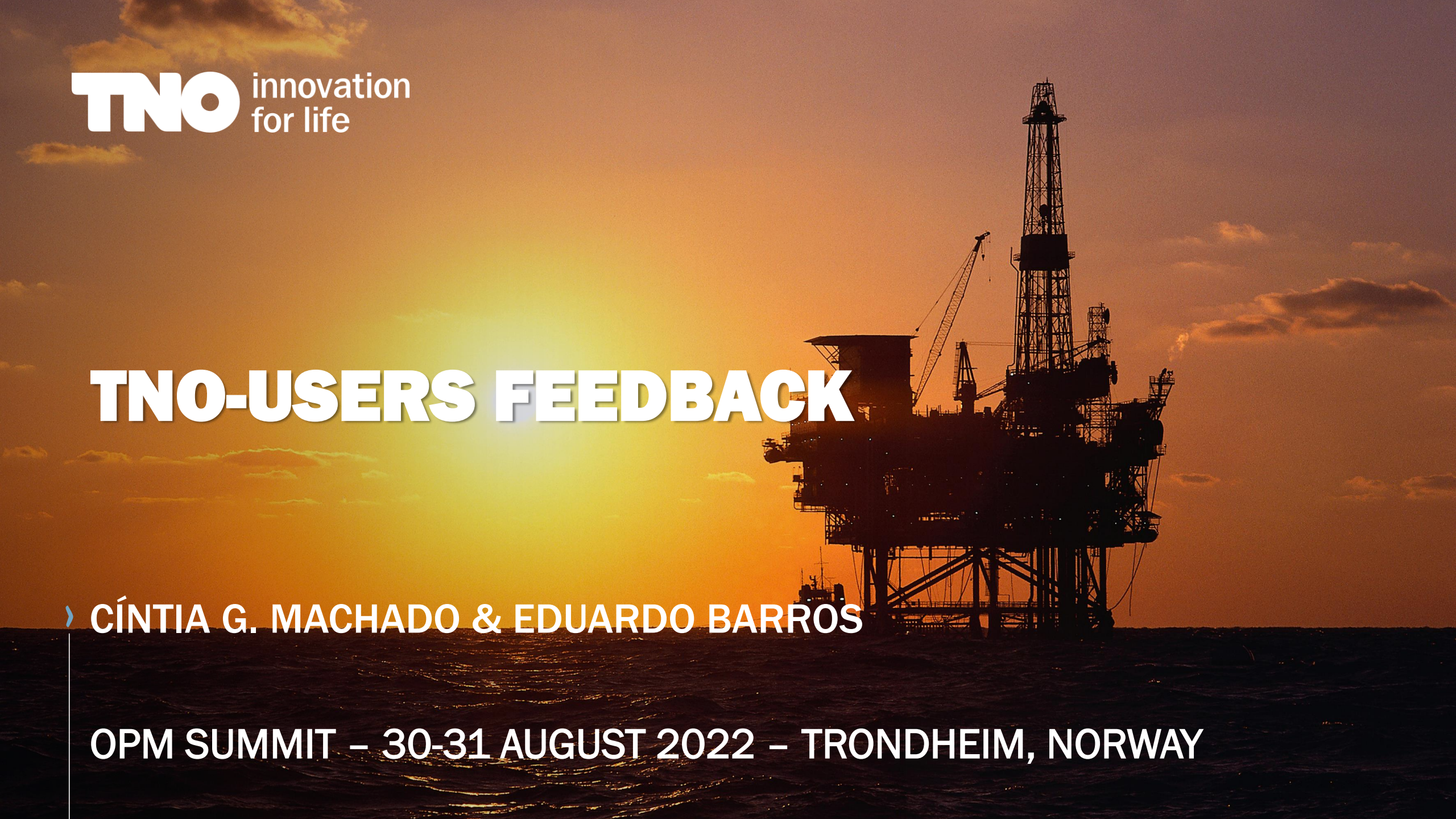


TNO-USERS FEEDBACK

CÍNTIA G. MACHADO & EDUARDO BARROS

OPM SUMMIT – 30-31 AUGUST 2022 – TRONDHEIM, NORWAY

OUTLINE

- Overview of TNO users and applications
- Feedback on:
  - Hydrocarbon
  - Thermal module
  - CO_2 storage
  - H_2 storage
- Summary

USERS AND APPLICATIONS AT TNO

- ~10-15 users of OPM in TNO (mostly reservoir engineers and geologists)
- Main applications:
  - Oil & Gas
  - Geothermal / heat storage
  - CCS / H_2 storage
  - Geomechanical studies
  - Workflows: history matching, field development optimization, etc.
- Why they choose OPM?
  - Possibility of running multiple runs simultaneously in HPC (free license)
  - User-friendly
  - Not a black-box
  - Proximity with developers / potential of extensions
- Other software's used:
  - Eclipse
  - CMG
  - TOUGH2 (+ PHREEQC)
  - DoubletCalc
  - Intersect
  - etc.

FEEDBACK ON OPM HYDROCARBON

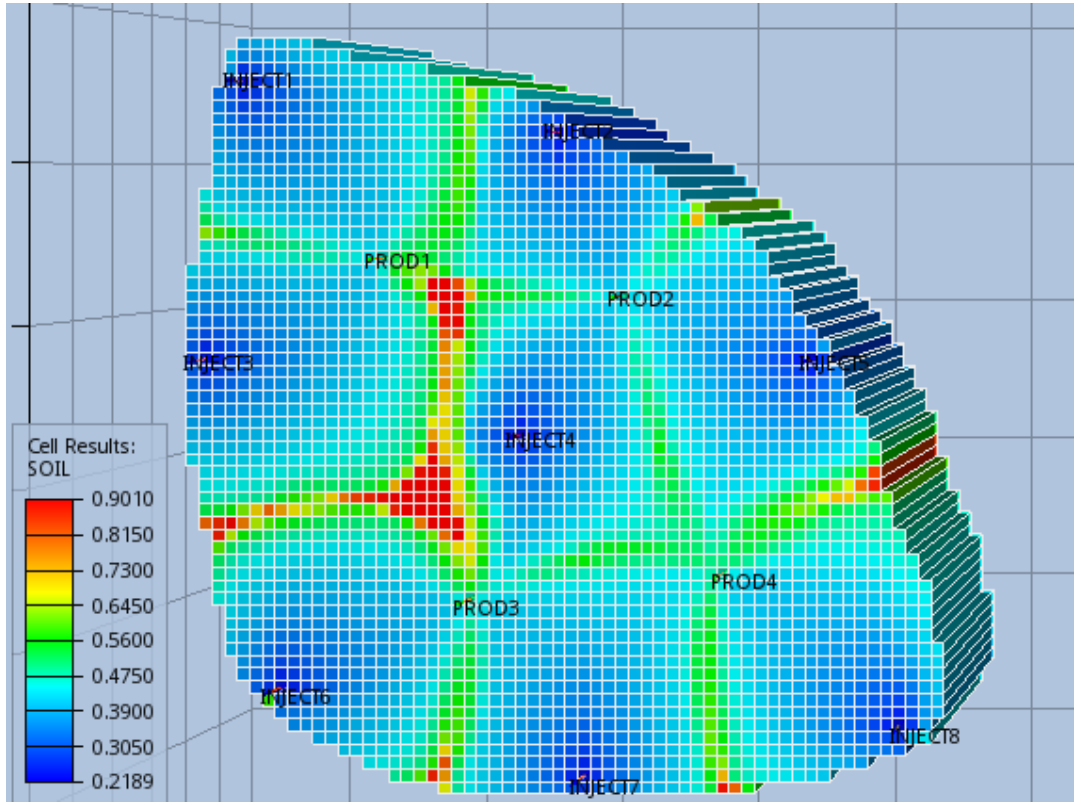
- User-friendliness:
  - Everybody loves ResInsight! ☺
  - Everybody already knew how to use Eclipse
  - Difficult to figure out input errors:

Example: if well diameter > grid cell size:

Eclipse: Error: UNREALISTIC CONNECTION DATA FOR all CONNECTION OF WELL . EITHER THE WELL RADIUS IS TOO BIG, OR...
OPM: Start simulation, shuts well and give the error:
Error: [BlackoilModelEbos.hpp:319] NaN residual found![0m
Well will be shut because it cannot get converged.

- Improvements for workflows: well trajectory and fault parametrization
- Cannot run several benchmark cases
- Convergences issues, wells shutting, etc...
- New versions sometimes:
  - Break features in use
  - Convergence issues in previously running models

Egg model in E100



Egg model in OPM-Flow (oil-water)

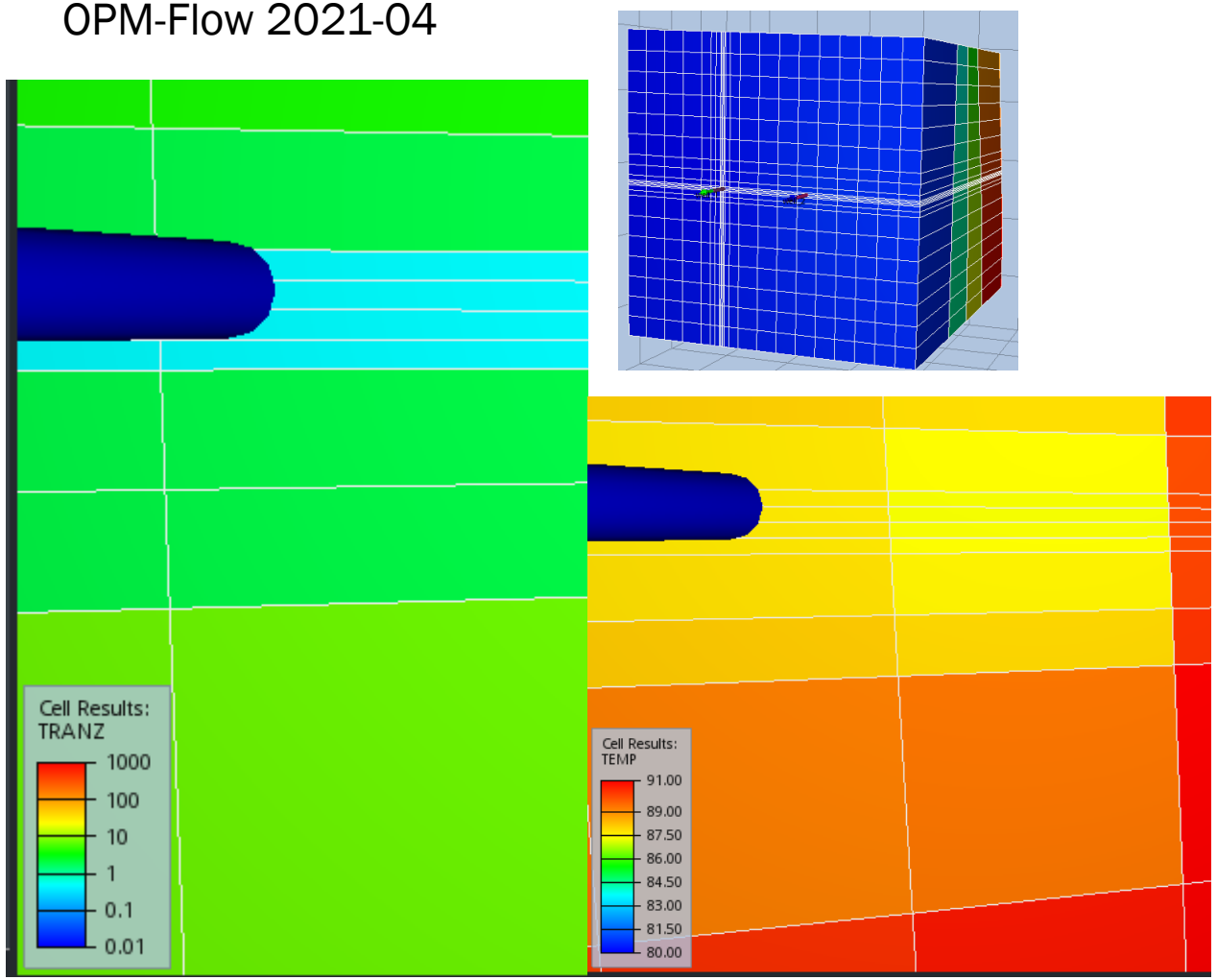
```
Starting time step 0, stepsize 0.0117406 days, at day 1/367, date = 01-Jan-2000

Problem: Solver convergence failure - Iteration limit reached
Timestep chopped to 0.003874 days


Starting time step 0, stepsize 0.0038744 days, at day 1/367, date = 01-Jan-2000
flow: /build/opm-simulators-aT7FfI/opm-simulators-2022.04/opm/simulators/timestepping/TimeStepControl.cp
ssertion `errors_[i]>0' failed.
[PC-40167:05621] *** Process received signal ***
[PC-40167:05621] Signal: Aborted (6)
[PC-40167:05621] Signal code:  (-6)
[PC-40167:05621] [ 0] /lib/x86_64-linux-gnu/libpthread.so.0(+0x153c0)[0x7fe63a8053c0]
[PC-40167:05621] [ 1] /lib/x86_64-linux-gnu/libc.so.6(gsignal+0xcb)[0x7fe6393f818b]
[PC-40167:05621] [ 2] /lib/x86_64-linux-gnu/libc.so.6(abort+0x12b)[0x7fe6393d7859]
```

FEEDBACK ON OPM

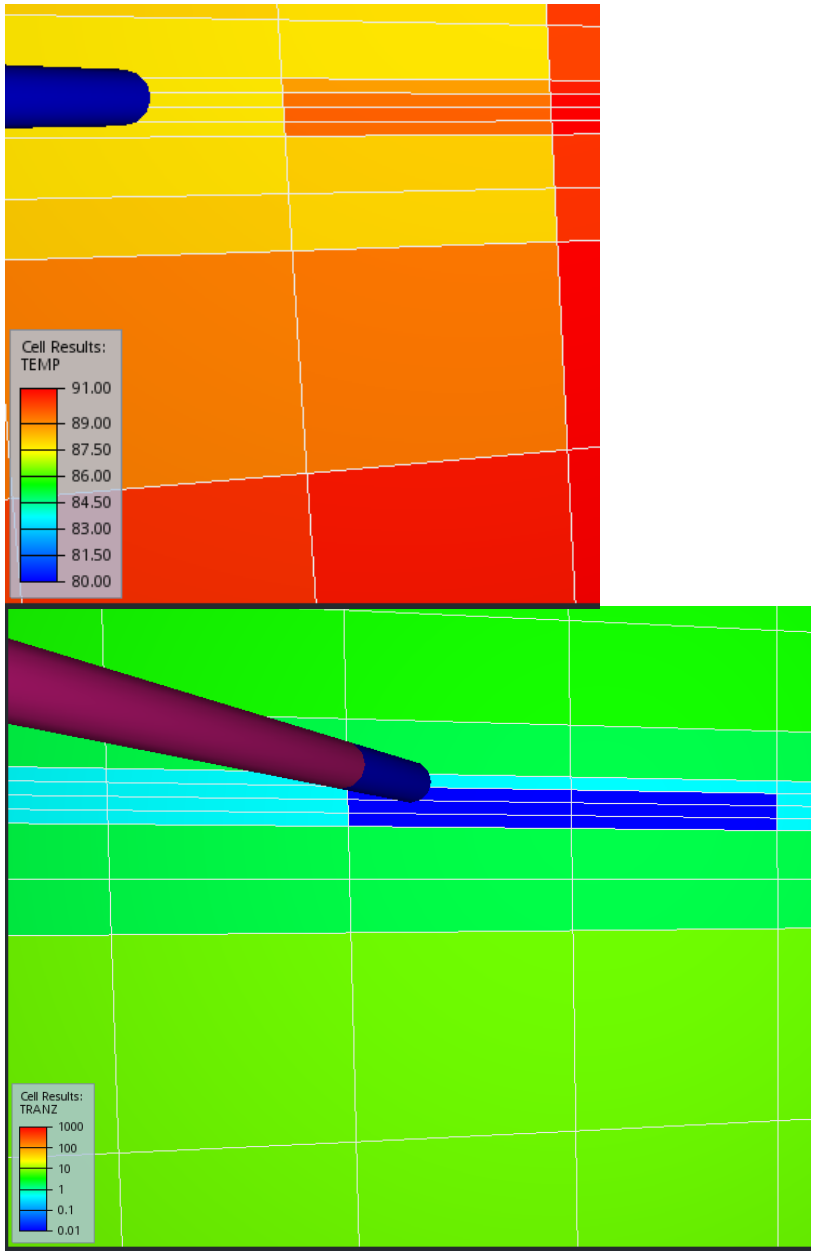
TARTAN GRID

In new versions, some small cells have zero transmissibility's, leading to discontinuity in the solution

OPM-Flow 2021-04



OPM-Flow 2022-04



GEOTHERMAL APPLICATIONS

OPM-TESTS: SPE1CASE2_THERMAL_ONEPHASE.DATA

- “Hot” injection: similar run time for E100 and OPM-Flow

```
RTEMPVD
8300 150
8450 200 /

WTEMP
        'INJ' 200 /
/
```

E100

```
Error summary
Comments                1
Warnings                1
Problems                0
Errors                  0
Bugs                    0
Final cpu       1.40 elapsed       1.40
Total number of time steps forced to be accepted          0
```

OPM

```
================    End of simulation     ===============

Number of MPI processes:         1
Threads per MPI process:         2
Total time (seconds):            0.85
Solver time (seconds):           0.74
 Assembly time (seconds):        0.02 (Failed: 0.0; 0.0%)
   Well assembly (seconds):      0.01 (Failed: 0.0; 0.0%)
 Linear solve time (seconds):    0.01 (Failed: 0.0; 0.0%)
   Linear setup (seconds):       0.00 (Failed: 0.0; 0.0%)
 Update time (seconds):          0.03 (Failed: 0.0; 0.0%)
 Pre/post step (seconds):        0.11 (Failed: 0.0; 0.0%)
 Output write time (seconds):    0.64
Overall Linearizations:         57    (Failed:   0; 0.0%)
Overall Newton Iterations:      40    (Failed:   0; 0.0%)
Overall Linear Iterations:     252    (Failed:   0; 0.0%)
```

- Cold injection: OPM-Flow takes 300 times longer to finish run

```
WTEMP
        'INJ' 30 /
/
```

E100

```
Error summary
Comments                1
Warnings                1
Problems                0
Errors                  0
Bugs                    0
Final cpu       1.37 elapsed       1.37
Total number of time steps forced to be accepted          0
```

OPM

```
================    End of simulation     ===============

Number of MPI processes:         1
Threads per MPI process:         2
Total time (seconds):          304.30
Solver time (seconds):         304.19
 Assembly time (seconds):       91.95 (Failed: 75.7; 82.3%)
   Well assembly (seconds):     16.05 (Failed: 12.8; 80.0%)
 Linear solve time (seconds):   23.16 (Failed: 20.3; 87.5%)
   Linear setup (seconds):      11.85 (Failed: 10.4; 87.6%)
 Update time (seconds):        129.80 (Failed: 106.8; 82.3%)
 Pre/post step (seconds):       17.51 (Failed: 2.2; 12.5%)
 Output write time (seconds):    4.59
Overall Linearizations:     298955    (Failed: 249753; 83.5%)
Overall Newton Iterations:  282558    (Failed: 249753; 88.4%)
Overall Linear Iterations:  282706    (Failed: 249786; 88.4%)
```

THERMAL APPLICATIONS

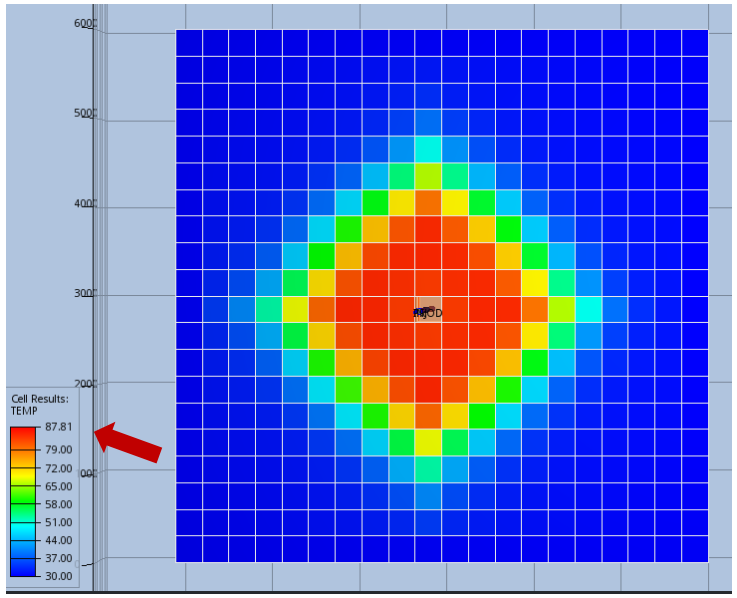
THERMAL FRONT

- OPM-Flow shows temperature out of range (initial, injection)
- Cold injection leads to non-physical solution, with reservoir temperatures not following RTEMPVD

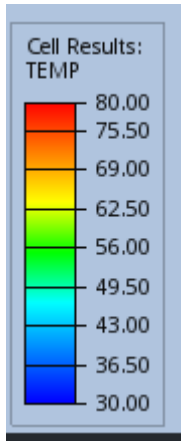
```
WTEMP
        'INJ' 80 /
/

RTEMPVD
2500 30
2530 30 /
```

Hot Injection

OPM

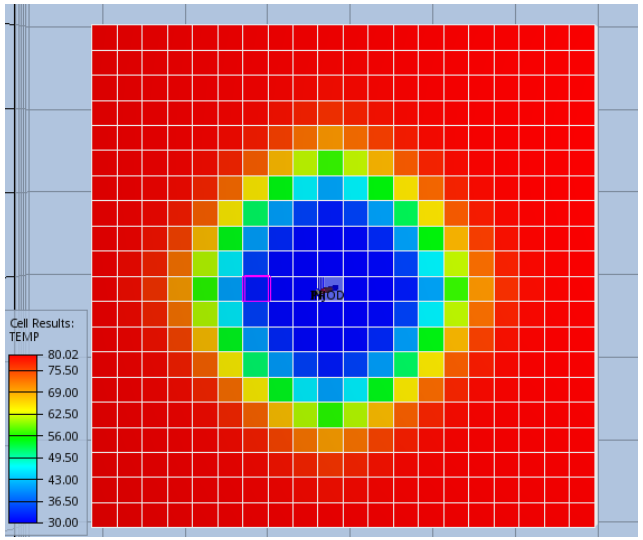


E100

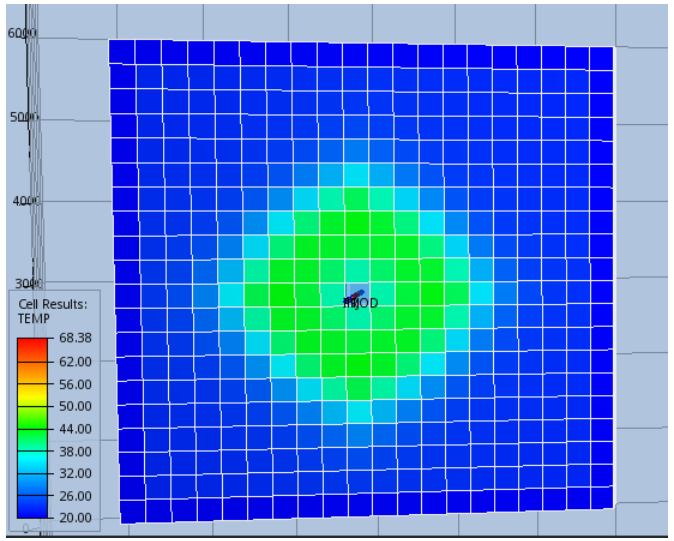


Cold Injection

```
RTEMPVD
2500 80
2530 80 /

WTEMP
        'INJ' 30 /
/
```



E100

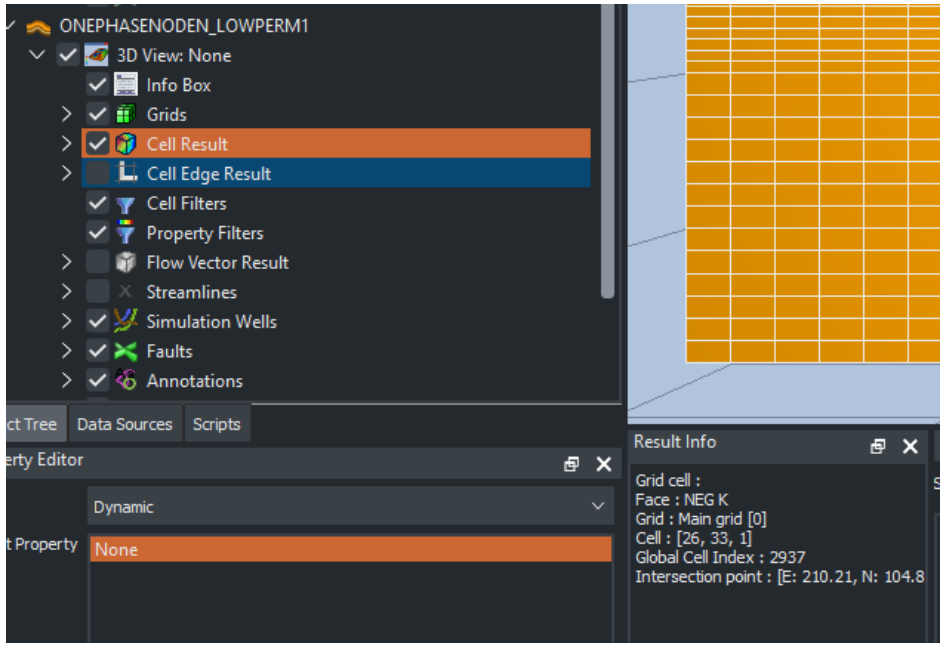


OPM

GEOTHERMAL APPLICATIONS
WATDENT AND WATVISCT

- Several bugs fixes related to WATVISCT and WATDENT
- Cases can run, but still convergence issues and very long runs times (time-steps chopped to less than 0.1 day)
  - WATDENT and WATVISCT keywords cannot run together in a reasonable time
  - Due these issues, DoubletCalc (in-house geothermal simulator TNO) is currently used for heat storage in TNO

Real heat storage case in the Netherlands



CCS
DEPLETED GAS FIELDS

- Missing features:
  - Advanced PVT
    - PVT table as function (P, T)
    - With current inter-tables interpolation:

      viscosity becomes up to twice the real values
  - Supercritical phase of CO2
  - Thermal model and performance
    - Combining JT + Evaporation
- Challenges:
  - Thermodynamics of phase transition
  - Sub-zero injection temperatures after shut-ins
- E300 and GEM have trouble near critical point
- STARS can handles water evaporation + energy

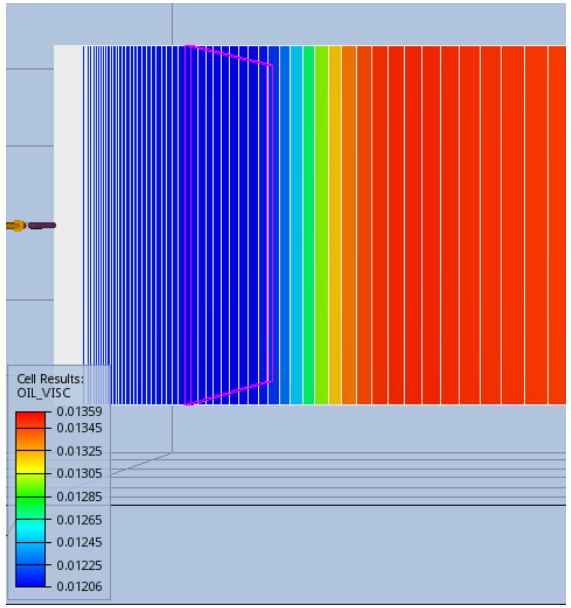
THERMAL_DEPLETED_GAS_COLDINJ.DATA

Modelling CO_2 with oil-phase in OPM:

```
OILVISCT
 -- TEMP   VISC
30     0.0118
80     0.0133 /
```

```
Error:
An error occurred while creating the reservoir properties
Internal error: Incorrect ordering of values in column: Viscosity
```

In Eclipse:



- Should loosen up restrictions for PVT tables? Or create a CO_2 phase?
- Eclipse can use oil-gas-thermal module. In OPM-Flow only three-phase (or water) + thermal

HYDROGEN STORAGE
DEPLETED GAS FIELDS

- TNO Reservoir Engineers are searching for a simulation tool to model H_2 storage
- Research-development on-going on DuMu^X (coding by TUC):
  - Microbiological activities
    - Sulfate-reducing bacteria
    - Methanogenic archae
    - Homoacetogenic archea
  - Chemical reactions (solid-gas), e.g. pyrite reduction:

$$FeS_2 + H_2 \longrightarrow FeS + H_2S$$

  - Pore clogging

- <u>Will OPM-flow be the tool for large **field-case** studies?</u>

SUMMARY

TNO USER'S FEEDBACK

- TNO OPM users pool has grown a lot in in these to years
- Missing things that block users from choosing OPM-Flow
  - New versions: breaking of old features and convergence issues in previously running models
  - Convergence issues
  - Often heard: "It runs in Eclipse, why not in OPM?"
- Main wishes:
  - More advanced PVT/ (simplified) compositional modelling
  - Better control of reporting (important for workflows)
  - Broader options of grid output (e.g., fluid properties)
  - More advanced boundary modelling (important for thermal and geomechanical studies)
  - More advanced wellbore modelling or coupling
- Comparing with other simulators
  - Difficult to find cause of errors
  - Slow performance (specially for thermal cases)
  - How to motivate people to report issues?

THANK YOU!

TNO innovation for life