TNO USER PERSPECTIVE: OPM

OPM meeting 1-2 June, Oslo | Rohith Nair and colleagues

OUTLINE

- TNO introduction
- TNO research interests
- Development experience with simulators
- First use experience with FLOW
- TNO-Statoil cooperation on robust optimization of field development
- Support, future development and collaboration

TNO: NETHERLANDS ORGANIZATION FOR APPLIED SCIENTIFIC RESEARCH

- Non-profit national applied research organization
- Approx. 3000 scientific staff
- Working on five themes

INDUSTRY

HEALTHY LIVING

DEFENSE, SAFETY & SECURITY

URBANISATION

ENERGY

ENERGY

FROM CONVENTIONAL SOURCES TO SUSTAINABLE ENERGY SYSTEMS

- In the Energy theme we develop innovations that help create a guaranteed supply of sustainable and efficient energy.

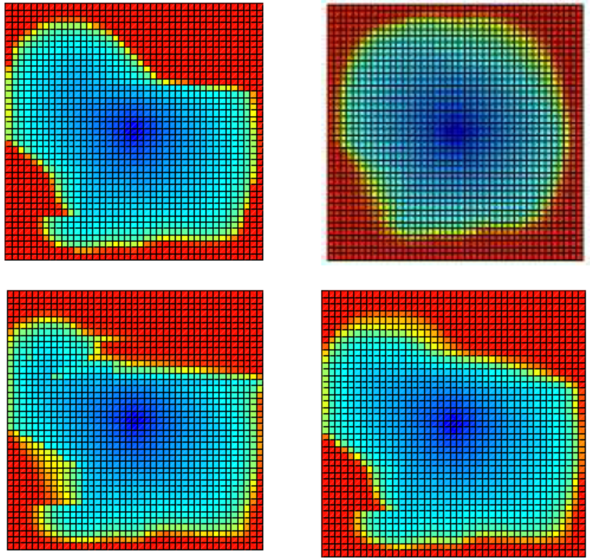
- ROADMAPS
  - Geo Energy (Oil and gas, CCUS, Geothermal, Energy storage)
  - Geological Survey of the Netherlands
  - Sustainable Energy (solar, wind, smart grids, …)
  - Maritime & Offshore

RESEARCH INTERESTS
RESERVOIR ENGINEERING AND OPTIMIZATION

- Advanced reservoir engineering and simulation workflows:
  - Model based life cycle production optimization
  - Closed loop reservoir management
  - CO2 WAG/EOR
  - Well trajectory optimization, including multilateral well design
  - Reservoir – Wellbore simulator coupling
  - Reduced Order Modelling

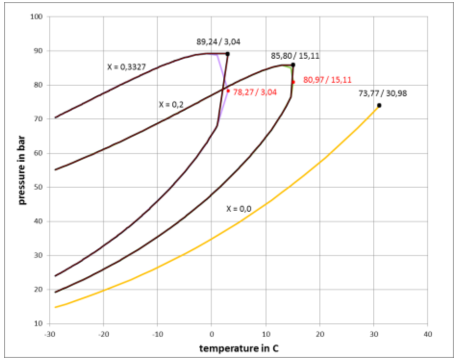
DEVELOPMENT EXPERIENCE WITH SIMULATORS:
ENSEMBLE KALMAN FILTER (EnKF) MODULE FOR MRST

- Functionality implemented includes
  - EnKF and EnRML schemes
  - Localization, inflation and asynchronous data
  - Allows for both production and seismic (saturation) data
  - Conventional and structural parameters can be updated

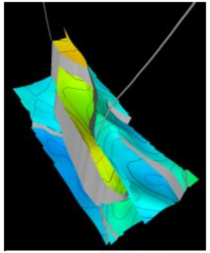


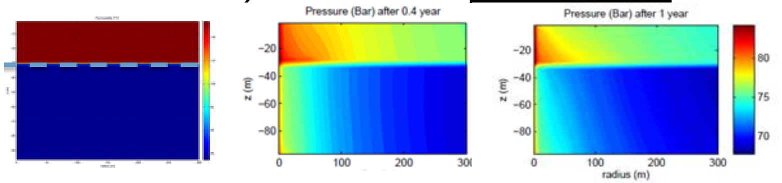
Leeuwenburgh et al., 73rd EAGE Conference & Exhibition SPE EUROPEC, Vienna, May 2011

DEVELOPMENT EXPERIENCE WITH SIMULATORS: CO2 INJECTION MODULE IN TOUGH-2



- **Injection of cold CO_2** for storage in Dutch offshore field
  - Relevant physical processes
    - Thermal effects (Joule-Thompson, hydrate formation, evaporation)
    - Phase transitions
    - Thermal fractures
    - Impurities (methane, nitrogen)
  - New TOUGH-2 module development ECO2MG
    - Best of both EOS7C, ECO2M
    - New EOS based on NIST data
    - New relperm model (phase relperm dependent on own saturation)
  - New module is able to model phase transitions of CO_2 (and CO_2 mixtures with methane and nitrogen)

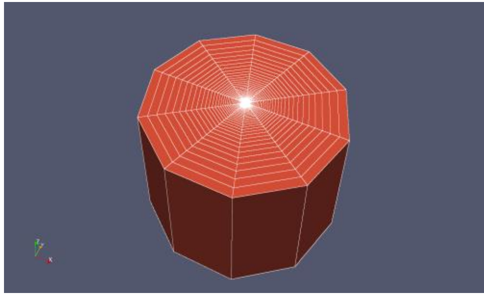




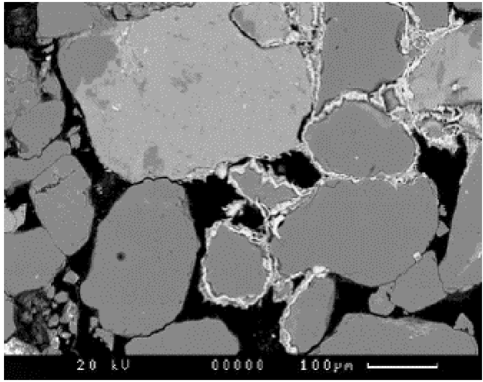
Loeve et al., TOUGH-2 symposium, Berkeley, CA, USA, Sept 2015

DEVELOPMENT EXPERIENCE WITH SIMULATORS: DuMu^X

- **Application – Near wellbore salt precipitation in gas reservoirs**
- Modelled and Simulated using DuMu^X – Adapted Soil Salinization model developed by university of stuttgart
- Tailored Dumux for modelling salt precipitation & dissolution in gas reservoirs by:
  - Incorporation of vapor pressure lowering due to salt content
  - Tabular input of material laws
  - Extending Brine-CH4 fluid system to allow for variable salinity
  - Dynamic scaling of capillary pressure to account for altering permeability and porosity
  - Capillary pressure capping for low liquid saturation



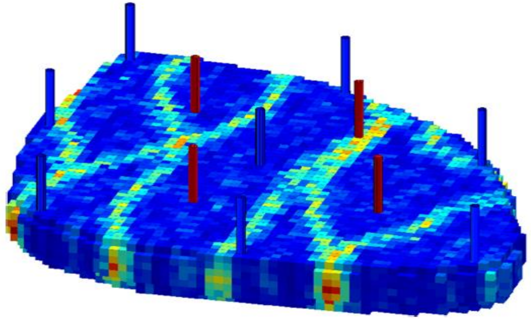
- **Application – Special Core Analysis(SCAL)**
- Developed SCORES, a web based user interface to DuMu^X for performing SCAL flow experiments and history matching experimental results



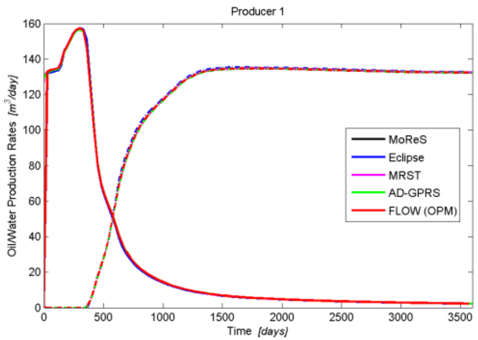
Loeve et al., International Symposium of the Society of Core Analysts, Sep 2011

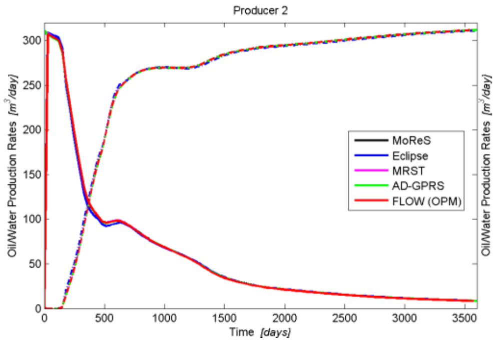
Egberts et al., Modelling of salt precipitation in the near well bore region, report TNO-TKI Sep 2015

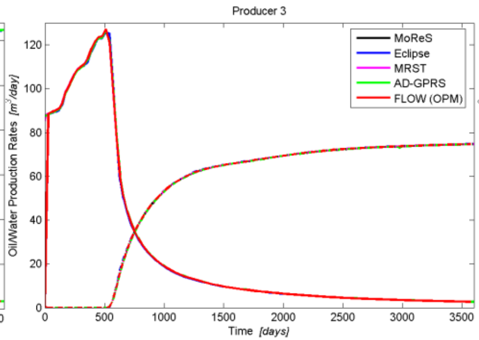
FIRST USE EXPERIENCE WITH FLOW:
'EGG' BENCHMARK MODEL

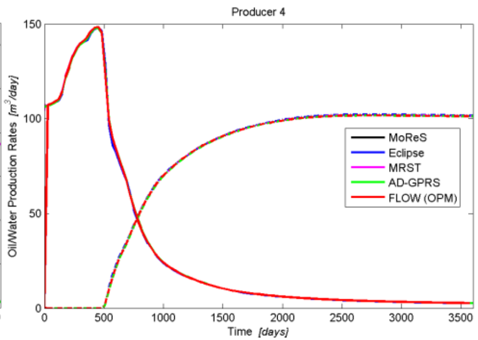


- The EGG Model
  - Synthetic 2-phase reservoir model developed by TU Delft
  - Utilized as research model for optimization
  - Benchmarked with Eclipse, MoReS, MRST, AD-GPRS and now with FLOW
  - Computational Time: FLOW ≈ E100_2015









Jansen et al., Geoscience Data Journal, Oct 2014

FIRST USE EXPERIENCE WITH FLOW:
SEISMIC HISTORY MATCHING - MODIFIED NORNE MODEL

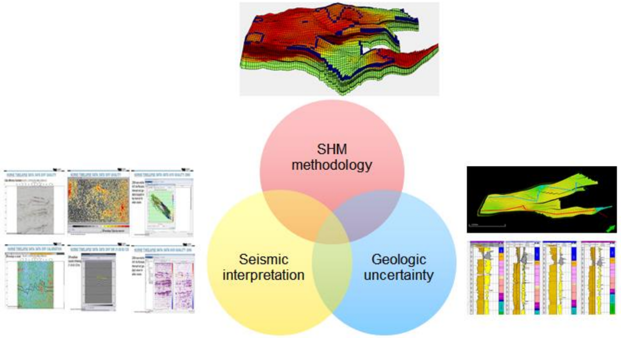
Motivation:
Parallel computing can dramatically reduce the running time for ensemble-based history matching methods in which normally hundreds of forward flow simulations are required.

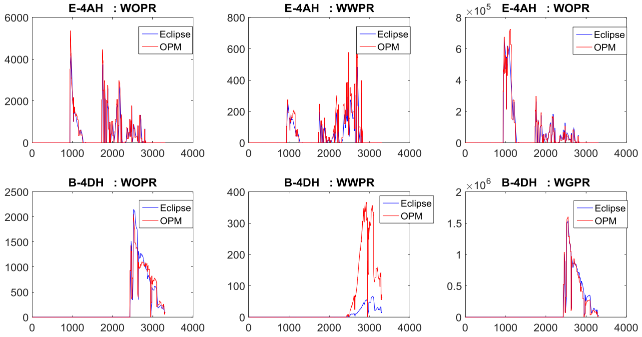
Comparative test with E100:

- Norne reservoir model with perturbed petrophysical properties
- Computation time:

$$FLOW \approx 2 \times Eclipse$$

- Comparable production profiles with Eclipse for most wells, but large deviations observed for some wells





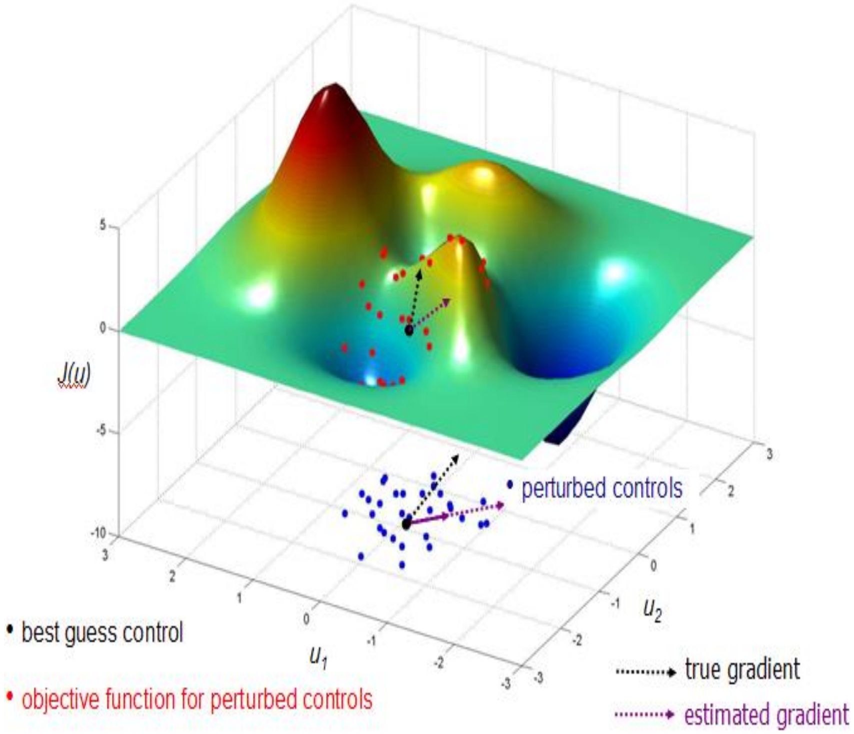
TNO-STATOIL COOPERATION ON ROBUST OPTIMIZATION OF FIELD DEVELOPMENT

- TNO-Statoil cooperation on robust well planning optimization
  - Workflow development
  - Field case application
  - Research aspects and best practices

- Workflow consists of three interacting components:
  - Optimizer and gradient computation module (EnOpt)
  - ERT as reservoir simulation framework
  - Reservoir simulator itself (Eclipse, to be replaced by FLOW)

ENSEMBLE OPTIMIZATION (ENOPT)

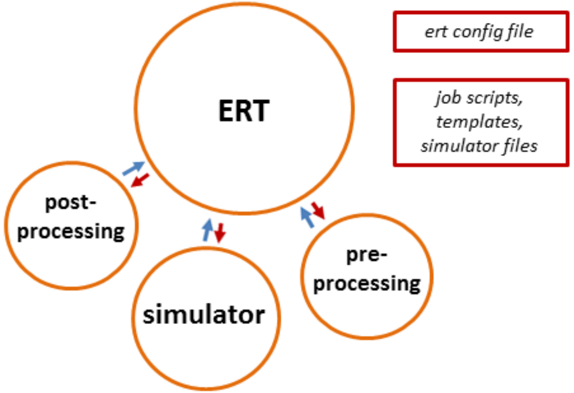
- Iterative optimization based on approximate gradients
- Introduced by Lorentzen et al (2006), Chen and Oliver (2008)
- Generate an ensemble of control vectors stochastically (blue dots)
- Evaluate each ensemble member of controls (red dots)
- Estimate a gradient from the ensemble of function evaluations



OPTIMIZING WELL CONTROL WITH ERT-FLOW

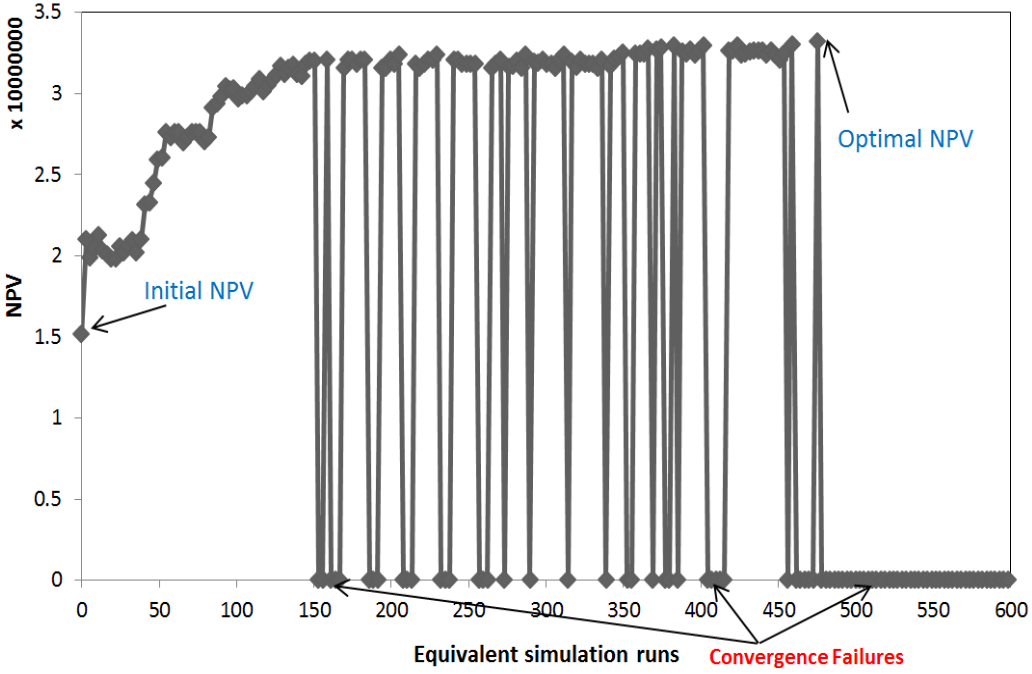
- Pre-processing to implement suggested controls (by the optimizer) in reservoir simulator input deck
- Reservoir simulation, and, in case of FLOW, numerical tuning
- Post-processing to compute objective function from reservoir simulator output
- Setup consists of templates, simulator files and (python) scripts

- Challenge: stable simulation for any suggested (perturbed) well controls (currently convergence problems), even if these include
  - wells coming online or shut-in
  - erratic well pressures or rates



COUPLING ENOPT WITH FLOW:
DETERMINISTIC LIFECYCLE OPTIMIZATION – WELL INJECTION RATES

- FLOW able to replace Eclipse for ensemble based robust/deterministic optimization, using the ERT framework
- Large number of simulations required for EnOpt – Parallel computing with FLOW very efficient
- Convergence failures with FLOW for erratic well rates and well opening times
- In an automated optimization workflow, tuning of numerical parameters for perturbed schedules not intuitive



SUPPORT, FUTURE DEVELOPMENTS AND COLLABORATION

- Well completion handling
- Handling complex well geometries
- Use of FLOW Solvent for CO2 WAG/EOR
- User Experience

THANK YOU FOR YOUR ATTENTION

TNO innovation for life