STOCHASTIC INVERSION OF TIME-LAPSE SEISMIC WITH FLOW SIMULATIONS

FOR THE WEYBURN CO₂-EOR PROJECT

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RESERVOIR MANAGEMENT WORKFLOWS

Development of workflows for model-assisted management of fields undergoing CO$_2$-EOR

- 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

After Jansen et al., 2009, SPE 119098
OVERVIEW

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

Results show that:

- Time-lapse seismic information on CO₂ spreading in the subsurface can be used to improve simulation models.
- CO₂-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

Simulated data

Reservoir simulator

- Reservoir properties (k, Ø)
- Dynamic variables (P, S)

Simulated front positions

Processing

Measured data

Real seismograms

Measured front positions
ENSEMBLE-BASED MODEL UPDATING

Geological concept(s)
Uncertainty estimates
Rock model parameters
NTG, facies type, K, Ø
Contact depths
Structural parameters
Fault transmissibilities
Rel-perms, PVT

Seismic data
Geology
Well logs
SCAL experiments

Well data
4D seismic, gravity, EM
Tracer concentration

Reservoir simulator
Seismic simulator
EnKF

Parameter updating

Geo- and simulation models
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

\[ |\nabla T(x)\| \cdot F(x) = 1 \]

› Capture uncertainty with multiple models (EnKF)
APPLICATION TO THE WEYBURN CO₂-EOR CASE

- Weyburn field in Canada
- Simultaneous injection of water and CO₂
- Focus on a single sector from a 19-pattern EOR area

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

Permeability and porosity realizations were generated
LIMITED / SYNTHETIC DATA EXPERIMENT

- 2002 seismic maps for part of the reservoir
- Before
  - member 1
  - member 2
  - member 3
  - data
- After
  - member 1
  - data
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.

![Graph showing RMS (S+P) over iterations](image1)

![Seismic data with models](image2)

![Comparison of sector and full model](image3)
A new efficient workflow based on front positions was developed for conditioning multiple models to time-lapse seismic data.

The workflow 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 CO₂ storage

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