STOCHASTIC INVERSION OF TIME-LAPSE SEISMIC WITH FLOW SIMULATIONS

FOR THE WEYBURN CO_2-EOR PROJECT

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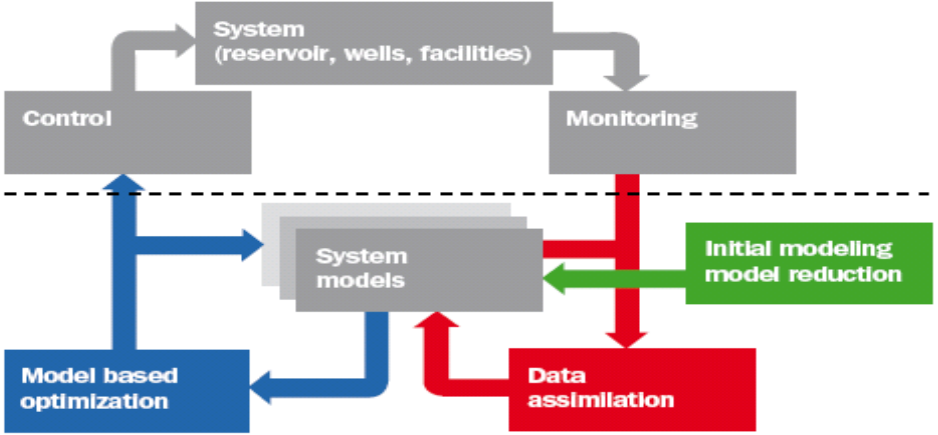
TNO innovation for life

RESERVOIR MANAGEMENT WORKFLOWS

- **Development of workflows for model-assisted management of fields undergoing CO_2-EOR**



After Jansen et al., 2009, SPE 119098

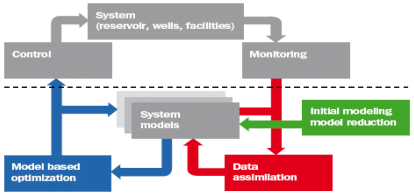
- Formalized workflow to make the best decisions on reservoir management considering uncertainty
- History matching of models
  - Reduce uncertainty
- Optimization of strategies
  - Increase value
  - Reduce risk

OVERVIEW

- I will discuss history matching of multiple dynamic flow models to time-lapse seismic data

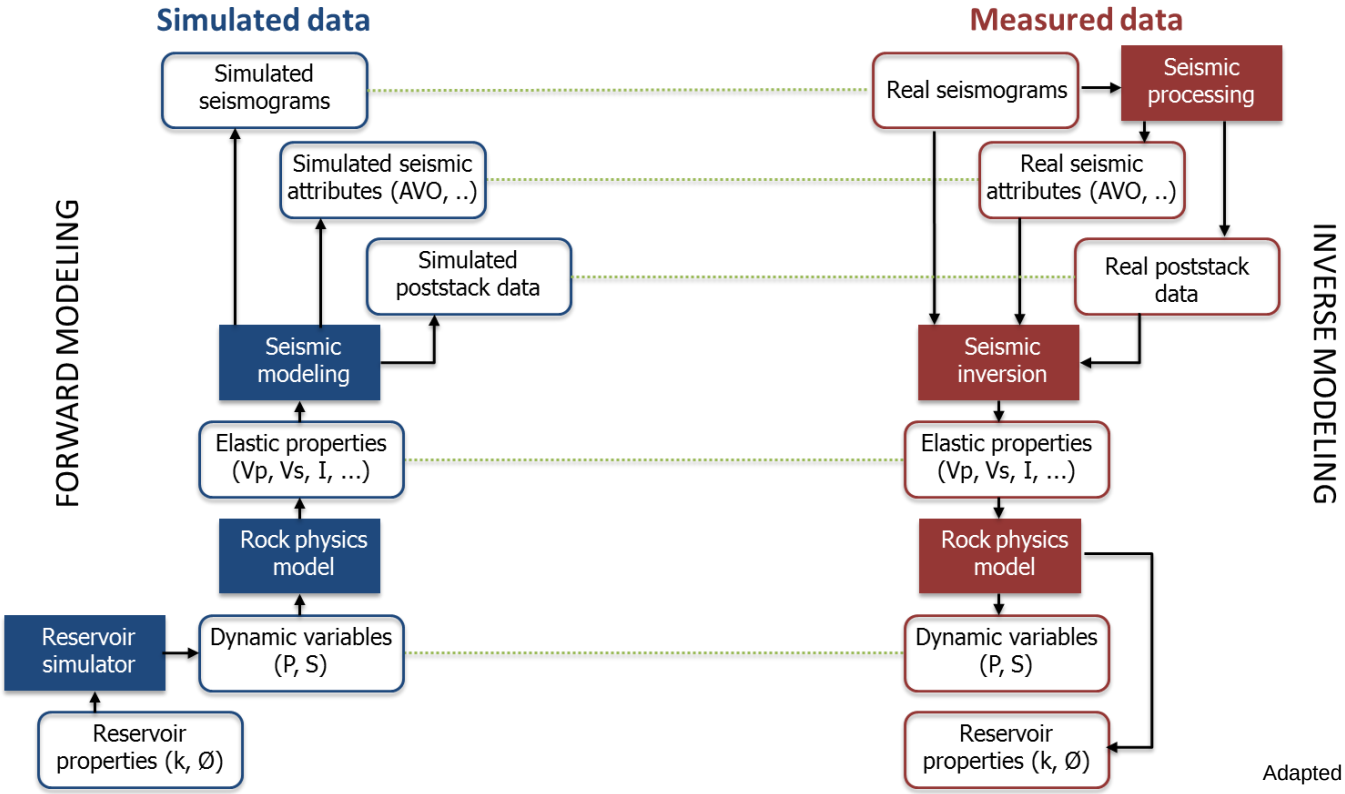
- Results show that:
  - Time-lapse seismic information on CO_2 spreading in the subsurface can be used to improve simulation models
  - CO_2-EOR strategies can be optimized using history matched models to increase value
  - Uncertainty can be reduced in both steps

SEISMIC HISTORY MATCHING



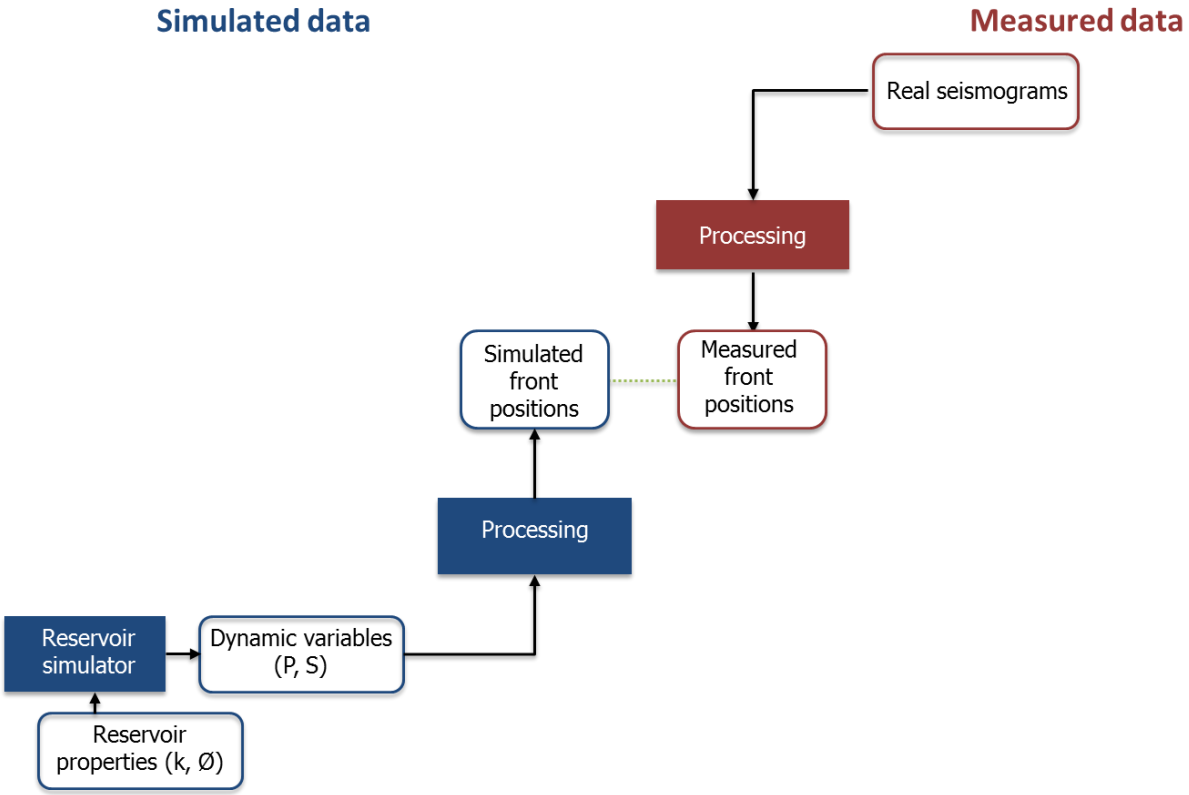
- Current approaches are mostly qualitative
- Challenges for quantitative use of seismic monitoring data:
  - Data quality
  - Data quantity
  - Requires forward modelling or inversion of seismic data
  - Large uncertainty in rock physics models
  - Highly nonlinear relationship between model parameters and data

MODEL-DATA MISMATCH EVALUATION

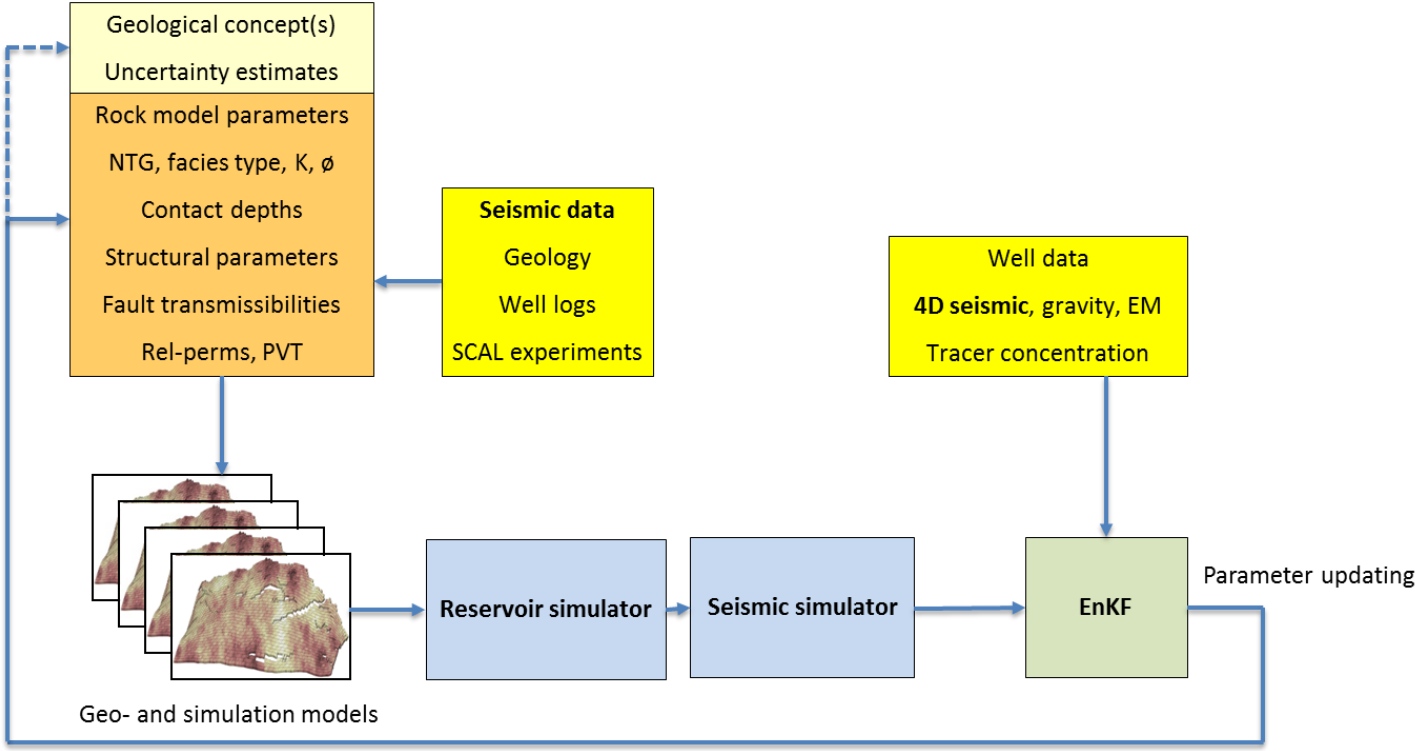


Adapted from Skjervheim (2007)

PROPOSED PARAMETERIZATION-BASED APPROACH

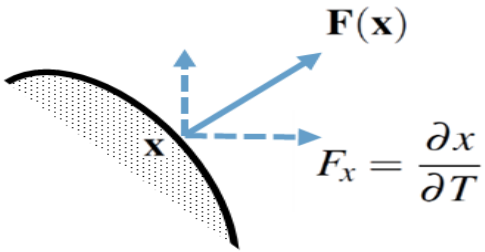


ENSEMBLE-BASED MODEL UPDATING



METHODOLOGY

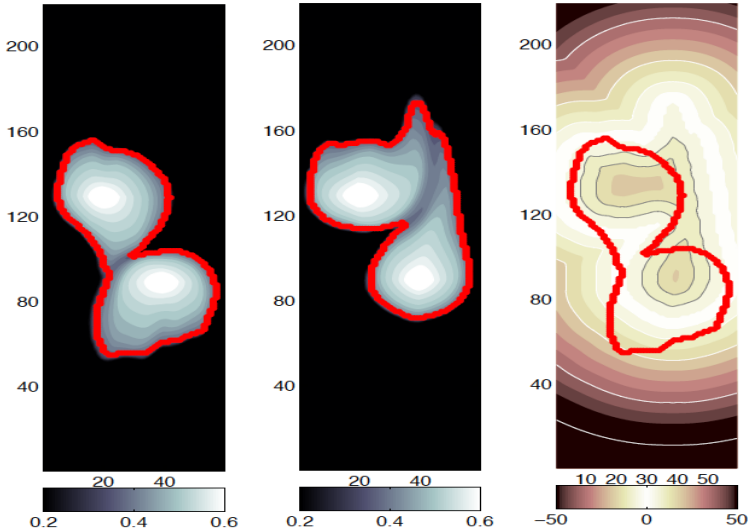
- Extract and use flood front information for matching
- Efficient distance parameterization of differences between observed and simulated front positions



- Solve Eikonal equation for monotonic front expansion

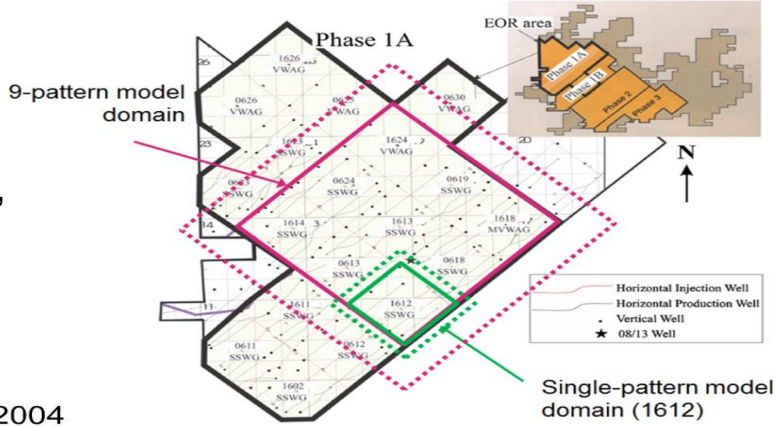
$$|\nabla T(\mathbf{x})| \cdot \mathbf{F}(\mathbf{x}) = 1$$

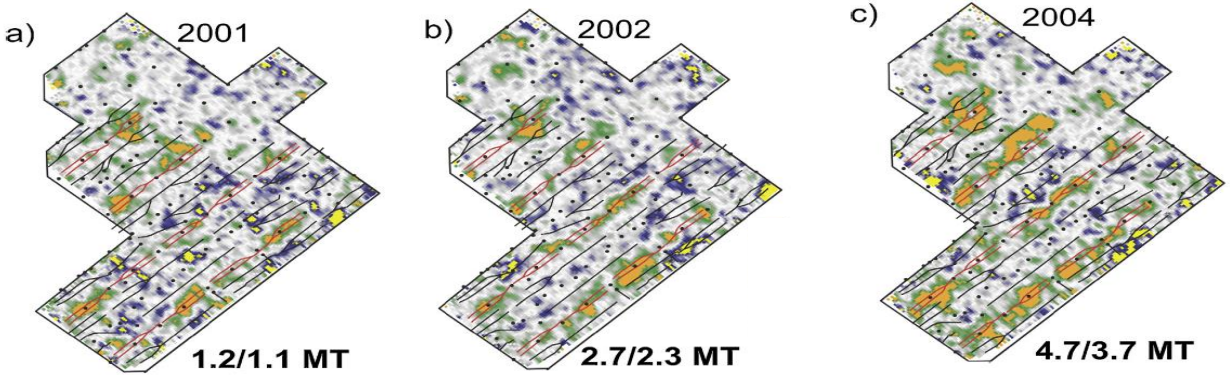
- Capture uncertainty with multiple models (EnKF)



APPLICATION TO THE WEYBURN CO_2-EOR CASE

- Weyburn field in Canada
- Simultaneous injection of water and CO_2
- Focus on a single sector from a 19-pattern EOR area
- Base and repeat seismic surveys in 1999 and 2001, 2002, 2004 and 2007



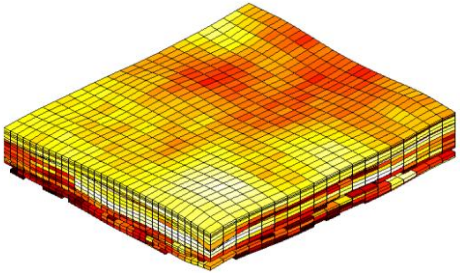


- Previous seismic HM study Ramirez et al., 2013) was unsuccessful due to extreme computational cost, poor data and initial model quality

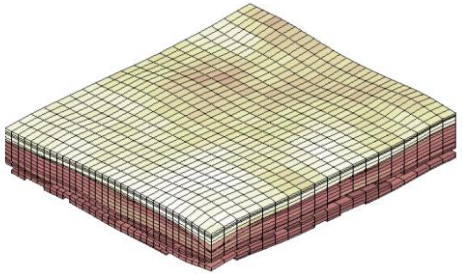
SECTOR MODEL ENSEMBLE

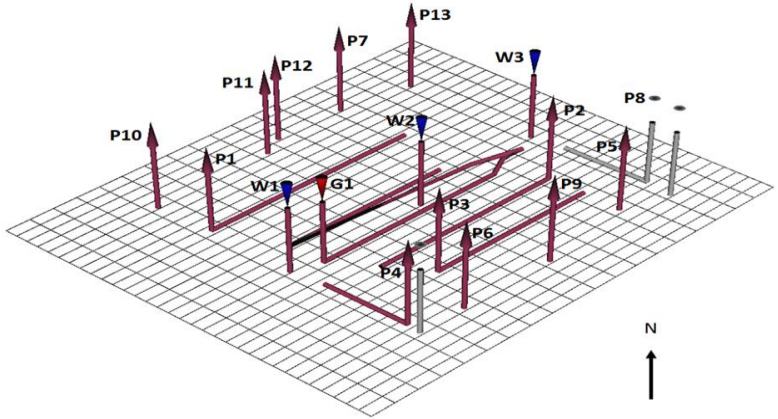
- Reference model was provided

Reference Perm



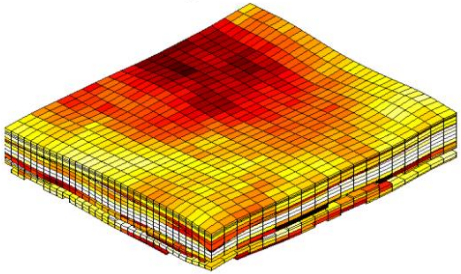
Reference Poro



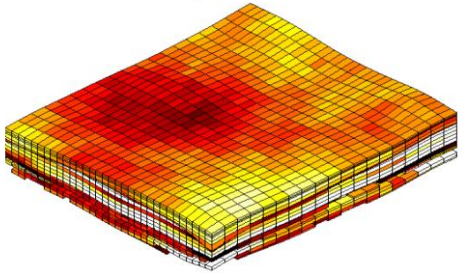


- Permeability and porosity realizations were generated

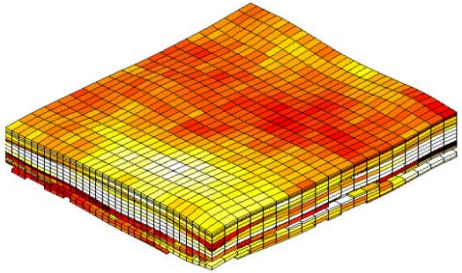
log Perm 1



log Perm 2

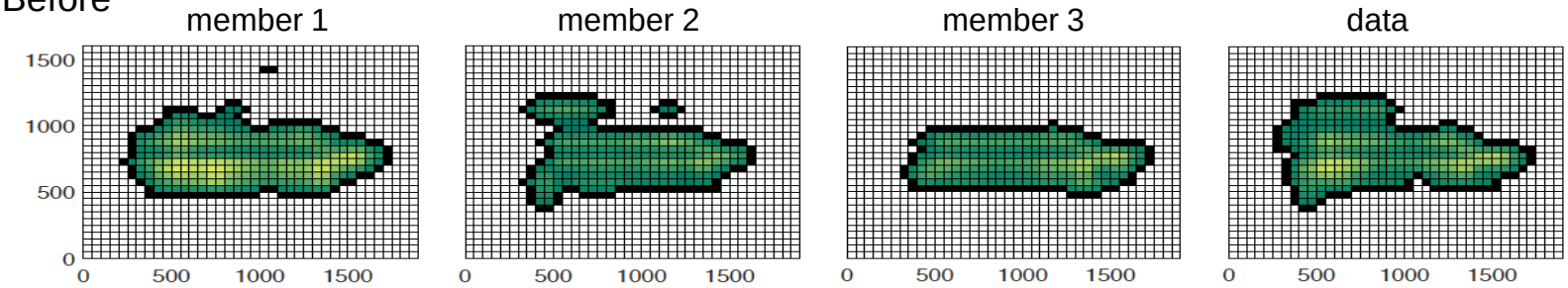


log Perm 3



LIMITED / SYNTHETIC DATA EXPERIMENT

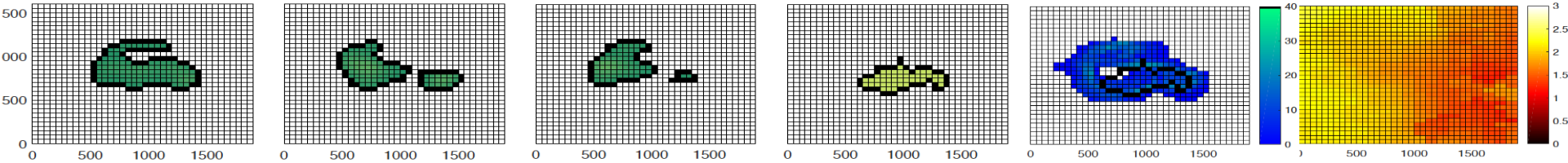
- 2002 seismic maps for part of the reservoir
- Before



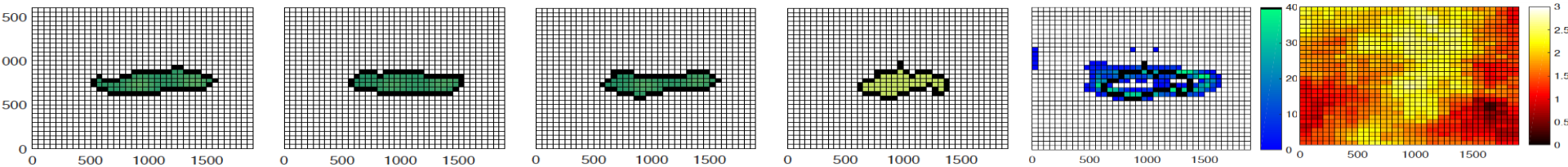
- After

REAL DATA EXPERIMENT

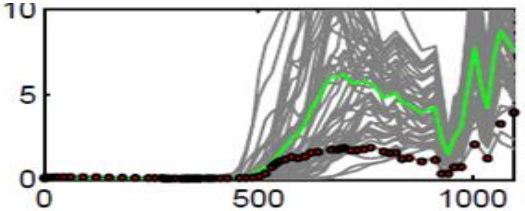
- Before



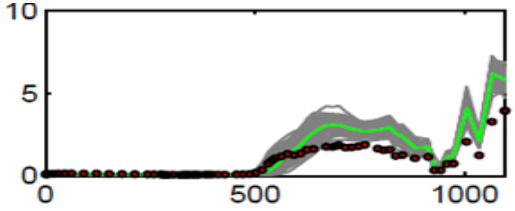
- After



gas rate - *before*

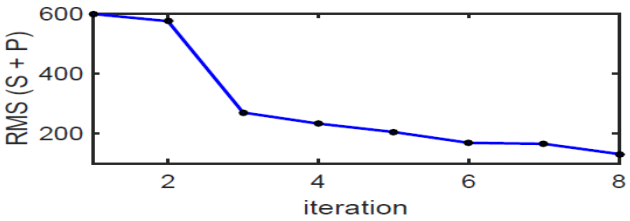


gas rate - *after*

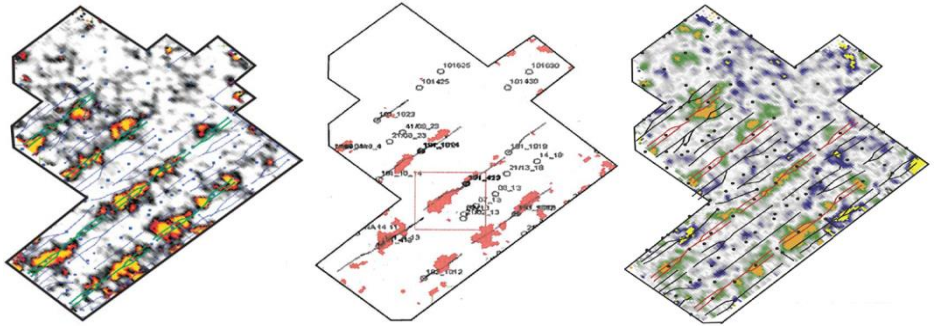


DISCUSSION

- Combined production and seismic data mismatch could be efficiently reduced by up to 80%

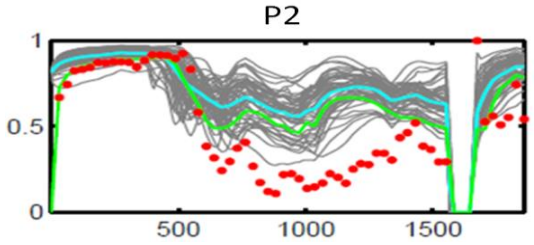


- Seismic data quality / interpretation is not “perfect”

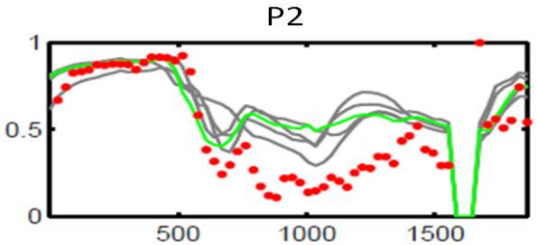


- Model contains biases related to neglected model uncertainty

sector model



full model



SUMMARY SEISMIC HISTORY MATCHING

- A new efficient workflow based on front positions was developed for conditioning multiple models to time-lapse seismic data
- The workfow was used to incorporate CO_2 front information from time-lapse seismic & production data into a sector model of the Weyburn field
- Updates of grid cell permeability and porosity led to 80% reduction of the total seismic and production data mismatch at a cost of only ~500 simulations
- Further improvements are thought to be hampered by low data quality and shortcomings of the initial model

OUTLOOK

- Currently working on the Norne field (Statoil)
- Will further try to improve the technique in general
- Develop new workflows to optimise models for CO_2 storage

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THANK YOU FOR YOUR ATTENTION

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