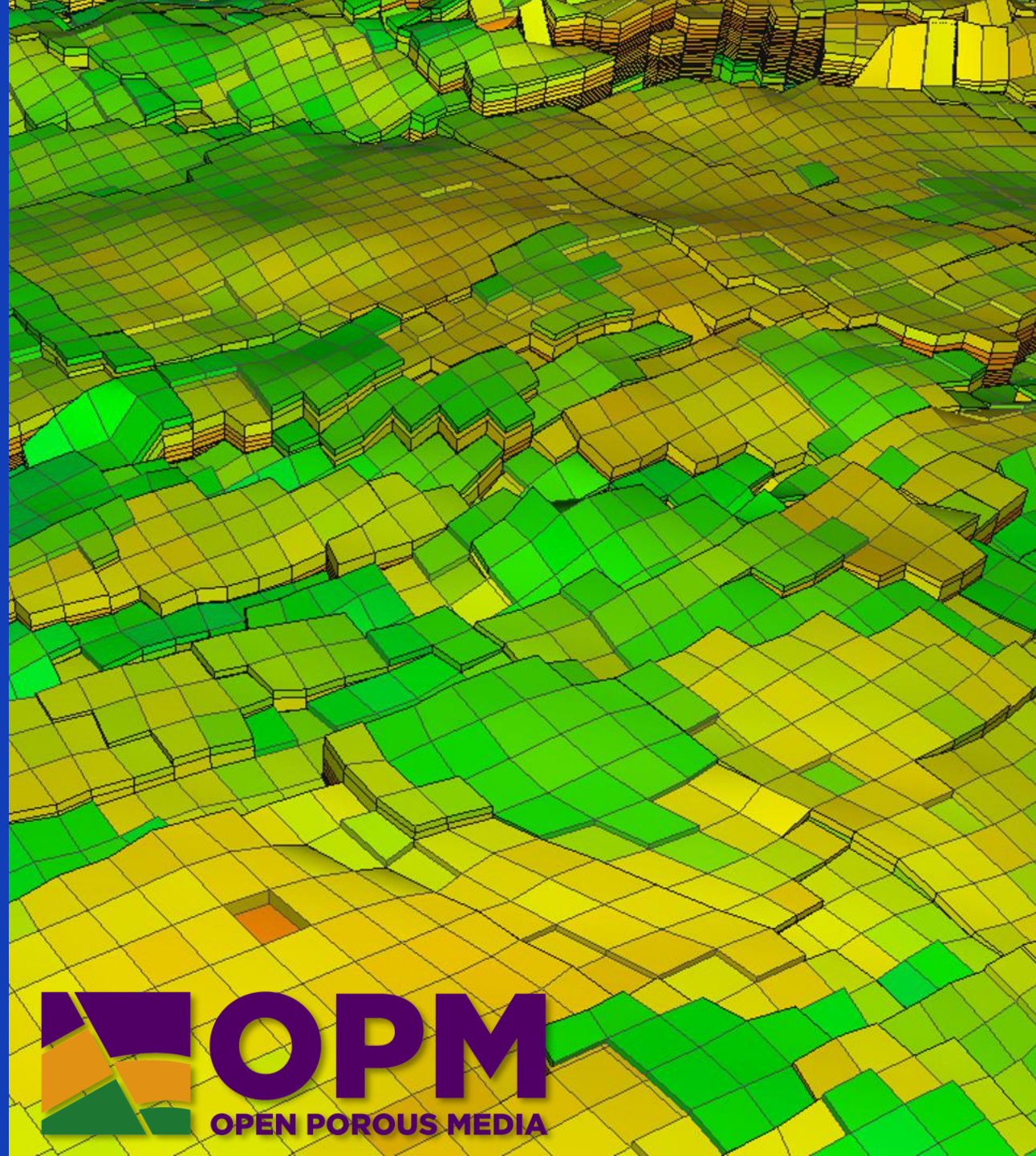
Recent OPM developments by TNO

OPM summit 2024

Paul Egberts

TNO innovation for life



Latest Activities

1. LGR
2. Output/input, bug fixes, error messages, code revision and documentation
3. **Salt precipitation comparison with CMG-GEM**
4. **Grid independent well trajectories**
5. **Network developments**

Salt precipitation comparison with CMG-GEM

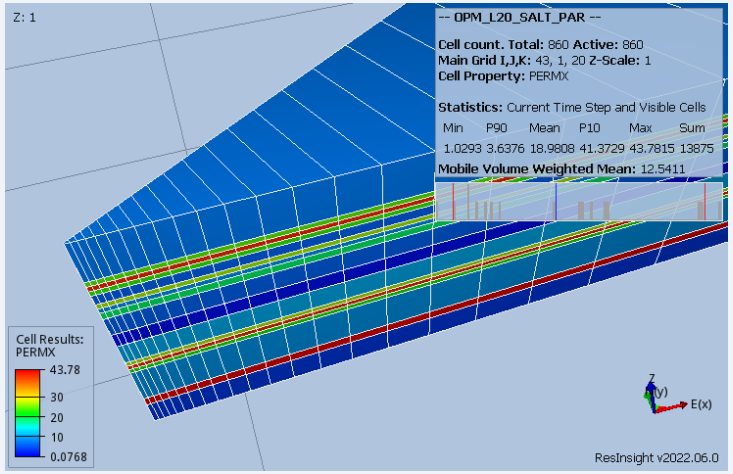
Salt precipitation comparison with CMG-GEM

Example case

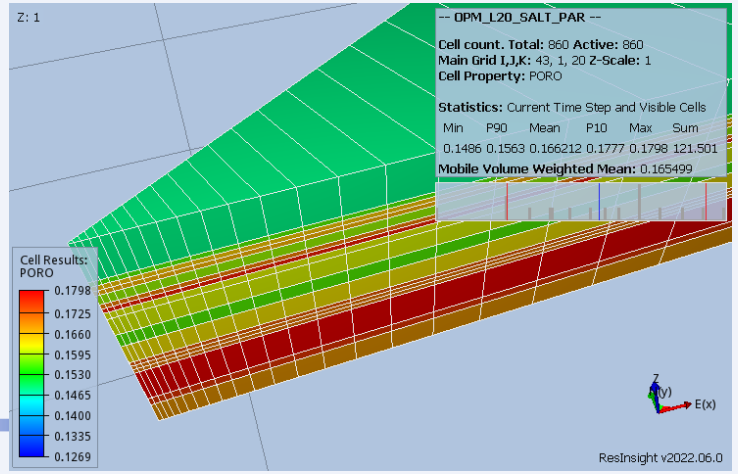
- Gas condensate reservoir with 20 layers (three-phase case)
- Provided by Equinor
- In github.com/OPM/opm-tests/

Rock-Fluid Properties	
Porosity	0.17 (avg), see Figure
Permeability [mD]	19.0 (avg), see Figure
Thickness [m]	32.0
Wellbore Radius [m]	0.1
Reservoir Radius [m]	1115.0
Reservoir initial Pressure [bar]	402.0
Initial water Saturation	0.32 (avg)
Initial salt in place [kg/m3]	88.0
Permeability-porosity relation	$\lambda = 3$
Solubility limit [kg/m3]	139.0
Salt density [kg/m3]	2170.0
Well control	Max rate 5000 Sm^3/day, Min BHP 90 bar

Permeability distribution



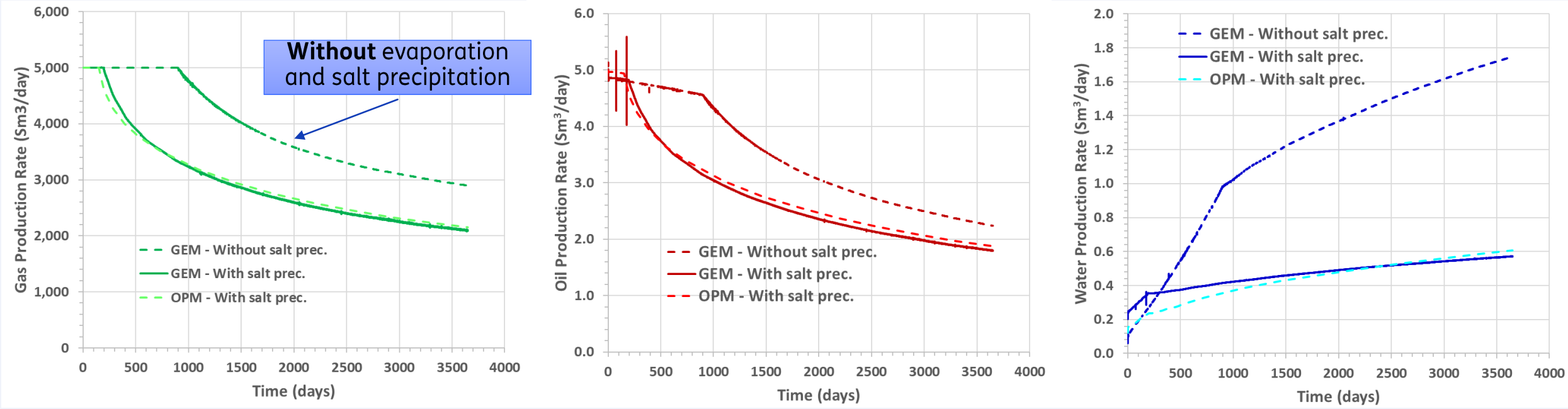
Porosity distribution



C.G. Machado, P. Egberts, TNO; J. Alvestad, O.S. Hustad, Equinor . "Salt Precipitation and Water Evaporation Modelling in a Black-Oil Reservoir Simulator", SPE RSC 2023, SPE-212257-MS

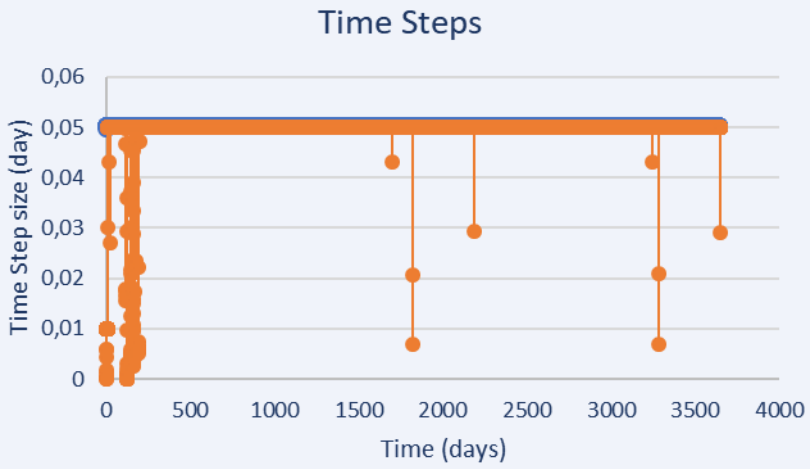
Comparison with CMG-GEM

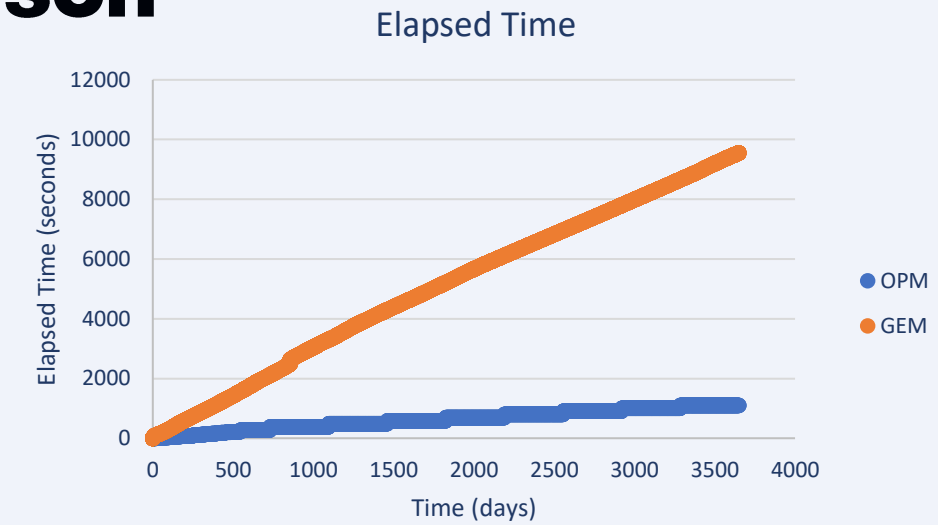
- Excellent match with CMG-GEM (compositional), for both
  - Well production
  - Salt precipitation time period and grid location
- Our black-oil formulation is much simpler and simulation cases are easy to set up

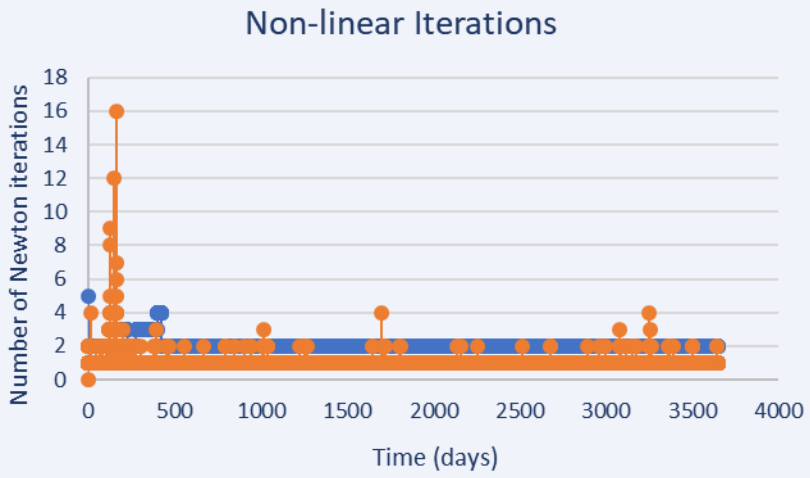


Numerical performance comparison

OPM-flow vs. CMG-GEM







- GEM has time-chopping
- OPM-flow ~ 10x faster
- OPM-flow version 2022.10 with default solver settings

*Intel Core i7-8850H, 6(12) @2.60GHz, RAM 128GB

Grid independent well trajectories

Grid independent well trajectories

Specification of well geometry and perforations independent of grid

- Grid independent description is relevant for:
  - Field cases with complex grids and deviated wells (grid-wise specification becomes cumbersome)
  - Optimization of well location and trajectories
  - Sensitivity Analysis study w.r.t. grid
  - LGR

- Several simulators can handle geometric description of wells
  - INTERSECT
  - tNavigator
  - MoReS

Grid ***dependent*** specification

```
-- WELL -- LOCATION -- OPEN SAT CONN WELL KH …
-- NAME  II JJ K1 K2  SHUT TAB FACT DIA FACT …
COMPDAT
PROD 1 1 1 1 OPEN 1* 1* 0.708 1* 0.0 1* 'Z' /
PROD 1 2 2 2 SHUT 1* 1* 0.708 1* 0.0 1* 'Z' /
PROD 1 2 3 5 SHUT 1* 1* 0.708 1* 0.0 1* 'Z' /
```

Keyword design

New keywords WELTRAJ and COMPTRAJ

- Replaces COMPDAT

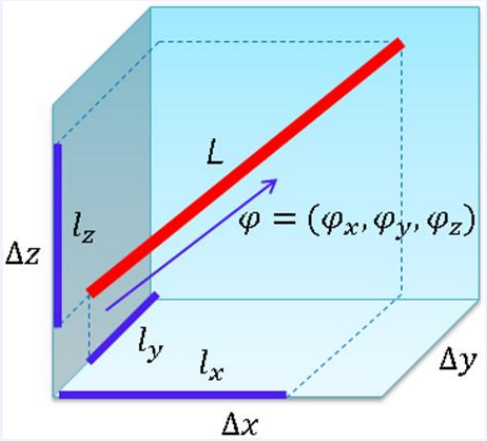
```
WELTRAJ
-- WELL    BRANCH_NO X          Y          TVD        MD
'PROD'     1*         950        950        -20.0      0.0 /
'PROD'     1*         950        950         2100.0    2100.0 /
'INJ'      1*         50         50         -20.0      0.0 /
'INJ'      1*         50         50          2000      2000/
'INJ'      1*         300        300         2100      2100.0 /

COMPTRAJ
-- WELL     BRANCH   PERF      PERF    PERF   COMPL STATE SAT     CONN DIAM KH   SKIN D_FACT
-- NAME     NO       TOP       BOT     REF    NO    --    TABLE   FACT  --   --   --   --
'PROD'     1*       2000.0    2100.0  1*   1*    1*    1*      1*   0.1  1*   0.1  1*   /
'INJ'      1*       2000.0    2100.0  1*   1*    1*    1*      1*   0.1  1*   0.1  1*   /
```

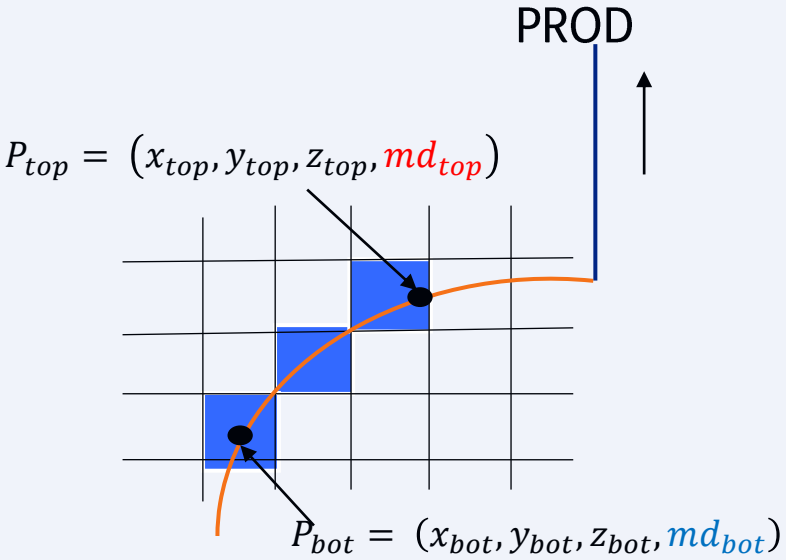
- Implementation done only for standard wells (STDW)
- Syntax already accommodates extension to multi-segment wells (MSW)

Deriving well block indices & intersection lengths

- Re-use of **ResInsight** implementation
  - To efficiently calculate well block indices (IJK)
    - Axis Aligned Bounding Box (AABB) Tree search algorithm
  - Derive well intersection length and projections
  - Isolated the relevant code from **ResInsight** and inserted in opm-common

- Projection method to calculate Connection Factor: $CF = \sqrt{CF_x^2 + CF_y^2 + CF_z^2}$
  - Used by petrel





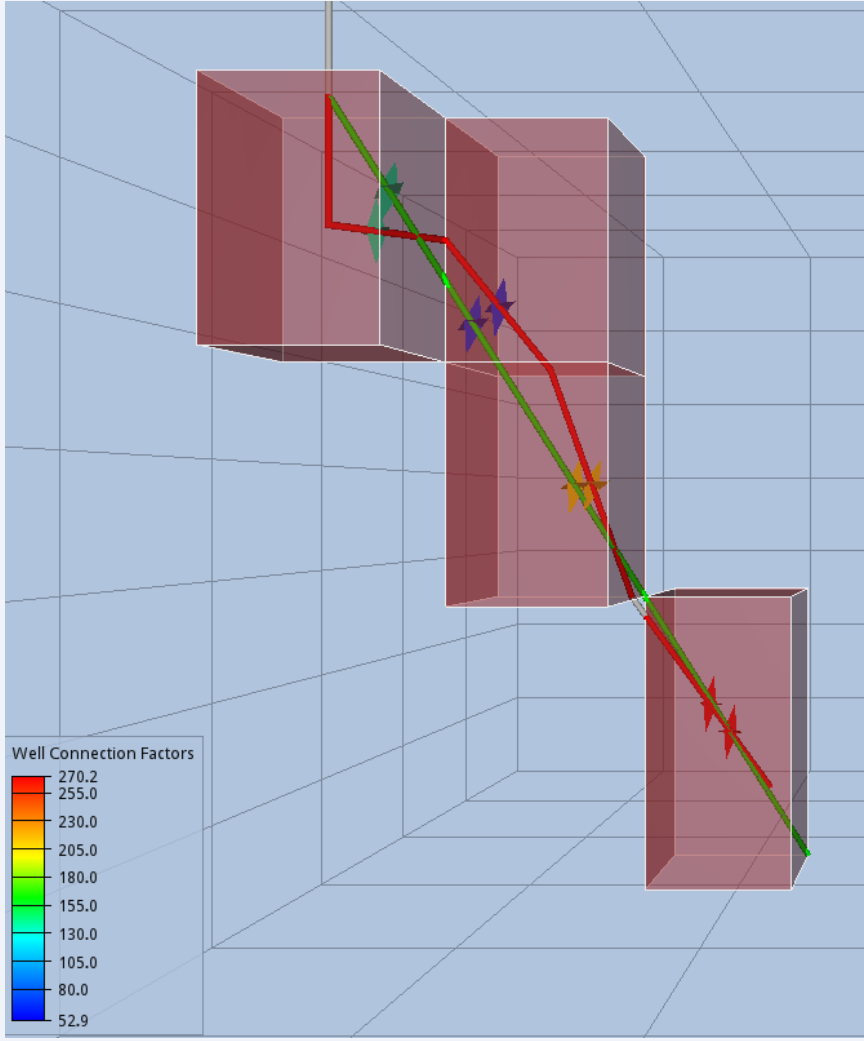
Comparing ResInsight and Flow

- Green well imported in ResInsight using deviation table:

```
WELLNAME: 'INJ1'
# X         Y          TVDMSL     MDMSL
50          50         -20.0      0.0
50          50         2000       2000
300         300        2100       2100.0
```

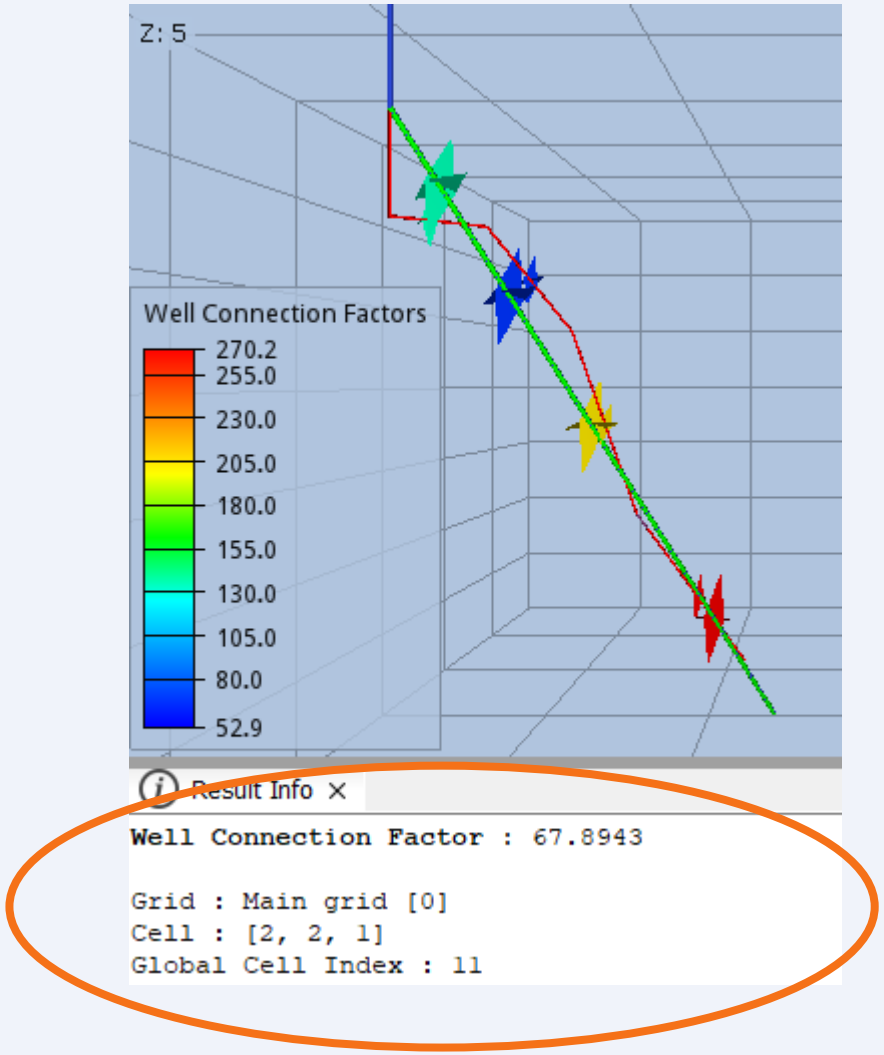
- Red well from Flow simulation case using

```
WELTRAJ
-- WELL    BRANCH_NO X          Y          TVD        MD
'INJ'      1*         50         50         -20.0      0.0 /
'INJ'      1*         50         50          2000      2000/
'INJ'      1*         300        300         2100      2100.0 /

COMPTRAJ
-- WELL     BRANCH   PERF   PERF   PERF COMPL STATE SAT     CONN DIAM KH   SKIN D_FACT
-- NAME     NO       TOP    BOT    REF  NO     --    TABLE   FACT  --   --   --   --
'INJ'      1*       2000.0   2100.0  1*   1*  1*     1*      1*   0.1  1*   0.1  1*   /
```

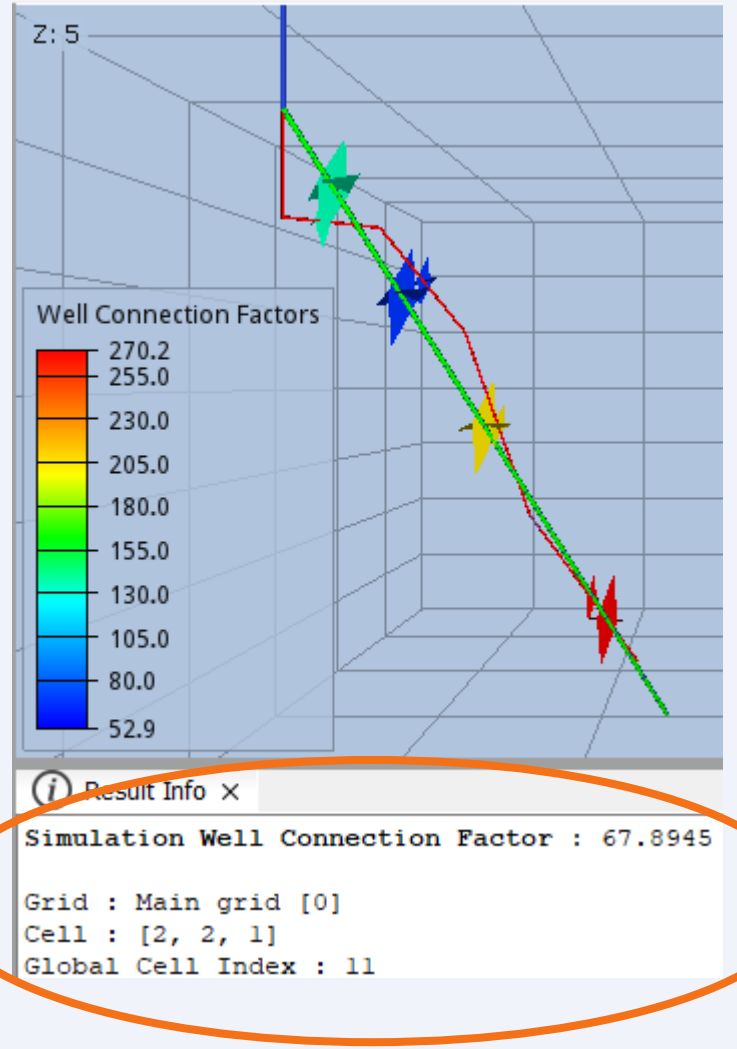


Comparison connection factors

ResInsight



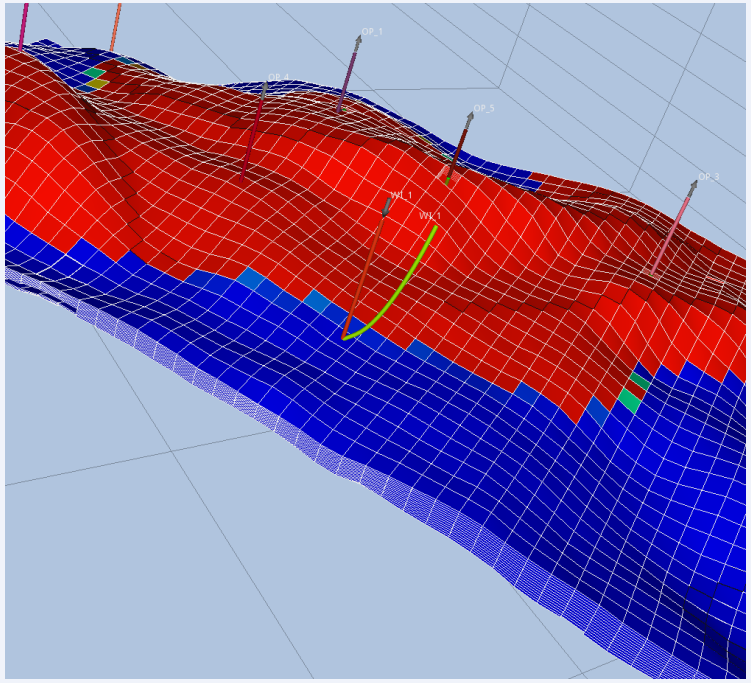
OPM-flow

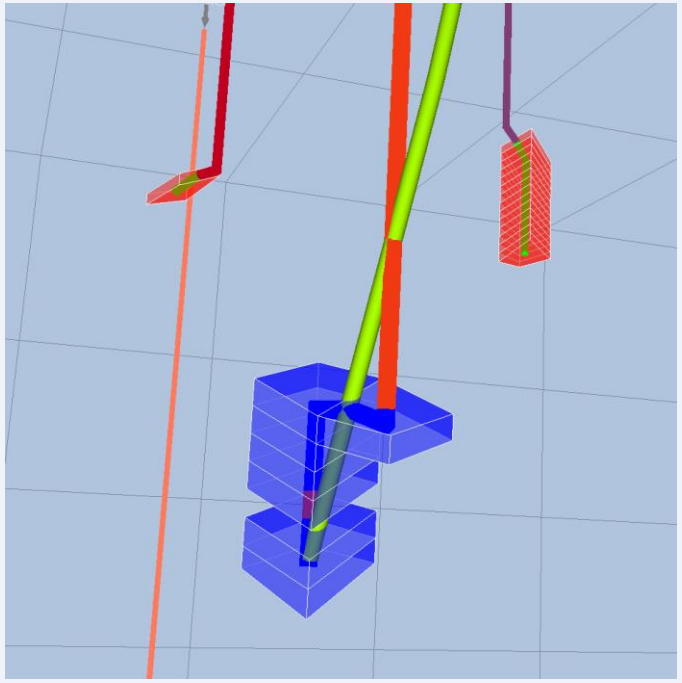


Next steps

- With `RPTSCHED` keyword, the `WELSPECS` and `COMPDAT` data generated internally can be reported in *.PRT pipe
- Currently the functionality is tested with more complex cases
- After testing start with enabling grid-independent well trajectories for **Multi-segment wells** (MSW)

Testing with complex cases and well geometries:





Network developments

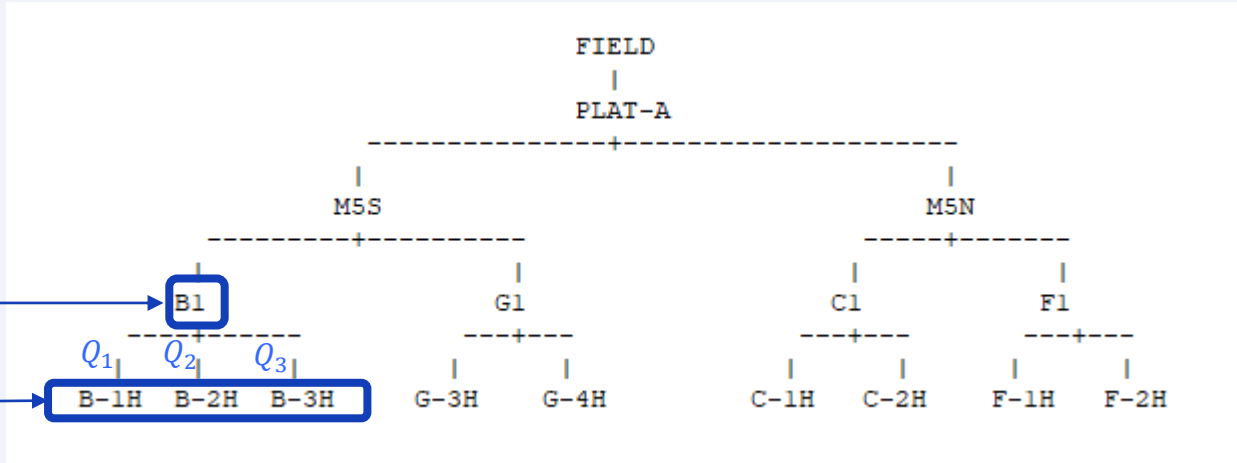
Group node representing a subsea manifold

- Wells belonging to such group node:
  - operate on a common THP (Tubing Head Pressure)
  - the THP is such that a group rate target is fulfilled
  - THP >= (unchoked) group nodal pressure
- Involved keywords:

```
GCONPROD   'B1'   ORAT   6000 /
```

```
NODEPROP
--   NodeName   Press   Choke
     PLAT-A     21.0    NO    /
     M5S        1*      NO    /
     B1         1*      YES   /
     C1         1*      NO    /
```

B1: subsea manifold

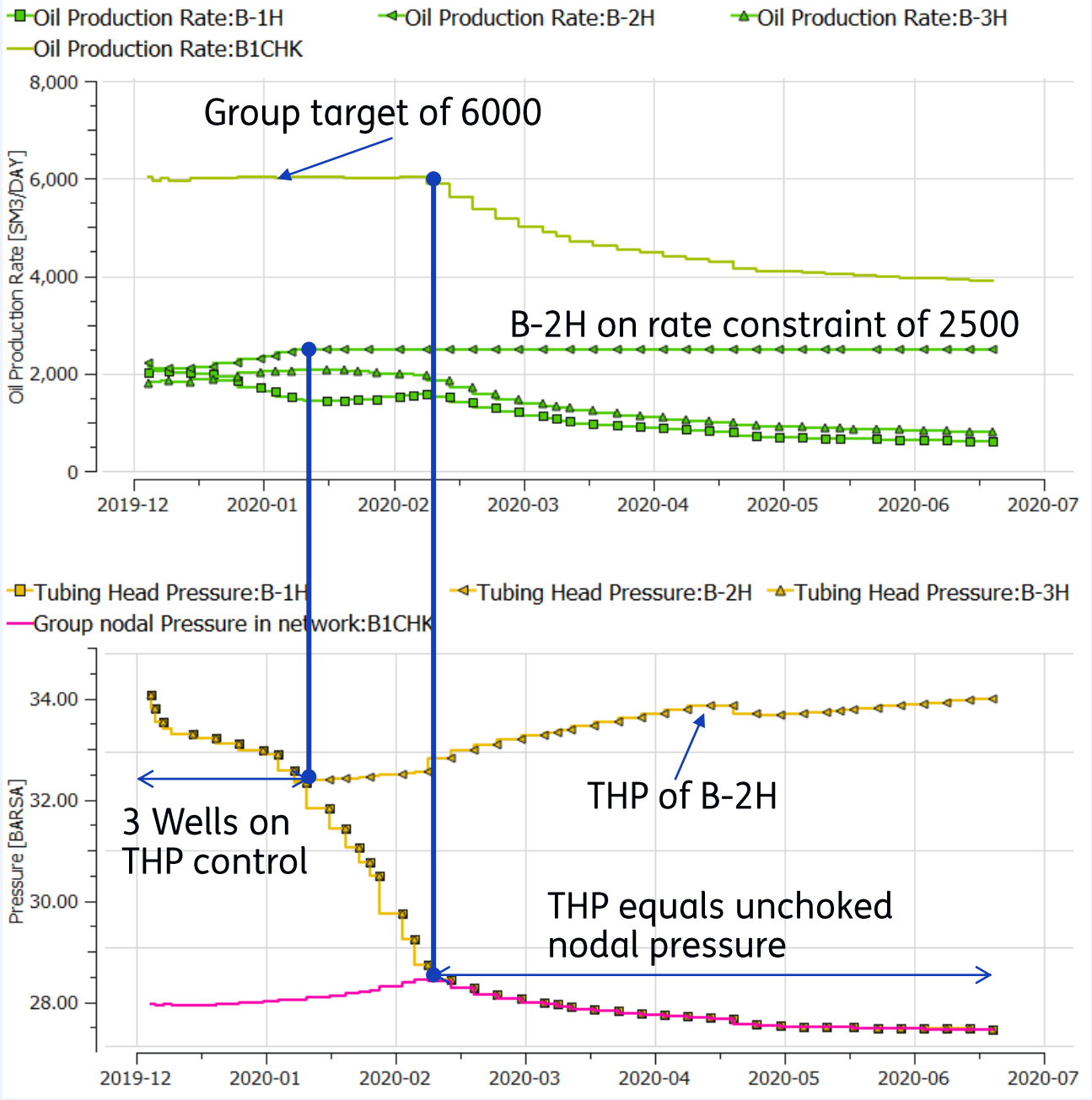


Group rate target Q

Same THP such that

$Q = Q_1 + Q_2 + Q_3$

Example 1

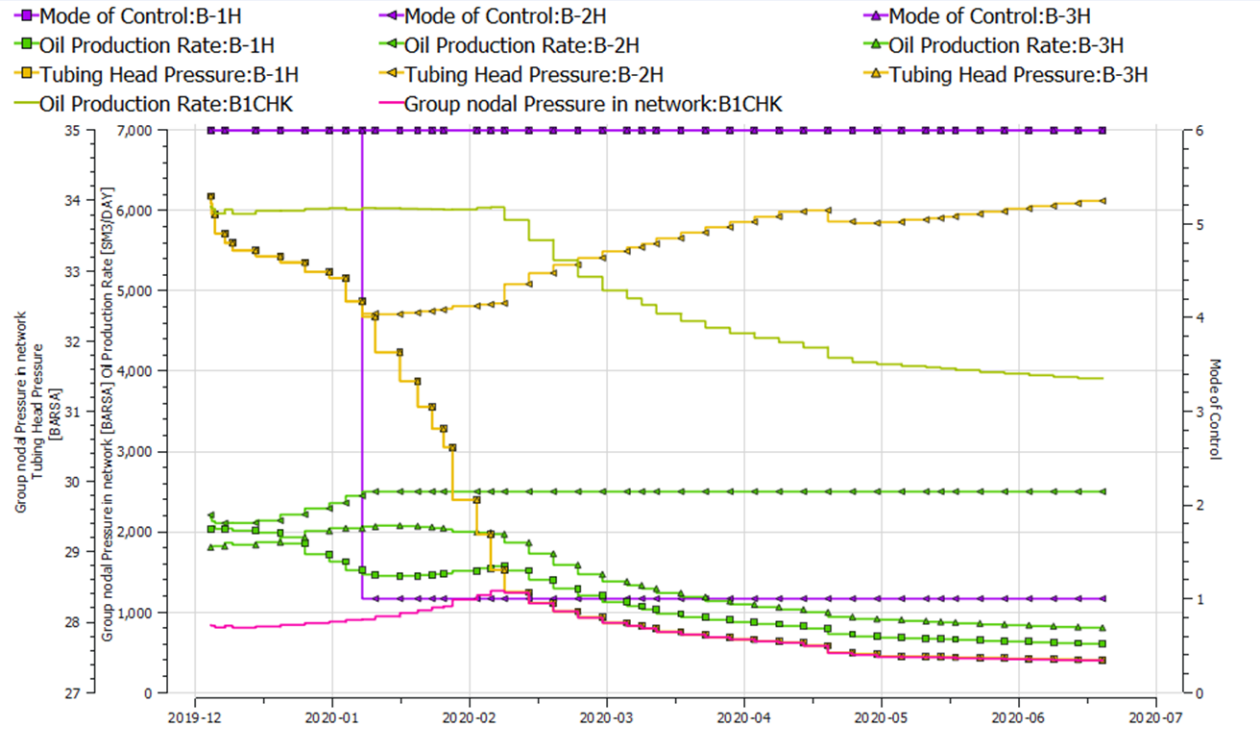


- Initial all 3 wells of the subsea manifold group run on common THP with the group **oil rate target of 6000 SM3/DAY**
- When well B-2H meets its **individual oil rate constraint of 2500 SM3/DAY**), its THP is derived independently of the other two wells
- As long as the common THP stays above the group nodal pressure, the group target of 6000 can be met.

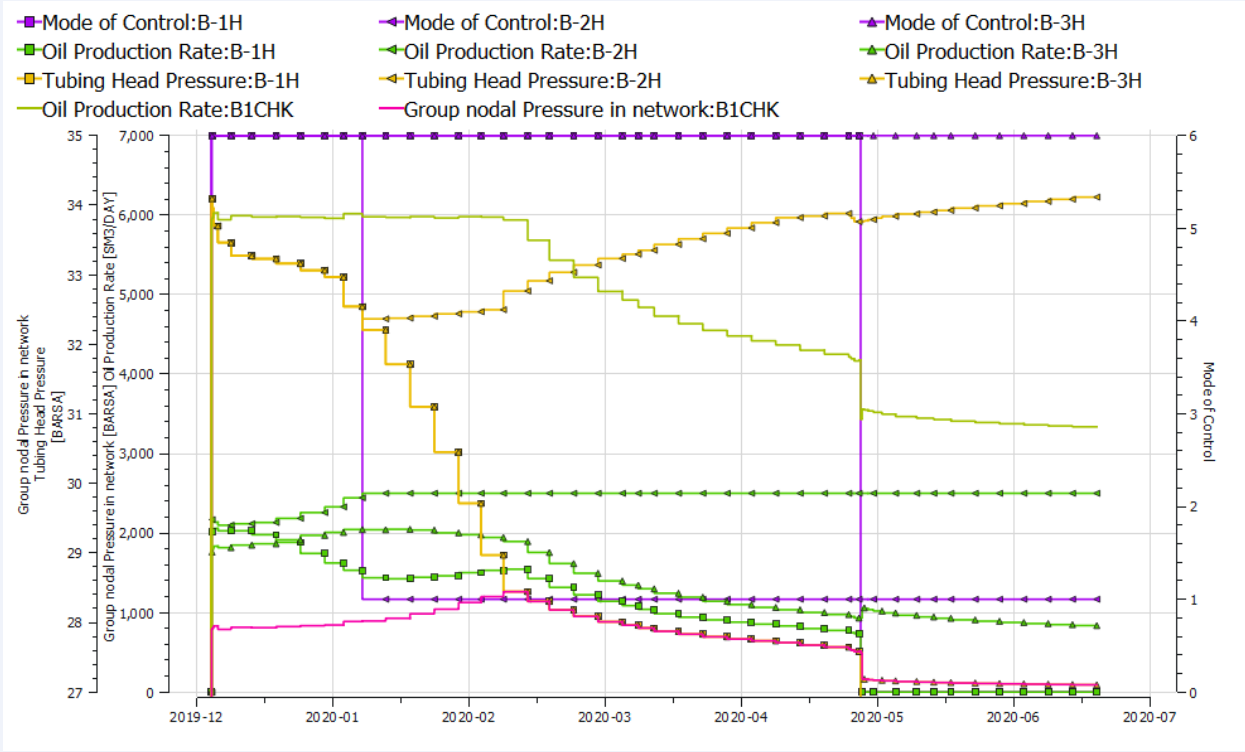
Comparison with reference simulator

- Good comparison
- Note: For the reference simulator well B-1H is shut-in while in OPM-flow the well stays open

OPM-flow

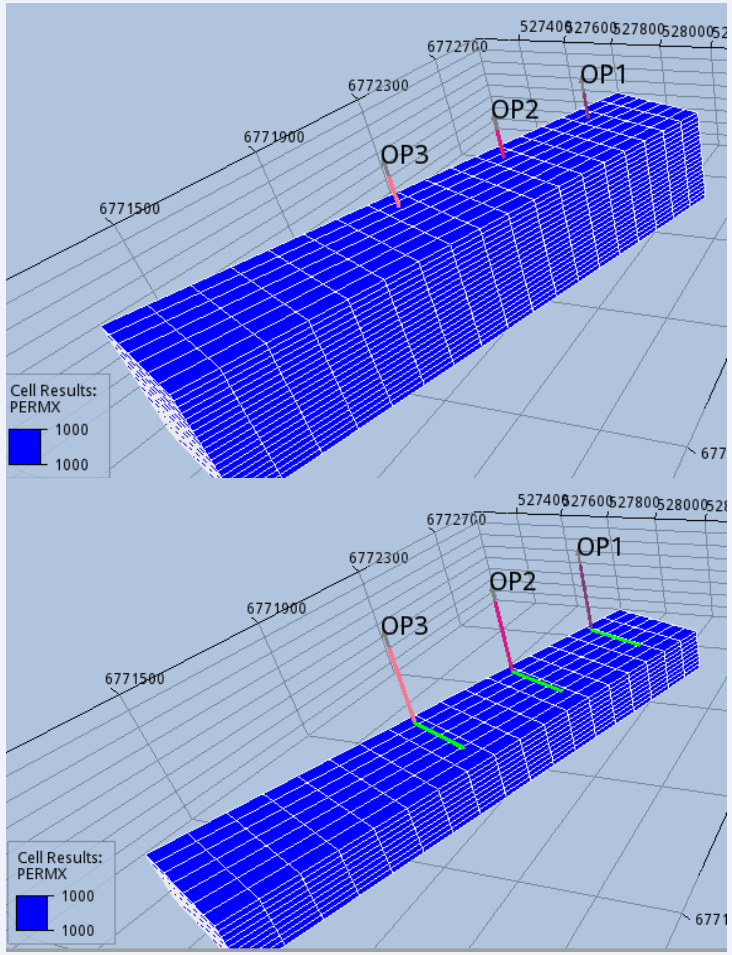


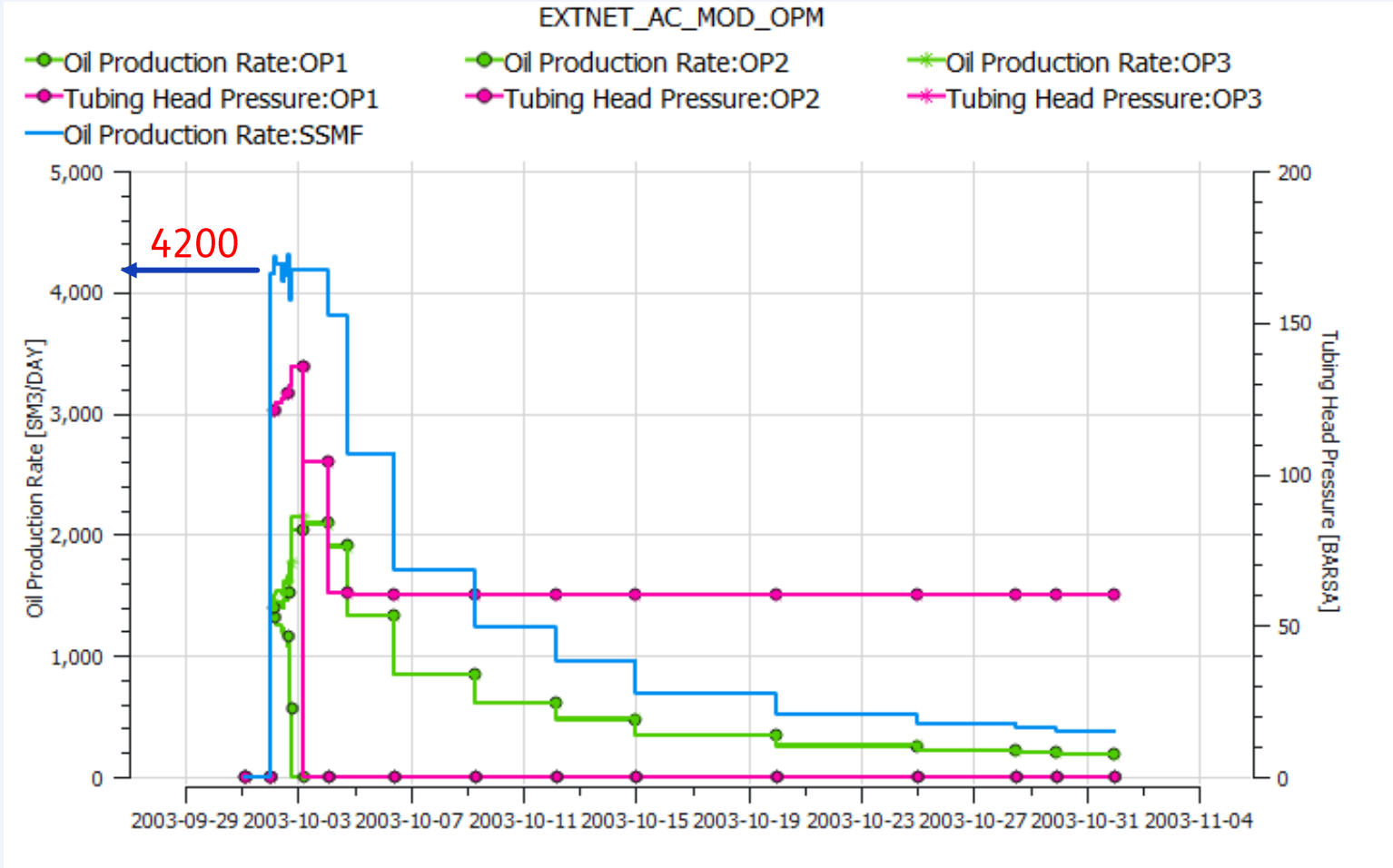
Reference simulator



Example 2

- SSMF: subsea manifold with oil rate target 4200 SM^3/Day
- 3 wells: OP1, OP2 and OP3

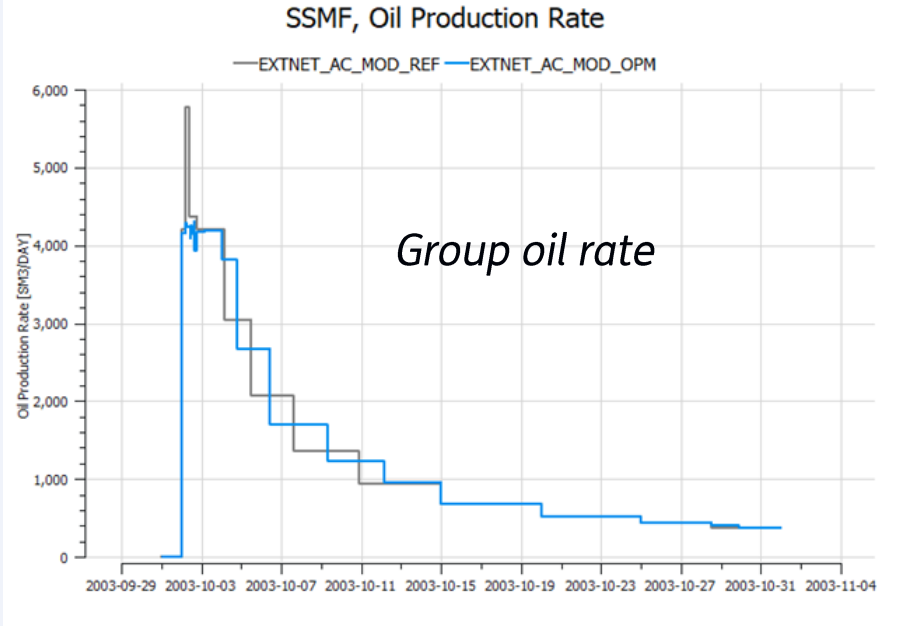




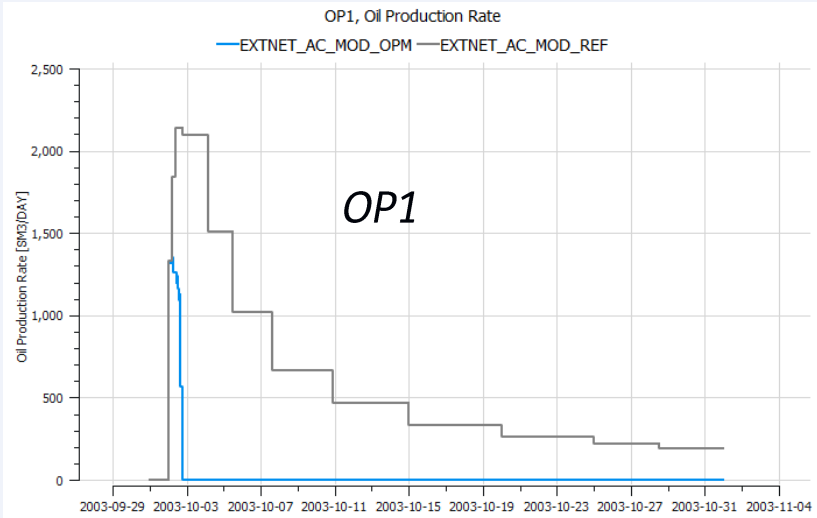
Comparison with reference simulator

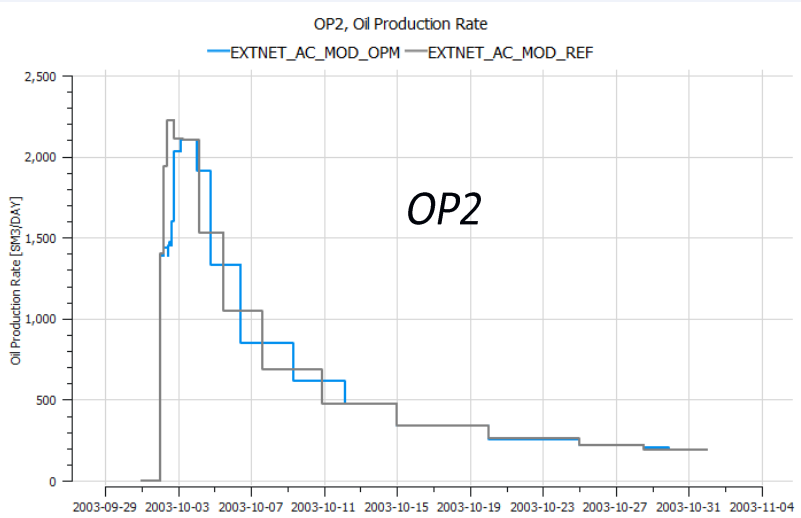
Observations:

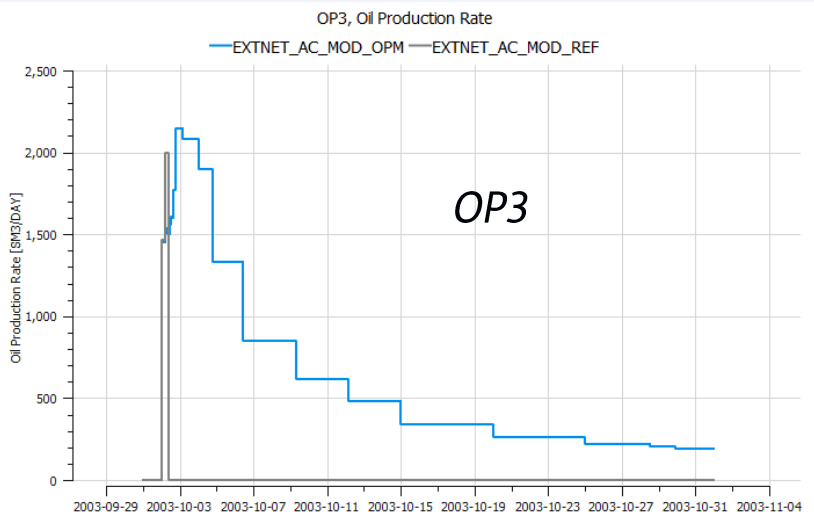
- OP1 in OPM-flow behaves like OP3 in Ref. sim.
- OP3 in OPM-flow behaves like OP1 in Ref. sim.
- OPM-flow has convergences issues for this case
  - `Well OP1 did not converge in 50 inner iterations (12 switches, 12 status changes)`



Well oil rates







Next steps

- Grid independent well trajectories
  - Testing for more complex cases
  - Extension to MSW yet to be done

- Network developments
  - opm-simulators PR under review/discussion
  - Convergence issues currently
  - Testing on assets cases

Contact at TNO: eduardo.barros@tno.nl / paul.egberts@tno.nl


Thank you
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