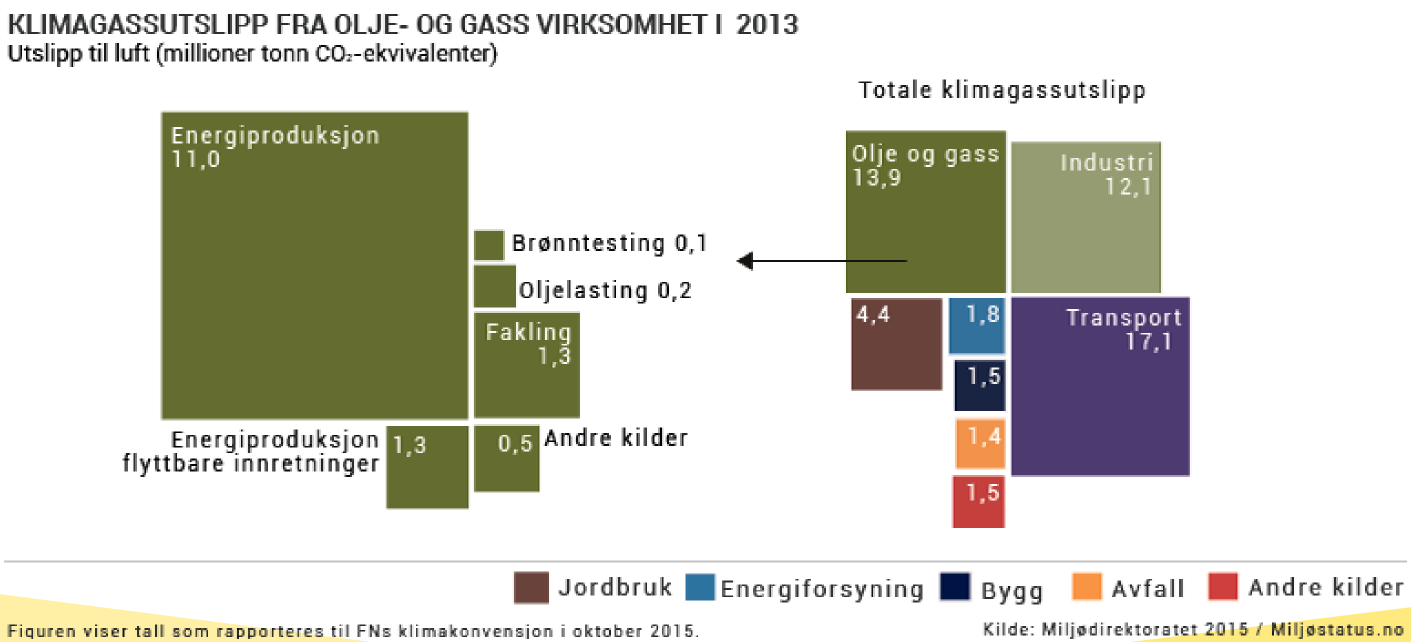
The solvent model for CO2-EOR simulations

OPM meeting in Oslo

Why CO2-EOR?

- PARIS COP21
- IEA: CO2-EOR - a stepping stone for CCS
- OG21 strategy: Make CO2 available offshore for EOR and/or storage



CO2-EOR. How does it work?

› Multi-contact miscible displacement

› CO2 → OIL (Condensing)

- Swelling of the oil phase
- Reduces viscosity of the oil
- Increases density of oil (brings it closer to water)

› OIL → CO2 (Vaporization)

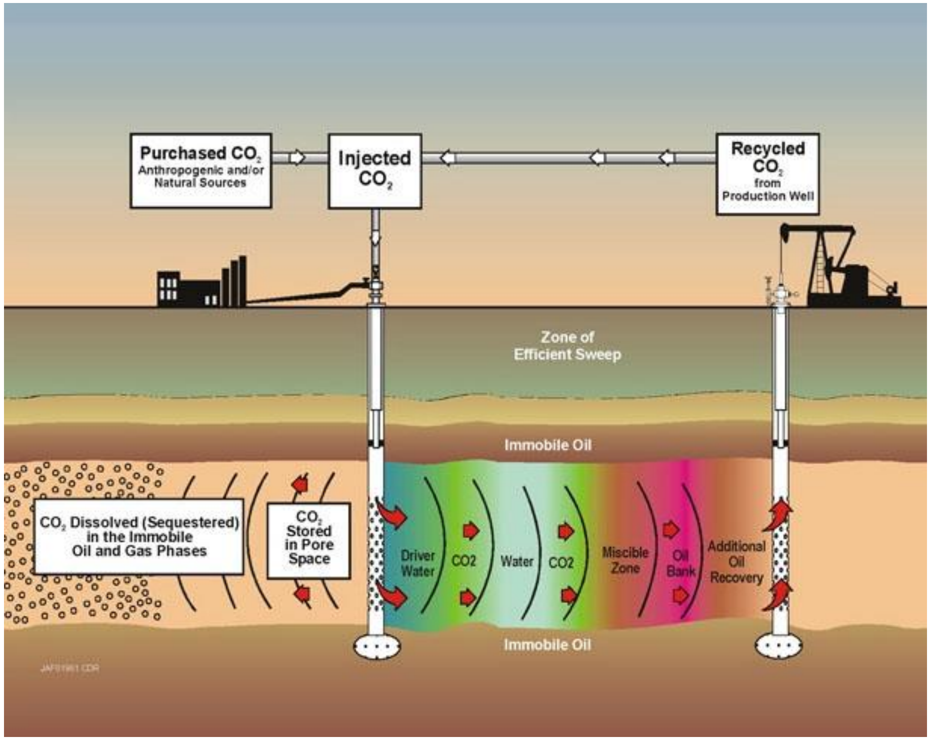
- Extraction of lighter hydrocarbons
- Increases viscosity of the gas

› Lowers the interfacial tension between the CO2 rich gas phase and the oil phase. → lower residual oil saturation.

› Forms single phase locally at minimum miscibility pressure (MMP)

› Dispersion

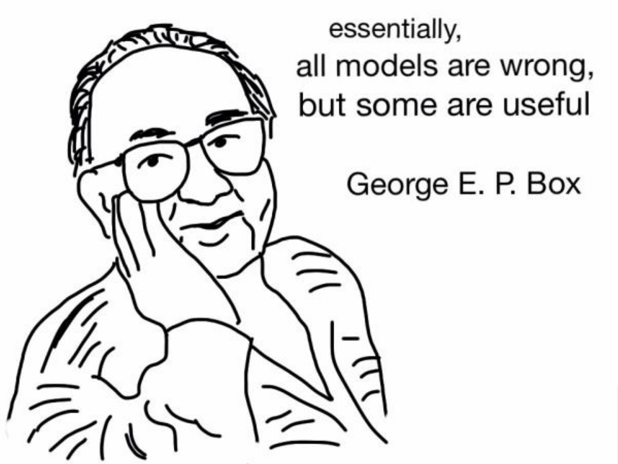
› CO2 → Water (Dissolve)



Why extended black-oil (solvent) simulator?

- Gas and oil is represented by three-pseudo components (oil, solution gas, and injected solvent)
- Effective hydrocarbon relative permeability and viscosity.

- PROS
  - Use existing blackoil models.
  - Computationally more efficient than compositional simulators.
- CONS
  - Can we trust the results?



Model formulation

› Effective hydrocarbon relative permeability

- $k_{roe} = M \cdot \left(\frac{S_o - S_{or}}{S_n - S_{gc} - S_{or}}\right) \cdot k_{rn} + (1 - M) \cdot k_{ro}$
- $k_{r*e} = M \cdot \left(\frac{S_g + S_s - S_{gc}}{S_n - S_{gc} - S_{or}}\right) \cdot k_{rn} + (1 - M) \cdot k_{r*}$

$* = g:$ $k_{rg} = \frac{S_g}{S_g + S_s} k_{rg}(S_s + S_g)$ (gas component)

$* = s:$ $k_{rs} = \frac{S_s}{S_g + S_s} k_{rg}(S_s + S_g)$ (solvent component)

$M = M(pressure, solvent\ fraction)$: Miscibility function
k_{ro} : oil rel.perm
k_{rg} : gas rel.perm
k_{rn} : hydrocarbon to water rel.perm
S_{or} : residual oil saturation
S_{gc} : critical gas saturation

Model formulation

- Effective viscosities
  - $\mu_{oe} = \mu_o^{1-\omega} \cdot \mu_{mos}^{\omega}$
  - $\mu_{se} = \mu_s^{1-\omega} \cdot \mu_m^{\omega}$
  - $\mu_{ge} = \mu_g^{1-\omega} \cdot \mu_{msg}^{\omega}$

  μ_{mos} : fully mixed viscosity of oil and solvent (using the ¼ power mixing rule)

  μ_m : fully mixed viscosity of oil, gas and solvent (using the ¼ power mixing rule)

  μ_{msg} : fully mixed viscosity of solvent and gas (using the ¼ power mixing rule)

  ω : is the Todd-Longstaff mixing parameter

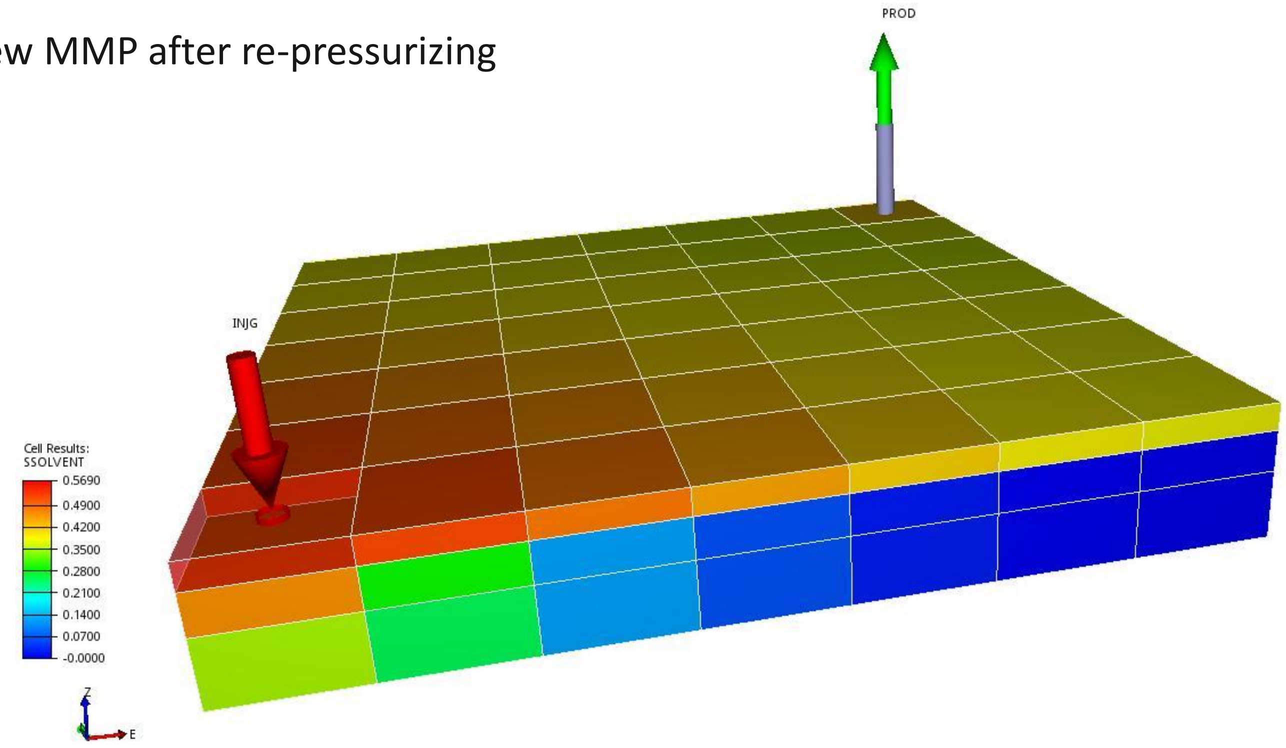
- Other effects
  - Effective densities
  - Modified residual oil saturation / critical gas saturation
  - Pressure effects on capillary pressure, viscosity and density miscibility
  - Pressure dependent Todd-Longstaff parameter

Comparison SPE 5:

› Comparison of 4-component miscible simulators and compositional simulators

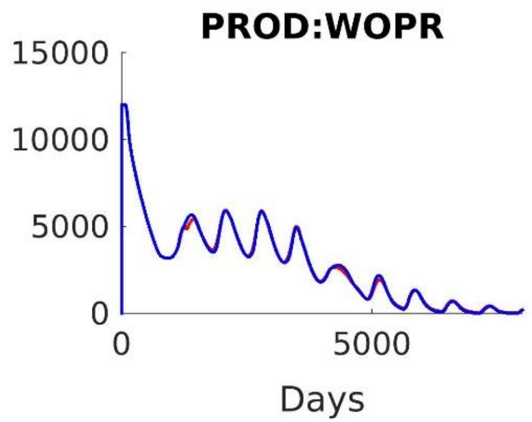
› Three cases. Where average reservoir pressure is:

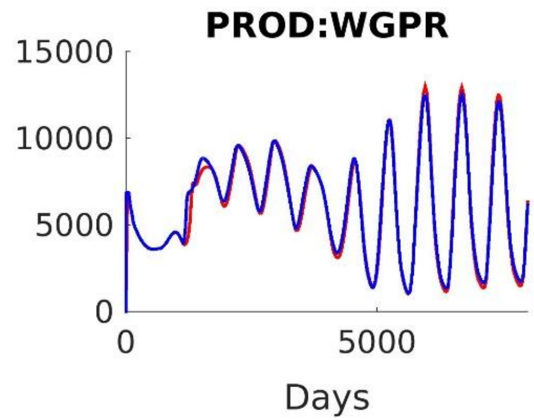
1. Much lower than MMP (immiscible case)
2. Near or above MMP
3. Below first, new MMP after re-pressurizing



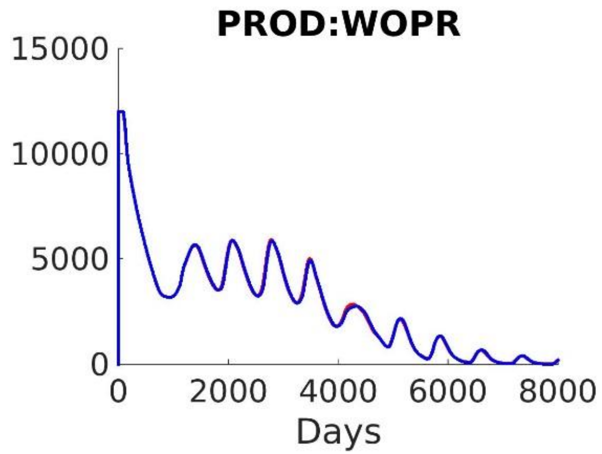
Comparison SPE 5: (OPM-FLOW, Eclipse)

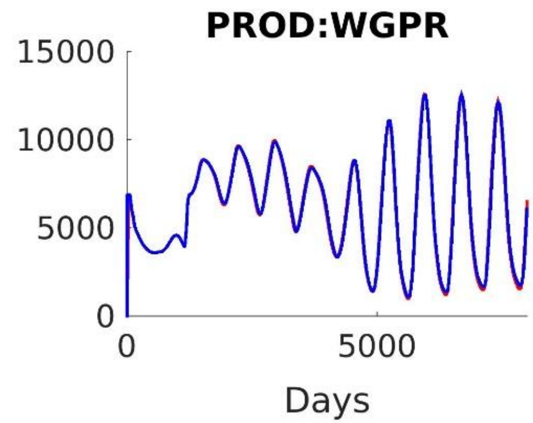
SPE 5 case 1





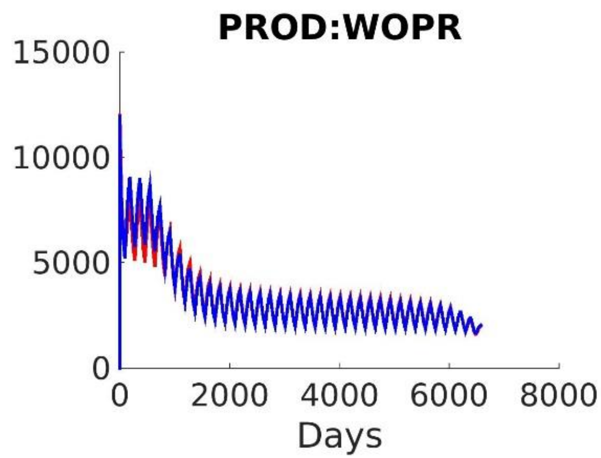
SPE 5 case 1:
With no mixing effect on the densities

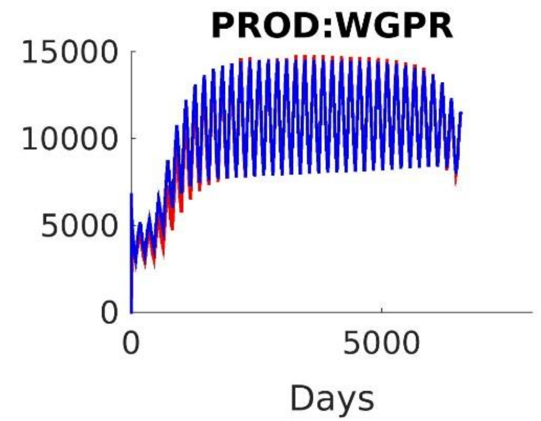




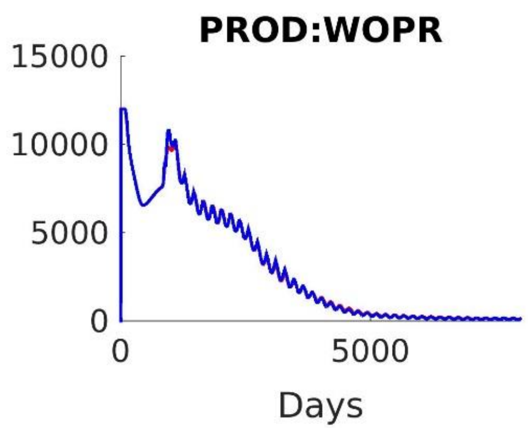
Comparison SPE 5: (OPM-FLOW, Eclipse)

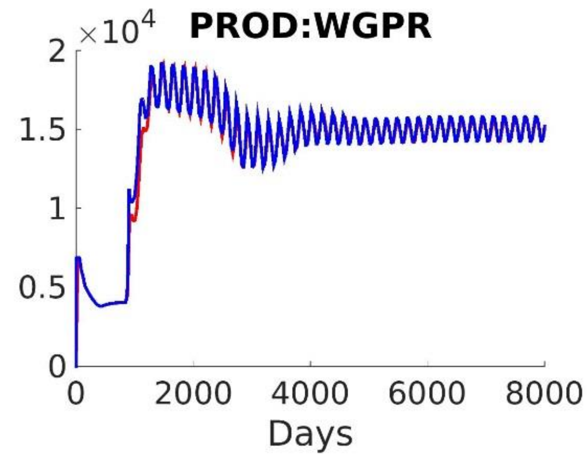
SPE 5 case 2





SPE 5 case 3

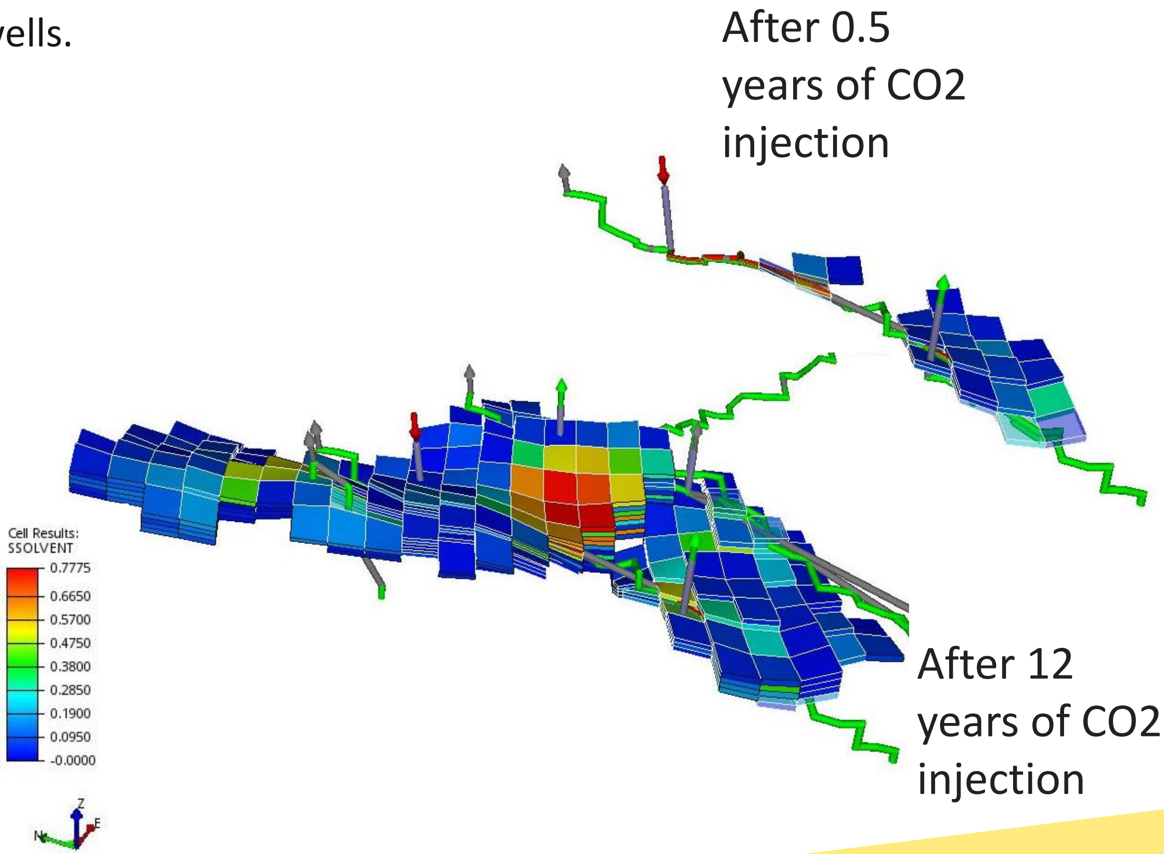




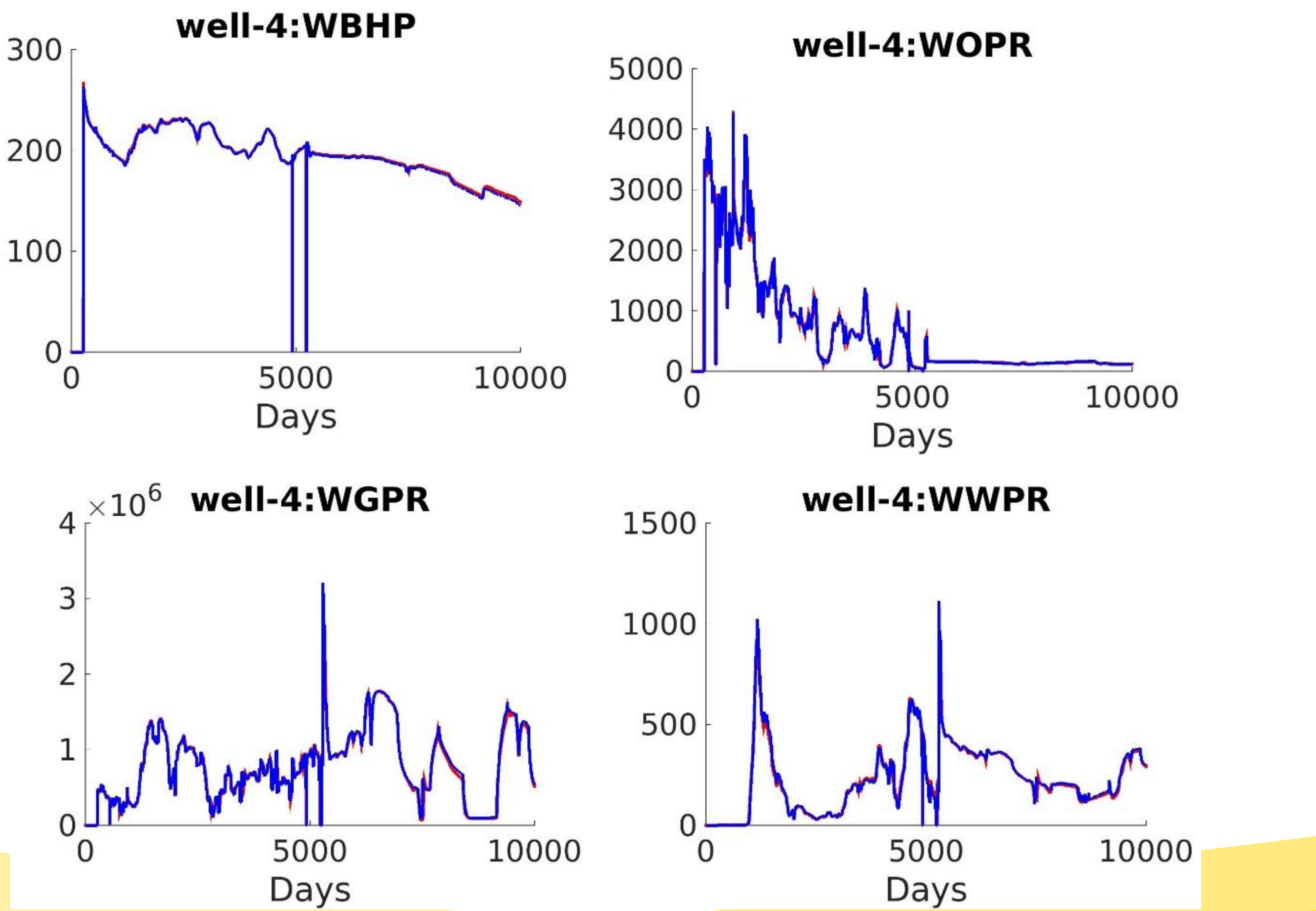
Field scale simulations

› **Setup**

- Run 5295 days of history.
- Group controlled production wells.
- CO_2 injected from day 5479
- Linear ramp between 100-250 Barsa to model pressure dependency in the miscibility
- The pressure dependency in the Todd-Longstaff parameter is neglected.



Field scale simulations (OPM-FLOW, Eclipse)



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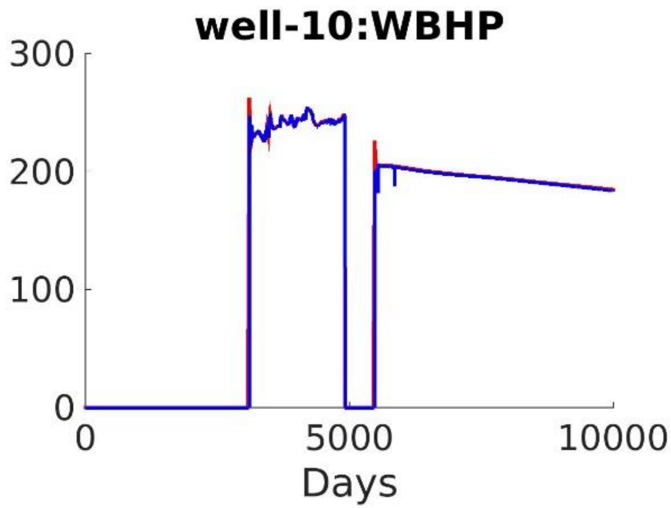

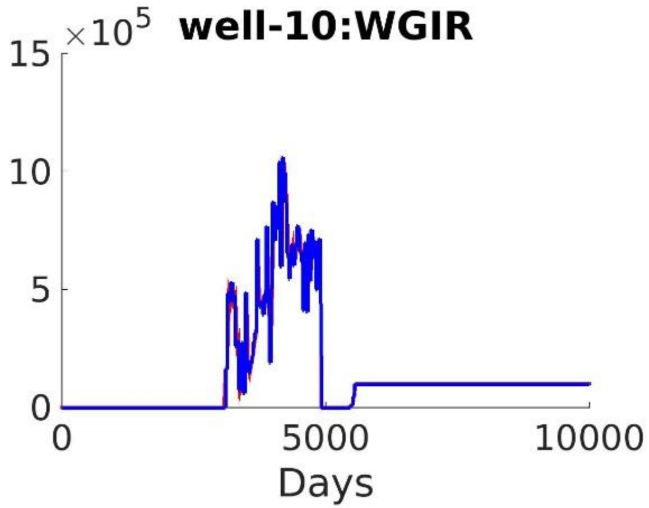

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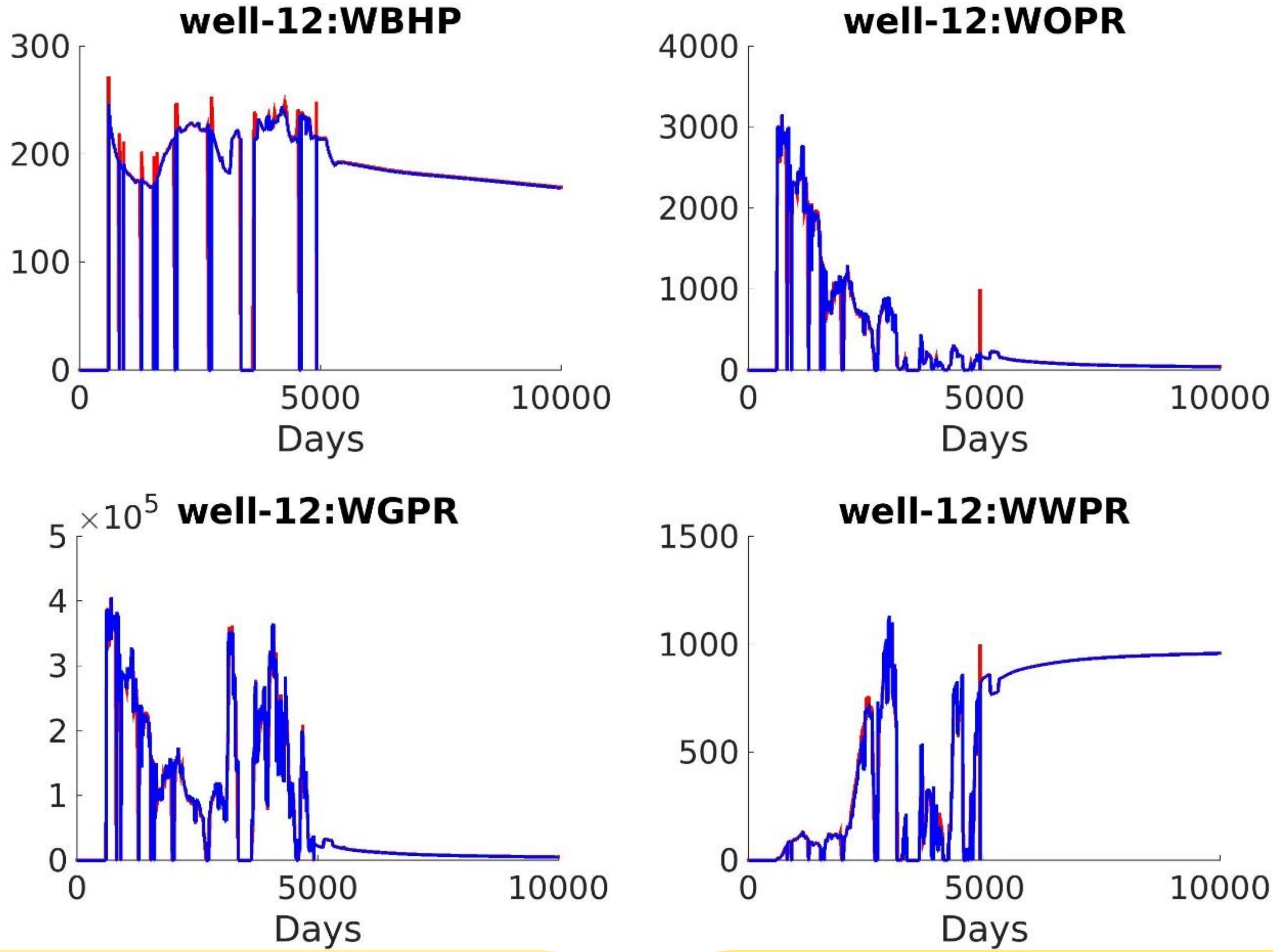

Summary

› FLOW-SOLVENT. Extended black-oil model for CO_2-EOR simulations

› Benchmarked against Eclipse

› New feature implemented. Pressure depended Todd-Longstaff parameter.

› Discussion:

- Can the relevant CO_2-EOR physics be modeled using an extended black-oil (solvent) model?
- How to determine the Todd-Longstaff parameter?