CO_2 simulations in OPM Flow

An overview

What is OPM Flow?

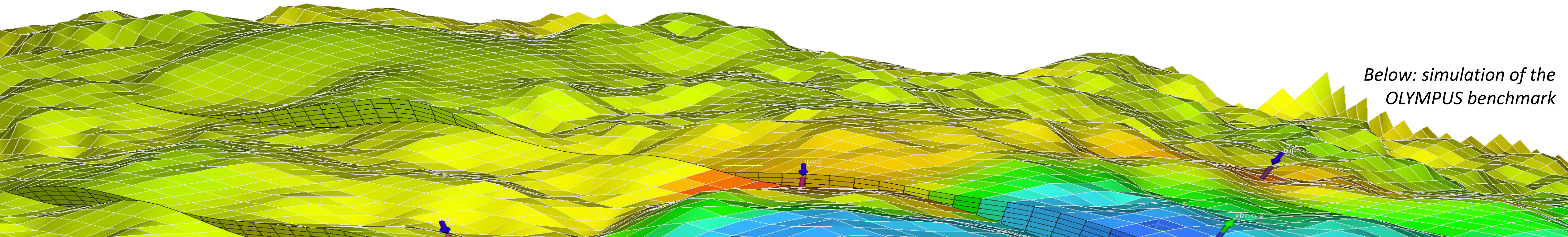
An open-source reservoir simulator

Extensible and flexible

Collaborative development

Industrial relevance

Below: simulation of the OLYMPUS benchmark



CO2 simulations in Flow

CO2STORE

- PVT and solubility computed internally and dynamically as function of temperature, pressure, composition and salinity.
- *DISGASW:* Dissolved CO2 in Brine
- *VAPWAT:* Vaporized water
- *THERMAL:* Dynamic temperature
- *DIFFUSE:* Diffusion
- *DRSDTCON*:* Upscaled convective dissolution rate control
- Combined with *BRINE* and *PRECSALT*

CO2STORE: CO2-Brine properties

Density	Brine	Water	Hu, J., Duan, Z., Zhu, C., & Chou, I. M. (2007), Wagner, W., & Pruß, A. (2002).
		Salinity	Batzle, M., & Wang, Z. (1992).
		Dissolved CO2	Garcia, J. E. (2001).
	CO2		Span, R., & Wagner, W. (1996)
Viscosity	Brine		Batzle, M., & Wang, Z. (1992).
	CO2		Fenghour, A., Wakeham, W. A., & Vesovic, V. (1998).
Solubility			Spycher, N., Pruess, K., & Ennis-King, J. (2003). Duan, Z., & Sun, R. (2003)
Enthalpy	Brine	Water	Wagner, W., & Kruse, A. (2013).
		Salinity	Daubert, T. E., Daubert, T. E., & Danner, R. P. (1989)
		Dissolved CO2	Duan, Z., & Sun, R. (2003)
	CO2		Span, R., & Wagner, W. (1996).

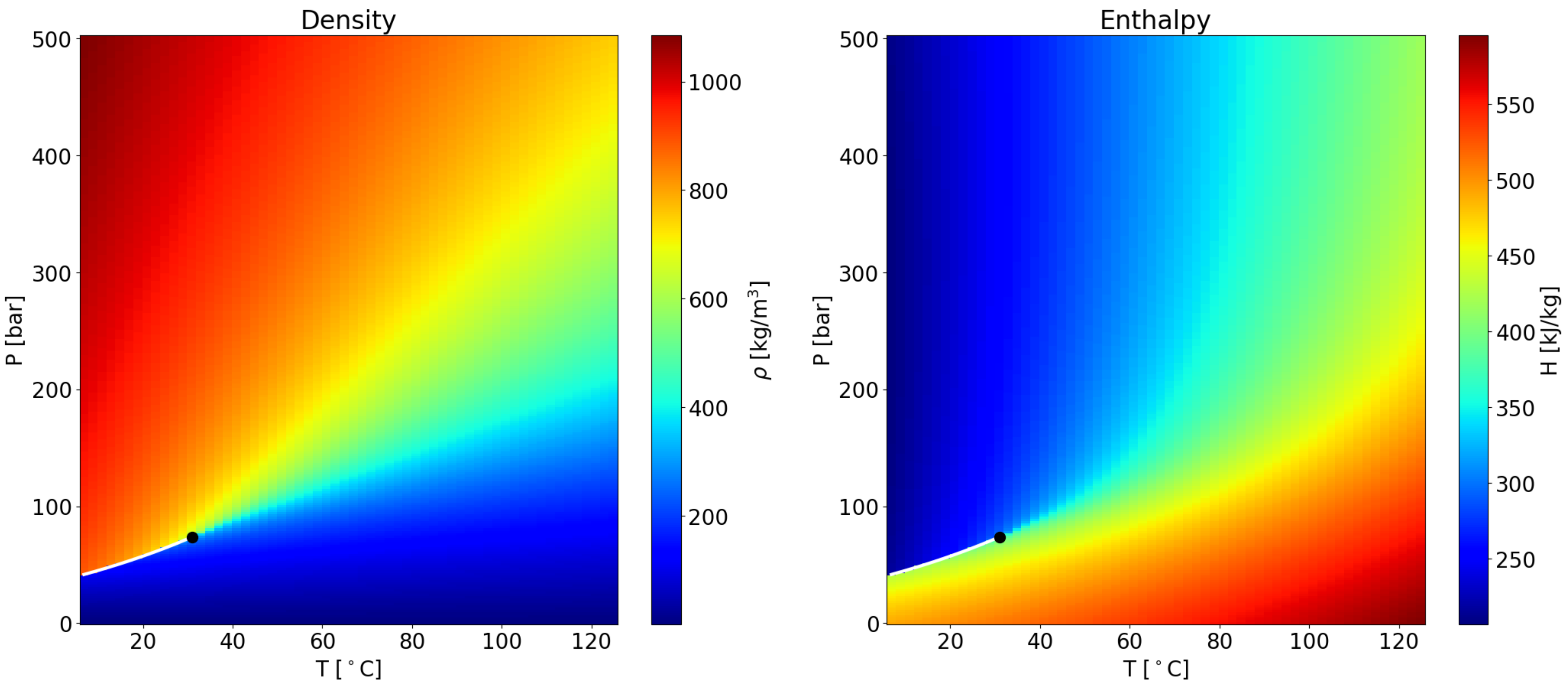
Diffusivity	Water	McLachlan, C. N. S., & Danckwerts, P. V. (1972).
	Salinity	Ratcliff, G. A., & Holdcroft, J. G. (1963)
	Tortuosity	Millington, R. J., & Quirk, J. P. (1961).

* Sandve, T. H., Gasda, S. E., Rasmussen, A., & Rustad, A. B. (2021). Convective Dissolution in Field Scale Co2 Storage Simulations Using the OPM Flow Simulator. In *TCCS–11. CO2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021 Short Papers from the 11th International Trondheim CCS Conference*. SINTEF Academic Press.

CO2STORE examples

https://github.com/OPM/opm-tests/blob/master/co2store/

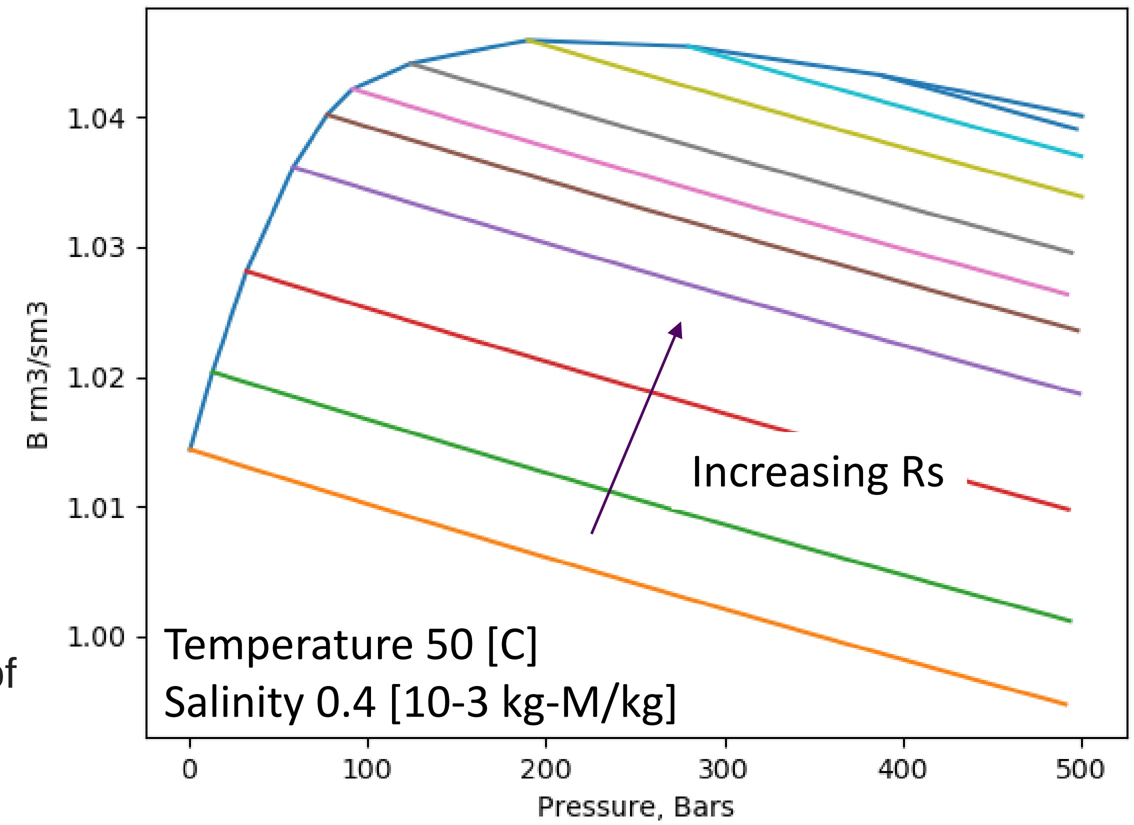
CO2 properties using Span-Wagner



Span, Roland, and Wolfgang Wagner. "A new equation of state for carbon dioxide covering the fluid region from the triple-point temperature to 1100 K at pressures up to 800 MPa." *Journal of physical and chemical reference data* 25.6 (1996): 1509-1596.

CO2 dissolution

- Phase partitioning
  - Modified Redlich-Kwong equatior (SRK) *
  - Modification salt **
- Density of Brine with CO2 ***

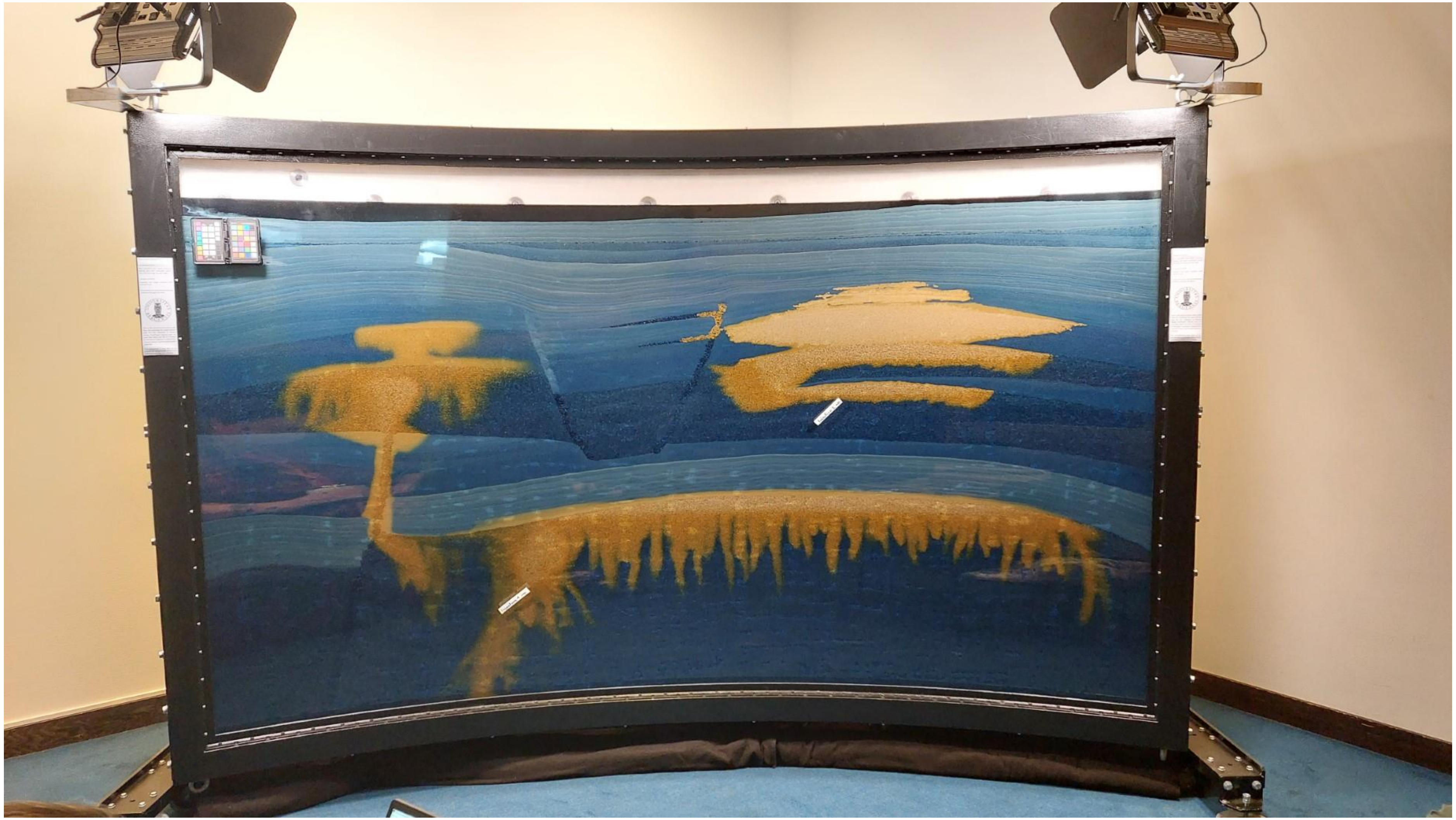


* Spycher, Nicolas, Karsten Pruess, and Jonathan Ennis-King. "CO2-H2O mixtures in the geological sequestration of CO2. I. Assessment and calculation of mutual solubilities from 12 to 100 C and up to 600 bar." *Geochimica et cosmochimica acta* 67.16 (2003): 3015-3031.

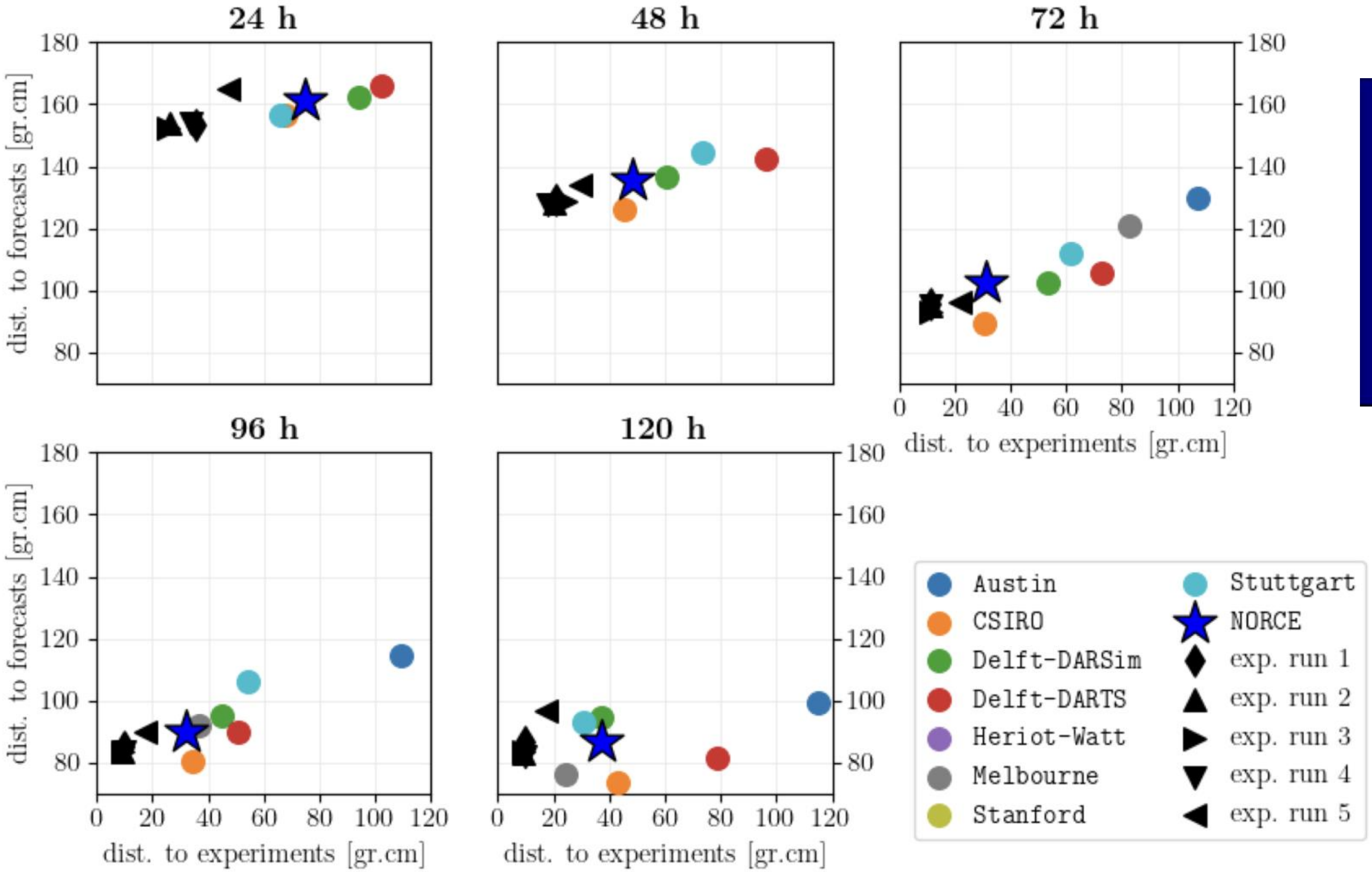
** Duan, Zhenhao, and Rui Sun. "An improved model calculating CO2 solubility in pure water and aqueous NaCl solutions from 273 to 533 K and from 0 to 2000 bar." *Chemical geology* 193.3-4 (2003): 257-271.

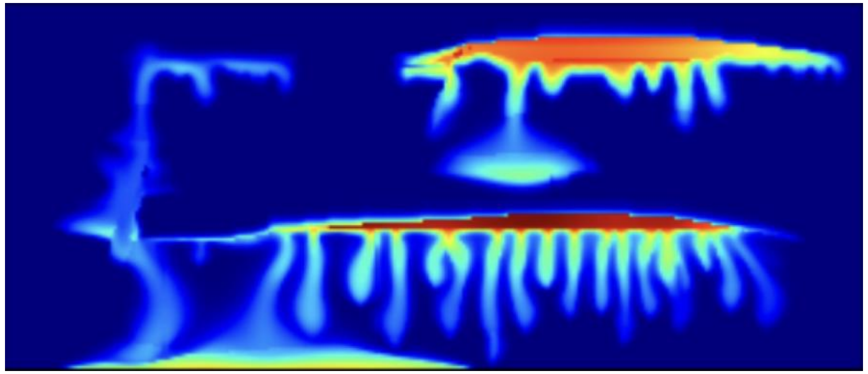
*** Garcia, Julio E. *Density of aqueous solutions of CO2*. No. LBNL-49023. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2001.

CO2 dissolution



The FluidFlower





Flemisch, Bernd, et al. "The FluidFlower international benchmark study: Process, modeling results, and comparison to experimental data." *arXiv preprint arXiv:2302.10986* (2023).

SPE 11

OPM
OPEN POROUS MEDIA

The 11th Society of Petroleum Engineers
Comparative Solution Project

Call For Participation

This call for participation in the 11th Society of Petroleum Engineers Comparative Solution Project (the 11th SPE CSP) is motivated by the simulation challenges associated with CO2 storage operations in geological settings, specifically developing simulations of realistic complexity.

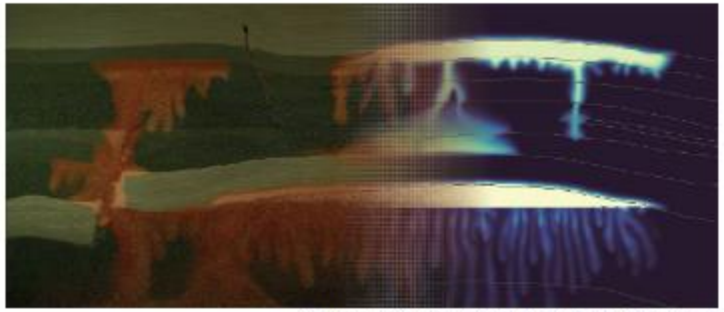


Image credit: Martin Fernø, Lluis Saló-Salgado and Jan Martin Nordbotten

Safe and efficient implementation of geological carbon storage (GCS) necessarily relies on reservoir simulators applied to uncertain geological data. While the strengths and limitations of reservoir simulation are well appreciated within petroleum production, GCS raises new challenges both in terms of physical processes and timescales.

As an example, the enhancement of dissolution from a CO2-rich supercritical phase to the aqueous phase through convective mixing ensures important long-term storage security, relevant on timescales from decades to centuries.

One consequence of the relative youth of the GCS industry, combined with the long timescales and new physical processes of interest, is that available field data for validation of simulation technology is still rare. This increases the importance of validation against proxy systems, and code verification through comprehensive benchmarking efforts.

TIMELINE

29 March 2023
Official announcement at 2023 SPE Reservoir Simulation Conference

16-18 October 2023
Special session at SPE ATCE

1 December 2023
Open call for participation period ends

1 March 2024
Deadline for submission of early results

31 March 2024
First intercomparison workshop (virtual)

1 September 2024
Deadline for submission of final CSP simulation results

30 September 2024
Final intercomparison workshop (hybrid)

December 2024
Completion of draft report on the results of the CSP

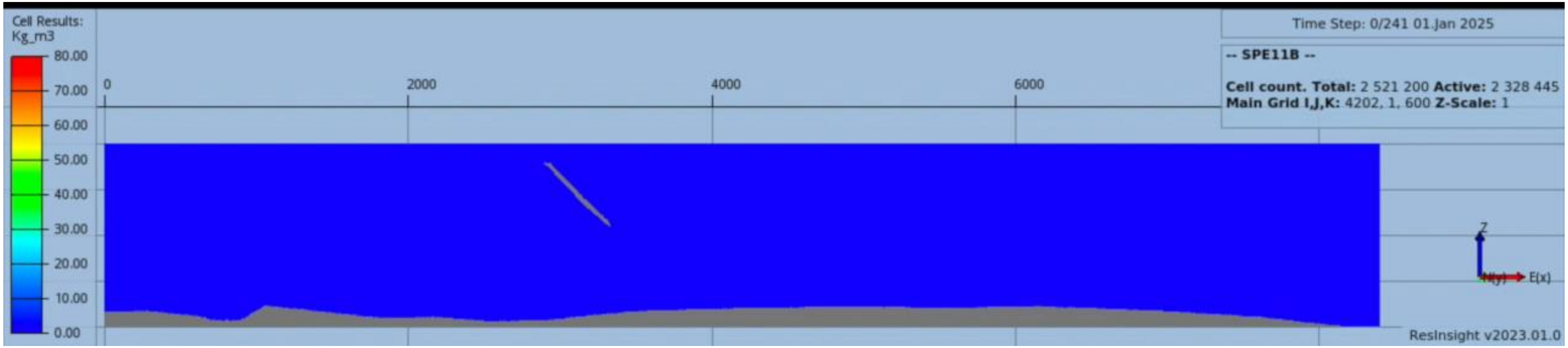
February 2025
Report on the results of the CSP finalized and submitted

March 2025
Special session at the 2025 SPE Reservoir Simulation Conference

https://daavid00.github.io/pyopmcsp11/introduction.html

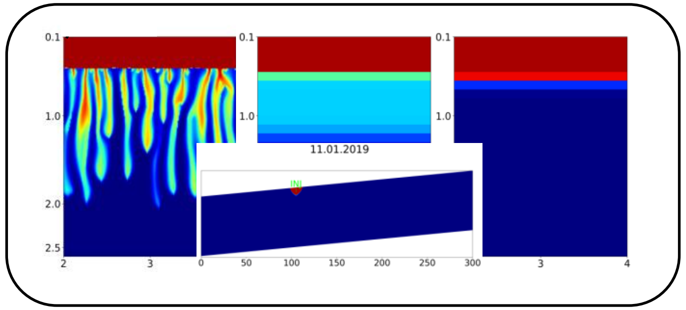
https://github.com/daavid00/pyopmcsp11

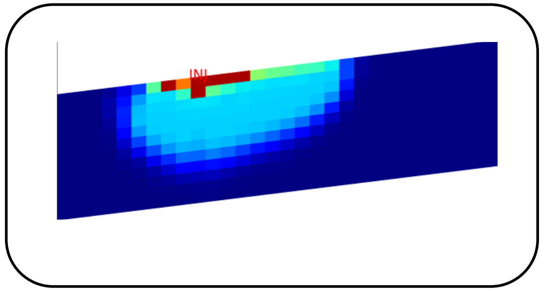
SPE 11



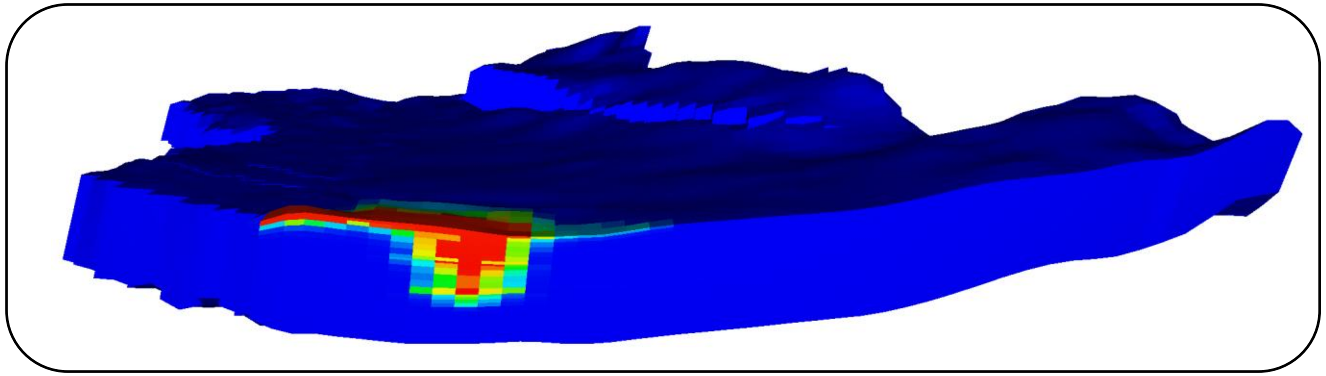
Cell Results:
Kg_m3
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
2000
4000
6000
Time Step: 0/241 01.Jan 2025
-- SPE11B --
Cell count. Total: 2 521 200 Active: 2 328 445
Main Grid I,J,K: 4202, 1, 600 Z-Scale: 1
Z
E(x)
ResInsight v2023.01.0

Upscaled dissolution





Study the effect of a fine-scale process on a coarse field-scale model

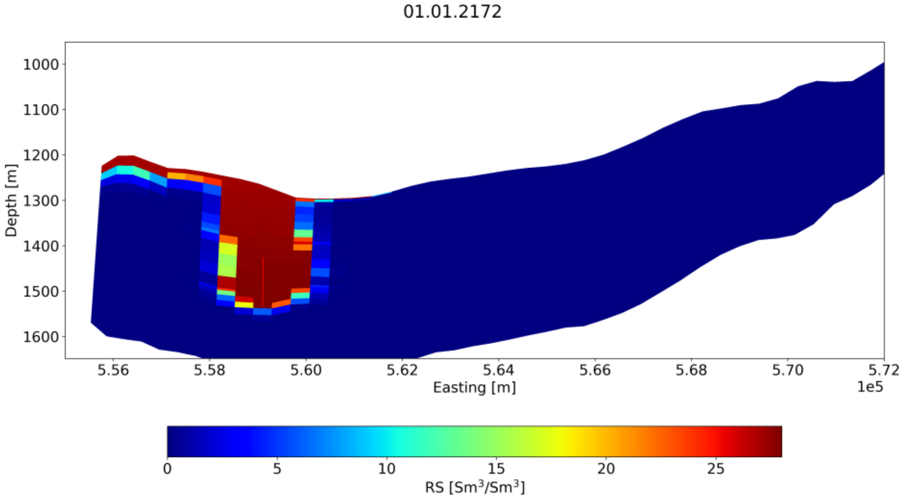


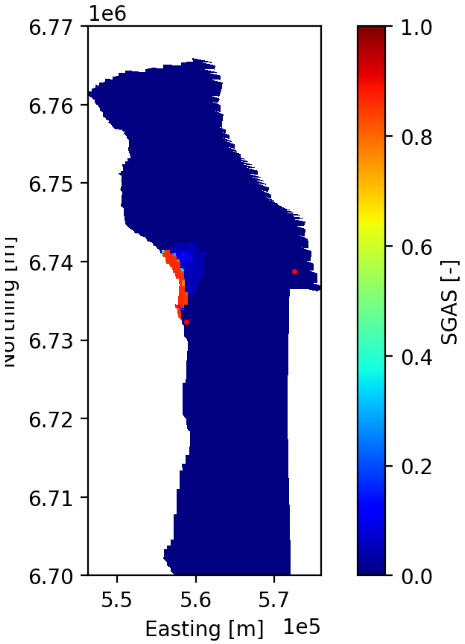
Mykkeltvedt, T., Sandve, T. H. and Gasda, S. E. "Upscaling convective mixing in reservoir simulation", 2023, In preparation

Upscaled dissolution

Smeaheia

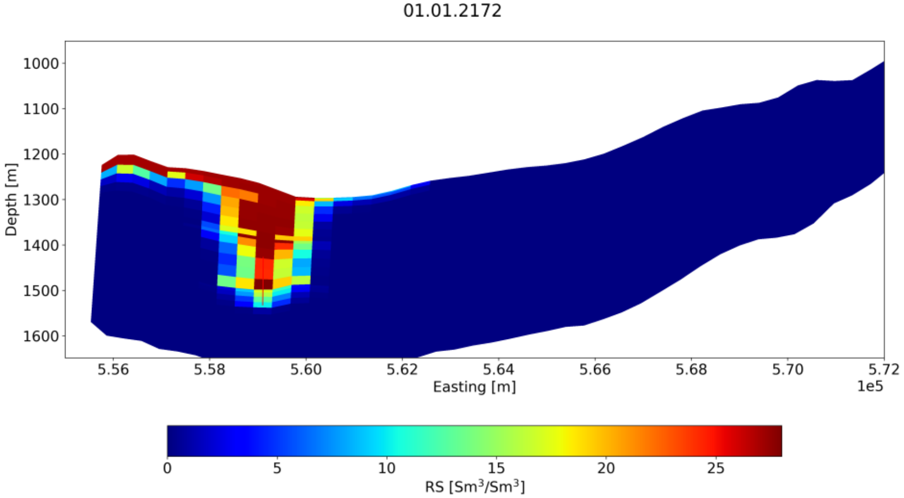
No upscaling

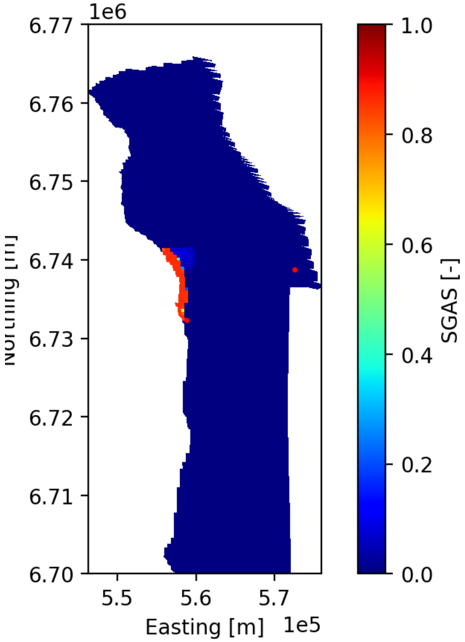




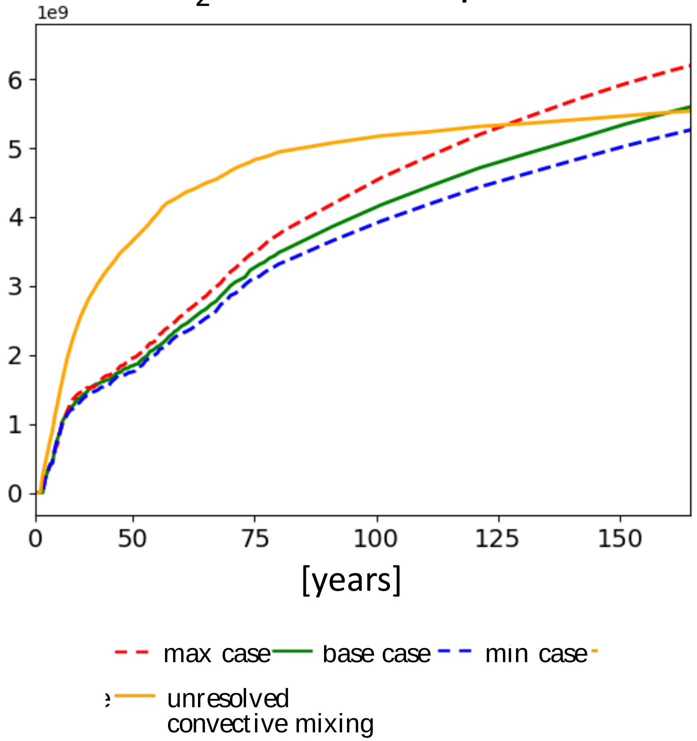
@ end of injection:

Upscaling convective mixing:





CO_2 in the brine phase



The Sleipner model

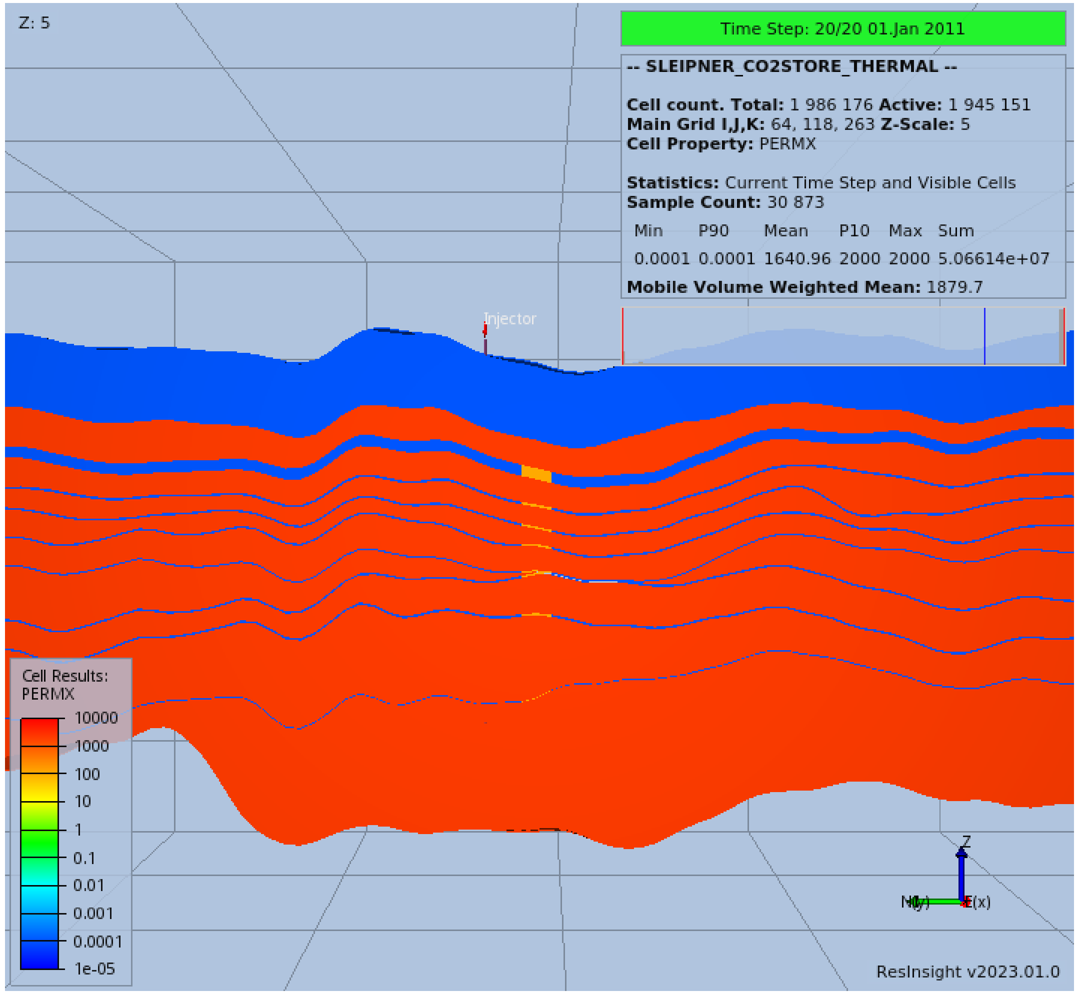
CO2DataShare
https://co2datashare.org/

Thermal properties

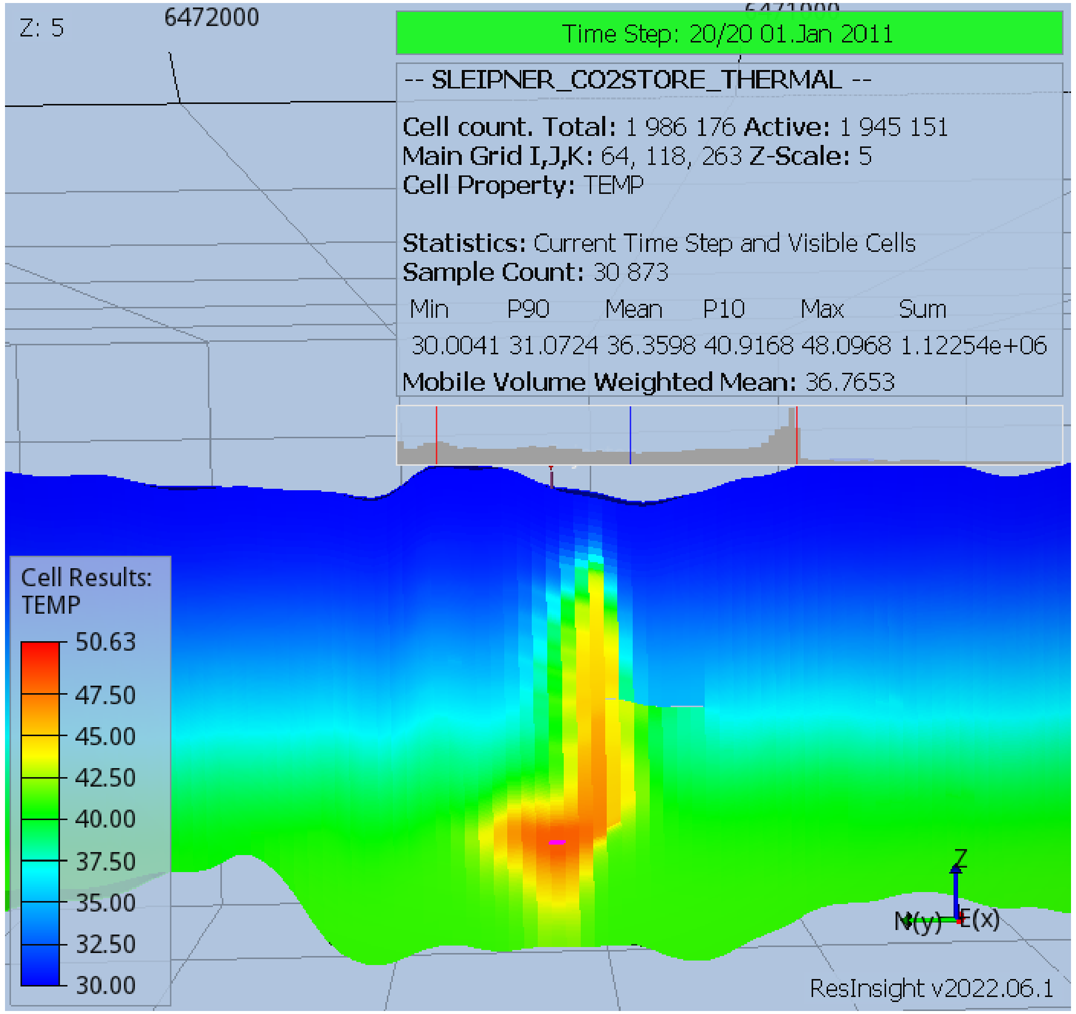
Williams, Gareth A., and R. Andrew Chadwick. "An improved history-match for layer spreading within the Sleipner plume including thermal propagation effects." *Energy Procedia* 114 (2017): 2856-2870.

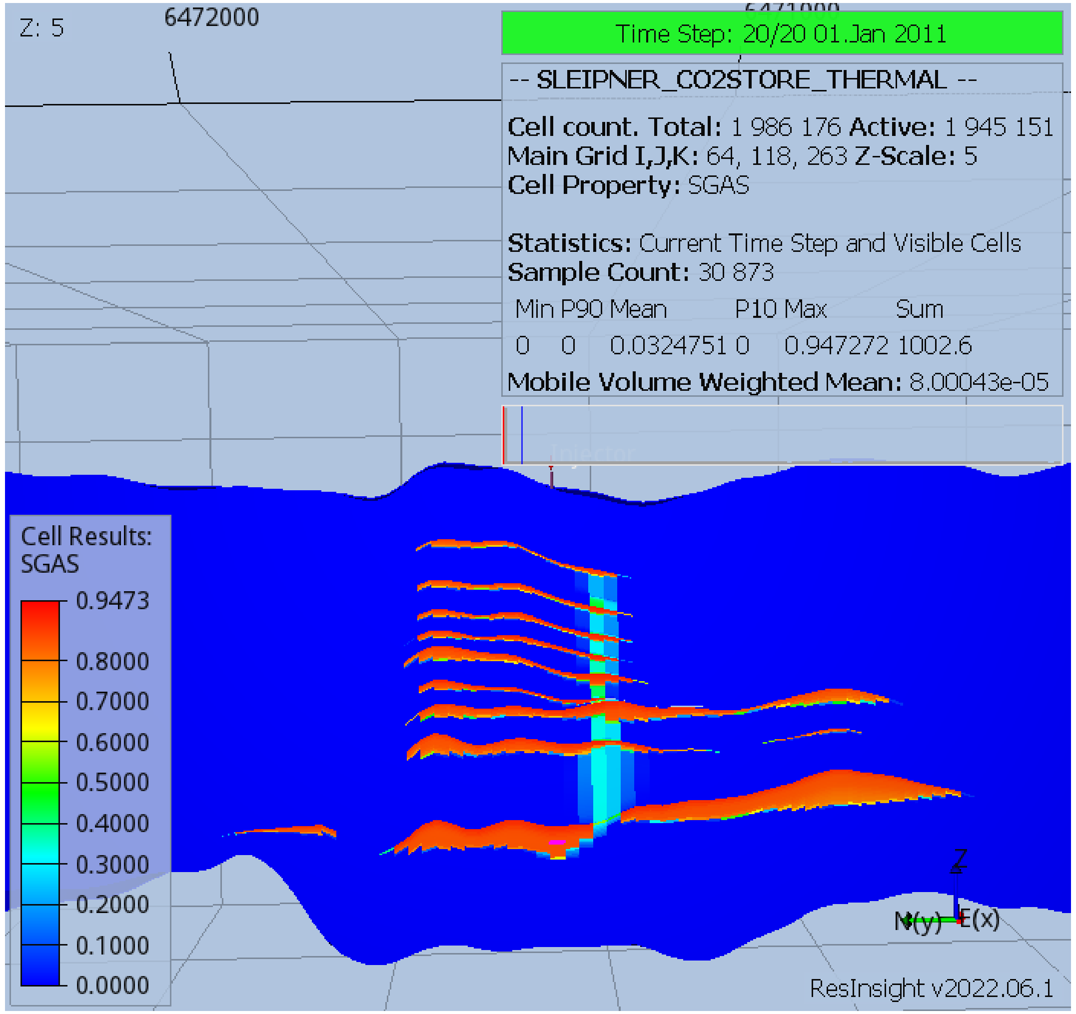
Chimney properties

Williams, G. A., and R. A. Chadwick. "Influence of reservoir-scale heterogeneities on the growth, evolution and migration of a CO_2 plume at the Sleipner Field, Norwegian North Sea." *International Journal of Greenhouse Gas Control* 106 (2021): 103260.



The Sleipner model





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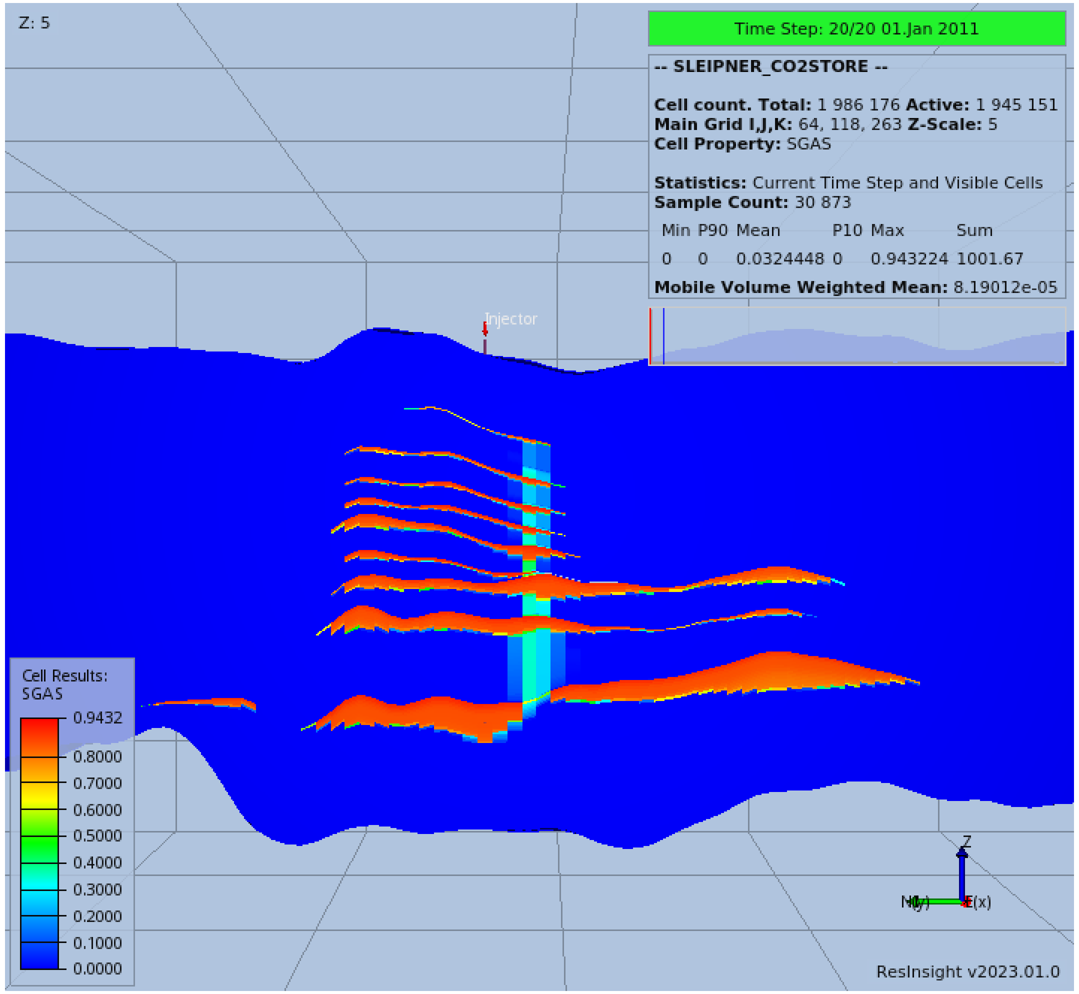

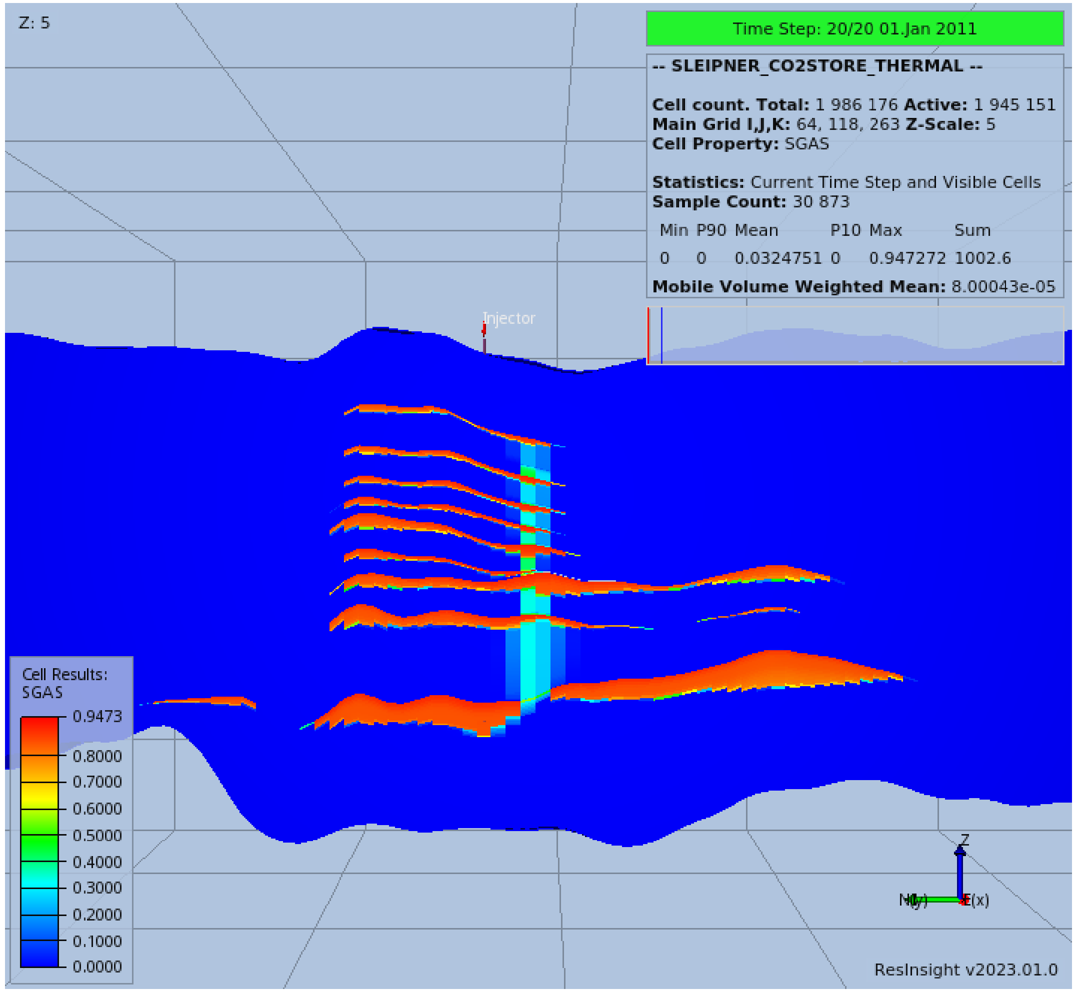

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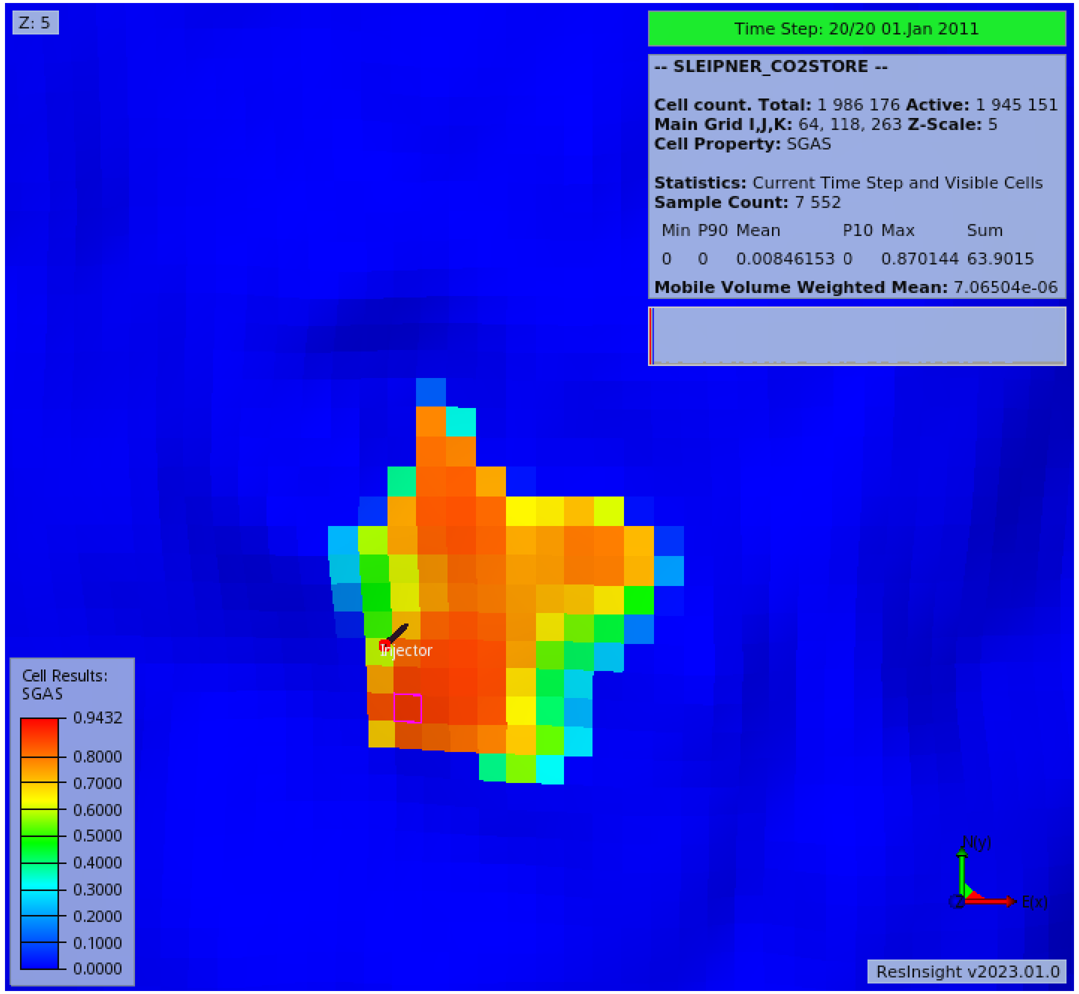

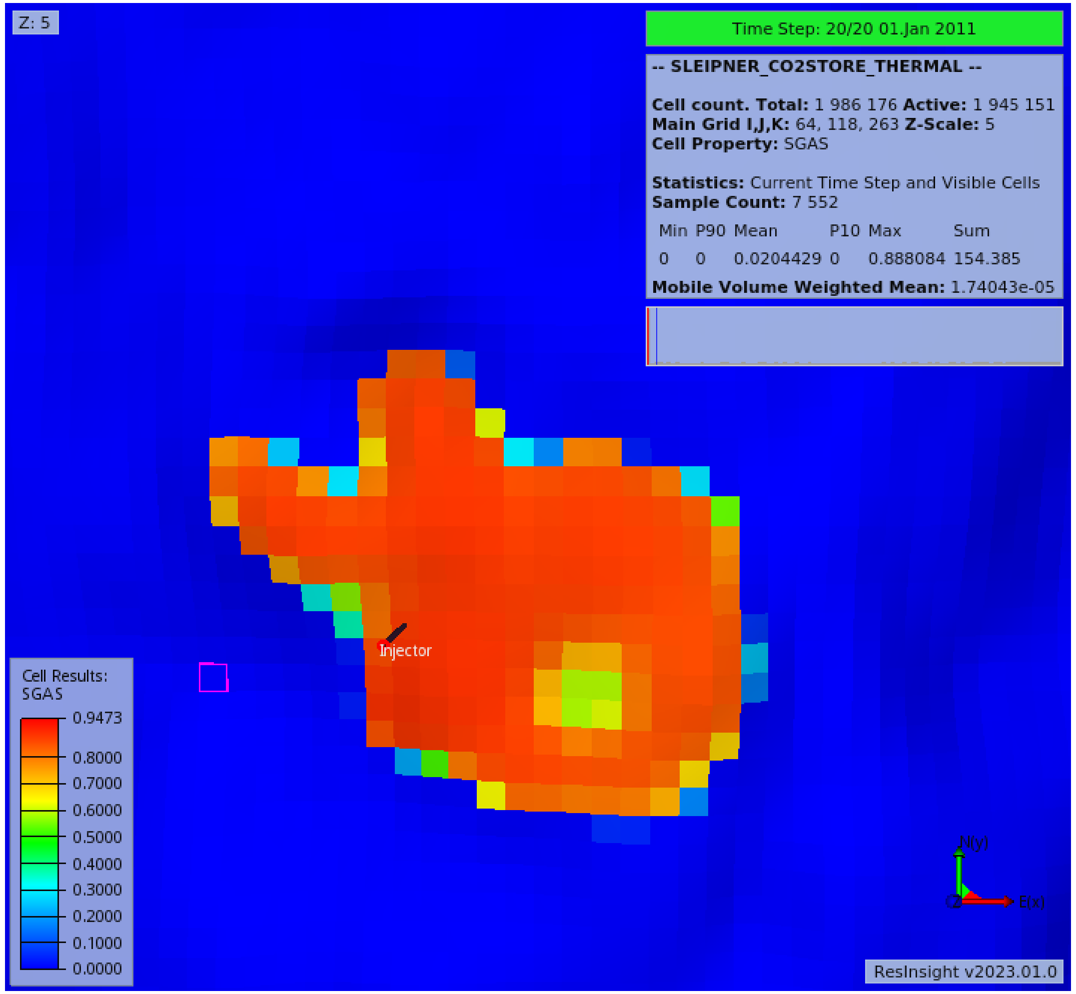

The Sleipner model