SPE11 CSP using OPM Flow

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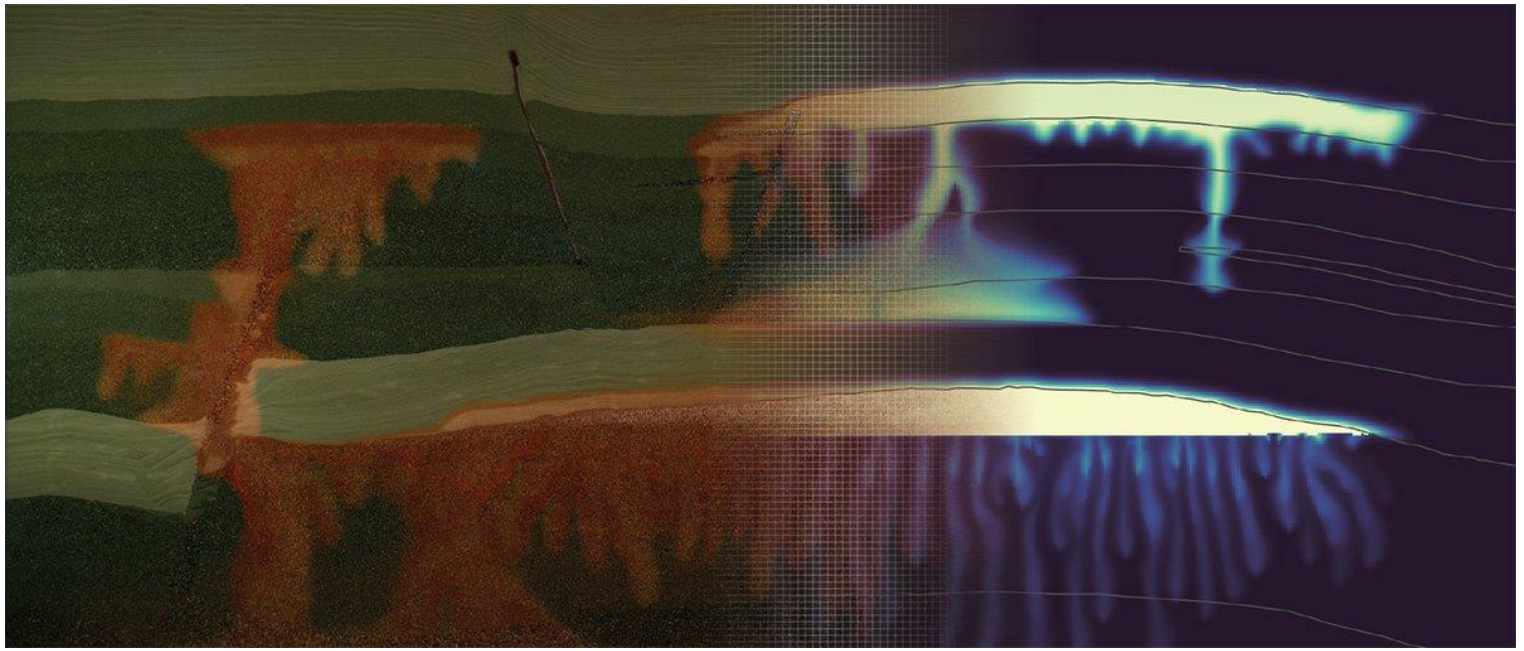
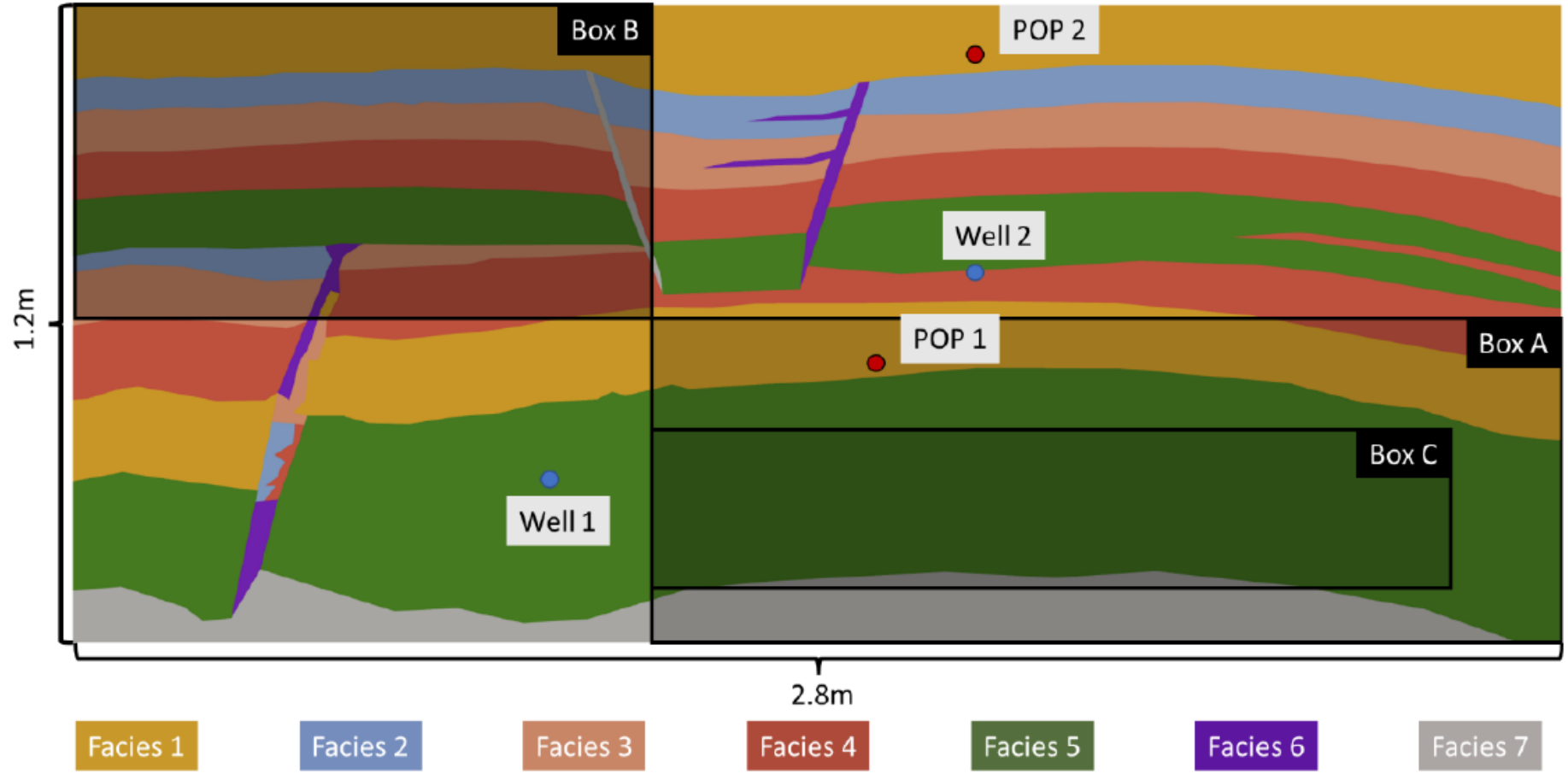
SPE11 CSP using OPM Flow

- The 11th Society of Petroleum Engineers Comparative Solution Project
- 11 participants that submitted results
- https://www.spe.org/en/csp/

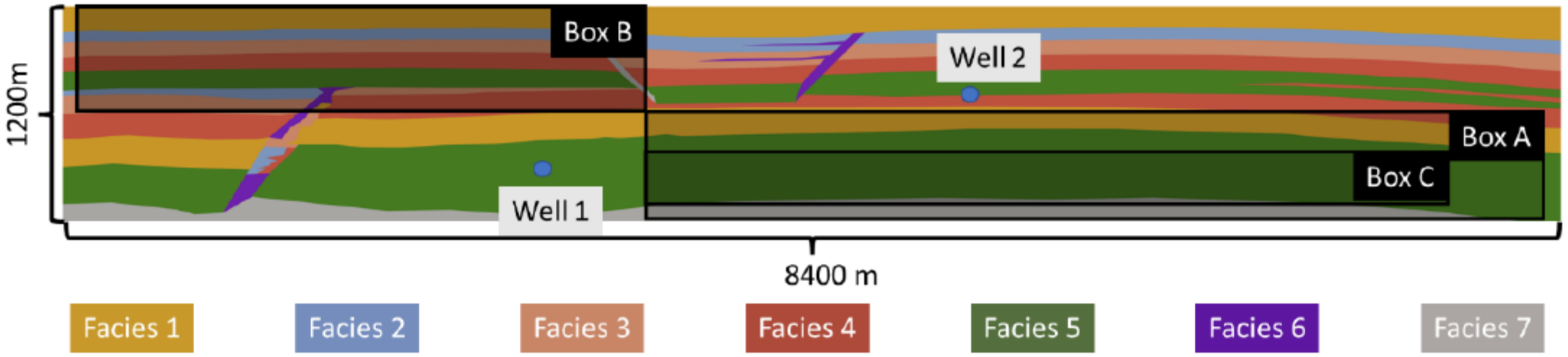


SPE 11 A



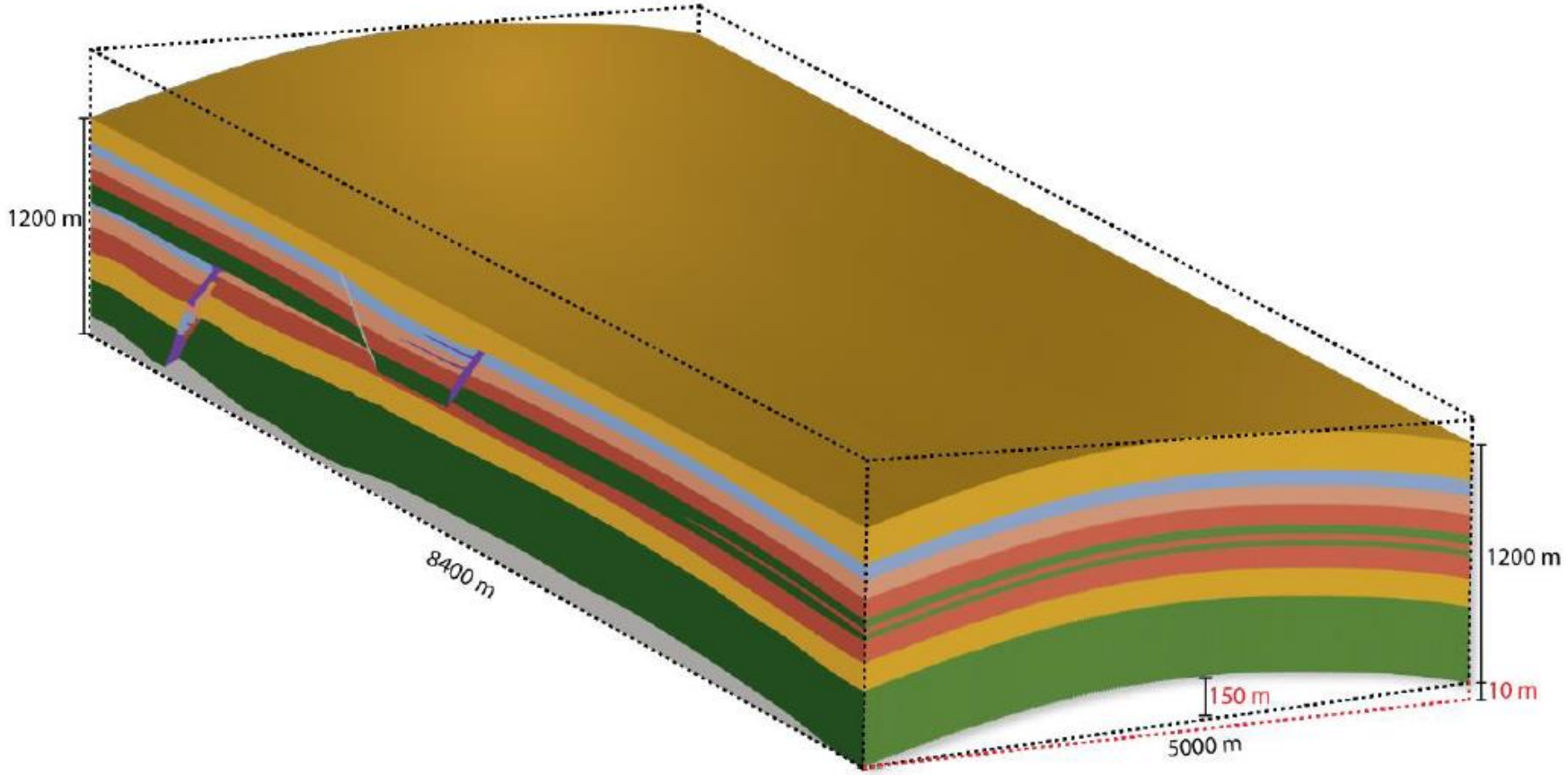
SPE 11A is a 2D geometry at the laboratory scale, inspired by a recent CO_2 storage forecasting and validation study (The FluidFlower).

SPE 11 B



For SPE *11B*, the 2D geometry and operational conditions from 11A are rescaled to field conditions characteristic of the Norwegian Continental Shelf.

SPE 11 C



SPE 11C, the geometry of version 11B is extruded to a full 3D field model.

A Python framework using OPM Flow for the SPE11 benchmark project

- Source code: https://github.com/OPM/pyopmspe11
- Documentation: https://opm.github.io/pyopmspe11/index.html
- Landa-Marbán, D. and Sandve, T. H., pyopmspe11: A Python framework using OPM Flow for the SPE11 benchmark project. Under review JOSS.

```
pyopmspe11 -i configuration_file
```

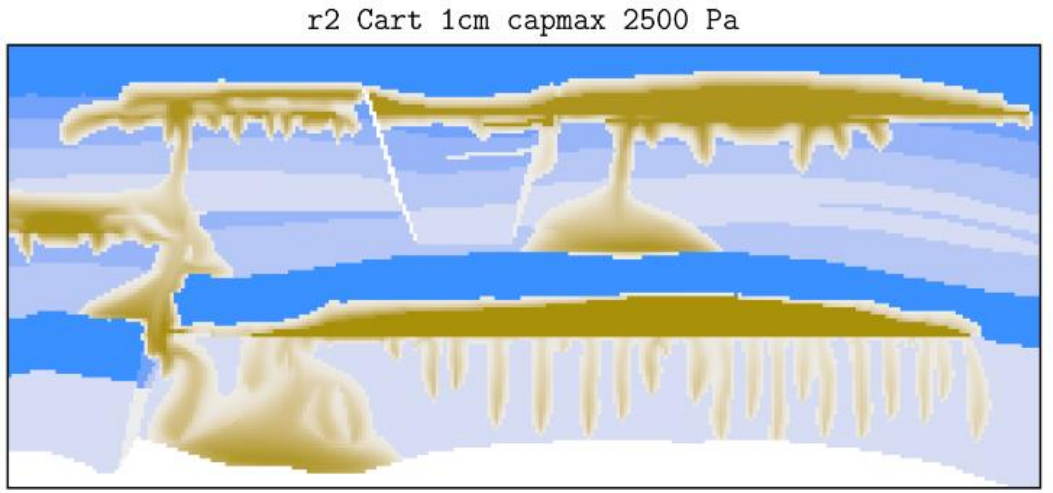
Configuration file

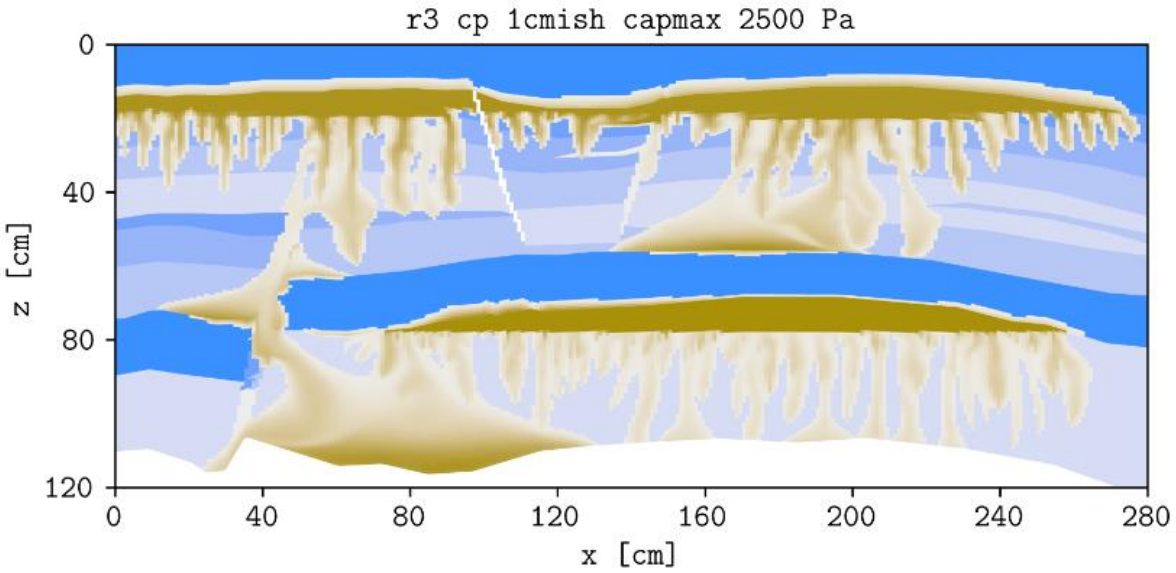
```
# Set the full path to the flow executable and flags
flow = "flow --enable-tuning=true --enable-opm-rst-file=true --output-extr

# Set the model parameters
spe11 = "spe11c" # Name of the spe case (spe11a, spe11b, or spe11c)
version = "release" # OPM Flow version (release or master)
model = "complete" # Name of the co2 model (immiscible, convective, or com
co2store = "gaswater" # co2store implementation (gaswater or gasoil [oil p
grid = "corner-point" # Type of grid (cartesian, tensor, or corner-point)
dims = [8400.0, 5000.0, 1200.0] # Length, width, and depth [m]
x_n = [420] # If cartesian, number of x cells [-]; otherwise, variable arr
y_n = [30, 40, 50, 40, 30] # If cartesian, number of y cells [-]; otherwis
z_n = [5, 3, 1, 2, 3, 2, 4, 4, 10, 4, 6, 6, 4, 8, 4, 15, 30, 9] # If carte
temperature = [70.0, 36.12] # Temperature bottom and top rig [C]
datum = 300 # Datum [m]
pressure = 3e7 # Pressure at the datum [Pa]
kzMult = 0.1 # Multiplier for the permeability in the z direction [-]
diffusion = [1e-9, 2e-8] # Diffusion (in liquid and gas) [m^2/s]
rockExtra = [8.5e-1, 2500.0] # Rock specific heat capacity [kJ/(kg K)] and
pvAdded = 5e4  # Extra pore volume per area on lateral boundaries [m] (for
widthBuffer = 1 # Width of buffer cells [m] (for spe11b/c)
elevation = 150 # Maximum elevation difference (relative to the baseline g
backElevation = 10 # Back boundary elevation w.r.t the front boundary [m]
dispersion = [10, 10, 10, 10, 10, 10, 0] # Dispersion rock [m], facie 1 to
rockCond = [1.9, 1.25, 1.25, 1.25, 0.92, 0.26, 2.0] # Thermal conductivity
radius = [0.15, 0.15] # Wells radius [m] (0 to use the SOURCE keyword inst
wellCoord = [[2700.0, 1000.0, 300.0], [5100.0, 1000.0, 700.0]] # Well posi
wellCoordF = [[2700.0, 4000.0, 300.0], [5100.0, 4000.0, 700.0]] # Well fir
```

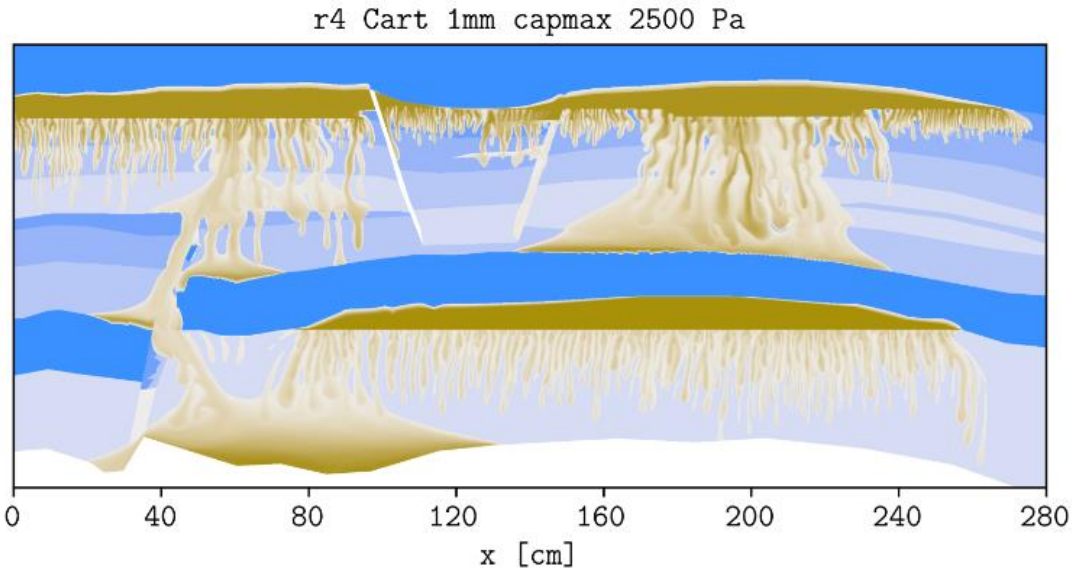
```
# Set the saturation functions
krw = "(max(0, (s_w - swi) / (1 - swi))) ** 1.5"
krn = "(max(0, (1 - s_w - sni) / (1 - sni))) ** 1.5"
pcap = "penmax * math.erf(pen * ((s_w-swi) / (1.-swi)) ** (-(1.0 / 1.5)) *
s_w = "(np.exp(np.flip(np.linspace(0, 5.0, npoints))) - 1) / (np.exp(5.0)

# Properties sat functions: 1) swi [-], 2) sni [-], 3) pen [Pa], 4) penmax
safu = [[0.32, 0.1, 193531.39, 3e7, 1000],
        [0.14, 0.1, 8654.99,   3e7, 1000],
        [0.12, 0.1, 6120.00,   3e7, 1000],
        [0.12, 0.1, 3870.63,   3e7, 1000],
        [0.12, 0.1, 3060.00,   3e7, 1000],
        [0.10, 0.1, 2560.18,   3e7, 1000],
        [0,      0,       0,   3e7,    2]]

# Properties rock: 1) K [mD] and 2) phi [-], facie 1 to 7
rock = [[0.10132, 0.10],
        [101.324, 0.20],
        [202.650, 0.20],
        [506.625, 0.20],
        [1013.25, 0.25],
        [2026.50, 0.35],
        [1e-5,    1e-6]]

# Define the injection values ([hours] for spe11a; [years] for spe11b/c):
inj = [[999.9, 999.9, 100, 1,  0, 10, 1,  0, 10],
       [  0.1,   0.1, 0.1, 1,  0, 10, 1,  0, 10],
       [   25,     5,   5, 1, 50, 10, 1,  0, 10],
       [   25,     5,   5, 1, 50, 10, 1, 50, 10],
       [   50,    25,  25, 1,  0, 10, 1,  0, 10],
       [  400,    50,  50, 1,  0, 10, 1,  0, 10],
       [  500,   100, 100, 1,  0, 10, 1,  0, 10]]
```

SPE11 A

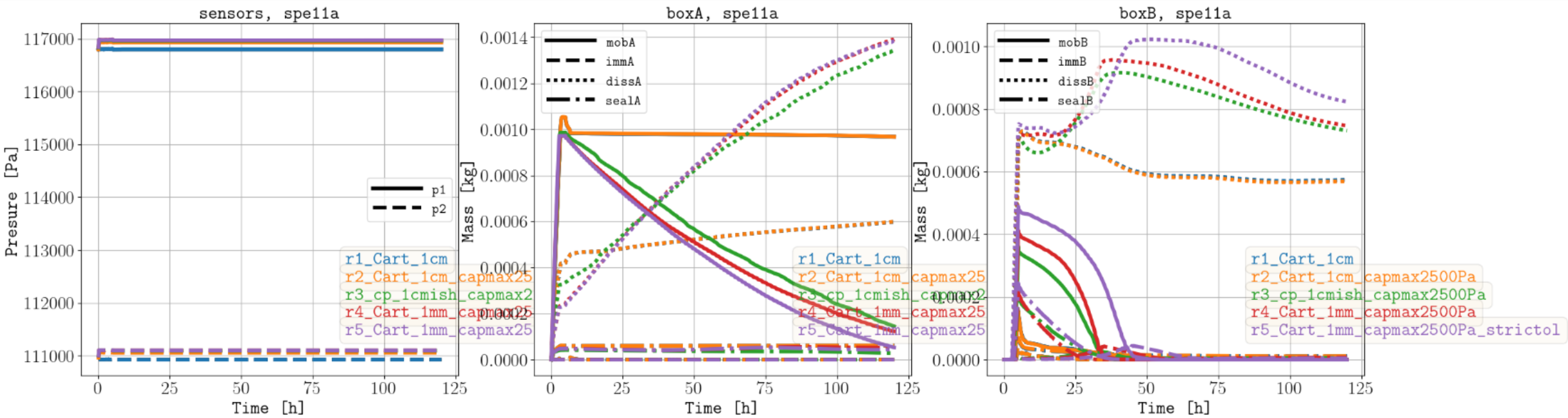

r1 Cart 1cm
z [cm]
0
40
80
120


r2 Cart 1cm capmax 2500 Pa

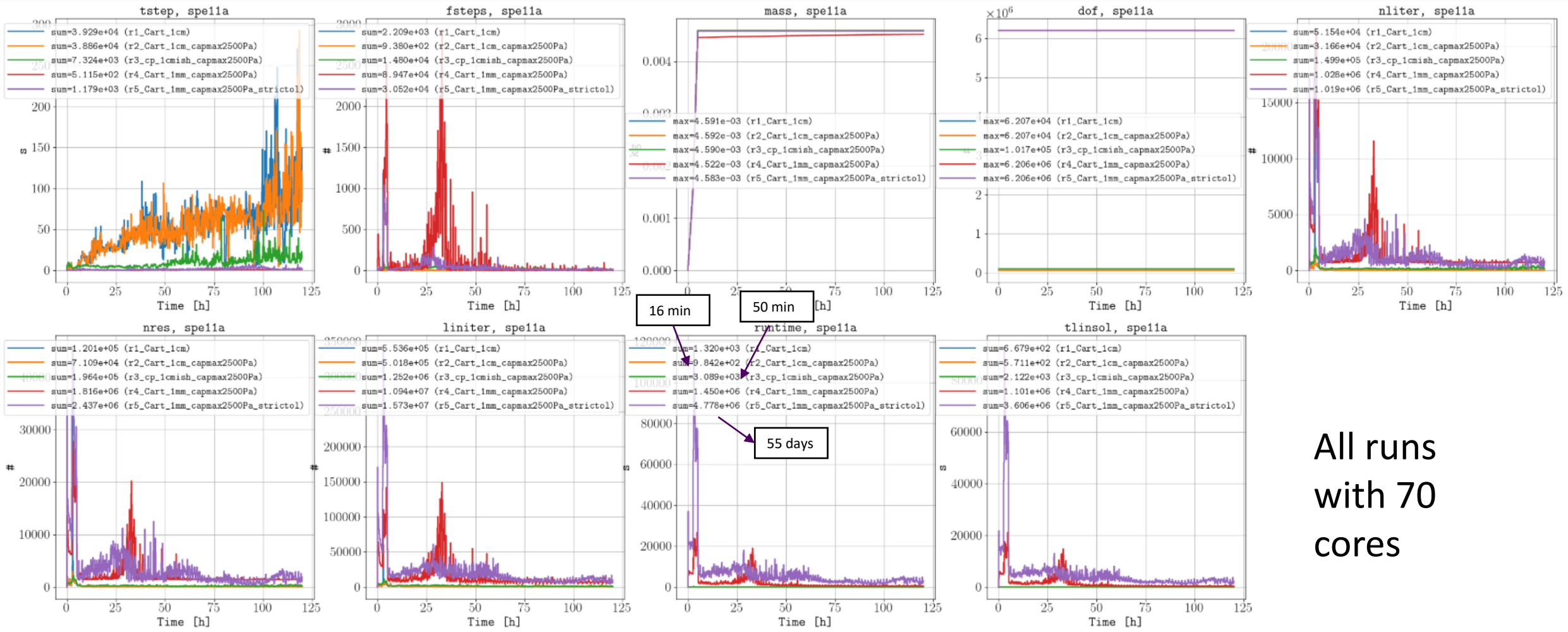

r3 cp 1cmish capmax 2500 Pa
z [cm]
0
40
80
120
0
40
80
120
160
200
240
280
x [cm]


r4 Cart 1mm capmax 2500 Pa
0
40
80
120
160
200
240
280
x [cm]

SPE11 A

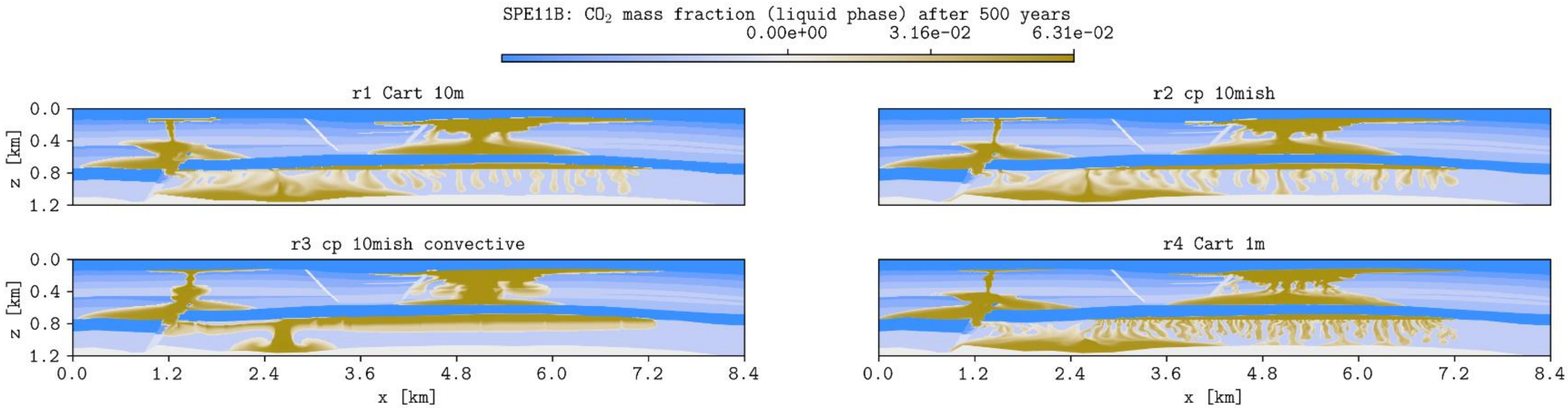

sensors, spe11a
Presure [Pa]
Time [h]
p1
p2
r1_Cart_1cm
r2_Cart_1cm_capmax25
r3_cp_1cmish_capmax2
r4_Cart_1mm_capmax25
r5_Cart_1mm_capmax25
boxA, spe11a
Mass [kg]
Time [h]
mobA
immA
dissA
sealA
r1_Cart_1cm
r2_Cart_1cm_capmax25
r3_cp_1cmish_capmax2
r4_Cart_1mm_capmax25
r5_Cart_1mm_capmax25
boxB, spe11a
Mass [kg]
Time [h]
mobB
immB
dissB
sealB
r1_Cart_1cm
r2_Cart_1cm_capmax2500Pa
r3_cp_1cmish_capmax2500Pa
r4_Cart_1mm_capmax2500Pa
r5_Cart_1mm_capmax2500Pa_strictol

SPE11 A



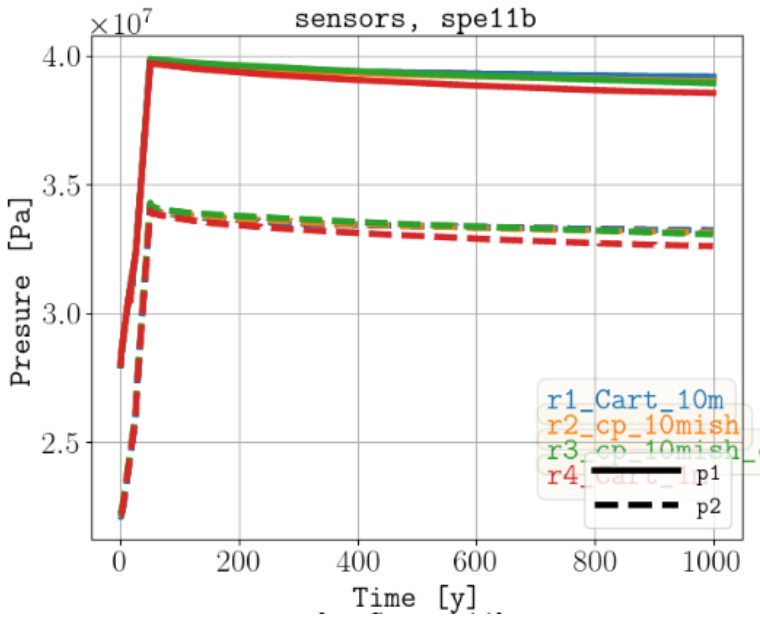
All runs with 70 cores

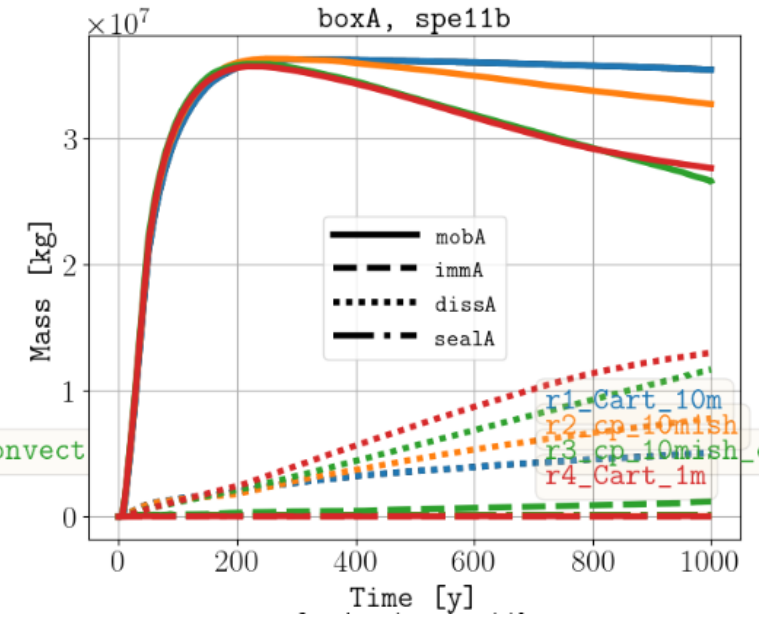
SPE 11 B

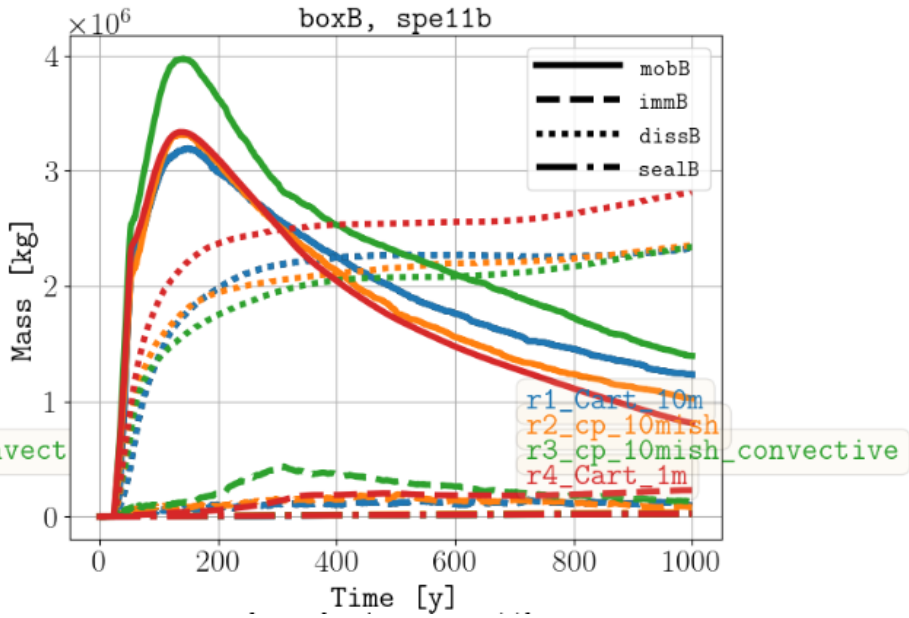


R3: “New sub-grid model for convective mixing in field-scale CO2 storage simulation”. Mykkeltvedt et al. In press TIMP 2024

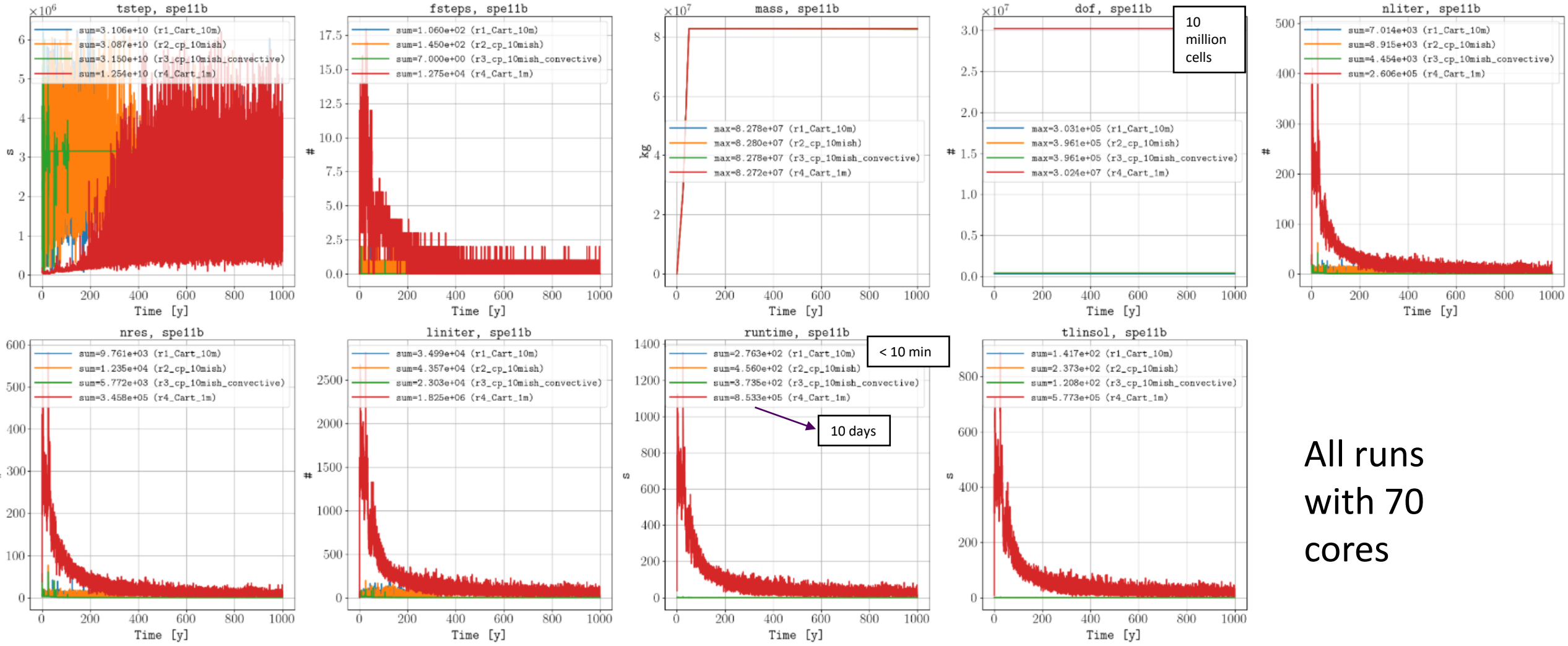
SPE 11 B


sensors, spe11b
×10^7
Presure [Pa]
Time [y]
p1
p2
r1_Cart_10m
r2_cp_10mish
r3_cp_10mish_convect
r4_Cart_1m


boxA, spe11b
×10^7
Mass [kg]
Time [y]
mobA
immA
dissA
sealA
r1_Cart_10m
r2_cp_10mish
r3_cp_10mish_convect
r4_Cart_1m

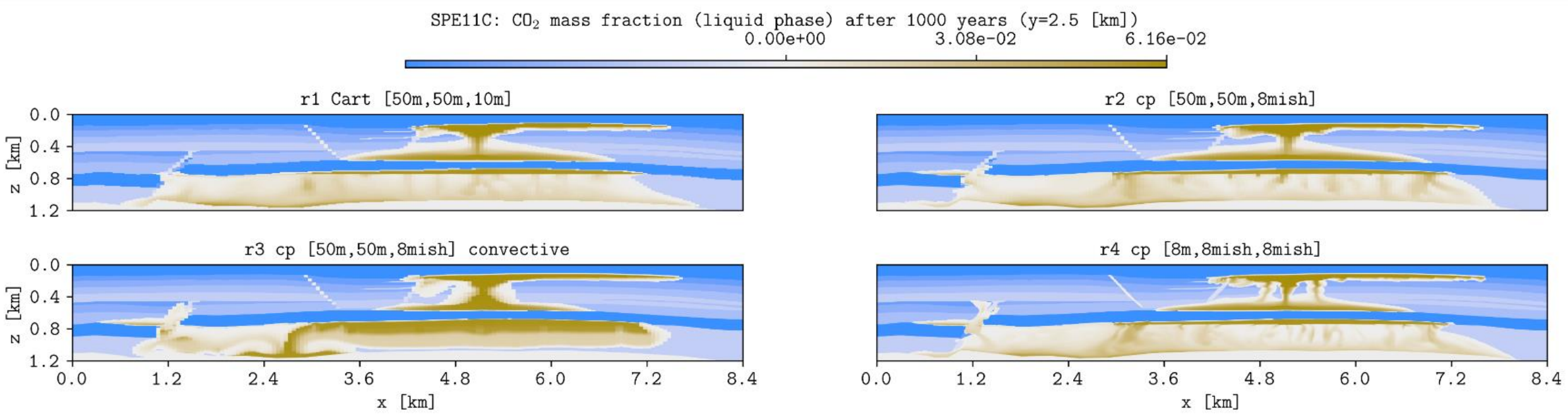

boxB, spe11b
×10^6
Mass [kg]
Time [y]
mobB
immB
dissB
sealB
r1_Cart_10m
r2_cp_10mish
r3_cp_10mish_convective
r4_Cart_1m

SPE 11 B



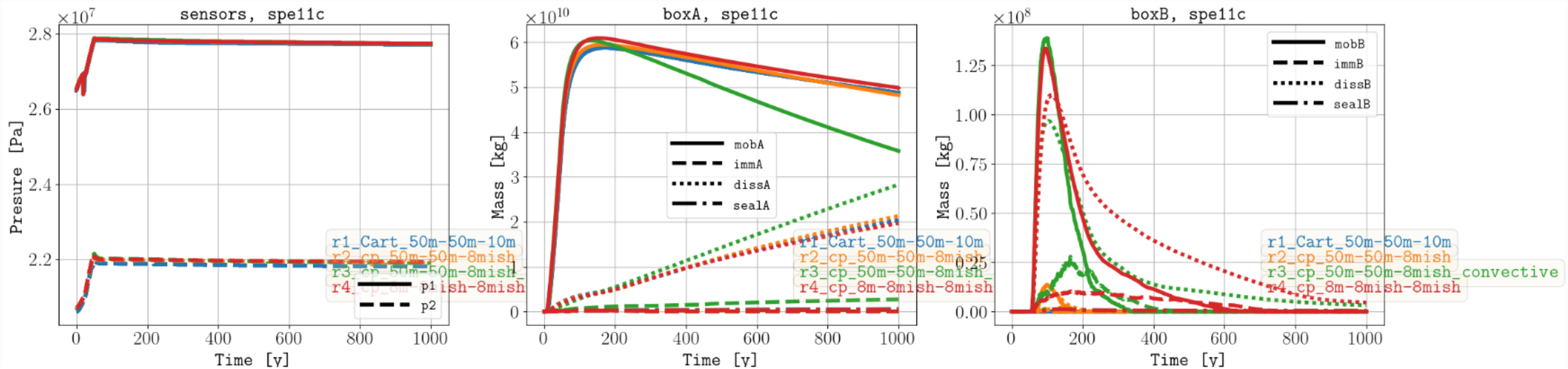
All runs with 70 cores

SPE11 C

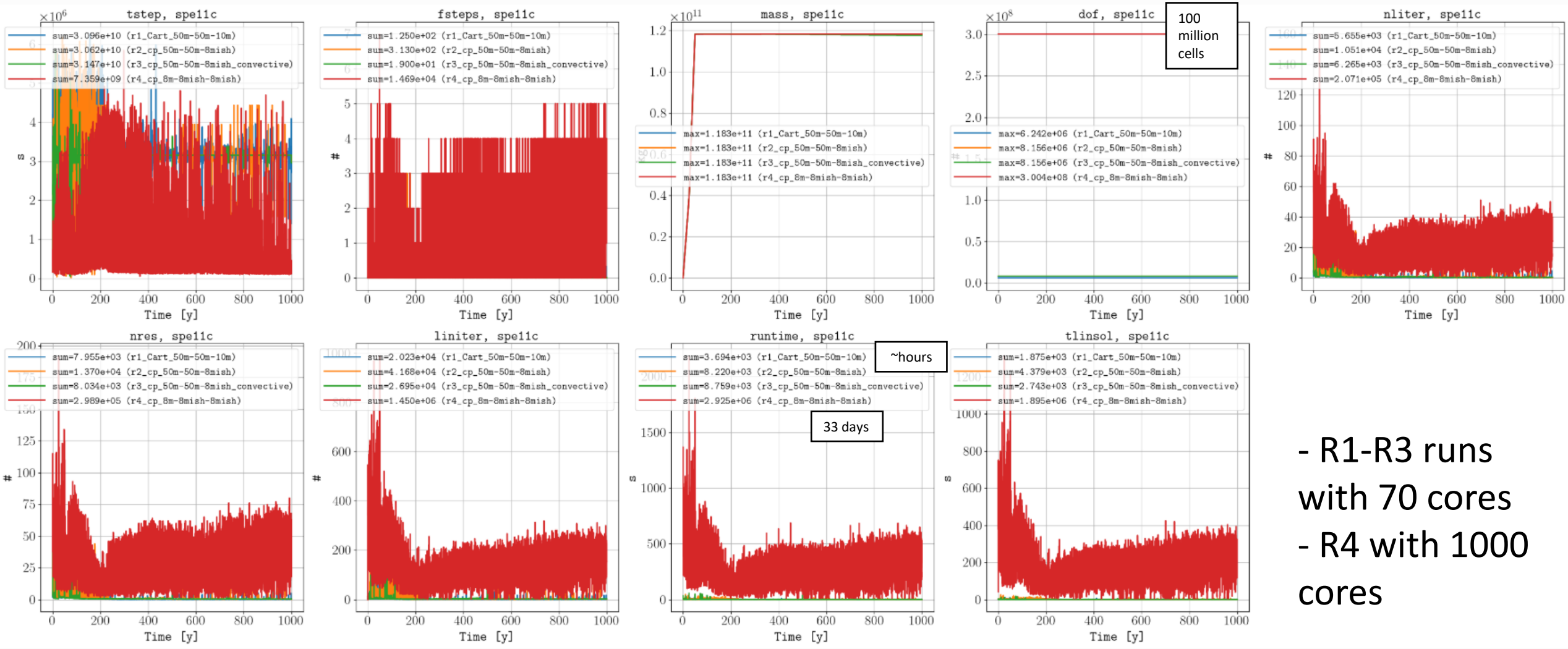


R3: “New sub-grid model for convective mixing in field-scale CO2 storage simulation”. Mykkeltvedt et al. In press TIMP 2024

SPE11 C


sensors, spe11c
×10^7
Presure [Pa]
Time [y]
p1
p2
boxA, spe11c
×10^10
Mass [kg]
Time [y]
mobA
immA
dissA
sealA
boxB, spe11c
×10^8
Mass [kg]
Time [y]
mobB
immB
dissB
sealB
r1_Cart_50m-50m-10m
r2_cp_50m-50m-8mish
r3_cp_50m-50m-8mish_convective
r4_cp_8m-8mish-8mish

SPE11 C



- R1-R3 runs with 70 cores
- R4 with 1000 cores

Summary

- Pyopmspe11
- CO2 simulations in OPM Flow using CO2STORE
- OPM Flow HPC simulations
- SGM for convective mixing (DRSDTCON)

The OPM team: