Status of simulation software in OPM

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OPM meeting, Trondheim, 11 March

Overview of simulators

IRIS

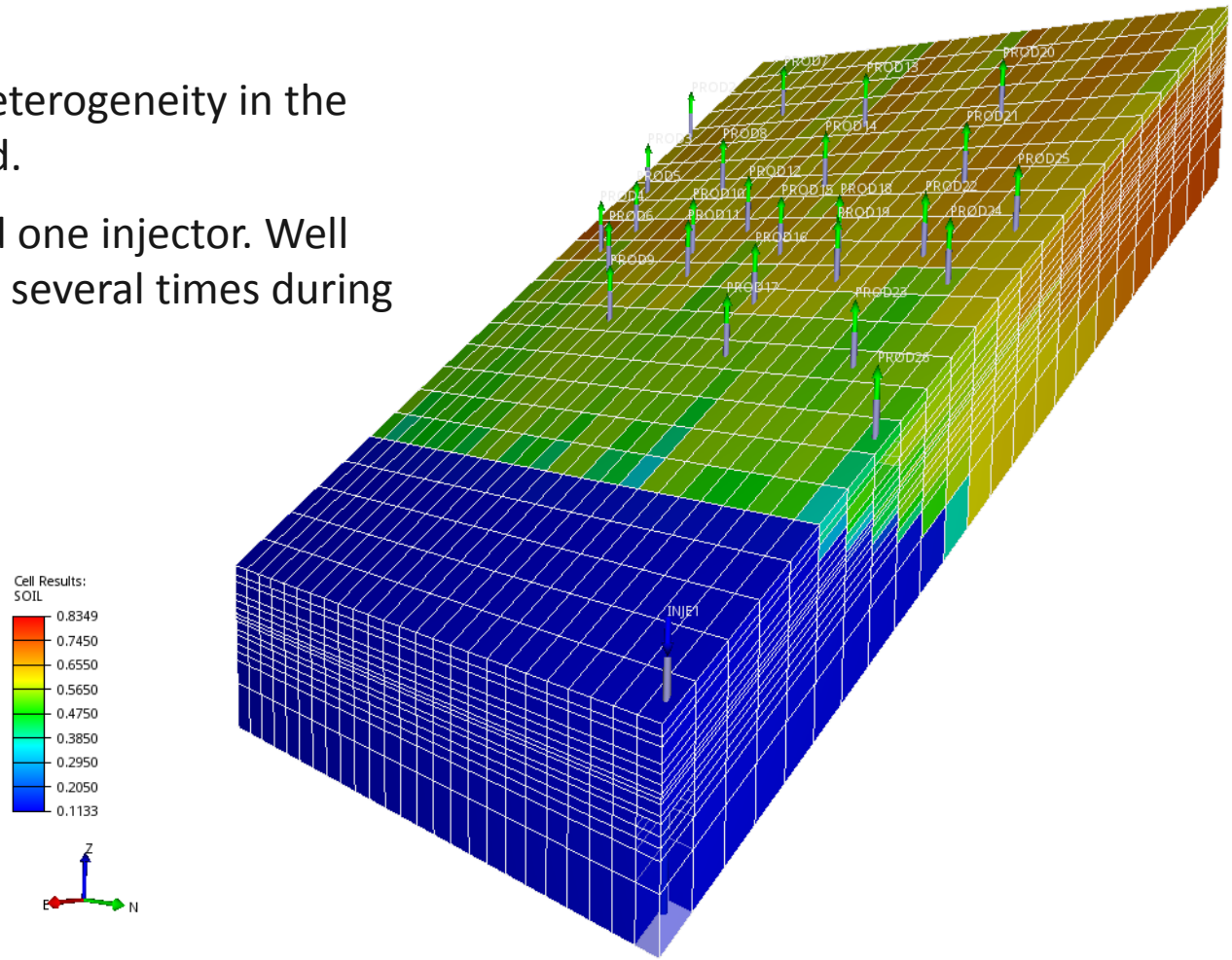
- **FLOW (Fully implicit black-oil simulator)**
  - Polymer flooding
  - Thermal simulations
- Ewoms
- Single-phase and steady state upscaling
- PORSOL (IMPES black-oil simulator)
- Multiple solvers for 2-phase flow
- Vertical equilibrium simulator (2-phase flow)

FLOW (Fully implicit black-oil simulator)

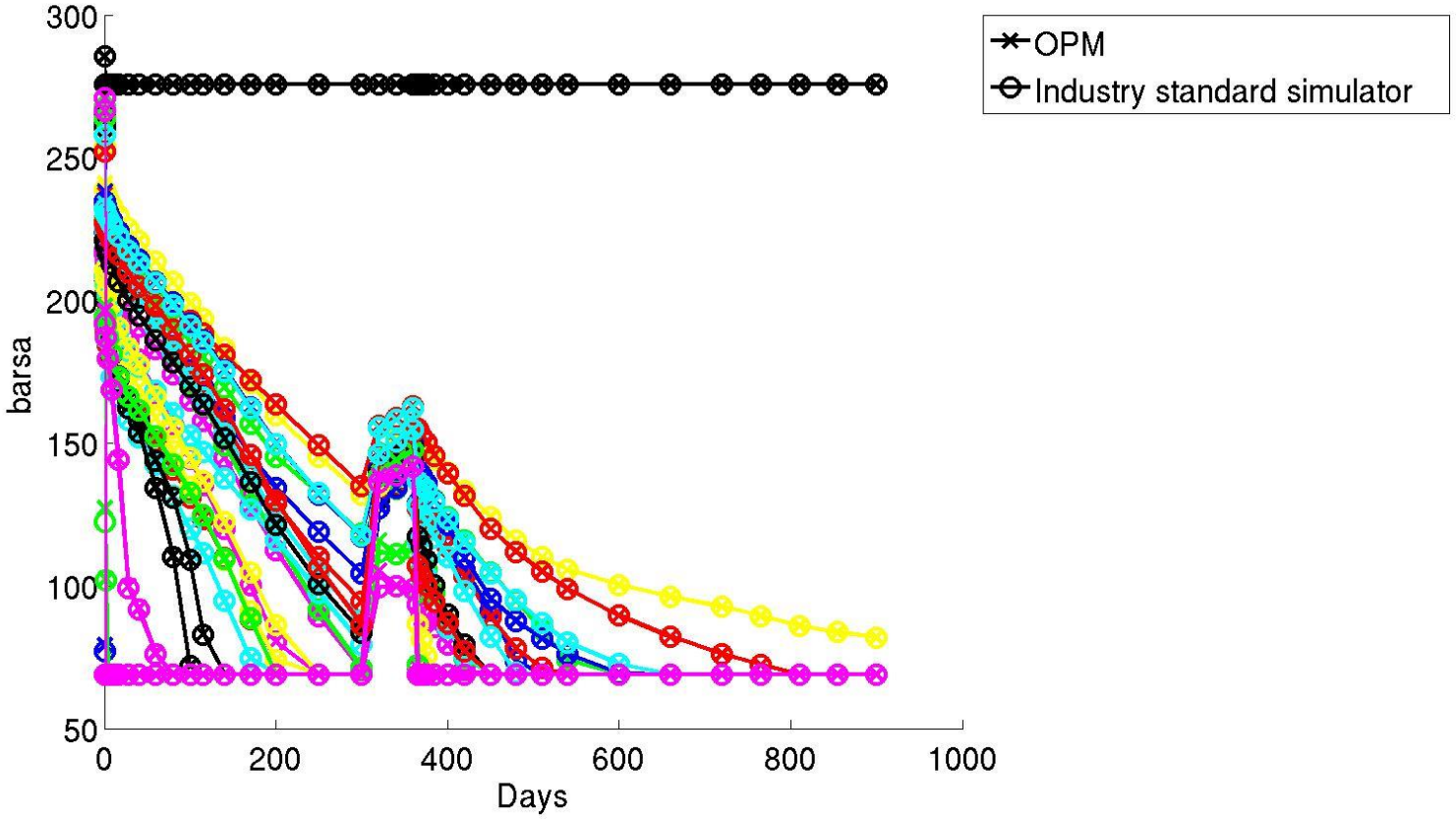
- Based on automatic differensialization
- IO
  - Read Eclipse decks
  - Output Eclipse summary, restart and egrid files
- Grid
  - Corner point geometry with faults
  - Modification of transmissibilities
    - Region multipliers
    - Fault multipliers
  - Net-to-gross
  - MINPV / PINCH
- Initialization
  - Equilibrium
  - Initial water saturation
- Properties
  - Dissolved gas
  - Vaporized oil
  - Capillary pressure
  - End-point scaling
  - Hysteresis (using end-point scaling)
  - Oil vaporization controls (VAPPARS)
- Wells
  - Control: BHP, surface rates and reservoir rates, (Group)
  - Shutting/Stopping/Opening wells and individual completions
  - History matching wells
- CPR preconditioner
- Time-step controls

Comparison SPE 9

- 9000 cells
- high degree of heterogeneity in the permeability field.
- 25 producers and one injector. Well controls changed several times during simulation.



BHP


300
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200
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800
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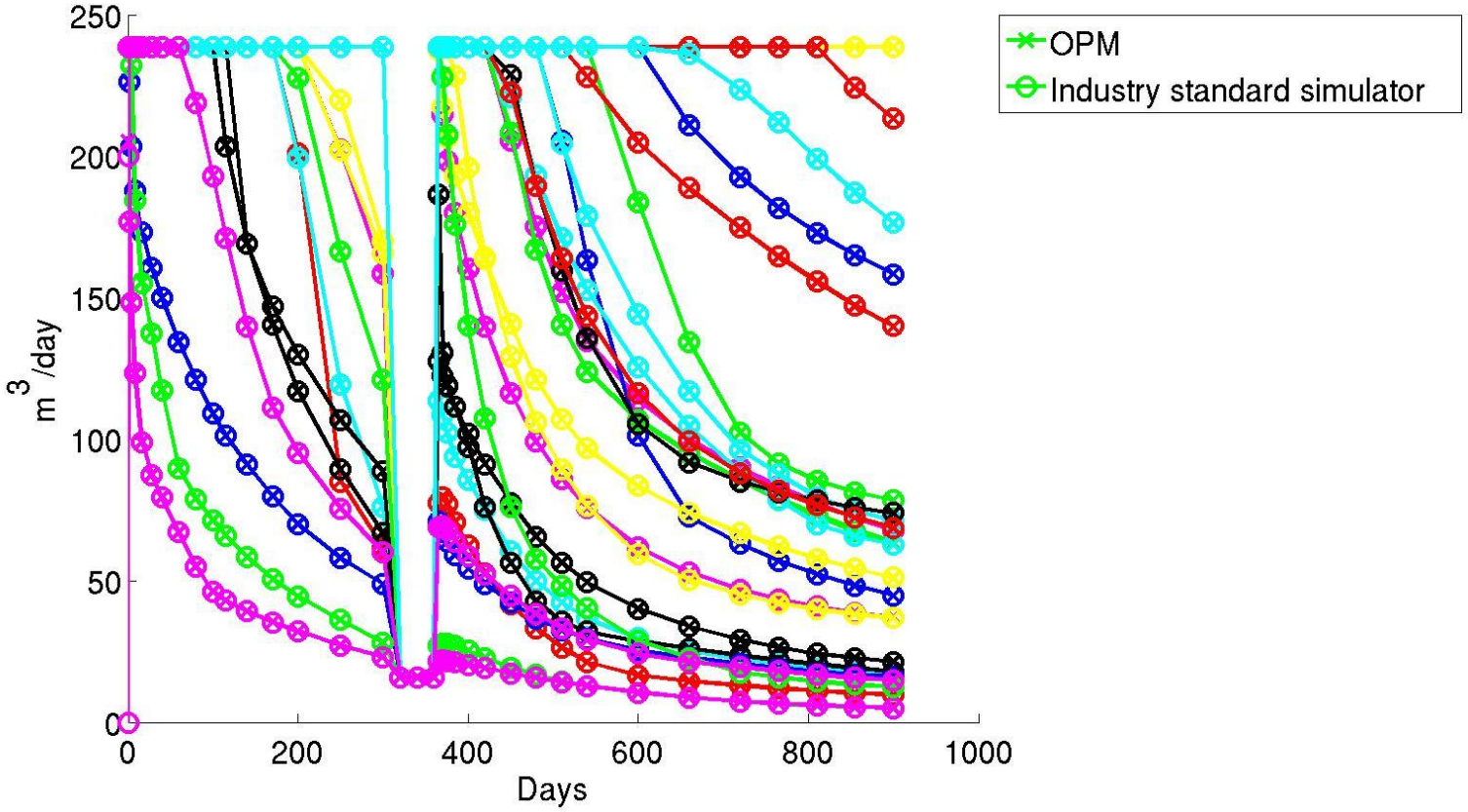
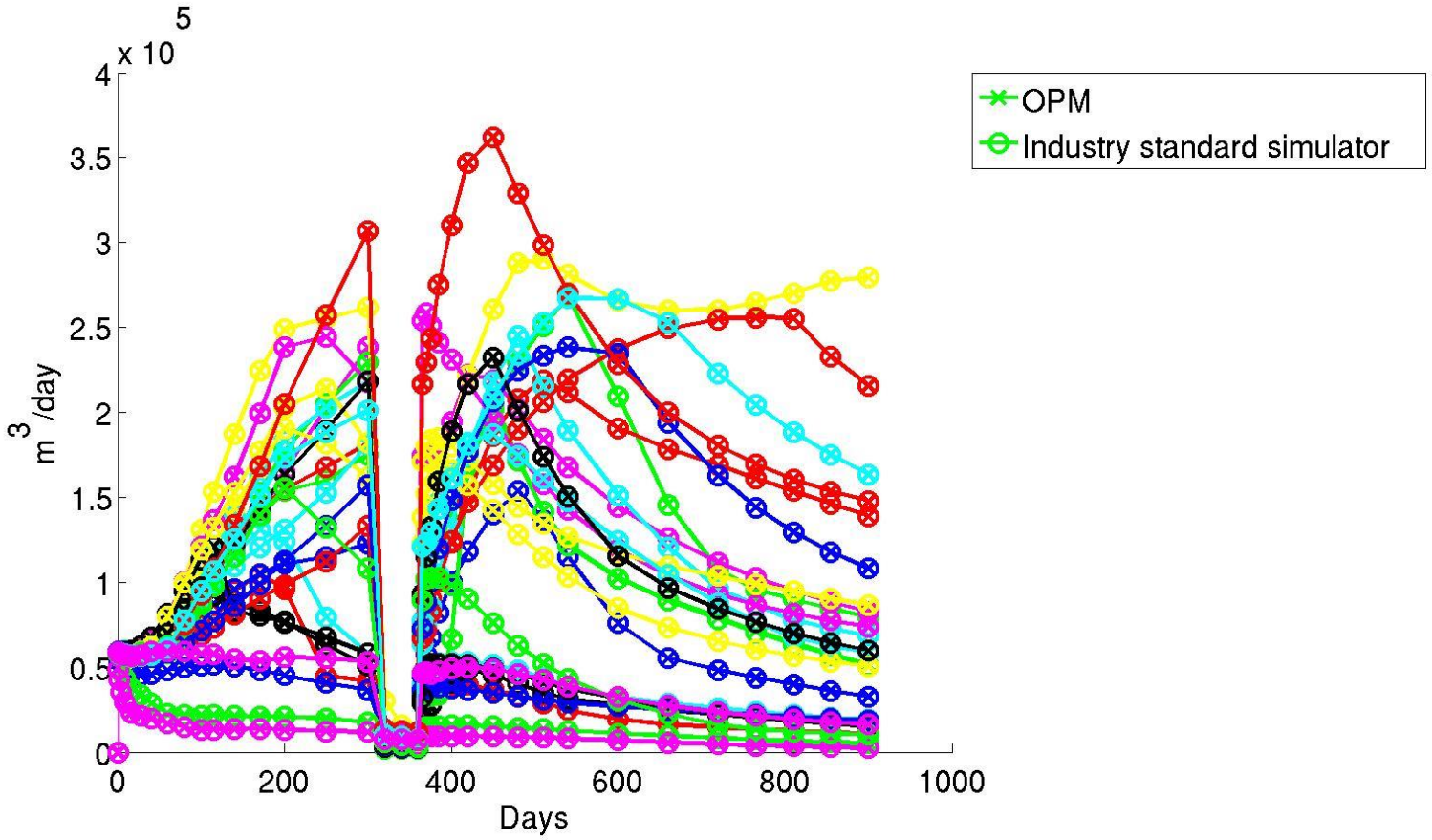
Days
OPM
Industry standard simulator

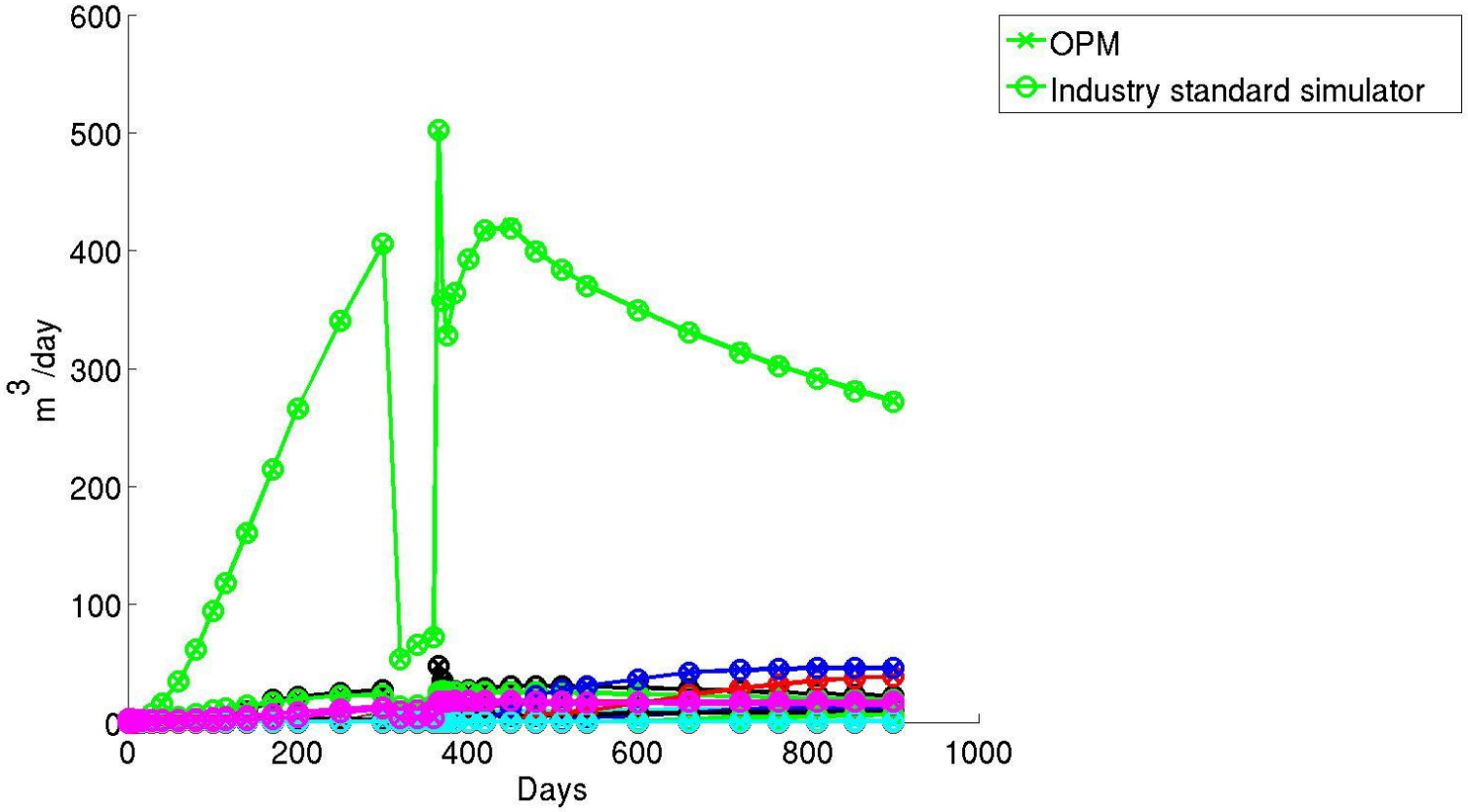
Oil production



Gas production

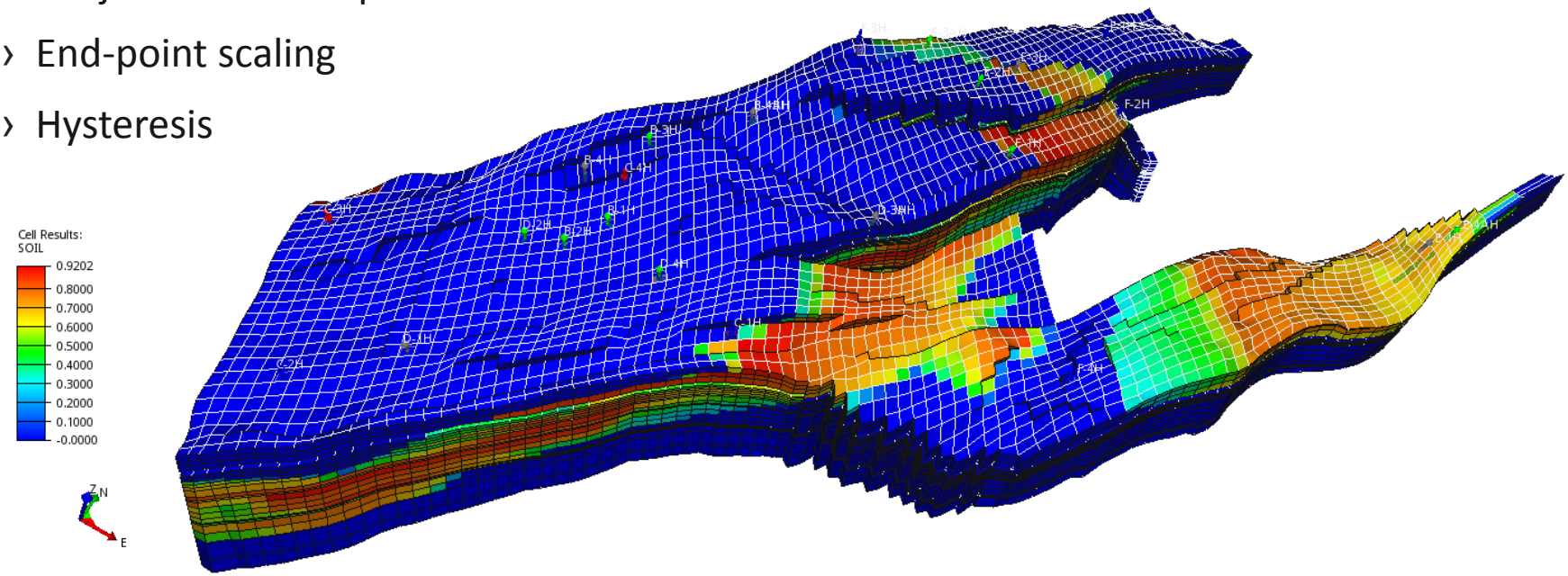


Water production

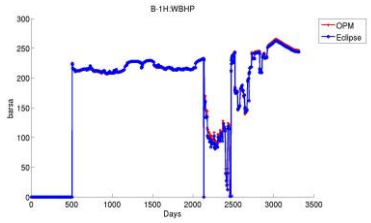
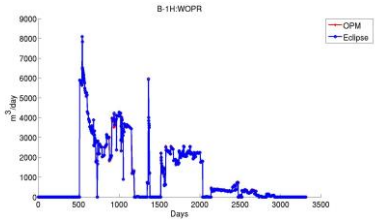
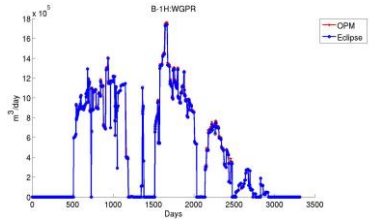
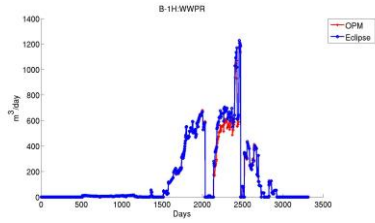
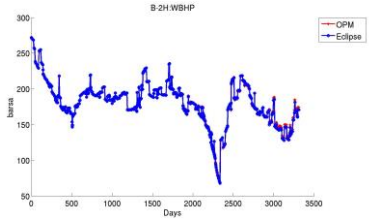
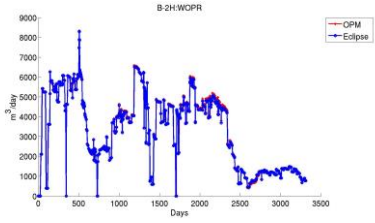
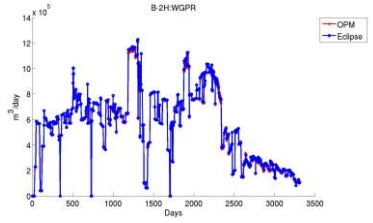
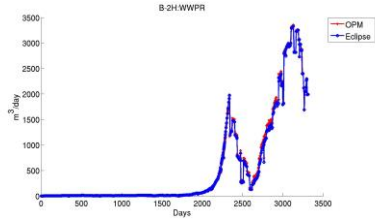
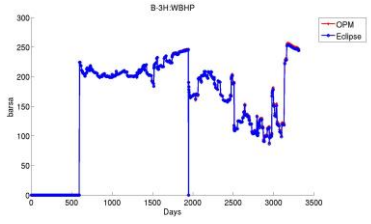
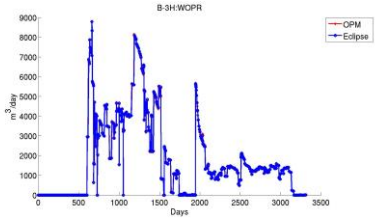
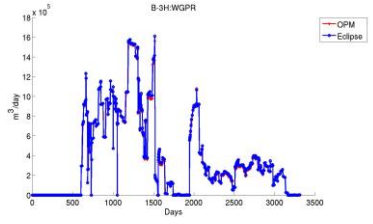
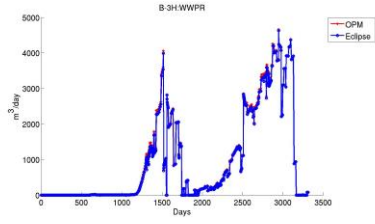


Comparison Norne

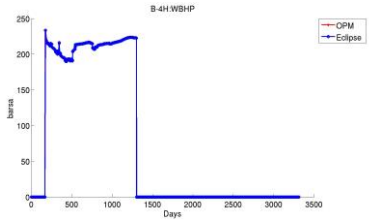
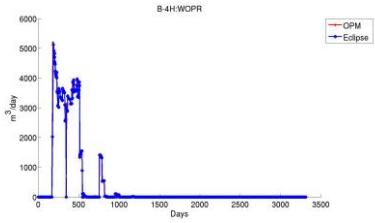
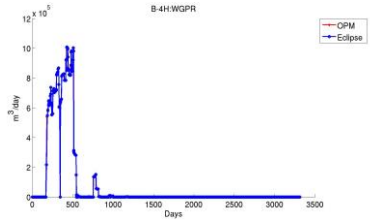
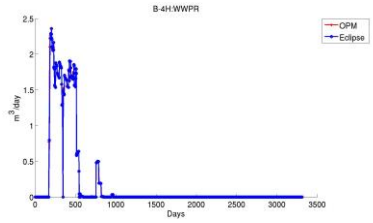
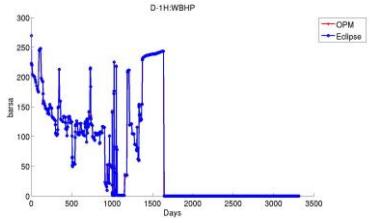
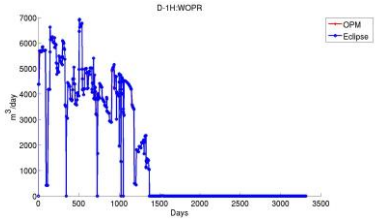
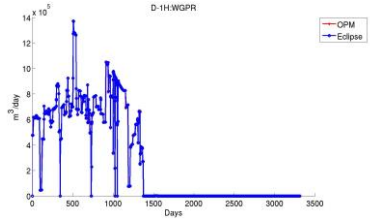
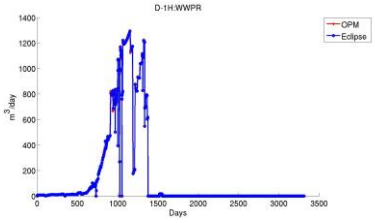
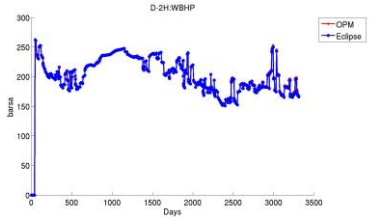
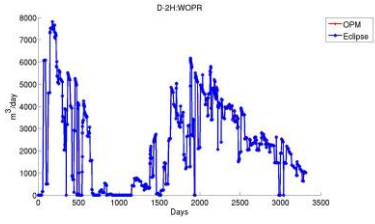
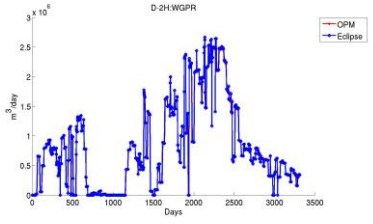
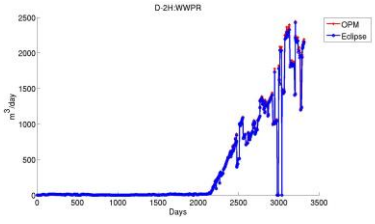
- 44431 active cells
- 10 years of historical injection and production rates
- 8 injectors and 28 producers
- End-point scaling
- Hysteresis



Norne results: Production wells

	BHP	Oil	Gas	Water
B-1H				
B-2H				
B-3H				

Norne results: Producing wells

	BHP	Oil	Gas	Water
B-4H				
D-1H				
D-2H				

Norne results: Producing wells

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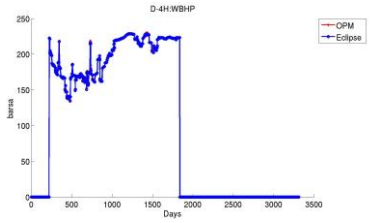
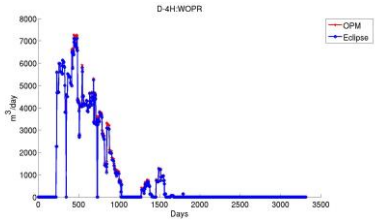
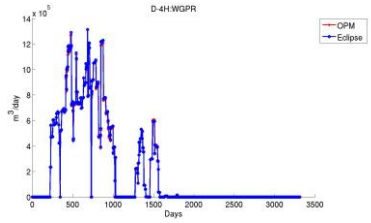
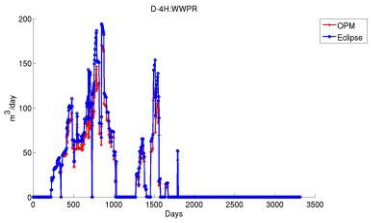
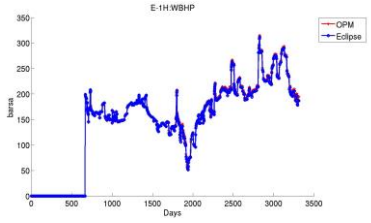
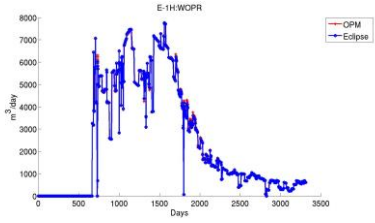
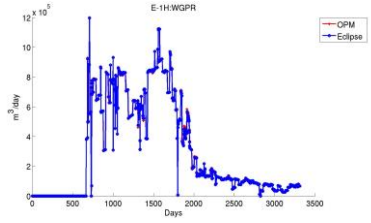
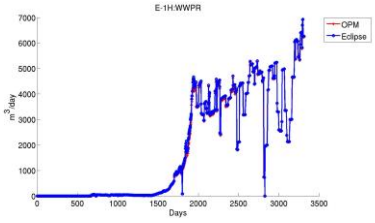
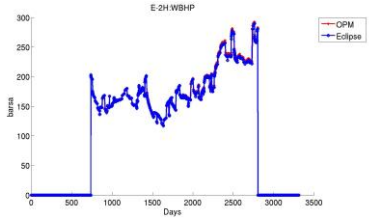
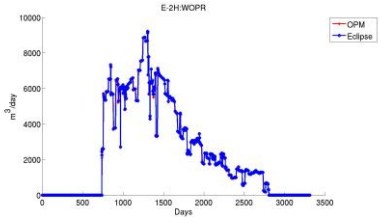
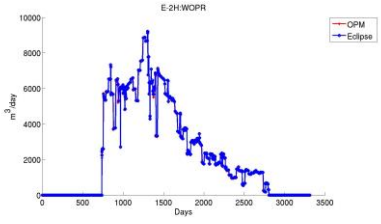
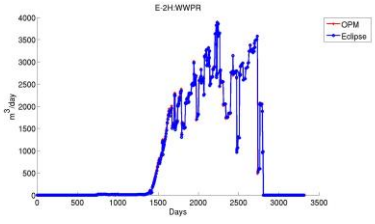
D-4H				
E-1H				
E-2H				

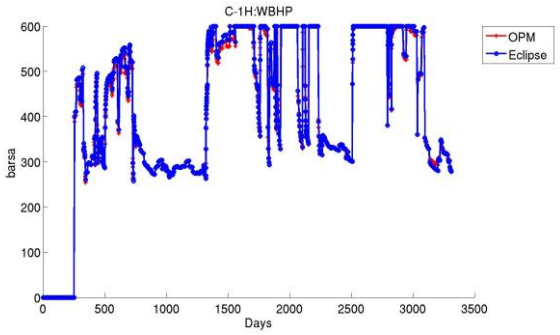
Norne results: Injecting wells

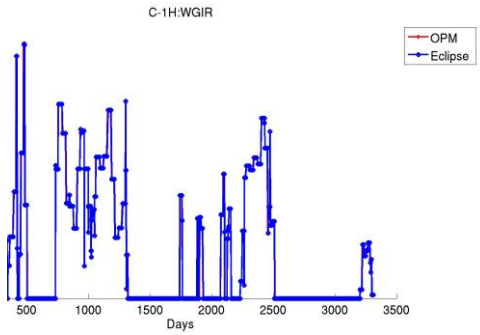
BHP

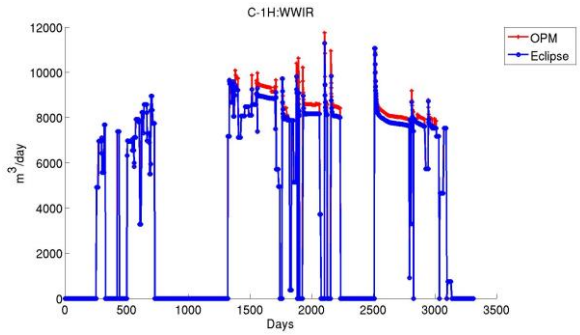
Gas

Water

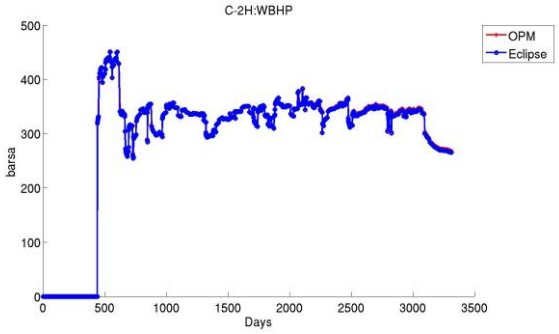
C-1H

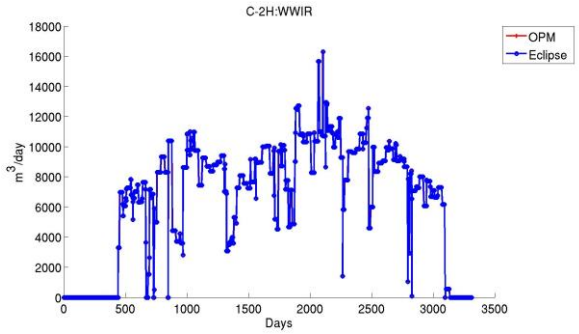






C-2H





Norne results: Injecting wells

BHP

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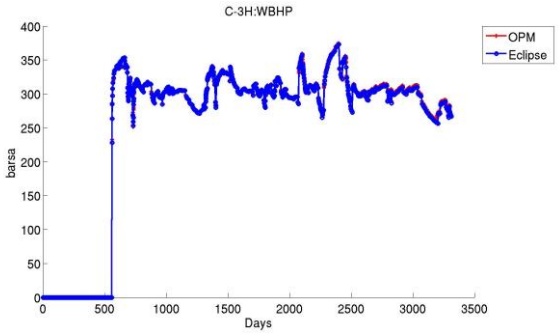
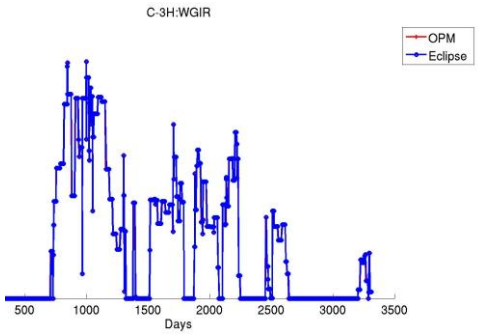
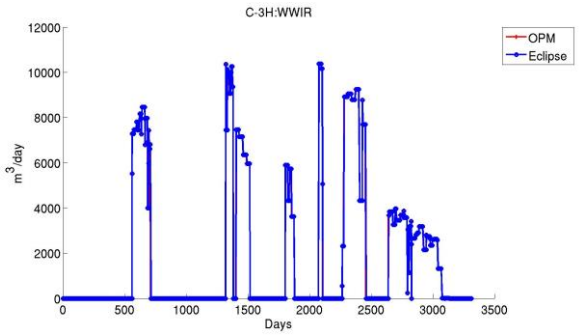
Water

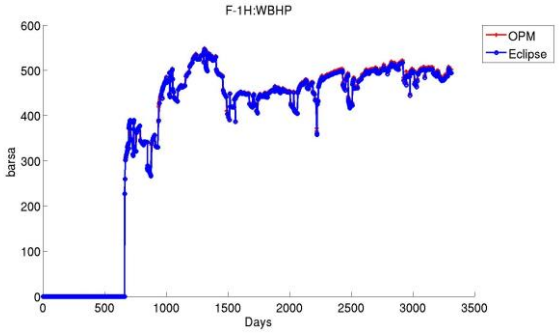
C-3H

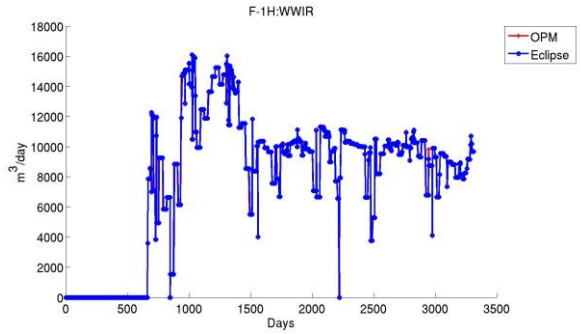






F-1H





Performance SPE1 and SPE9

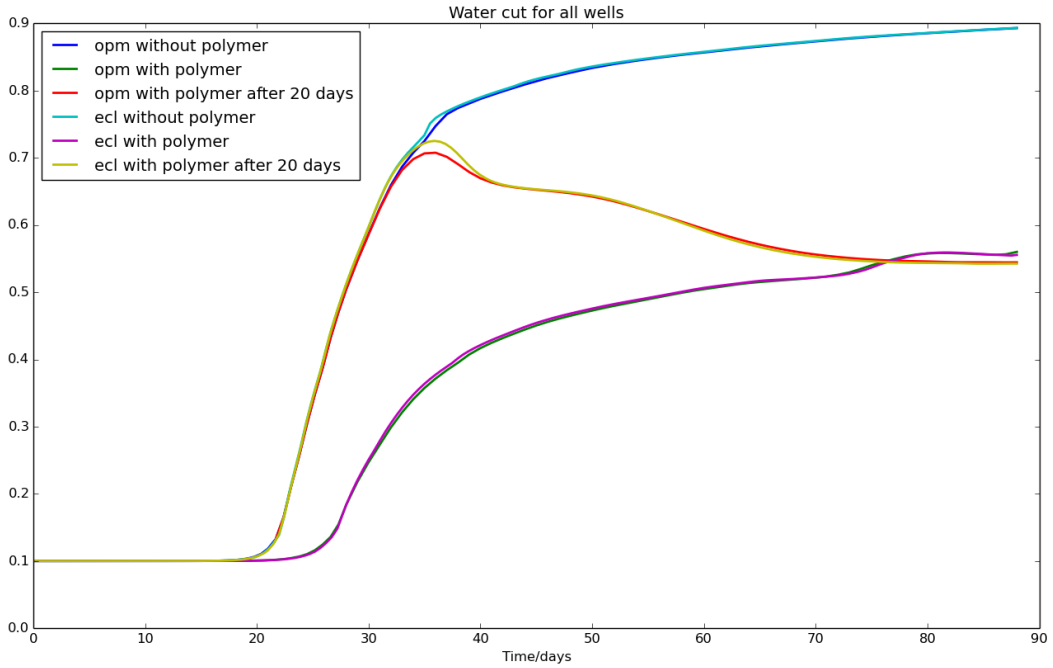
		SPE 1	SPE 9
Total time (sec.)	Eclipse OPM (BiCG + iLU + tuning) OPM (Gmres + iLU)	0.4 1.65 (4.1) 3.19 (7.9)	3.3 39.2 (11.9) 67.4 (20.4)
Total Newtons	Eclipse OPM (BiCG + iLU + tuning) OPM (Gmres + iLU)	246 190 331	154 167 206
Total linear solves	Eclipse OPM (BiCG + iLU + tuning) OPM (Gmres + iLU)	639 450 1476	892 406 1510

Performance Norne

		Norne
Total time (sec.)	Eclipse OPM (BiCG + fastAMG + tuning) OPM (BiCG + fastAMG + tuning) OPM (Gmres + iLU)	852 5452 (6.4) 7848 (9.2) >15000 (>17.6)
Total Newtons	Eclipse OPM (BiCG + AMG + tuning) OPM (BiCG + AMG + tuning) OPM (Gmres + iLU)	2241 2635 3882 >4000
Total linear solves	Eclipse OPM (BiCG + AMG + tuning) OPM (BiCG + AMG + tuning) OPM (Gmres + iLU)	20852 7922 12593 >20000

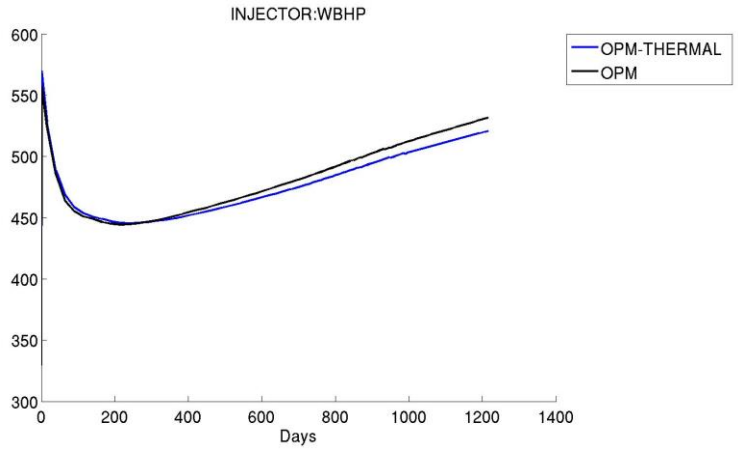
FLOW-Polymer

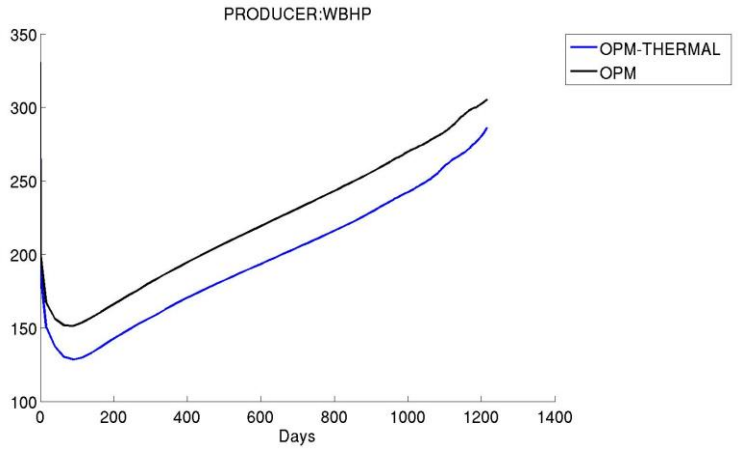
- Compressible oil-water-polymer solver
- Black-oil-polymer solver
- (Also a sequential version)



FLOW-Thermal

- Temperature dependent properties (x(p,T) = x_p(p) *x_T(T))
- Iso-thermal
- TODO: Solve energy equation





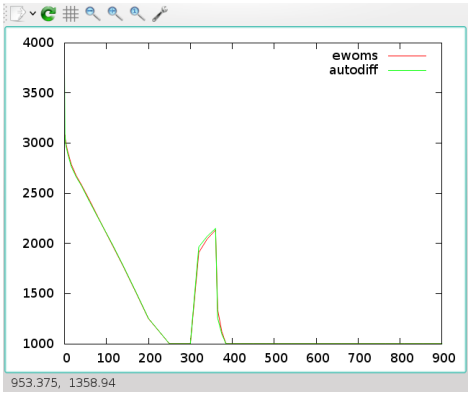
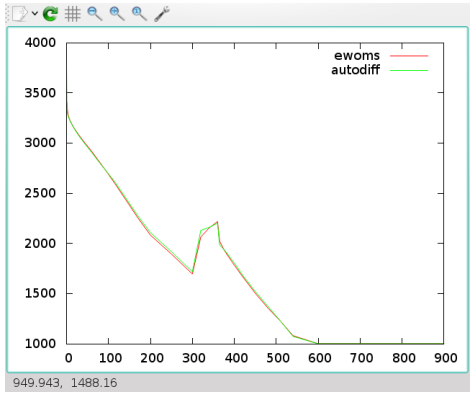
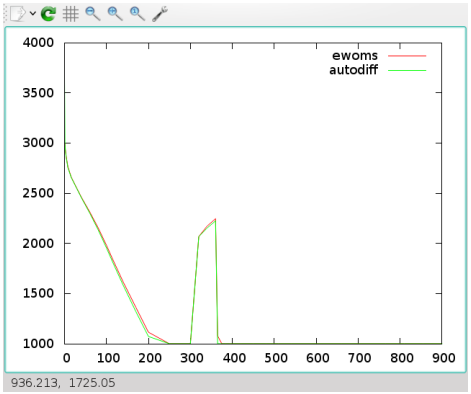
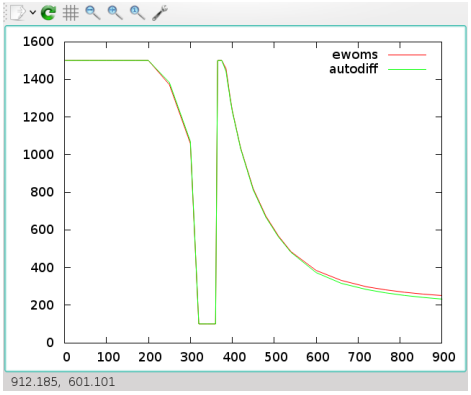
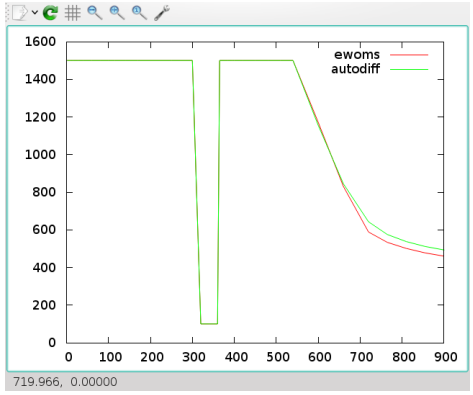
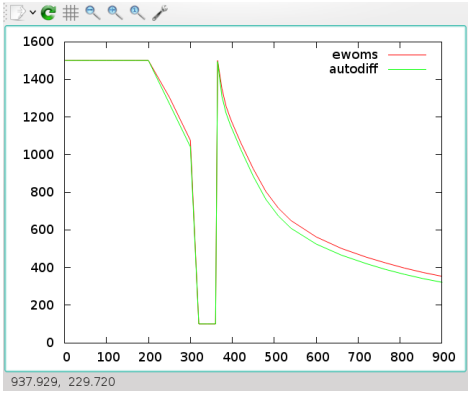
eWoms

eWoms not a simulator, but a framework to easily create one:

- Fully implicit solvers:
  - Element centered finite volume method
  - Vertex centered finite volume method
  - Implicit Euler for time discretization
- Currently featuring 7 porous media flow models, including
  - Richards
  - Immiscible fluids
  - Black-oil
  - Three fully compositional models
- Support for MPI and OpenMP (thread) parallelism
- Uses linear solvers of Dune-ISTL
- Support for the ECL decks via 'ebos' simulator
  - Same results as 'flow' and Eclipse 100 for SPE1 and SPE9
  - Some more advanced features not yet implementet
- Support for arbitrary number of fluid phases in all "generic" model
- Optional energy conservation for most model
- All models switchable between Darcy and Forchheimer velocities

SPE 9 results. EBOS

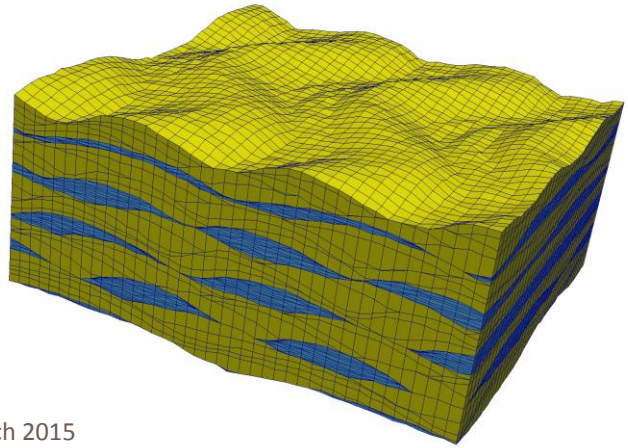
IRIS

	Prod 3	Prod 10	Prod 20
BHP			
Gas/Oil ratio			

Upscaling

IRIS

› Permeability (single-phase)
  - Flow-based: solve directional pressure problems
  - Much more accurate than harmonic averaging etc.
  - Mimetic discretization of pressure
  - Linear solver: dune-istl AMG (or FastAMG)
  - Fixed, Linear or Periodic boundaries
  - Produces symmetric tensor (with periodic boundaries)



› Relative permeability (two-phase)
  - Compute a steady-state for given configuration
  - Depends on flow direction, pressure drop, initial saturation
  - Compute upscaled perm based on phase mobilities
  - Produces full tensor relperm as output
  - Computing steady states
    - Two-phase incompressible, immiscible flow
    - Include capillary pressure, gravity
    - Fixed, Linear or Periodic boundaries
    - Pressure: mimetic discretization, AMG
    - Saturation: TPFA discretization, explicit or implicit Euler

Next steps (for the FLOW simulator)

- Energy equation
- Extended black-oil model (3 phase, 4 component) for CO2-EOR simulations
- Continue adding features to support new fields.
- Parallelization
- Refactoring
- Performance
- Release