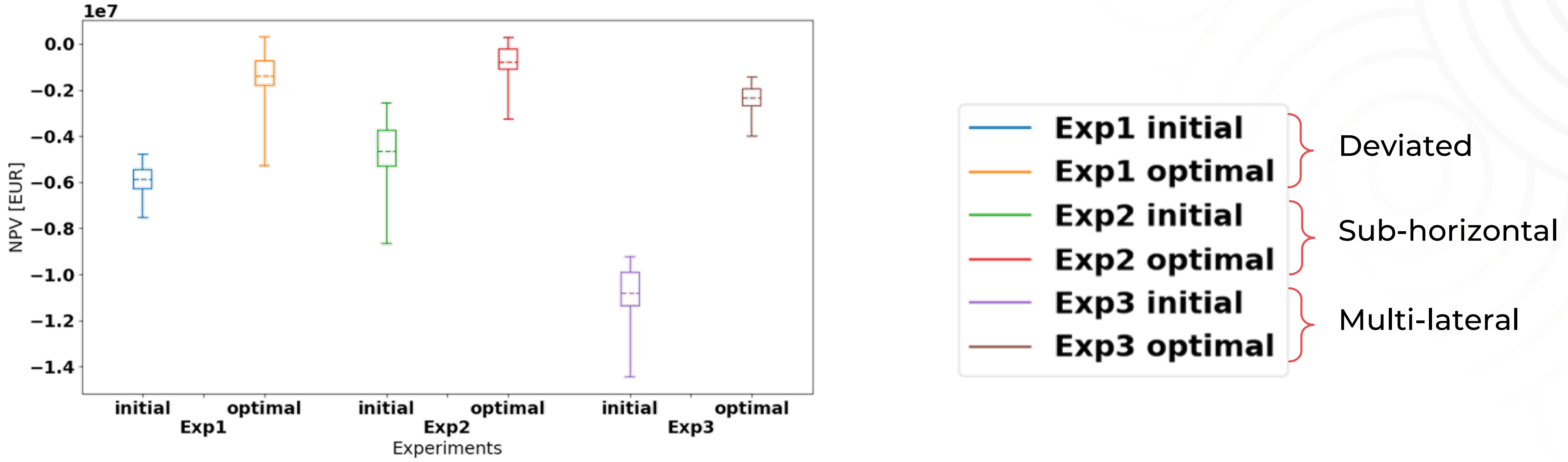


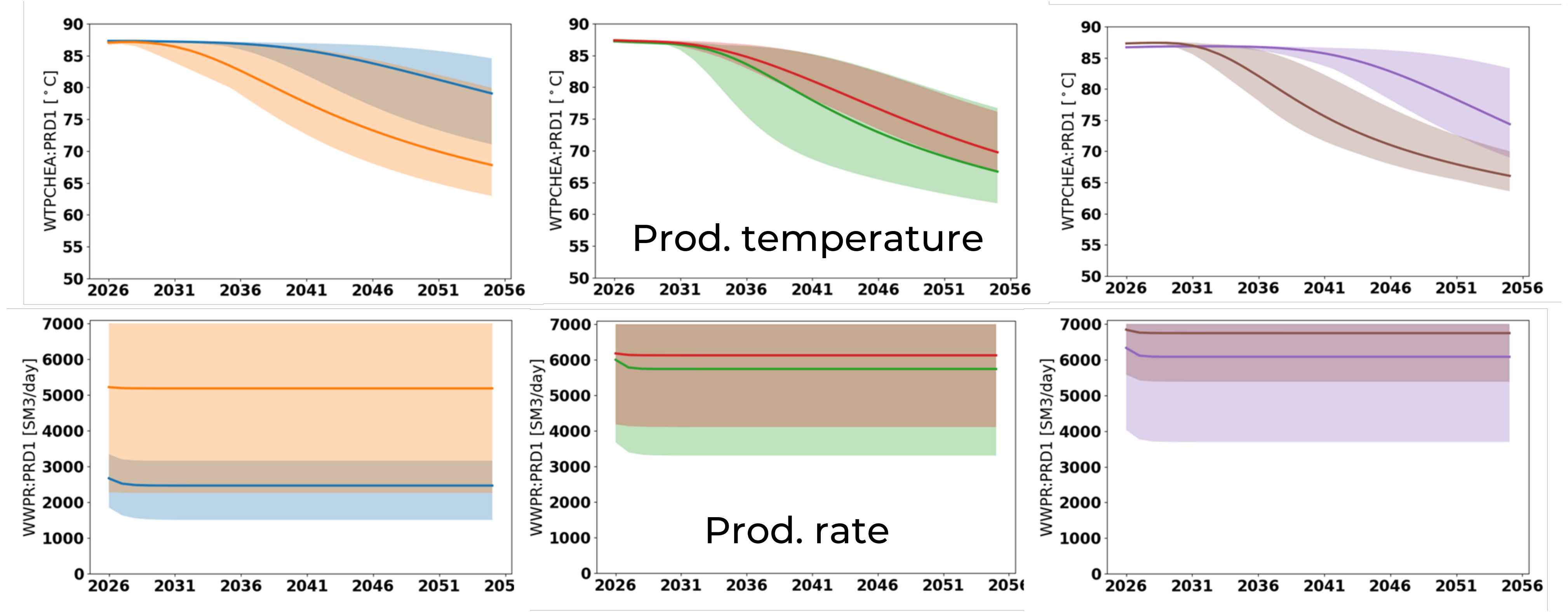
RESULT: OPTIMIZATION STUDY

Zwolle case study: improved well trajectories

- For each well concept, optimization was able to significantly improve techno-economic performance of the doublet system by changing locations and trajectories of both wells
- Optimization helps find the fine balance between flow rates, cold water breakthrough and costs







TKI GEO4ALL PROGRAM

WP2: dissemination of optimization best-practices

- Main objective: raise awareness of modern decision support best-practices across the Dutch geothermal sector
  - Apply RESULT / EVEREST optimization methodology to a broad range of geothermal sites in the Netherlands
  - Improve methodology with additional real-life considerations, e.g.: more detailed drilling constraints, geomechanical constraints

TKI NIEUW GAS
Topsector Energie

Geo4all
innovatieprogramma

- On-going GEO4ALL-WP2 optimization case studies:
  - Koekoekspolder
  - Amsterdam
  - Almere
  - Luttelgeest

GEO4ALL: OPTIMIZATION STUDY

Geo4all innovatieprogramma

Refined drilling constraints and indicators

- EVEREST well trajectory optimization workflow has been extended to include more detailed drilling constraints associated with wellbore stability
- Now all constraints below can be imposed:
  - Maximum allowed dogleg severity
  - Maximum allowed well length
  - Maximum allowed inclination
  - Maximum allowed build rate
  - Maximum allowed turn rate
  - Maximum allowed step-out / TVD ratio

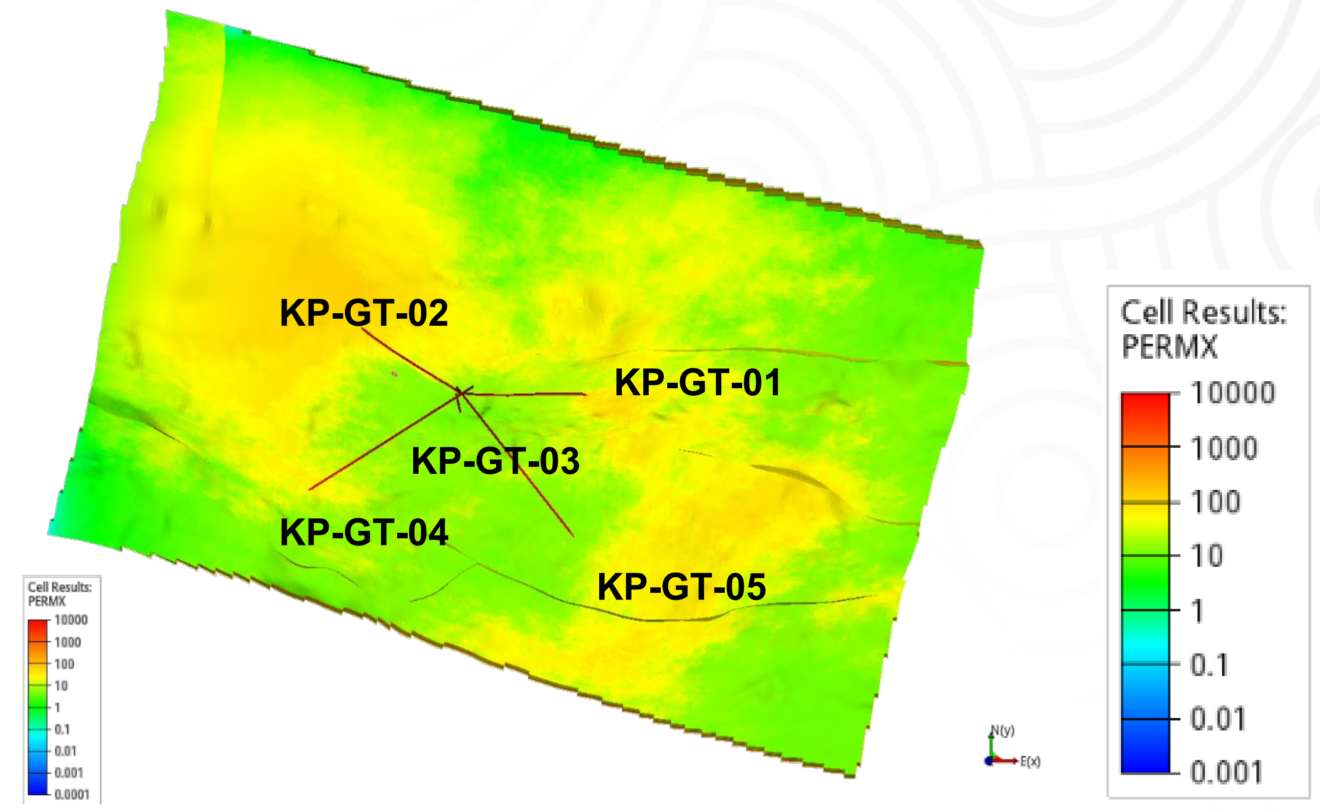
- Calculation of Directional Difficulty Index (DDI) is also available now:
  - Not used as a constraint, but more as a performance indicator / objective function
  - Goal: maximize NPV while minimizing DDI (multi-objective optimization)
- Fault stability constraints can also be imposed: Shear Capacity Utilization (SCU) indicator
- GEO4ALL-WP2 optimization case studies will leverage workflow enhancements listed above

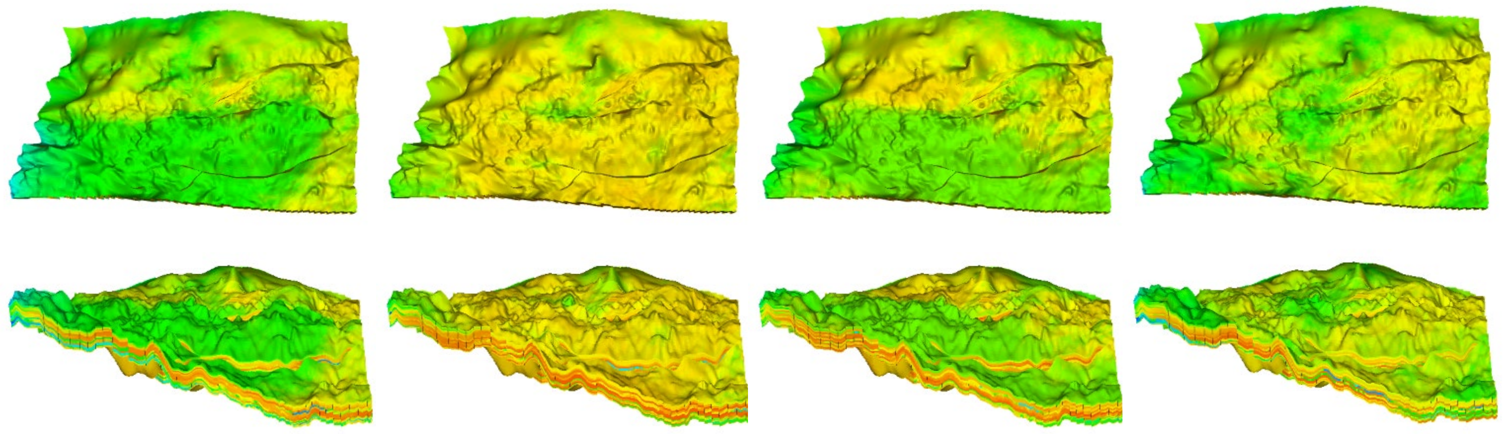
GEO4ALL: OPTIMIZATION STUDY

Geo4all innovatieprogramma

Koekoekspolder case: reservoir model

- Operational geothermal project with an existing triplet (KKP-GT-01, KKP-GT-02 and KKP-GT-03)
  - 12 years of production
  - Simulation model:
    - Information from seismic data (HIPE project): local structure with faults
    - History matched model with production data by updating global and local permeability multipliers
    - Geological realizations randomly generated with permeability and porosity ranges from upscaled well logs
    - Fault multipliers updated to match pressure in wells
- New doublet being considered (KKP-GT-04 and KKP-GT-05)
  - Same surface drilling location as existing triplet
  - What is the best possible configuration?
    - Well shapes and locations
    - Drilling constraints: max. well length, step-out, dogleg, ...
    - Fault stability constraints: SCU indicator



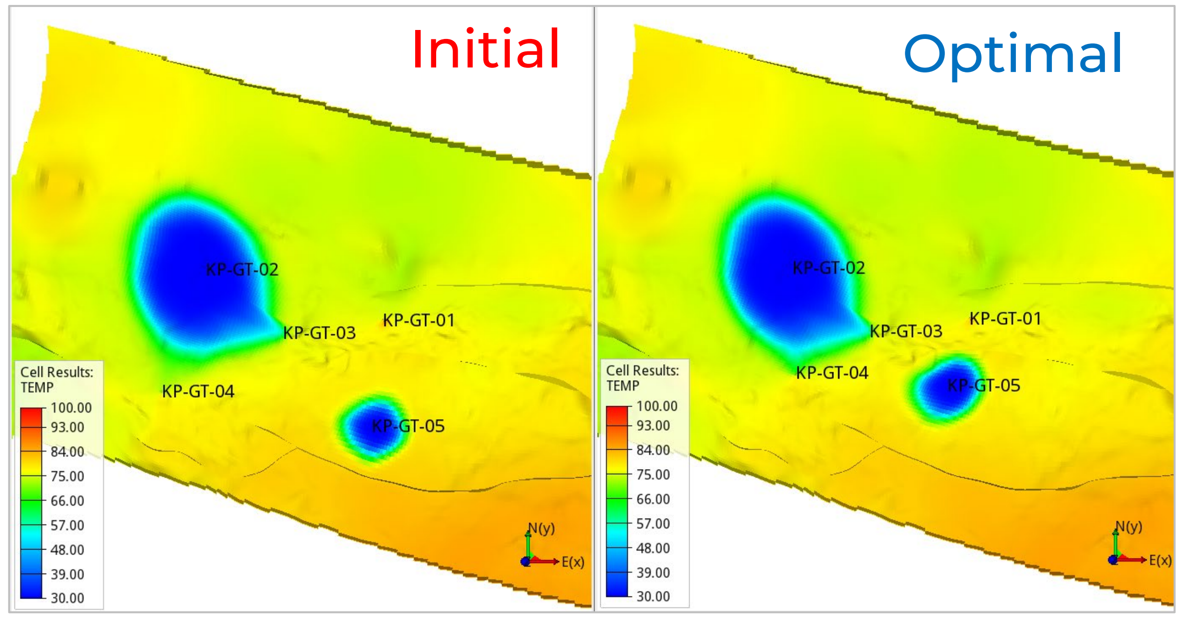


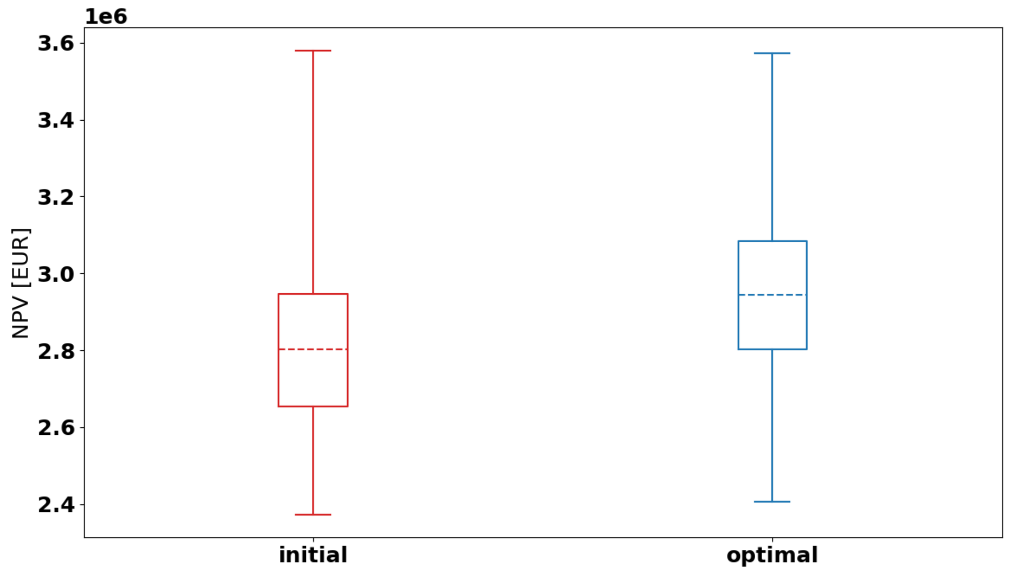
100 model realizations

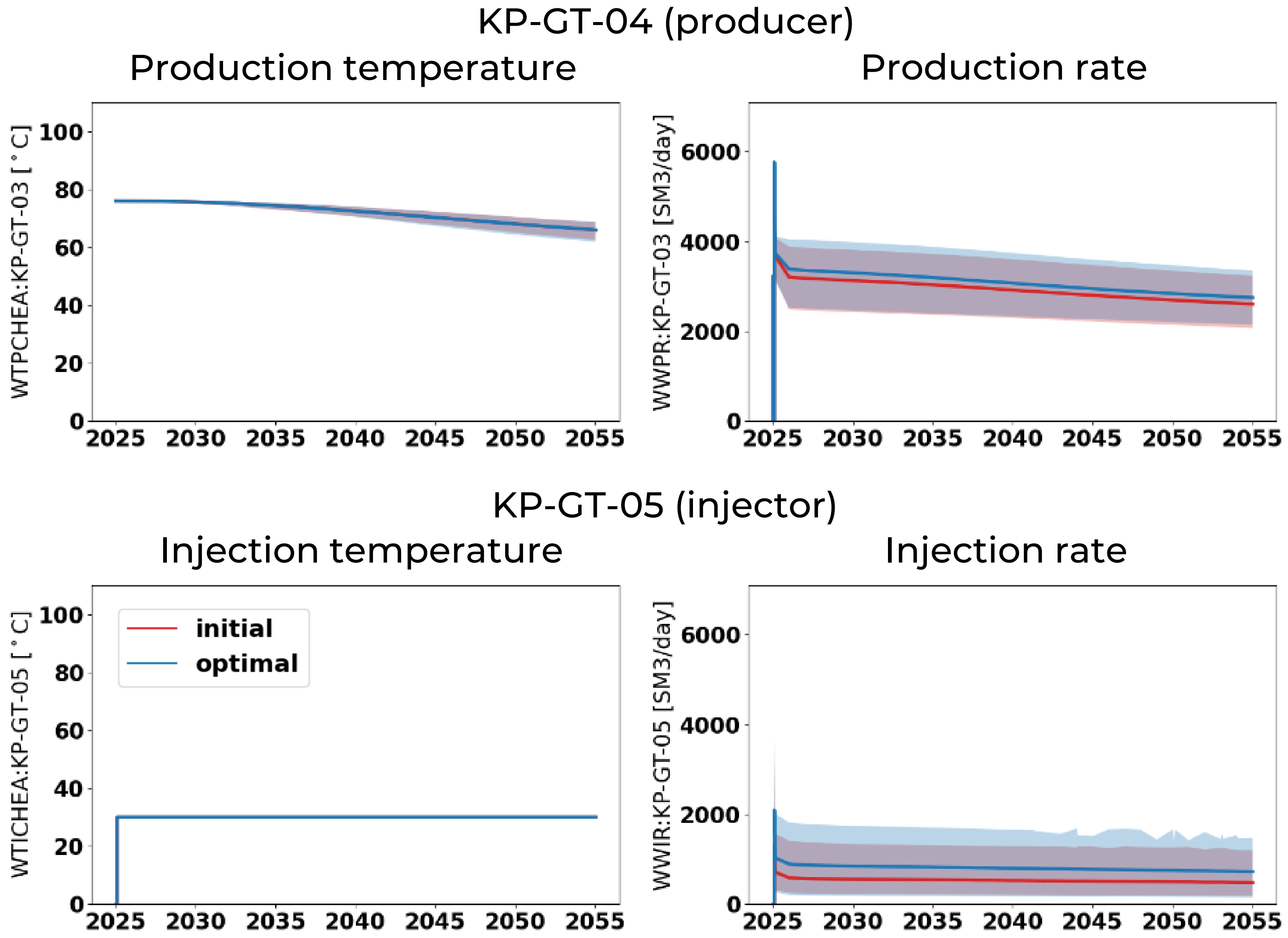
GEO4ALL: OPTIMIZATION STUDY

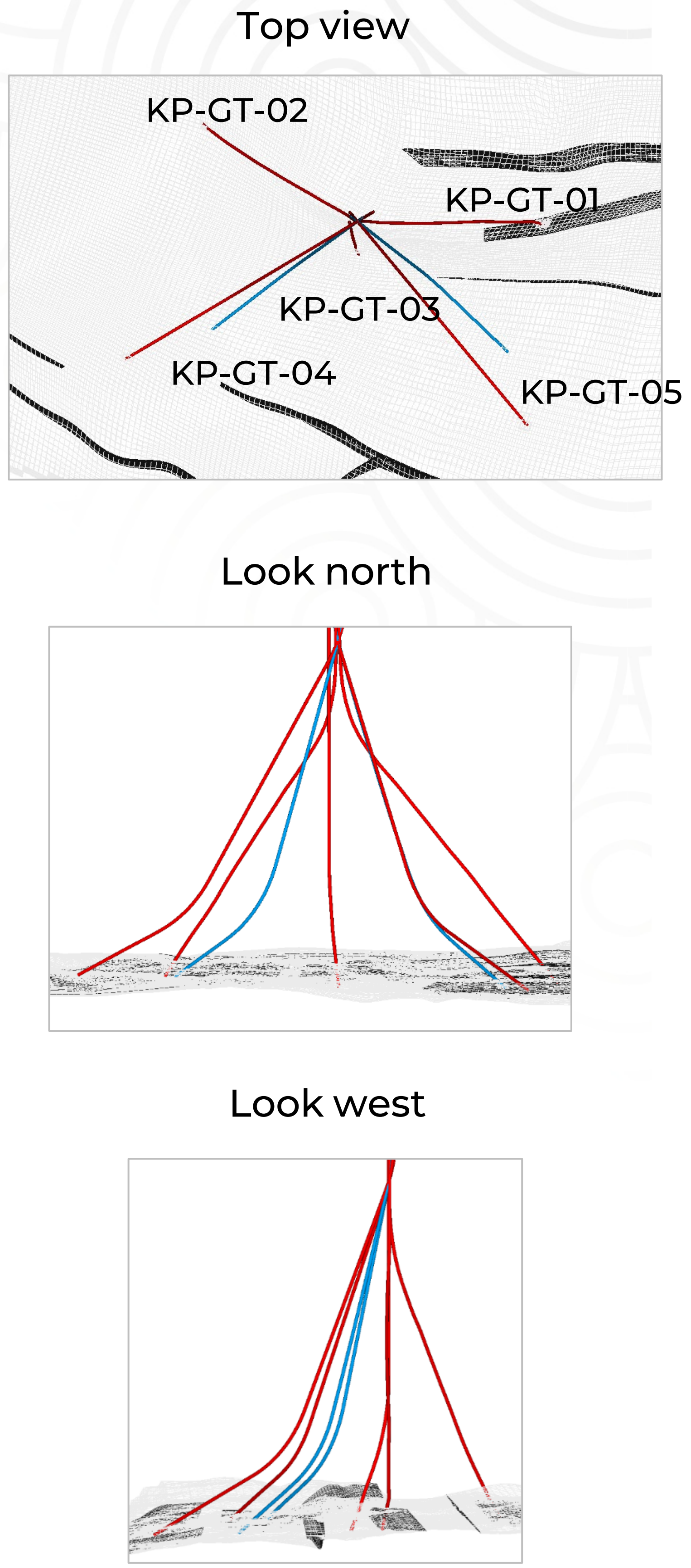
Koekoekspolder case: results

- Improvement in NPV values of about 0.15 million EUR
- All shape and fault stress constraints satisfied in optimal solution
- Similar uncertainty range for initial and optimal solutions, however improved worst-case scenario





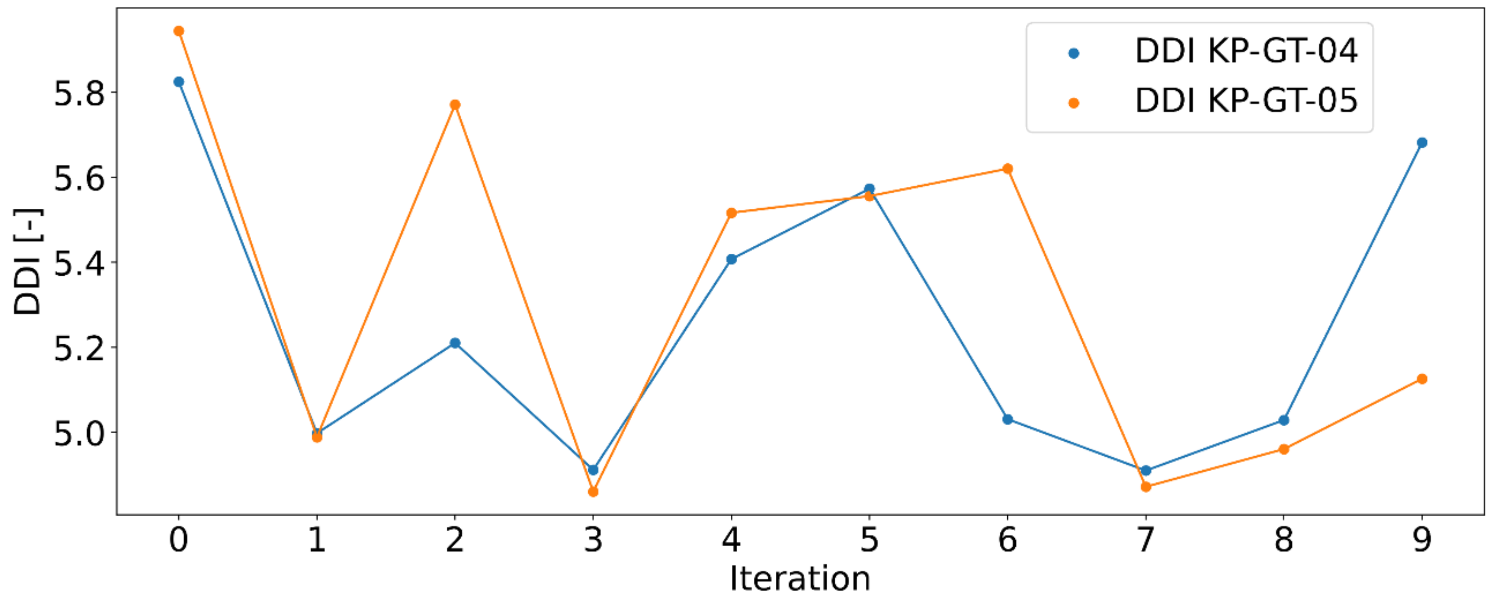




GEO4ALL: OPTIMIZATION STUDY

Koekoekspolder case: constraints

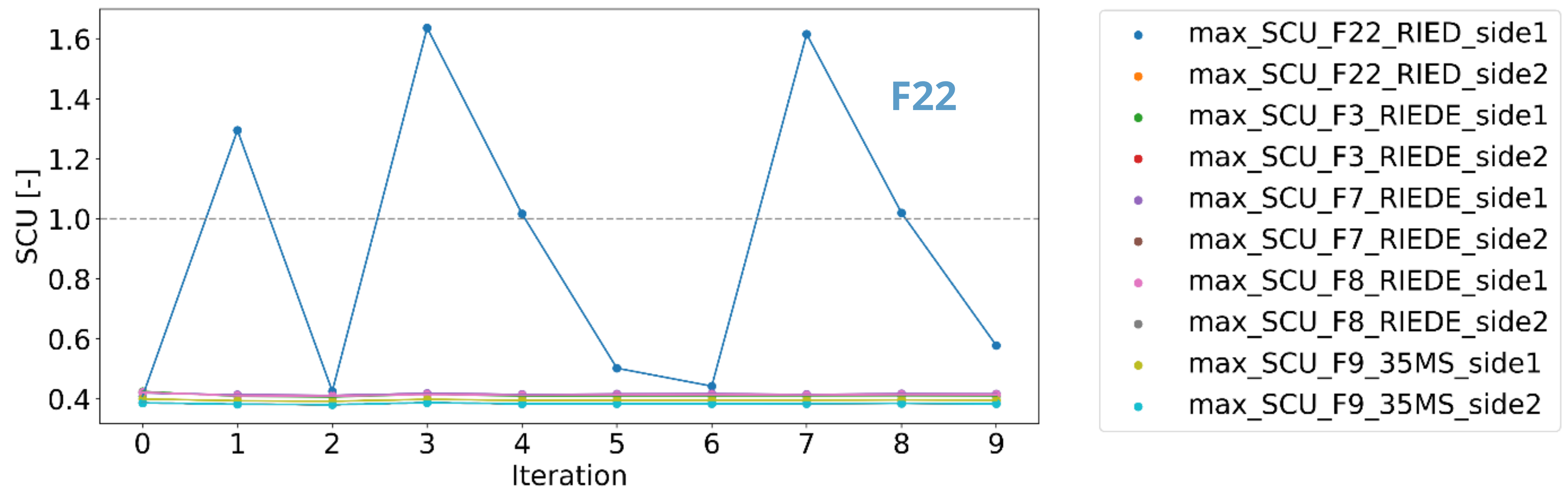
- Drilling difficulty (DDI) reduced and < 6 therefore more simple well profiles

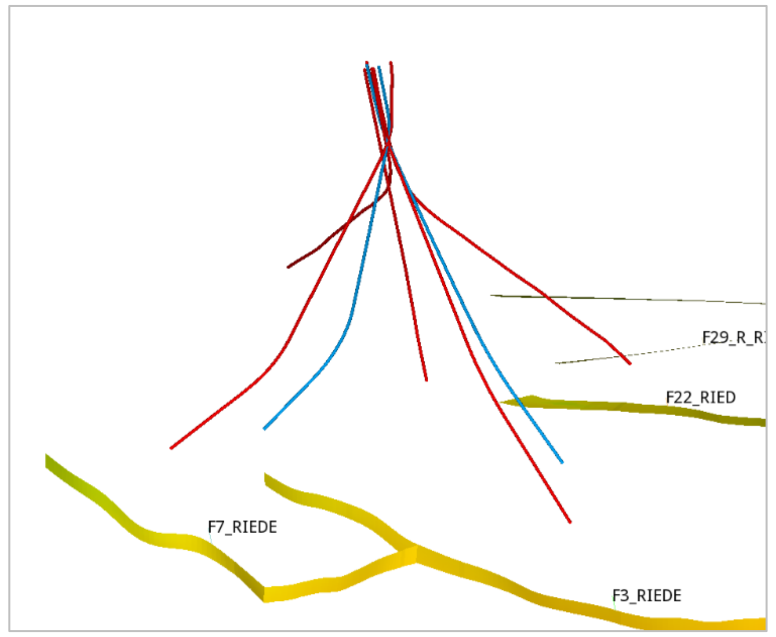


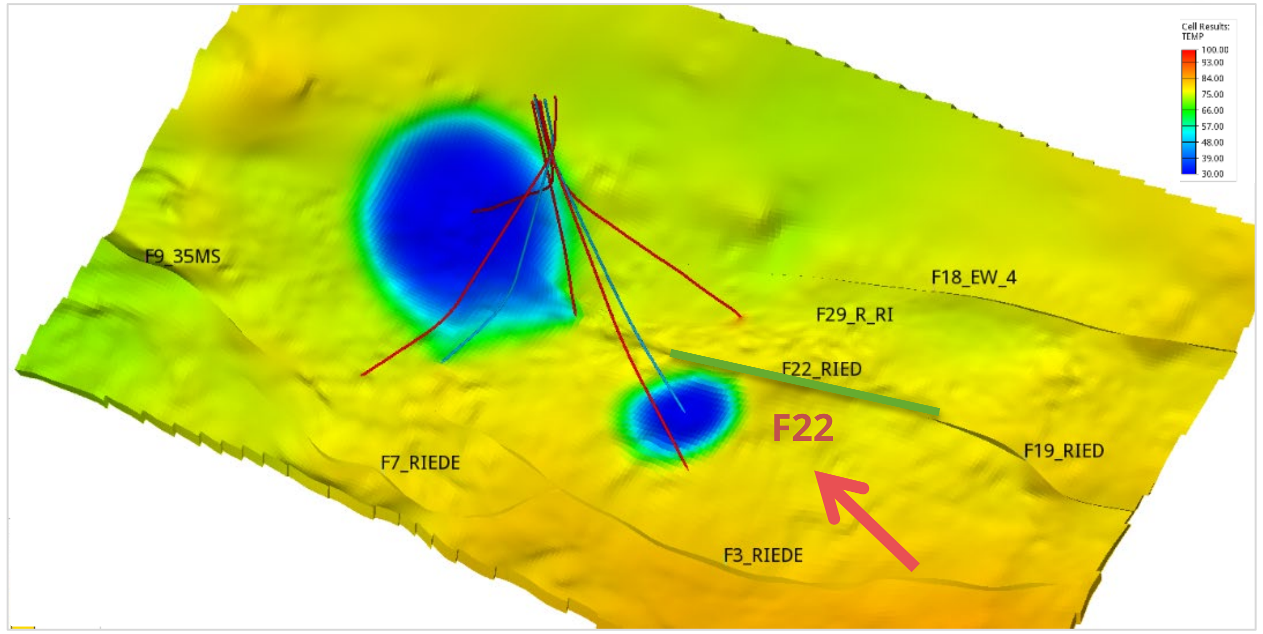
Difficulty	Well Type	Proposed Modifier
Less than 6	Relatively short wells. Simple profiles with low tortuosity	**minus 10%**
6.0 to 6.4	Either shorter wells with high tortuosity or longer wells with lower tortuosity	**0**
6.4 to 6.8	Longer wells with relatively tortuous well paths	**plus 5%**
Greater than 6.8	Long tortuous well profiles with a high degree of difficulty	**plus 10%**

Alistair W. Oag (2000), SPE 59196

- Optimal solution guided to satisfy stress change indicator (SCU) below 1 at fault F22







CONCLUSION

Take-home messages

- Optimization can help improve business case of geothermal projects by enhancing cost-effectiveness of field development activities
- No one-size-fits-all solutions, optimization can assist practitioners in devising site-specific optimized solutions
- Real-life decisions require realistic considerations: potentially complex reservoir models, design alternatives, objective functions, constraints and uncertainties
- EVEREST + all workflow components used to obtain presented results are open-source
- It is not only about putting in place an optimization tool, but also the know-how of framing the field development decisions as an optimization problem
  - Some decisions are recurring → Best-practices can be fully supported in tools
  - But every case is unique, flexibility to customize tool to problem at hand is extremely valuable

ACKNOWLEDGEMENTS

Thank you for your attention!
Questions?

RESULT

GEOTHERMICA

The RESULT project (Enhancing REServoirs in Urban deveLopmenT: smart wells and reservoir development) has been subsidized through the ERANET Cofund GEOTHERMICA (EC Project no. 731117), supported by the Ministry of Economic Affairs and Climate Policy (the Netherlands), Rannis (Iceland) and GSI (Ireland).

TKI NIEUW GAS Topsector Energie

Geo4all innovatieprogramma

The TKI GEO4ALL program has been carried out with a PPP program allowance subsidy from the Ministry of Economic Affairs and Climate for TKI Nieuw Gas, Topsector Energy. www.topsectorenergie.nl

- Check out these open-source tools:

EVEREST transforming uncertainty into opportunity

https://www.everest.tools/

OPM OPEN POROUS MEDIA

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ResInsight

https://resinsight.org/

PyThermoNomics

https://github.com/TNO/pythermonomics

Eduardo Barros: eduardo.barros@tno.nl

WHEN TO USE OPTIMIZATION ?

Typical concerns (and misconceptions…)

- Too little data, thus no models available
- Too much subsurface uncertainty, thus too early
- Too many open questions, not clear what must be optimized first
- Our reservoir engineering team is small, no time to adopt new tools

However, in fact…

- If there are decisions being made, these can be optimized
- Decisions are made even without fully detailed models, numerical optimization can also be used with such early-stage models
- The later optimization is considered, the less room for value generation there is
  - Fewer degrees of freedom left
- Numerical optimization reduces turnaround time to devise development strategies
  - Reservoir engineers can focus on analyzing and understanding reservoir behavior instead of creating and running simulation cases