Reservoir characterization with ensemble Kalman filter

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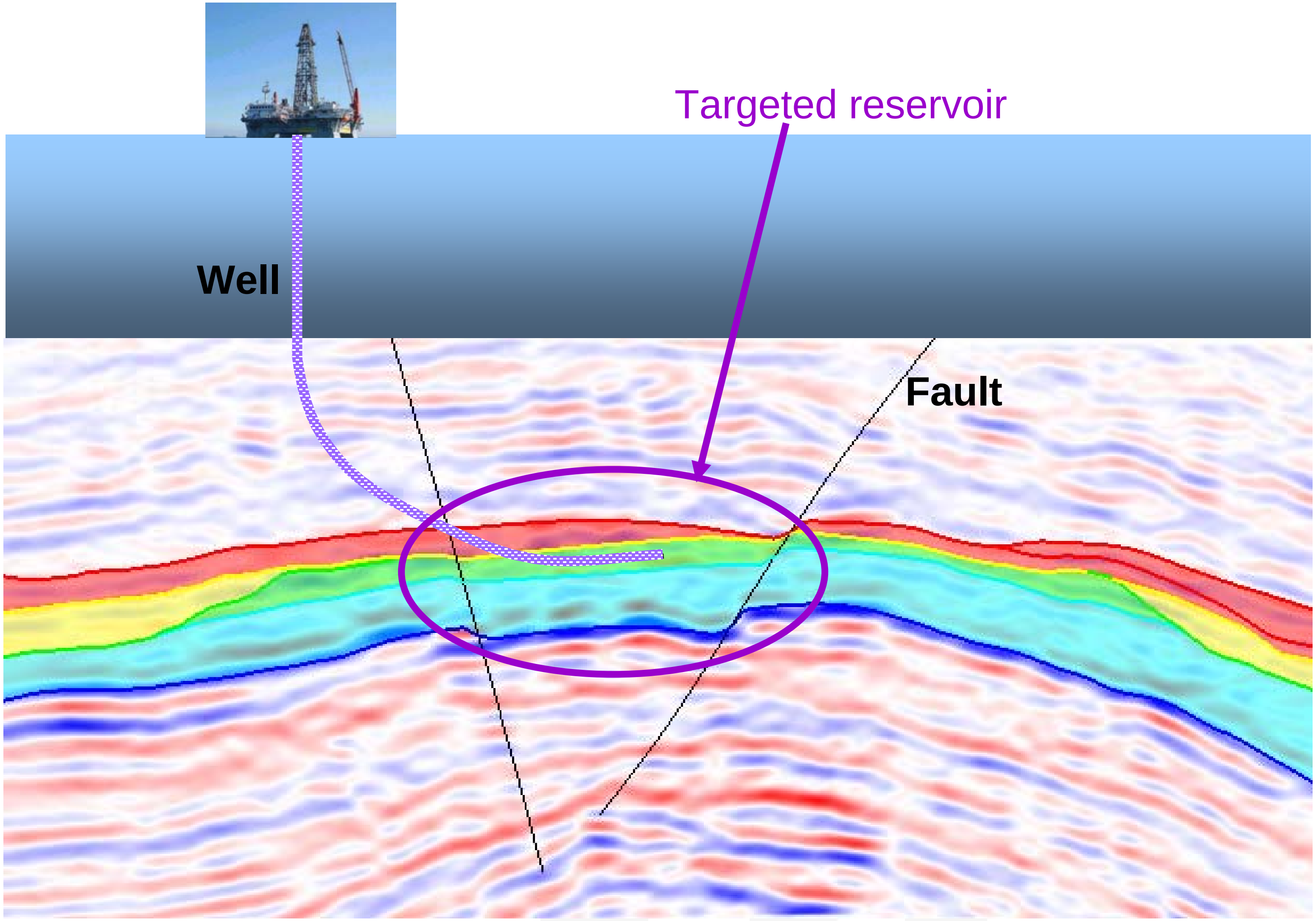
Outline

- Introduction and motivation
- Ensemble Kalman filter (EnKF)
- Examples
  - North Sea field case
  - Brugge study
- Conclusion

Geological oil/gas reservoirs



Technology gap in reservoir models

- Common practice
  - Seldom update of reservoir models
  - Too time consuming
  - Insufficient uncertainty quantification

- Future vision
  - Improve workflow for updating reservoir simulation models
  - Work in real time
  - Include uncertainty quantification

Reservoir simulation models

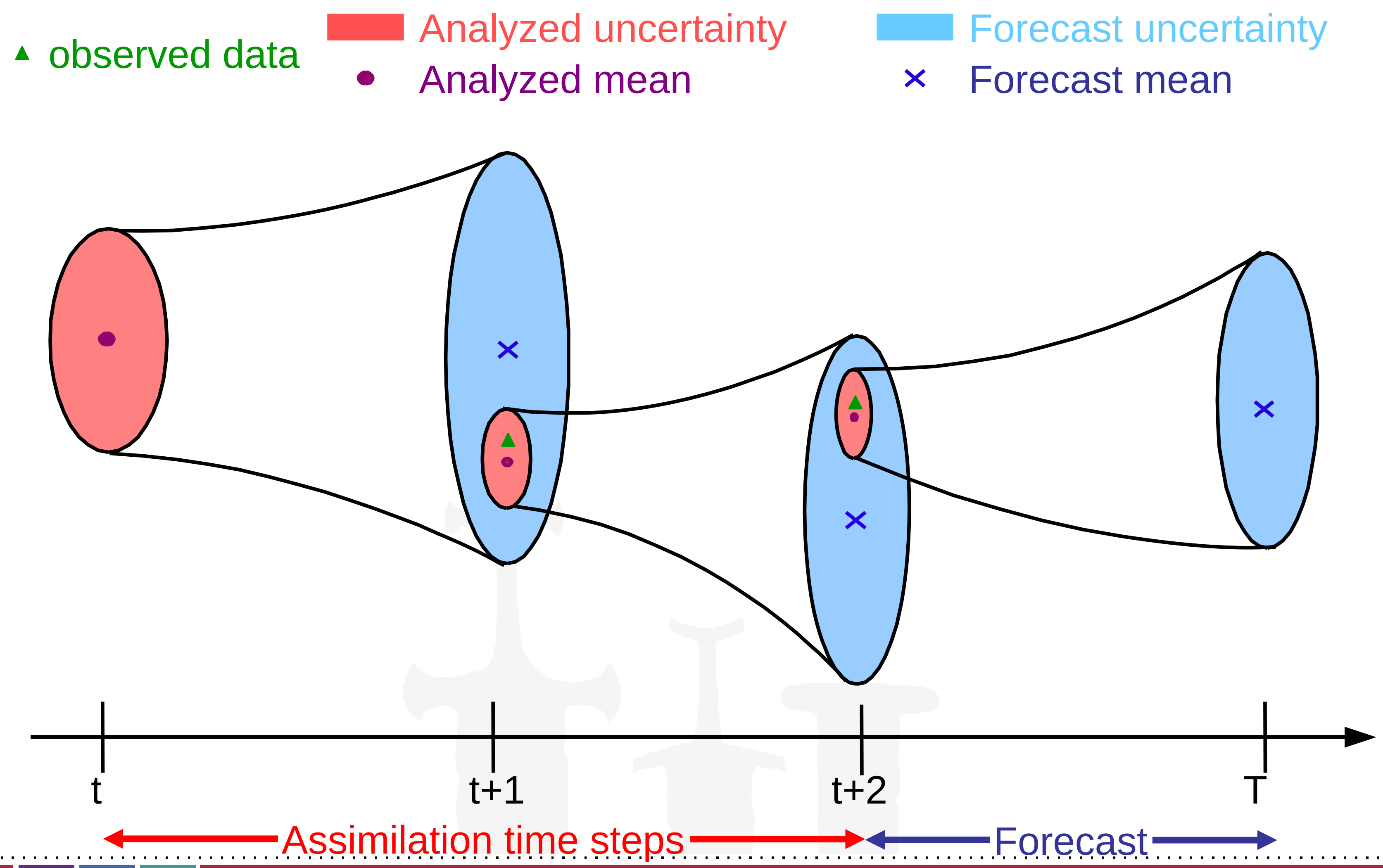
- Necessary coarse representation of geological model
  - To allow simulations in a reasonable time
- Characterized by petrophysical properties
  - Porosity
  - Permeability
- How to best characterize reservoir models?
  - Solving inverse problem using observed data
    - Bottom-hole pressure, oil production rate, water injection rate…
  - Two approaches
    - Global: invert porosity, permeability using all data in one single process
    - Sequential: update porosity, permeability each time new data are observed

Ensemble Kalman filter (EnKF)

- Introduced by Geir Evensen in 1994
  - Motivated by oceanography and atmospheric sciences
- Introduced to reservoir engineering by Nævdal (IRIS) in 2002

- Built for large scale nonlinear systems
- Bayesian framework
- Monte Carlo simulation
  - $\Rightarrow$ ensemble of realizations
  - $\Rightarrow$ uncertainty estimation

EnKF - schematic



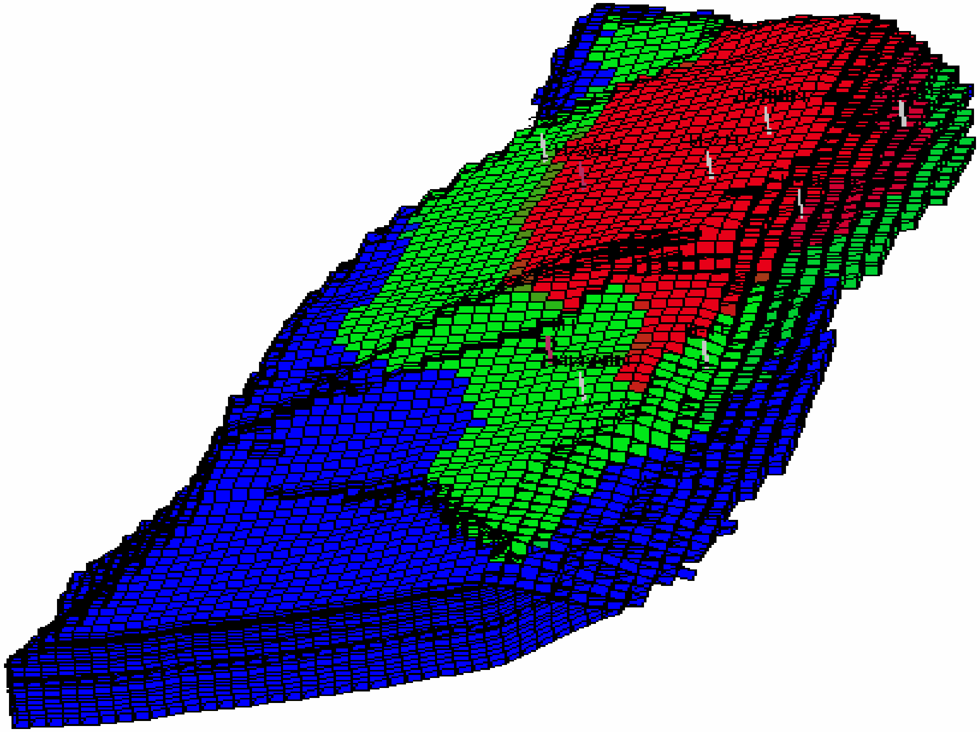
EnKF for reservoir applications

- Monte Carlo simulation
- Typically 100 ensemble members
  - 100 reservoir models!
- Computational load
  - 1 (reservoir simulator) simulation per ensemble member
  - Easy to run in parallel (1 simulation = 1 PE)
- Update
  - Porosity, permeability, pressure, saturations…

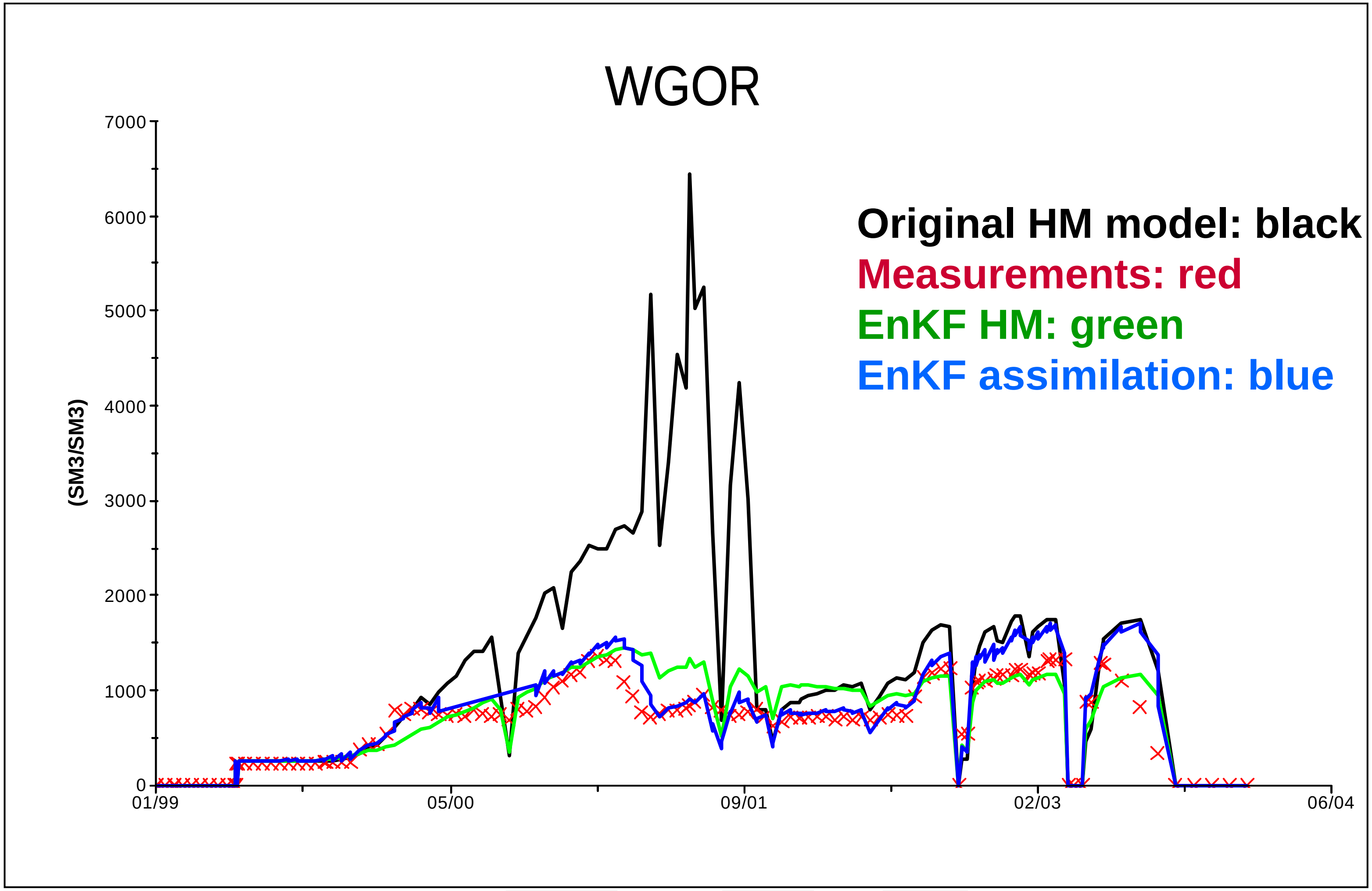
- Note: we do not say that “model parameters change in time” but “our knowledge of model parameters improve with time”!… hence the update

Examples

- Real Field – Haugen et al., 2006 (SPE 102430)
  - North Sea case
  - Grid size: 45 x 75 x 26
  - Active cells: 47795
  - 4 oil producers
  - 2 gas injectors

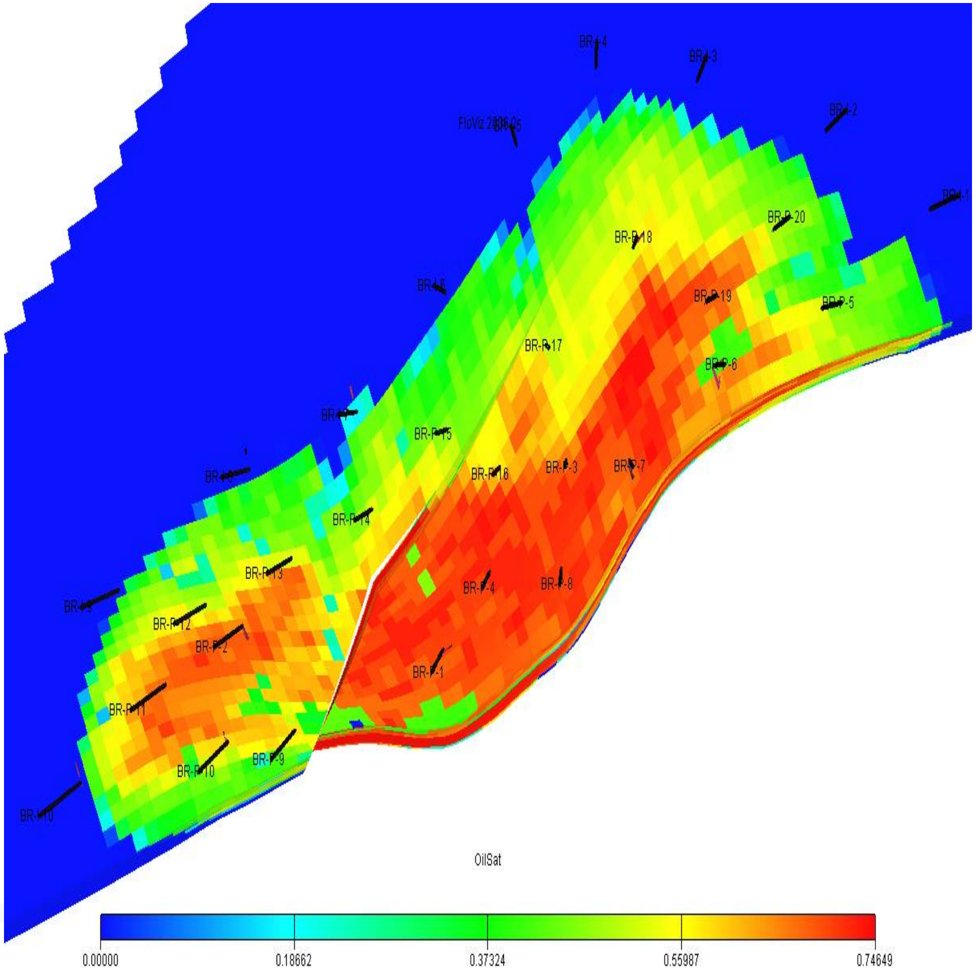


North Sea field case



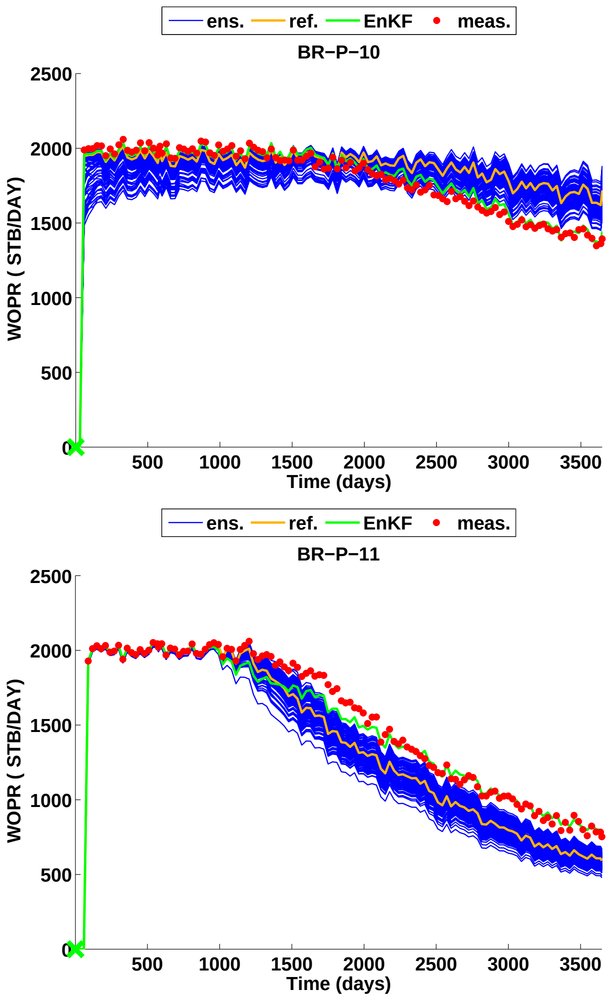
Brugge field

- Brent type of reservoir
- 9 layers
- Two phases:
  - Oil & water
- 10 injectors
- 20 producers

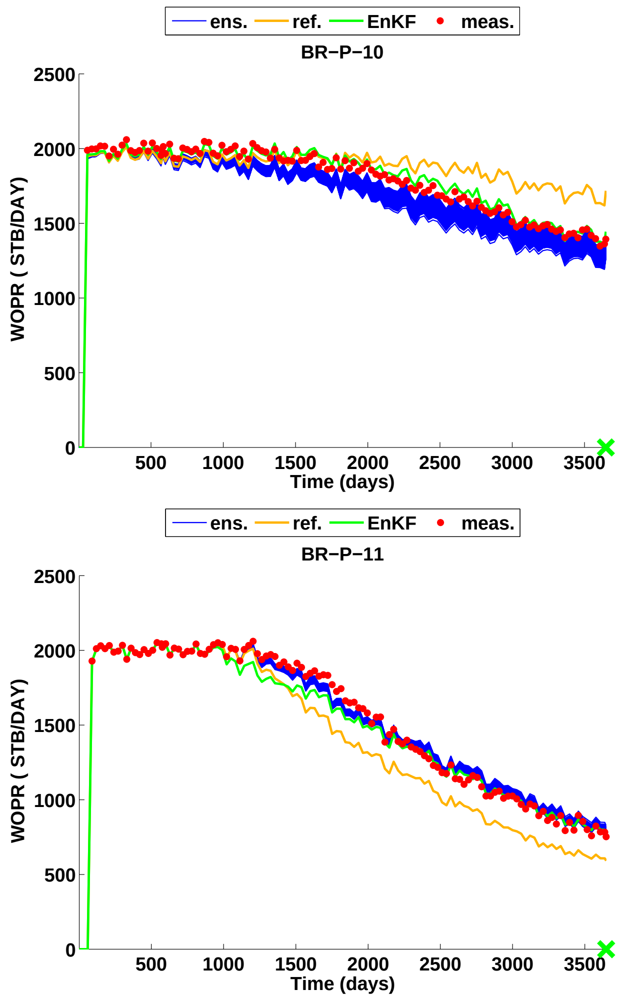


Forecasts

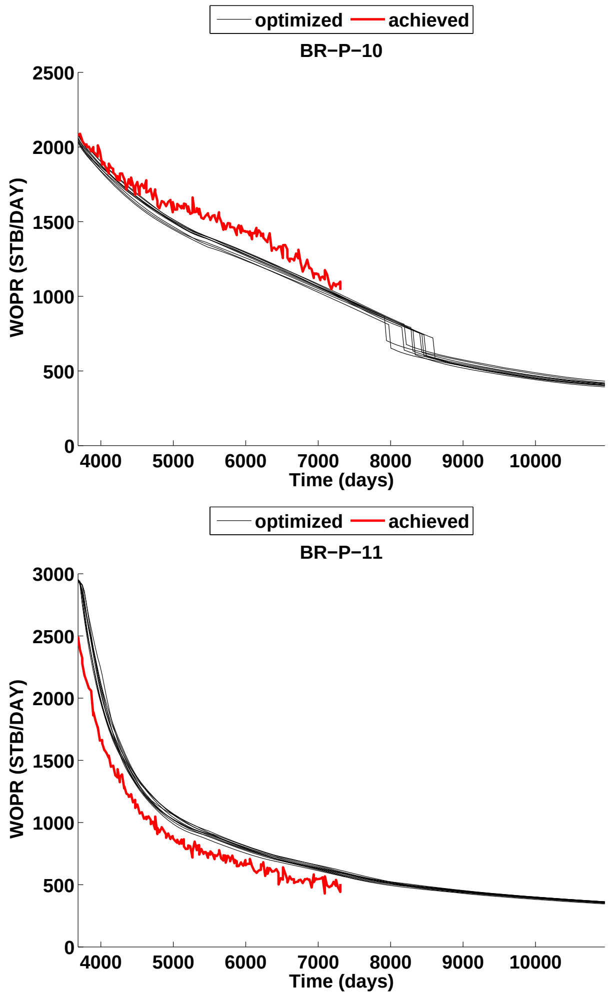
Before assimilation



After assimilation



After optimization



← History matching phase →

← Optimization →

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NPV

	First cycle (10^9 \$)	Second cycle (10^9 \$)
Initial	4.39 ± 0.04	4.38 ± 0.001
Optimized	4.51 ± 0.05	4.40 ± 0.001
Achieved	4.41	4.49

- First cycle
  - History matching: year 0 to year 10
  - Optimization: year 10 to year 30
- Second cycle (new observed data!)
  - Continue History matching: year 10 to year 20
  - Optimization: year 20 to year 30

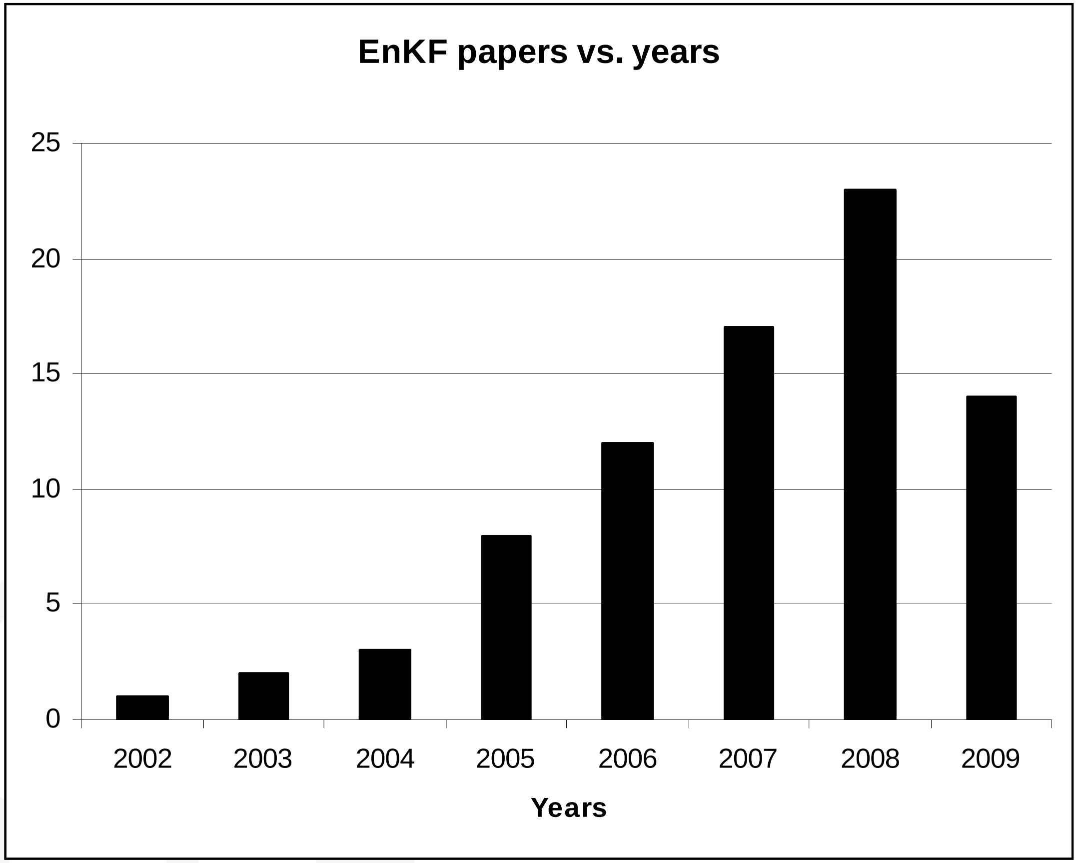
- University of Oklahoma achieved 4.42 and 4.53

Reservoir characterization using EnKF: state of the art

- EnKF fits into a complete workflow from geostatistics to production forecasts with/without optimization
- EnKF is suitable for (semi-)automatic history matching of production data
  - Confirmed by several studies, if geostatistical model is based on variogram description
  - Can also handle other parameters than permeability and porosity (MULTFLT, MULTZ, rel-perm…)
  - Research challenge: EnKF for models based on facies
- EnKF is suitable for producing forecasts with uncertainty in real time

EnKF for reservoir applications

- Several real field studies published since 2005



- 4th international EnKF workshop
  - June 22-24, 2009 Bergen

http://qp.rf.no/enkfseminar

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