Smart Water Injection:
Modeling of mechanisms & upscaling

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FORCE meeting, NPD, Stavanger 7th of November 2013

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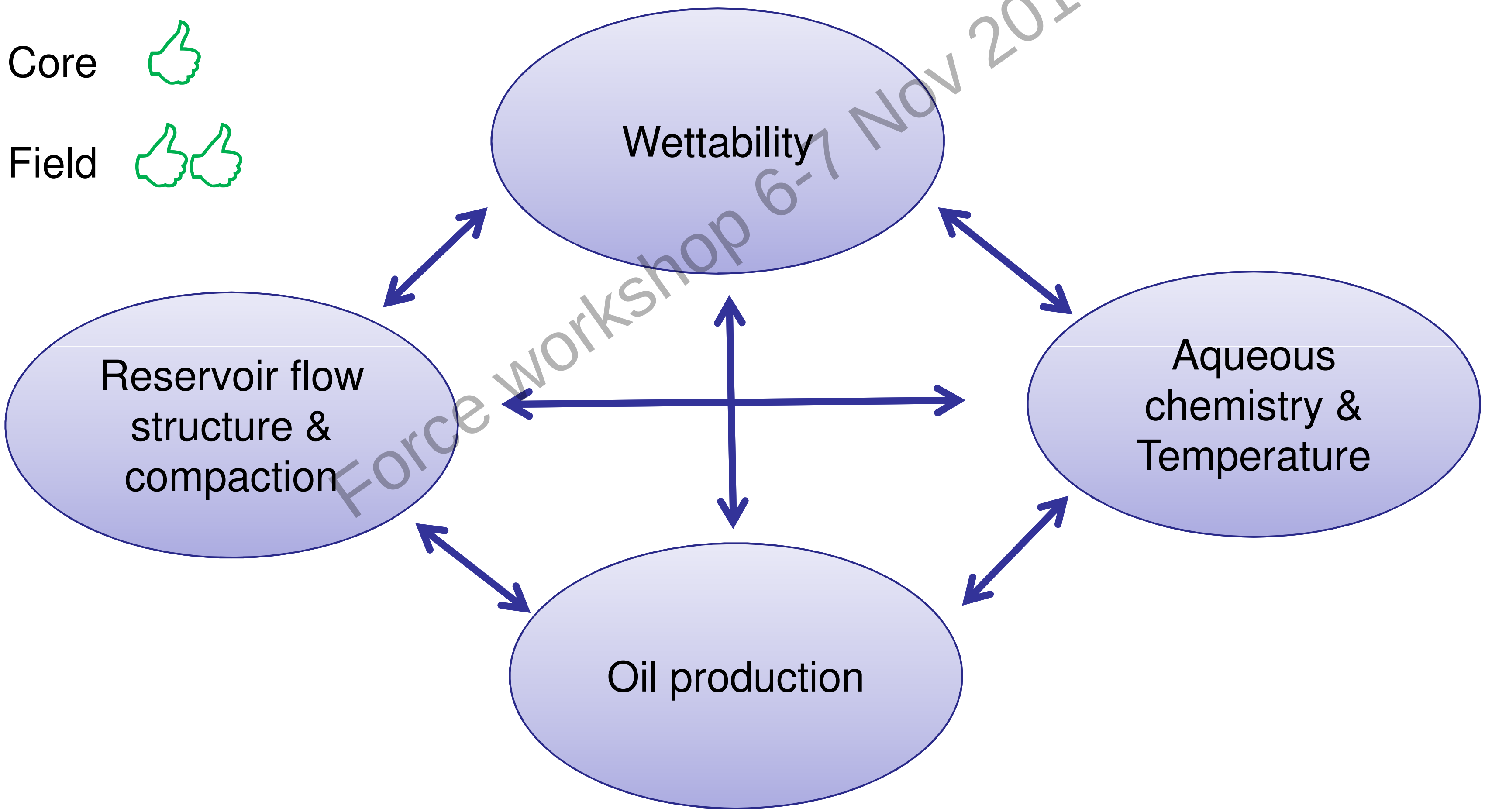
Acknowledgement

- Norwegian Research Council, CoP-Ekofisk License, and BP-Valhall License

Outline

- Strategic goals
- Smart water modelling
  - How to model mechanism
- Example: Ekofisk case
  - Pore water chemistry alteration on field scale

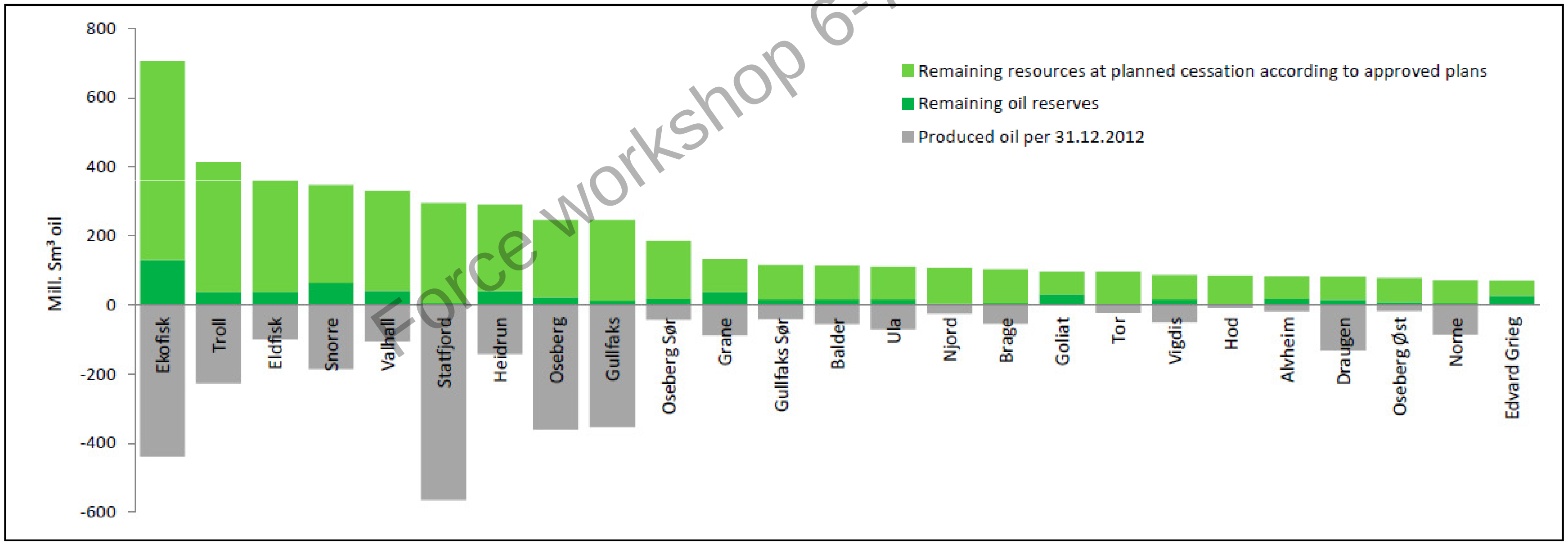
The Challenge(s)



The Goal

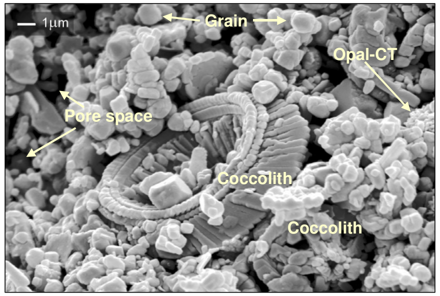
Increase oil recovery cost effectively and responsibly

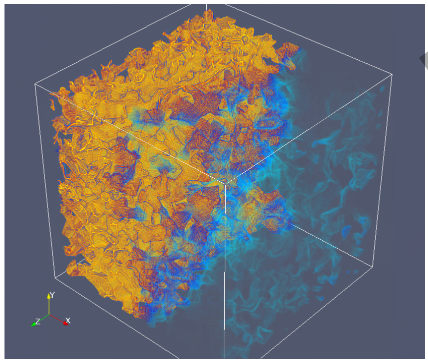
The opportunity



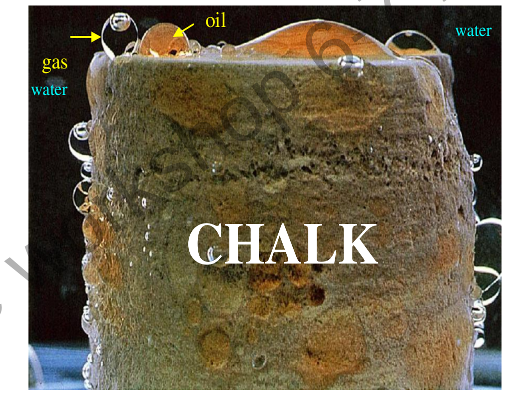
Multi scale understanding

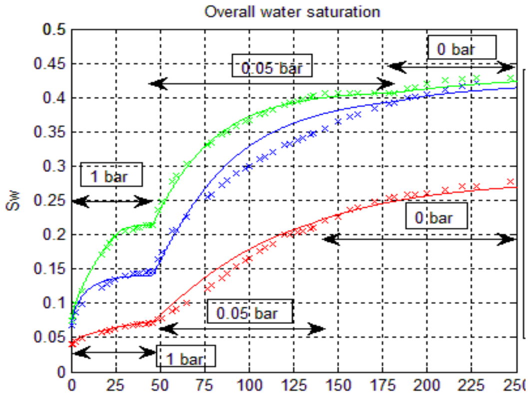
Pore



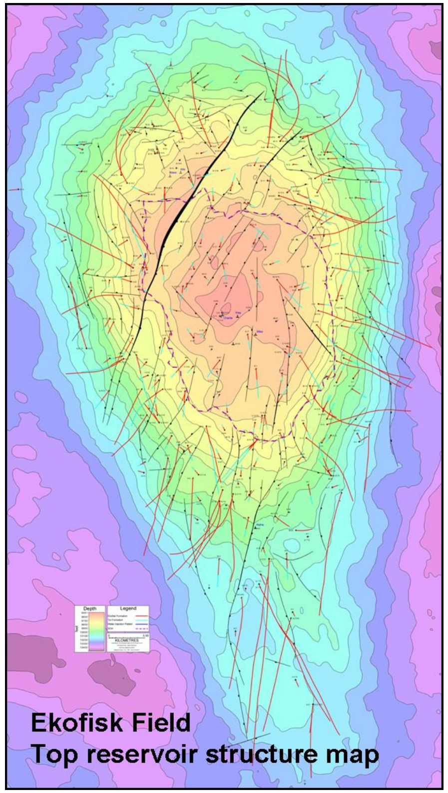


Core





Field



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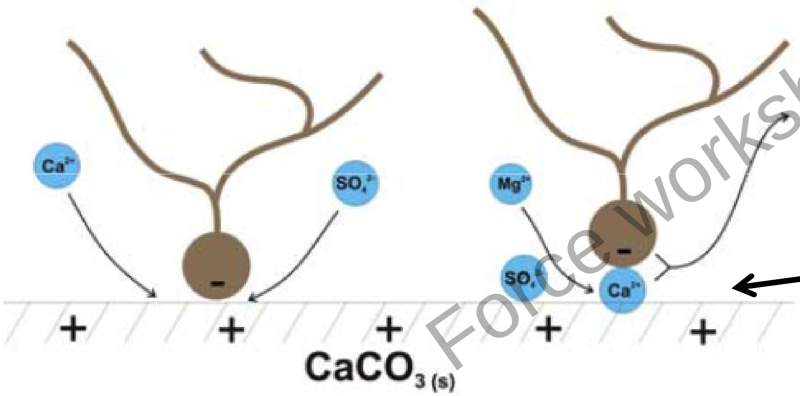
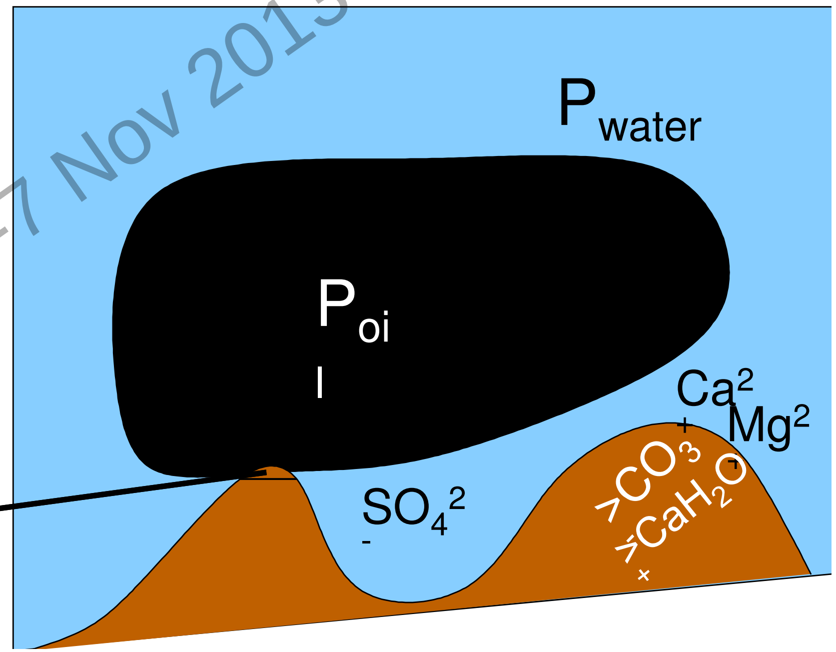
Modeling of Mechanisms

- Conceptual model





- Wettability is a dynamic quantity
  - Competition on the surface

Competition in the bulk - seawater

T=130 ℃

Ion	mol/l	Free Ion (percent)	Me-SO_4 Pair (percent)	Me-HCO_3 Pair (percent)	Me-CO_3 Pair (percent)	Me-Cl Pair (percent)
Na^+	0.45	85.9	2.6	0	0	11.4
Mg^{2+}	0.045	72.2	23.0	0.03	0.02	4.7
Ca^{2+}	0.011551	81.6	14.7	0.02	0.07	3.4
K^+	0.01	99.95	0.04	-	-	-

Ion	mol/l	Free Ion (percent)	Ca-anion Pair (percent)	Mg-anion Pair (percent)	Na-anion Pair (percent)	K-anion Pair (percent)
SO_4^{2-}	0.024	0.69	7.0	43.3	49.0	0.02
HCO_3^-	5.13E-05	69.6	5.1	25.2	0	-
CO_3^{2-}	1.73E-05	5.0	47.1	47.7	0	-
Cl^-	0.525	89.7	0.07	0.39	9.8	-

Competition on the surface

$$> CaRCOO^0 \rightleftharpoons\ > CaOH_2^+ + R - COO^- - H_2O$$

$$
\begin{aligned}
> CaCO_3^- &\rightleftharpoons\ > CaOH_2^+ + HCO_3^- - H^+ - H_2O,\\
> CaOH &\rightleftharpoons\ > CaOH_2^+ - H^+,\\
> CaHCO_3 &\rightleftharpoons\ > CaOH_2^+ + HCO_3^- - H_2O,\\
> CaSO_4^- &\rightleftharpoons\ > CaOH_2^+ + SO_4^{2-} - H_2O,\\
> CO_3H &\rightleftharpoons\ > CO_3^- + H^+,\\
> CO_3Ca^+ &\rightleftharpoons\ > CO_3^- + Ca^{2+},\\
> CO_3Mg^+ &\rightleftharpoons\ > CO_3^- + Mg^{2+}.
\end{aligned}
$$

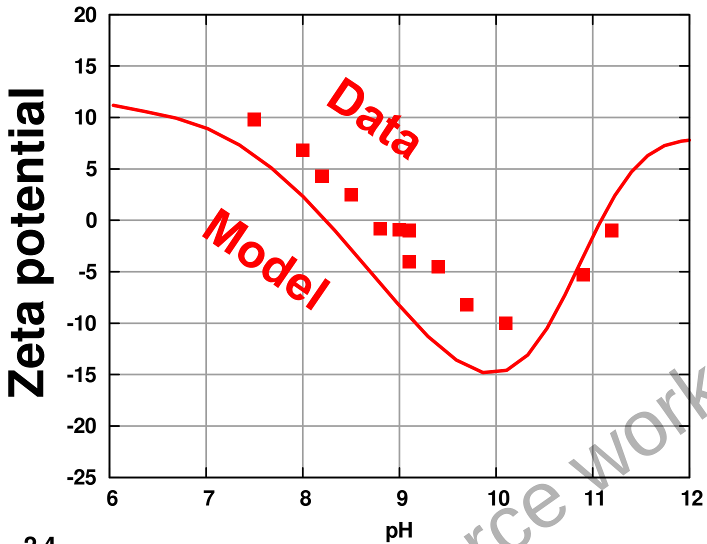
$$> A \rightleftharpoons\ > B + C \quad \Leftrightarrow \quad K = \frac{a_{>B}\, a_C \exp\{-Z_C F\psi/(RT)\}}{a_{>A}},$$

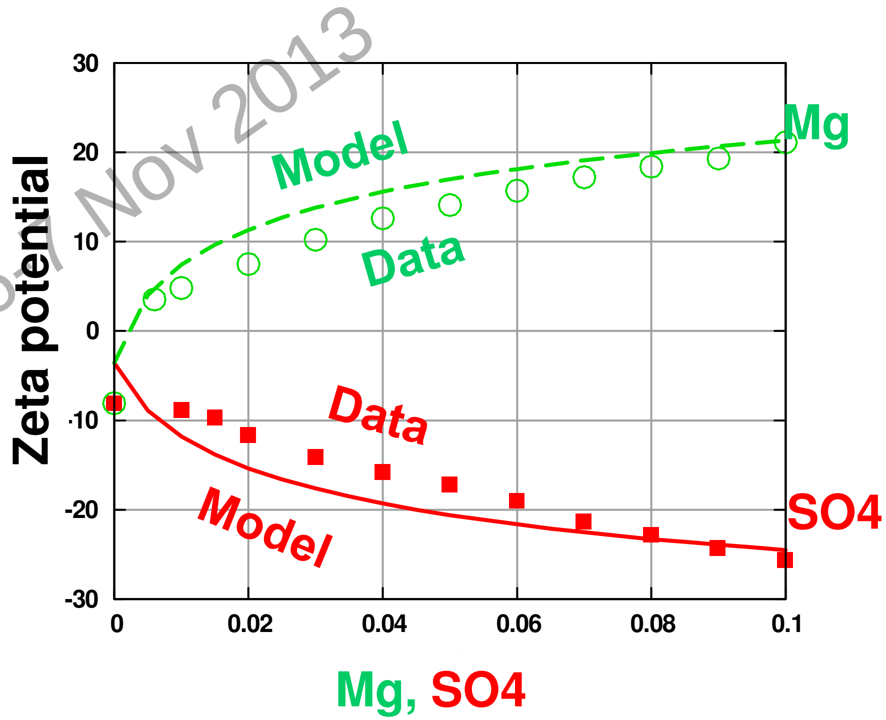
$$\sigma^2 = 2\varepsilon\varepsilon_0 k_B T\left(\sum_i m_i \exp\{-Z_i F\psi/(RT)\} - m_i\right),$$

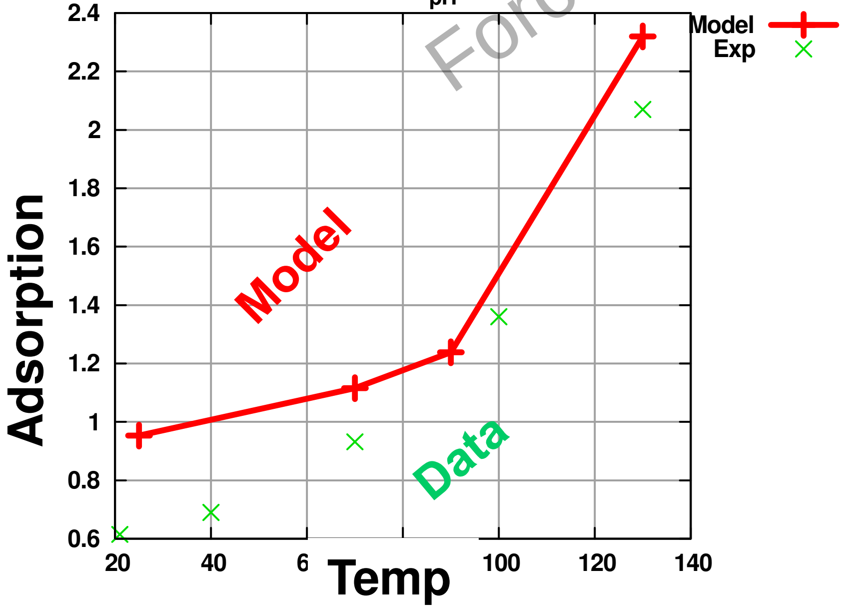
$$\sigma = F\left(m_{>CaOH_2^+} - m_{>CaCO_3^-} - m_{>CaSO_4^-} - m_{>CO_3^-} + m_{>CO_3Mg^+}\right).$$

- Wettabillity should be related to amount of adsorbed oil

Comparison with experimental data







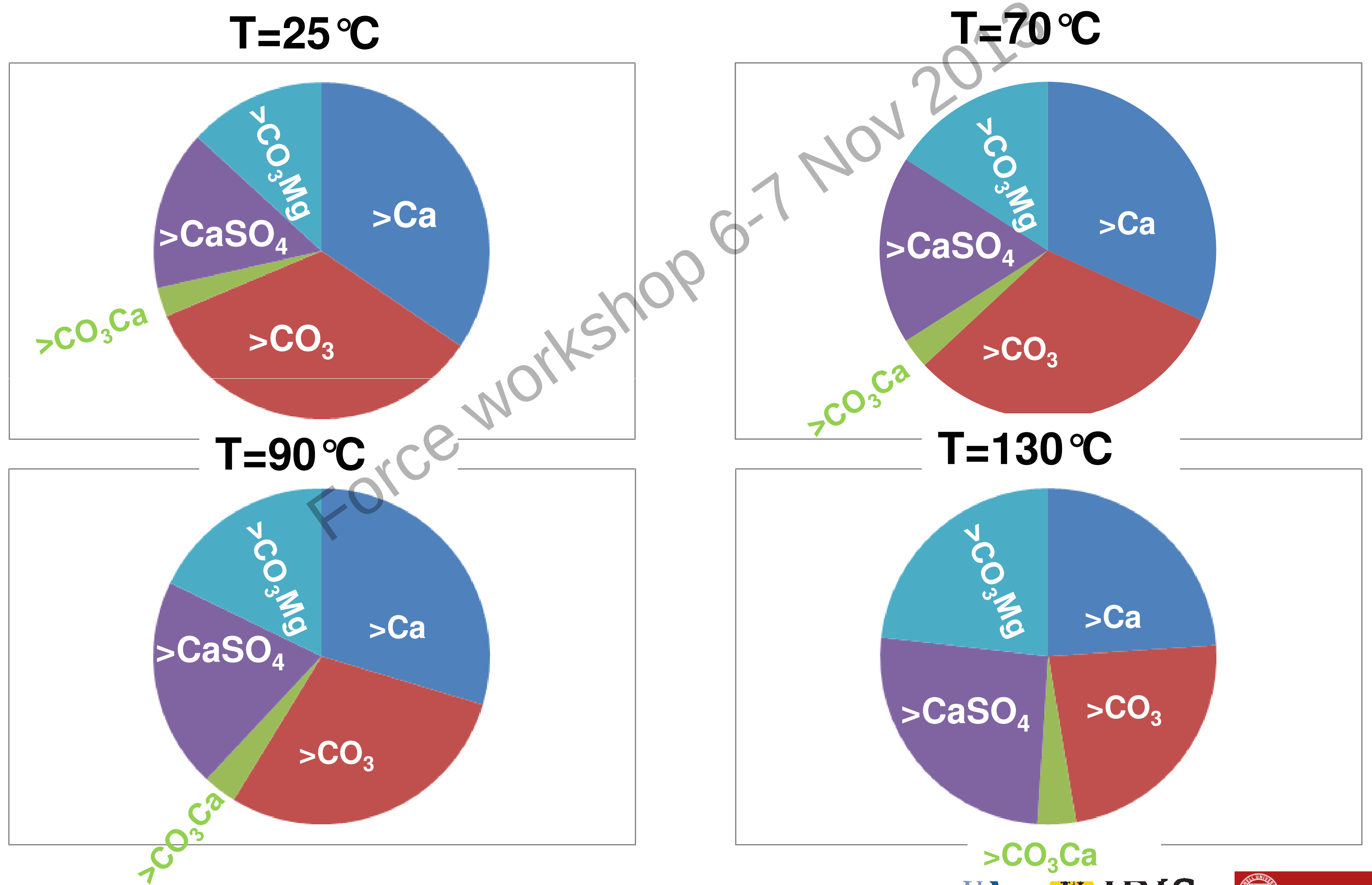
Model: A. Hiorth, L. M. Cathles, M. V. Madland
Trans. Porous Med. 85, 1-21 (2010)

PhD thesis P. Zhang, UiS, 2006

(Thompson D. And P. G. Pownall, *Surface Electrical Properties of Calcite*, J. Coll. Int. Sci., **131**, 74-82,1989)

Strand et al. 2006 Coll. Surf. Phys. Eng. Asp.

Surface speciation



Next steps

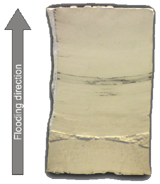
- Relate surface speciation to wettability
  - Work in progress

- Can use model to:
  - Optimize brine
  - Probe Temp and P dependence
    - Exp @ 8bar, Reservoir ~200bar
  - pH
  - Effect of live oil

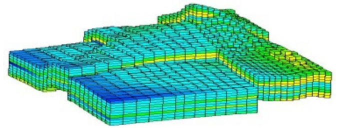
TRANSLATING ROCK FLUID INTERACTIONS TO FIELD

- How far into the reservoir is the injection water smart?
- Optimal water on core = optimal water field?

A. Hiorth, E. Jettestuen, J. L. Vinningland, L. M. Cathles, M. V. Madland. **IEA EOR 34th Annual Symposium Stavanger 2013**



Core vs field



«Typical» Core

- 1D flow
- Constant temperature
- Constant flooding rate
- Molecular diffusion important
- Usually matrix flow

Field

- Hard to know where water is flowing
- Temperature gradients
  - Cold inj. water hot reservoir
- Large variation in flooding rate
  - High flooding rates close to injector and producer
- Molecular diffusion?
- Fracture and matrix flow
- Dispersion

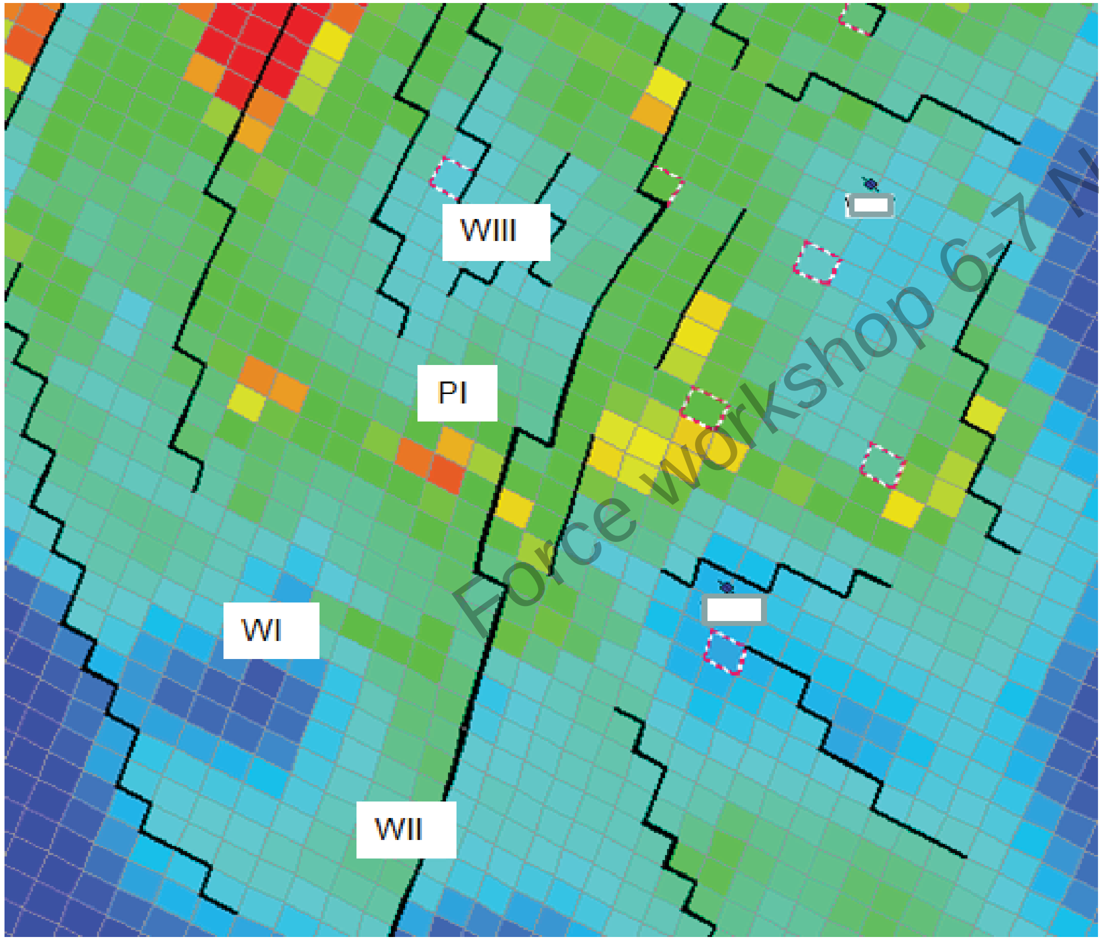
Reservoir model for smart water

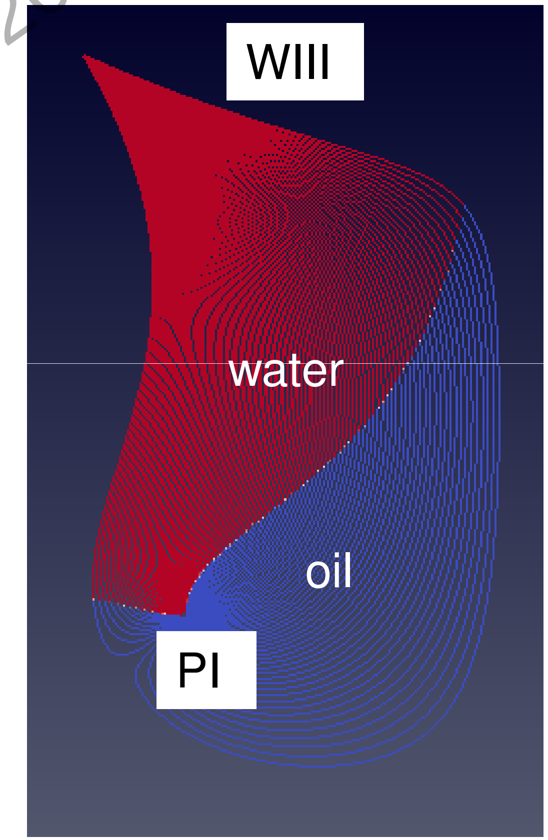
- Geochemical reactions
  - Bulk & surface aqueous chemistry
- Temperature model
- Interpolation between oil-wet and water wet Pc & rel. perm
- Good grid resolution

Simple flow model – adv chemistry

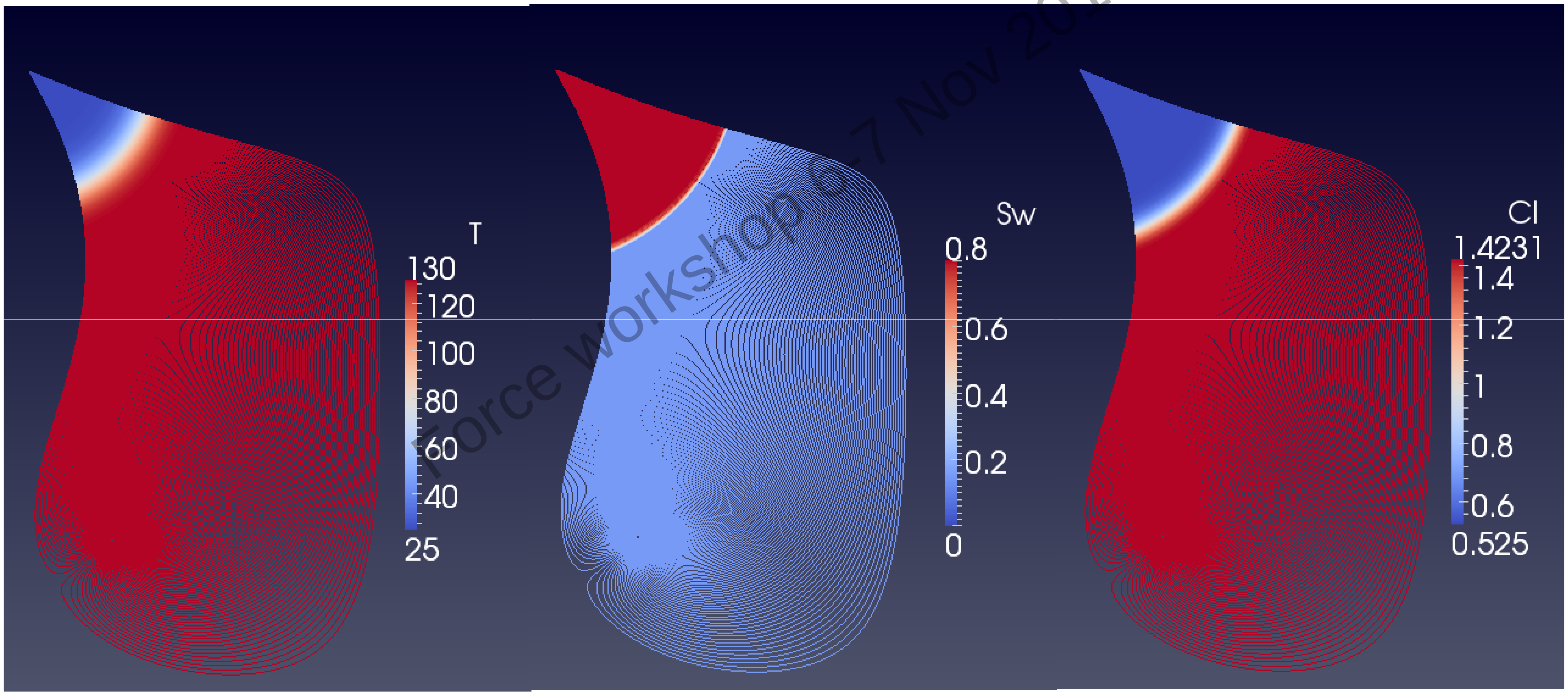
- 2D flow of incompressible fluids
- Homogeneous reservoir
- Streamlines constant in time
- Piston-like displacement of oil and water
- Negligible diffusion and dispersion
- Neglect heat exchange between streamlines & reservoir

Homogeneous matrix flow

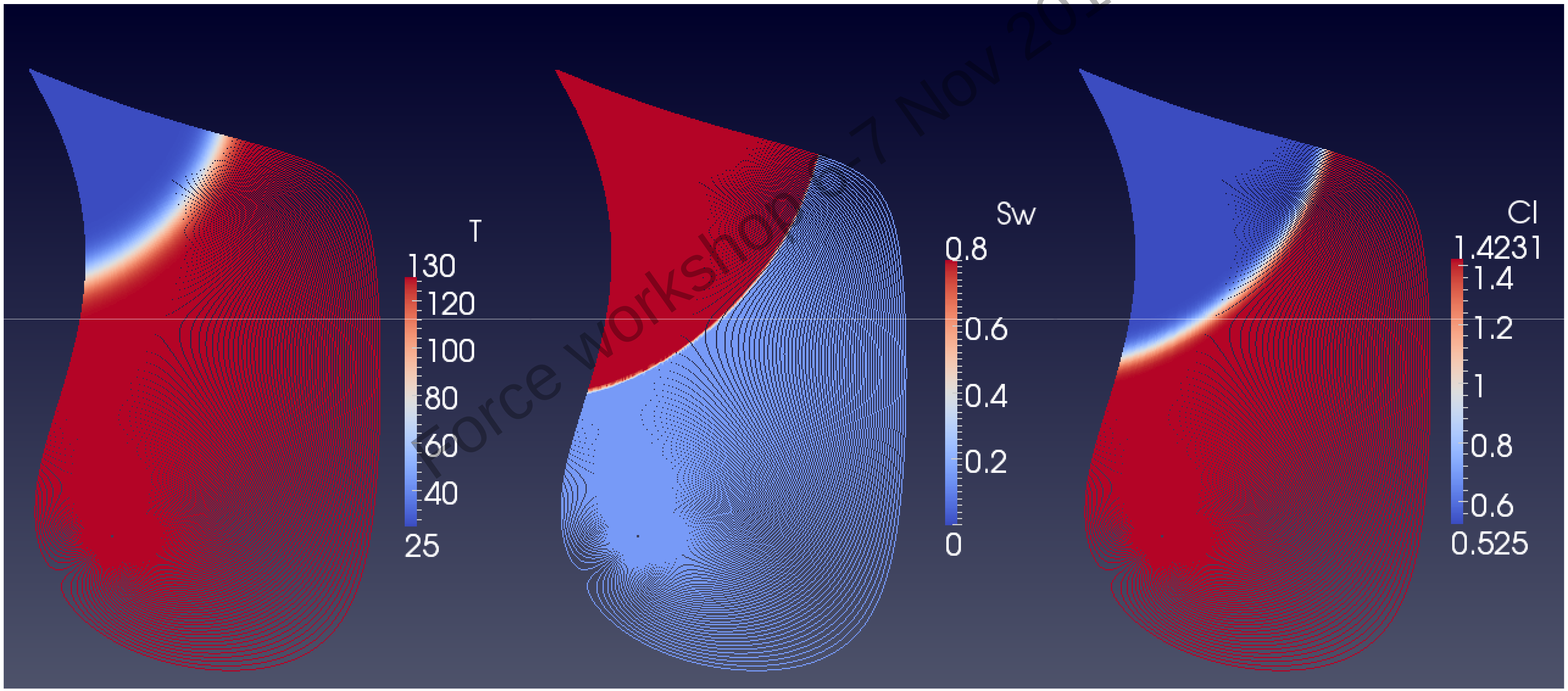




1 year



3 years



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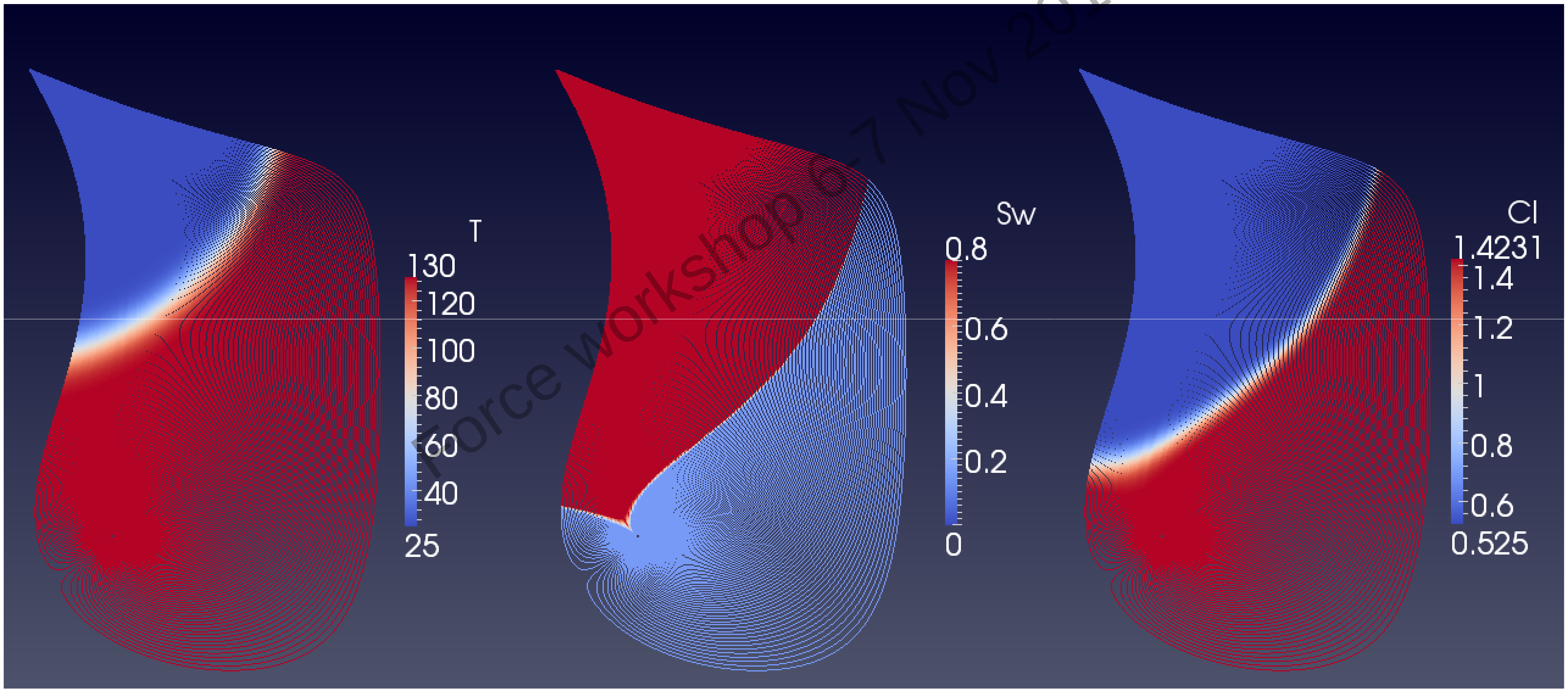
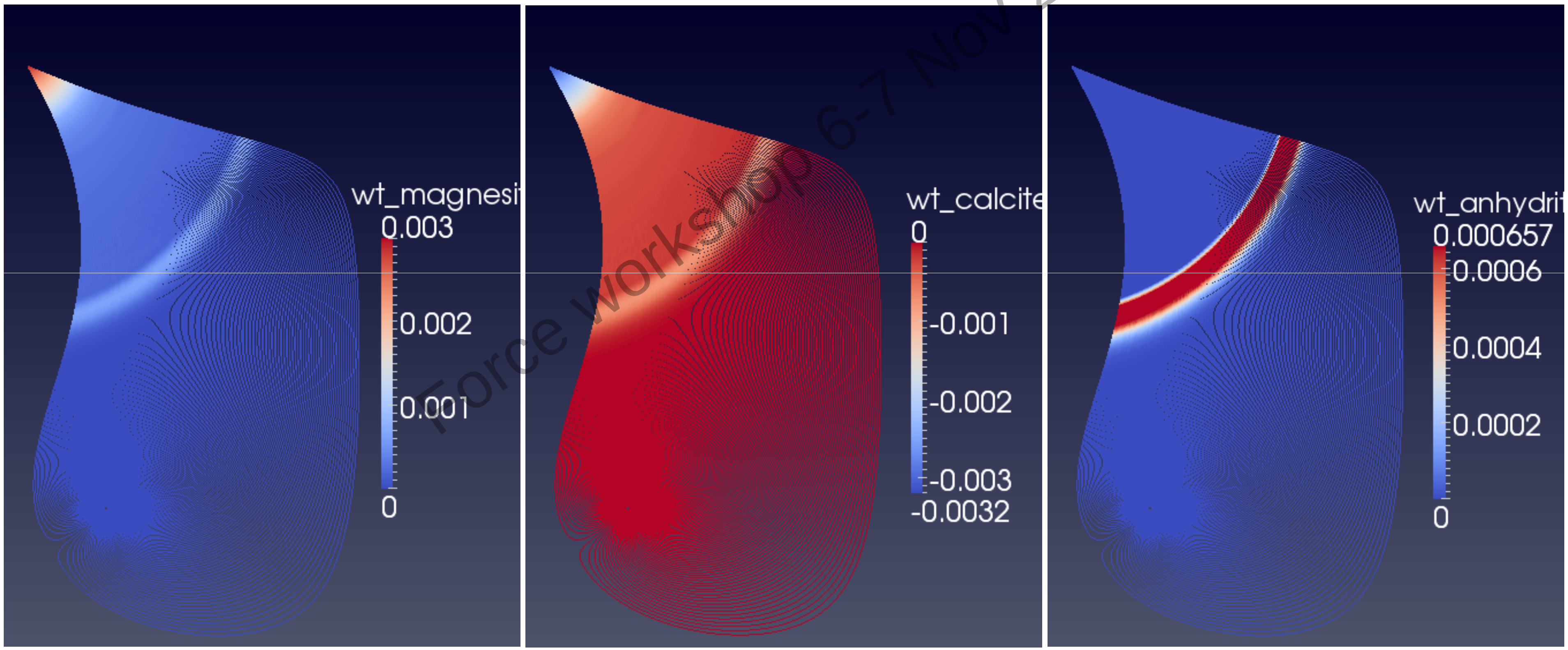
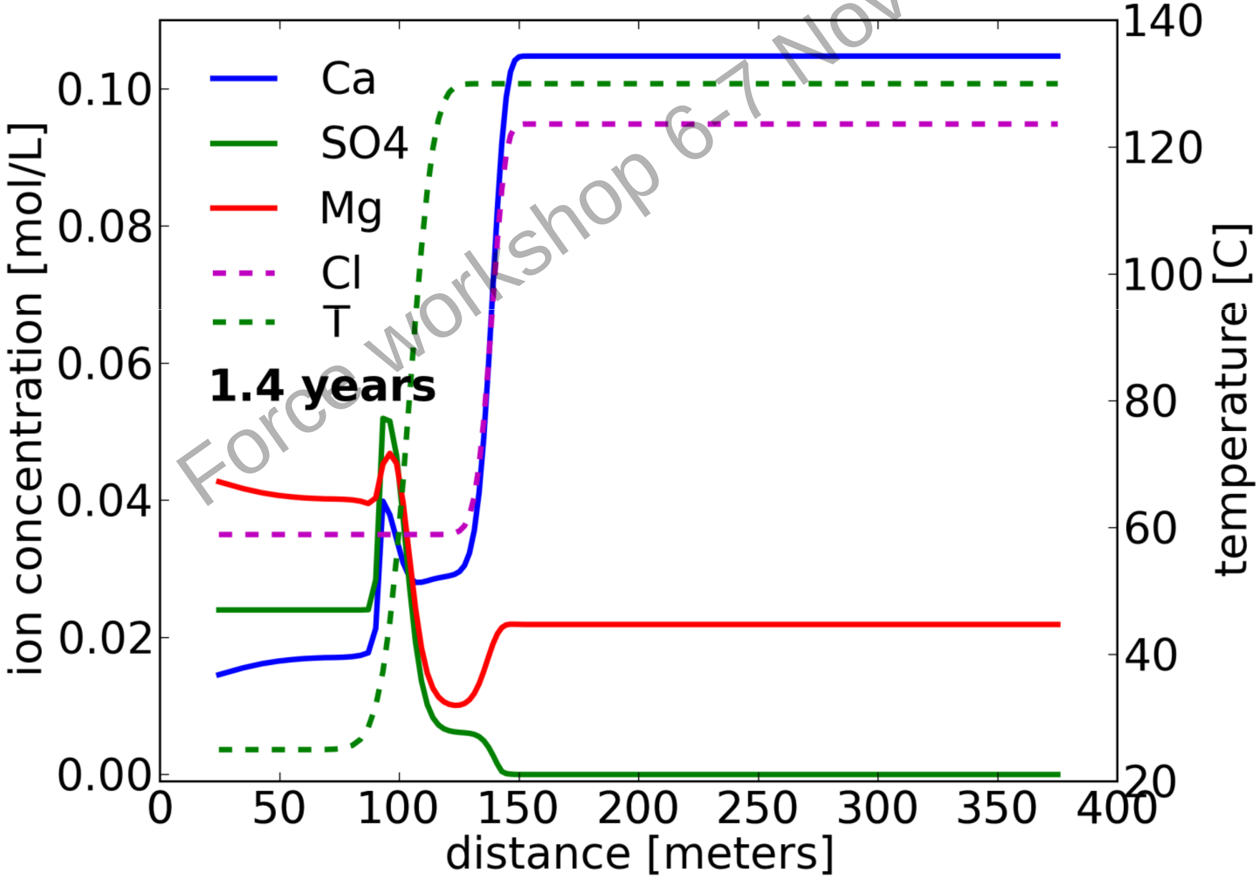
5.3 years



5.3 years mineral alteration



Ion profiles shortest streamline



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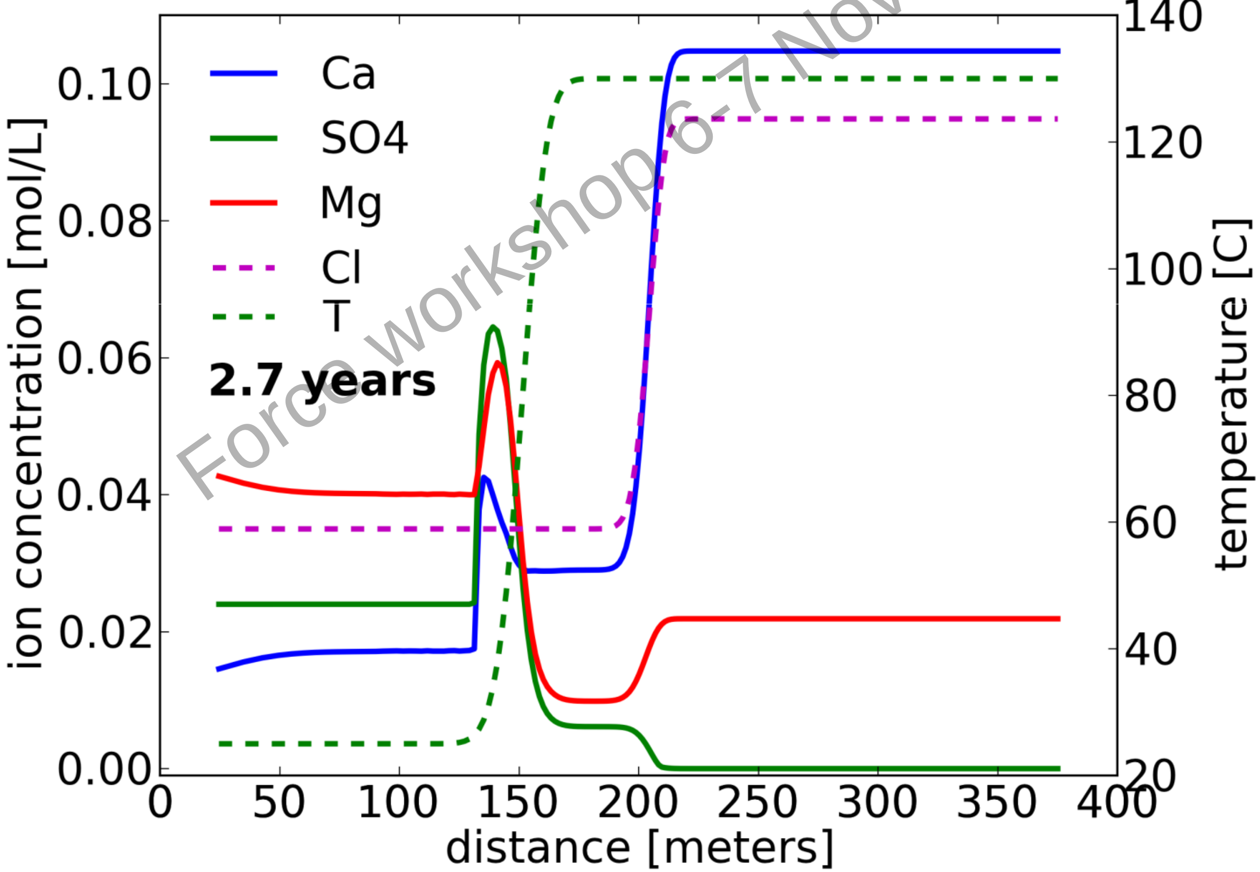

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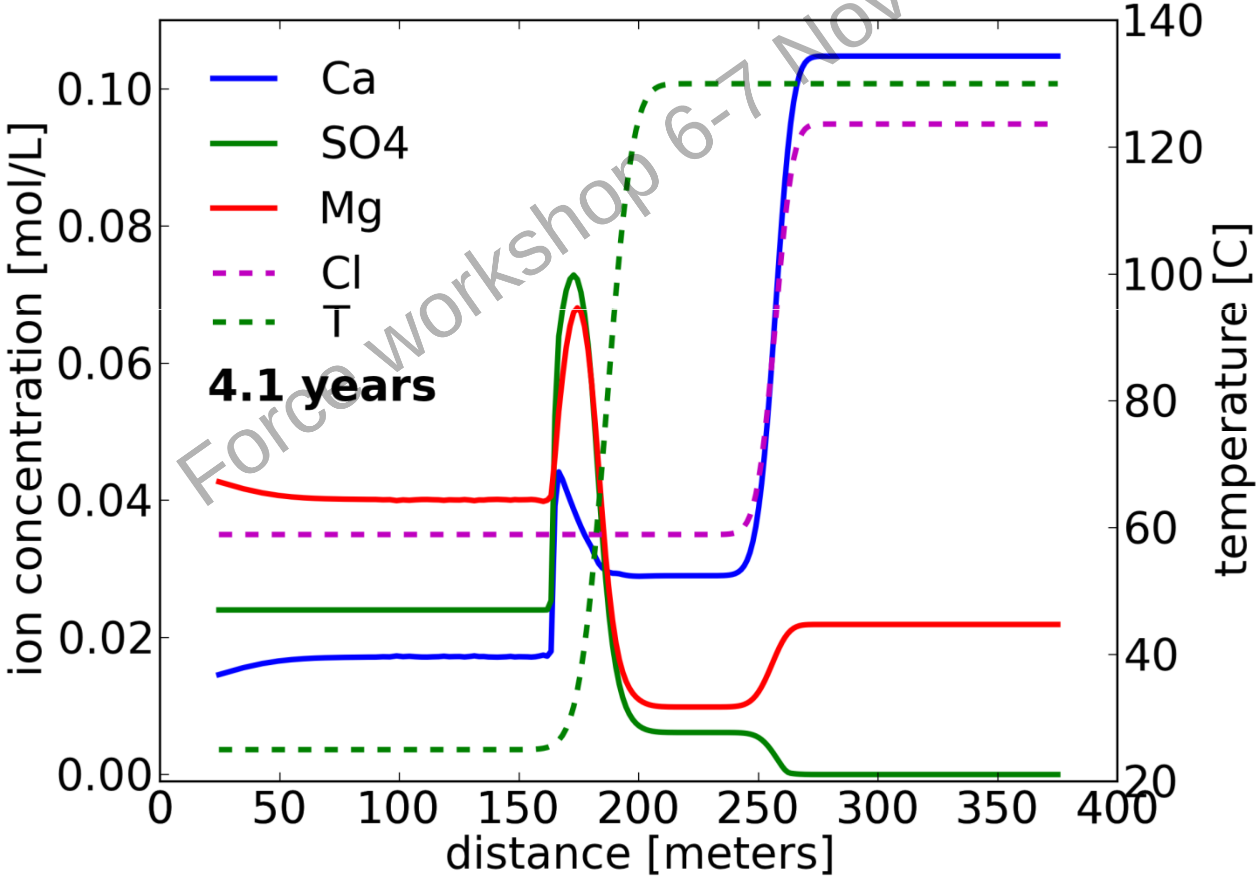

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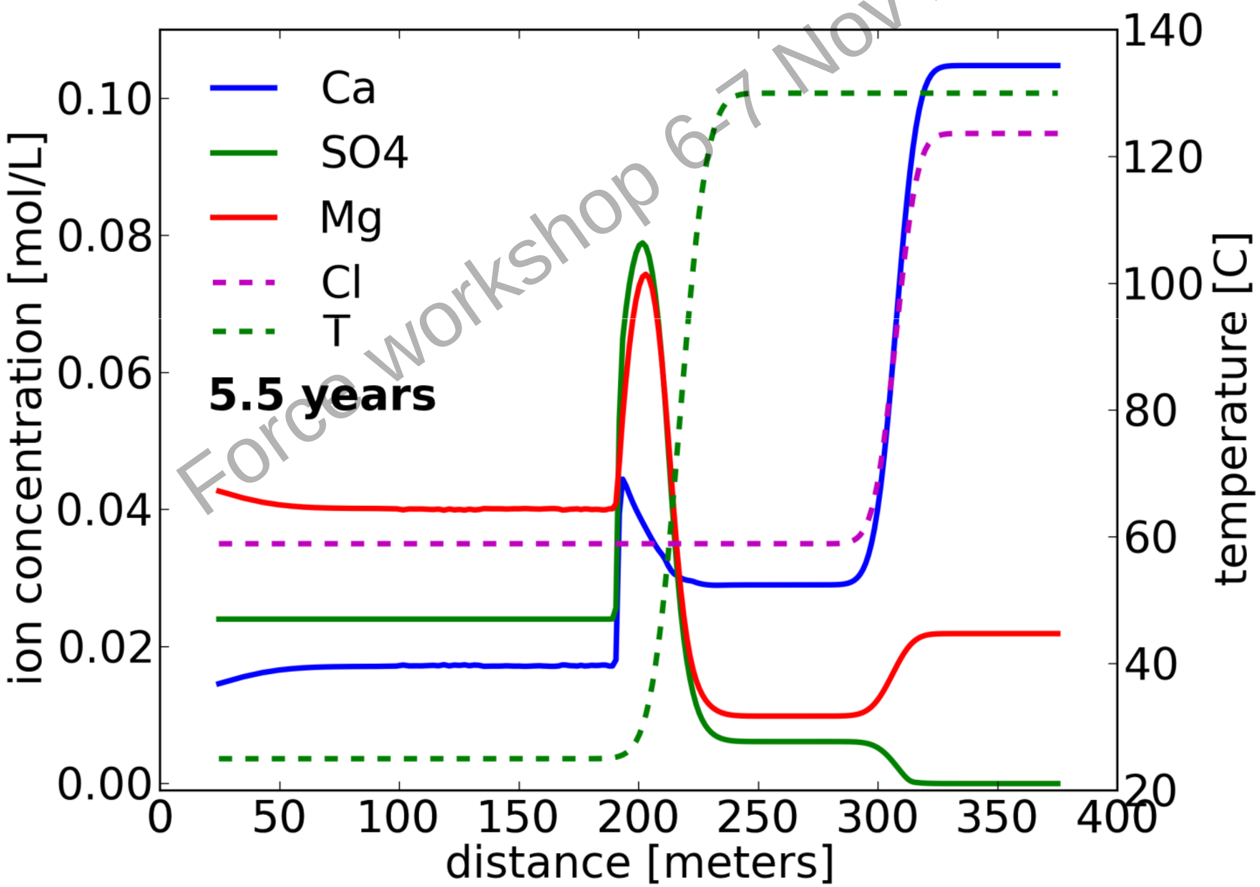

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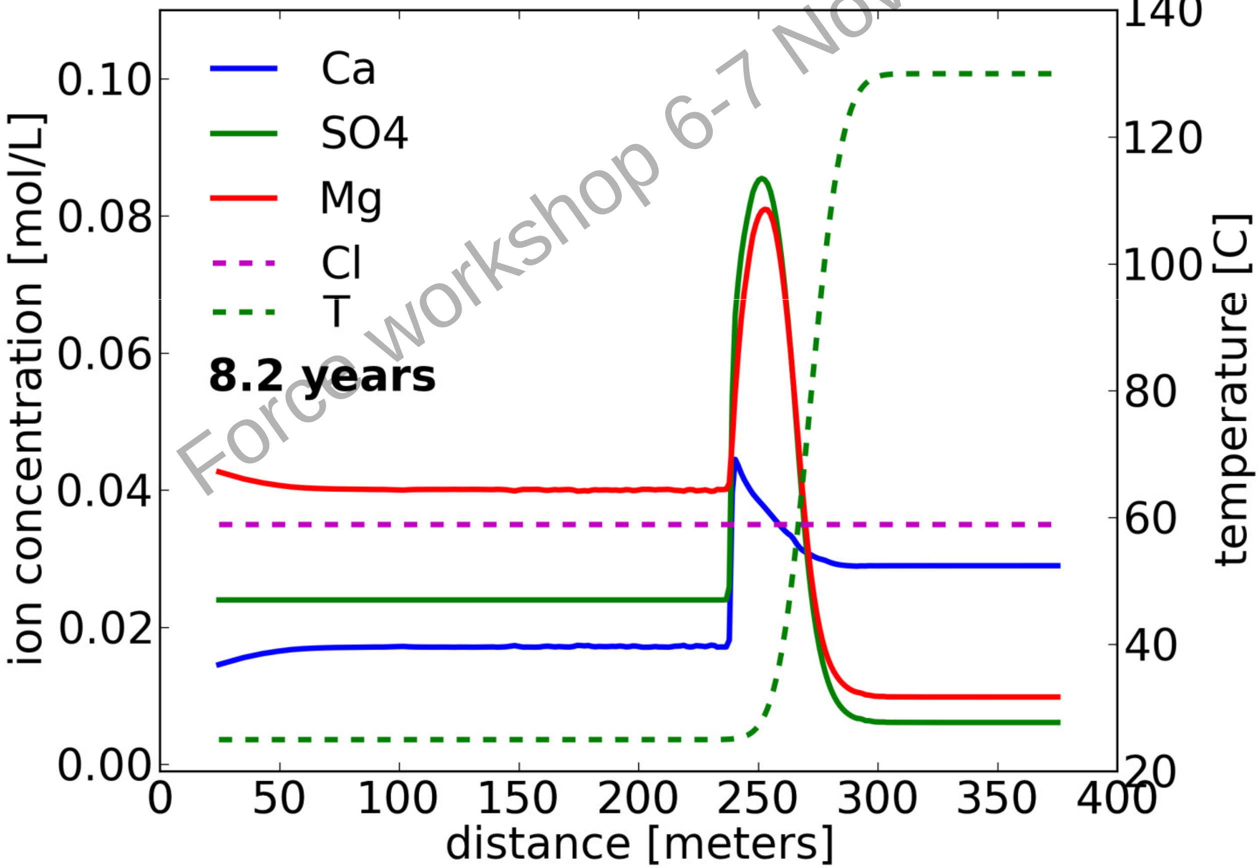

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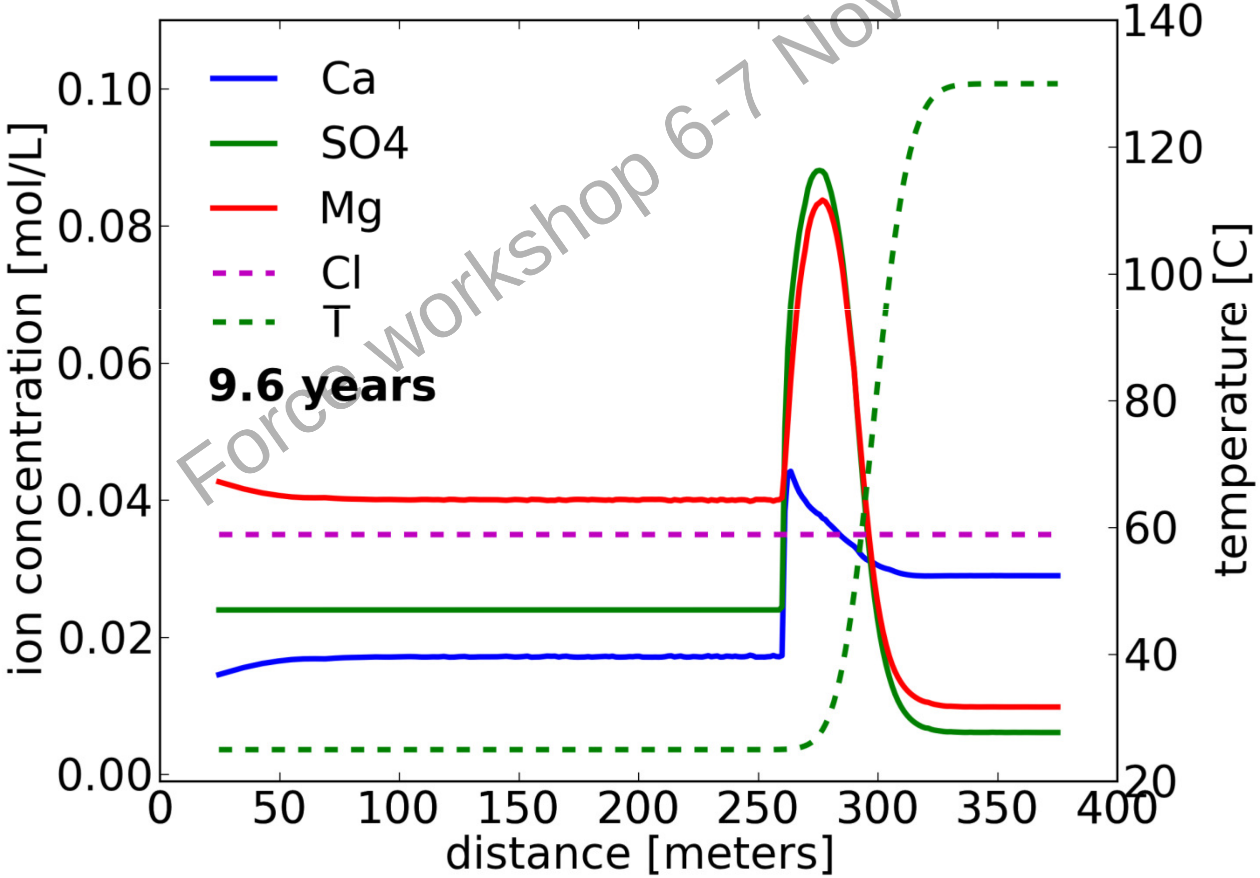

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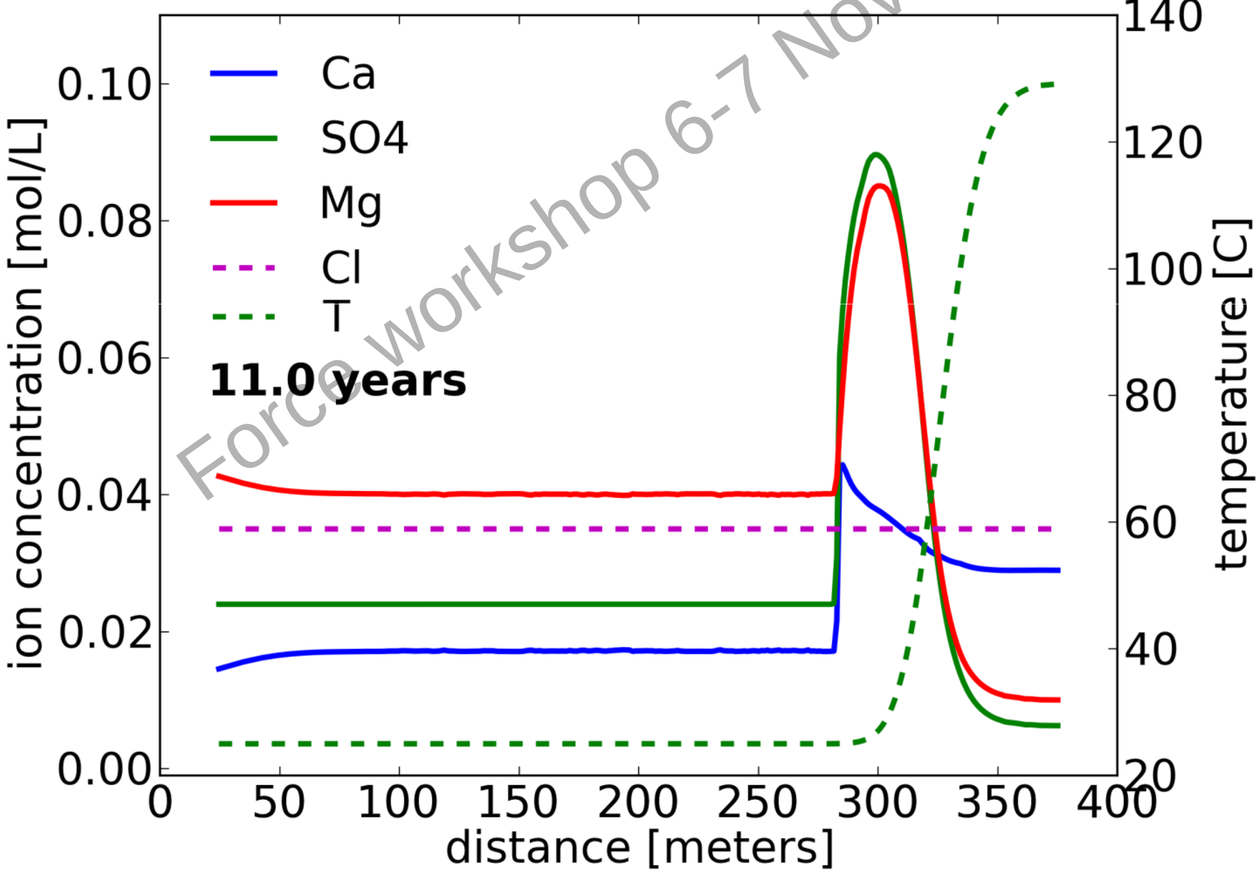

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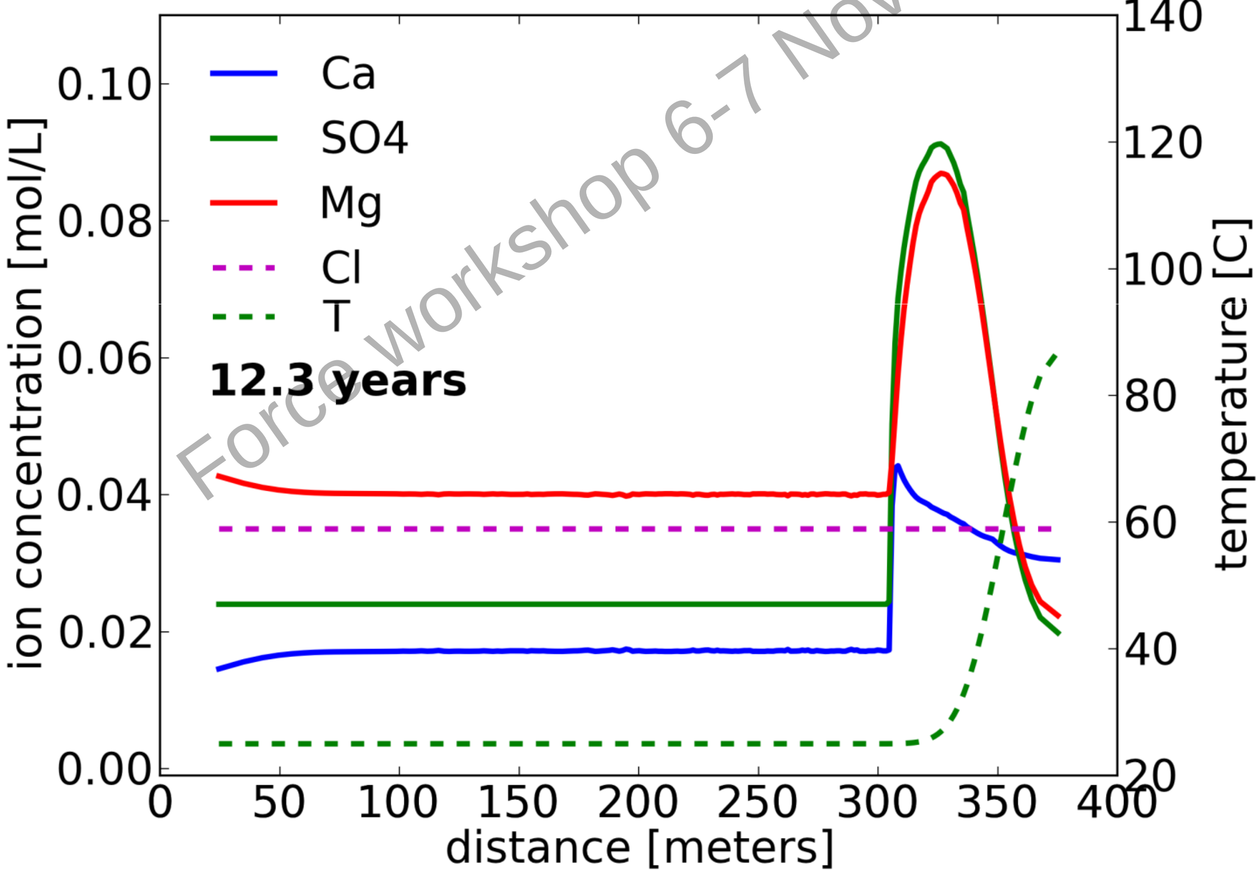
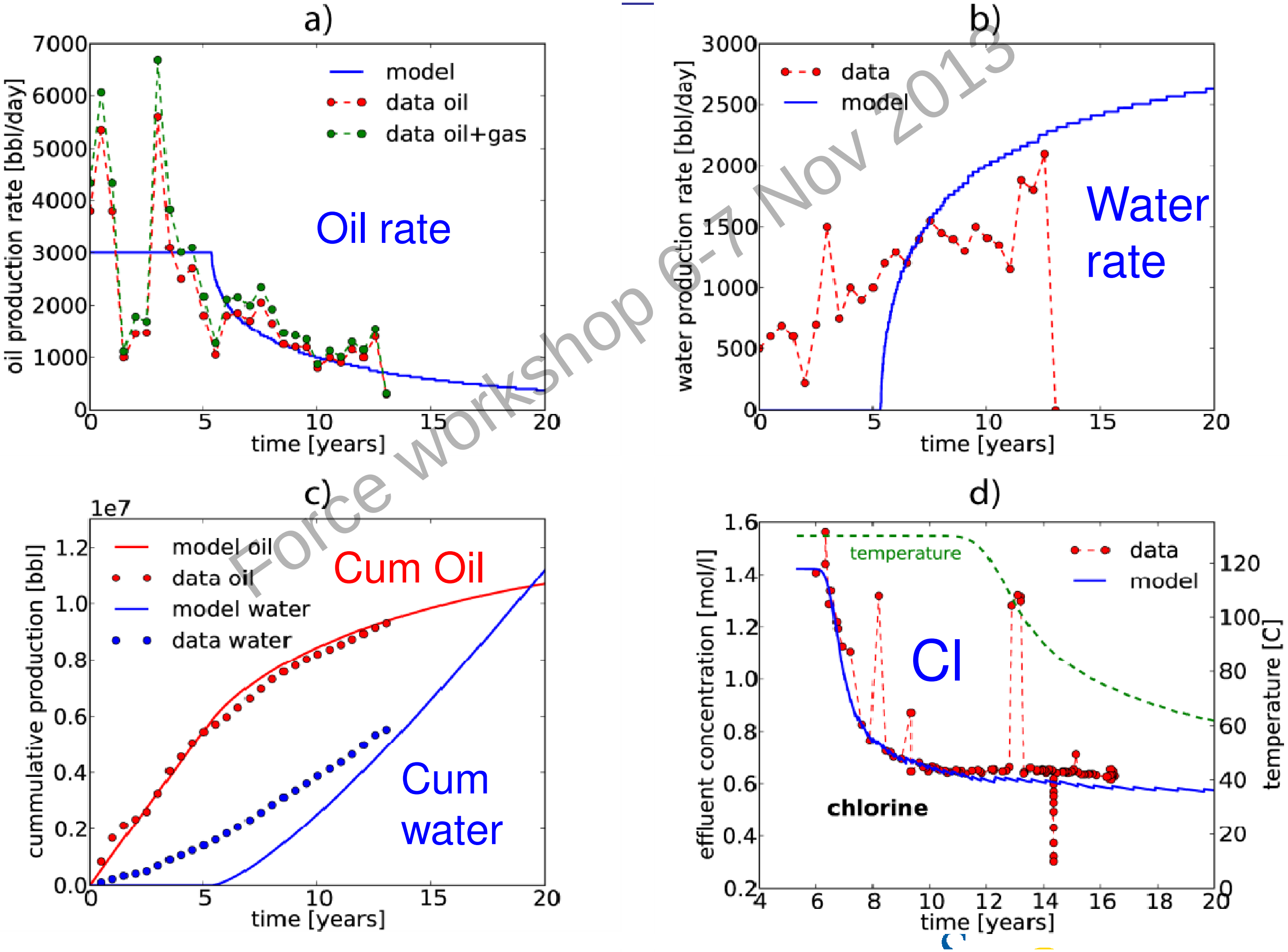
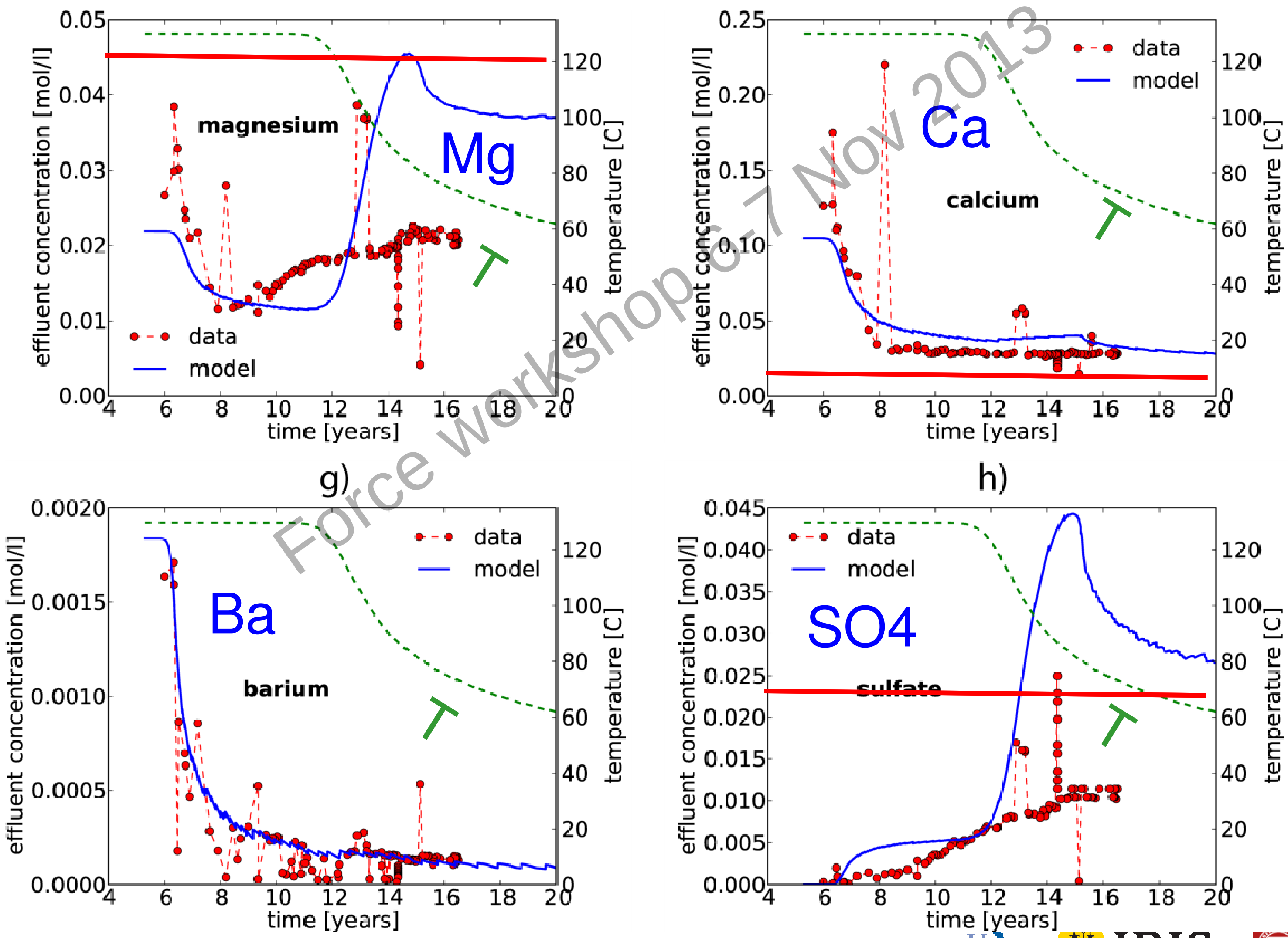


Comparison with data



Produced water ions



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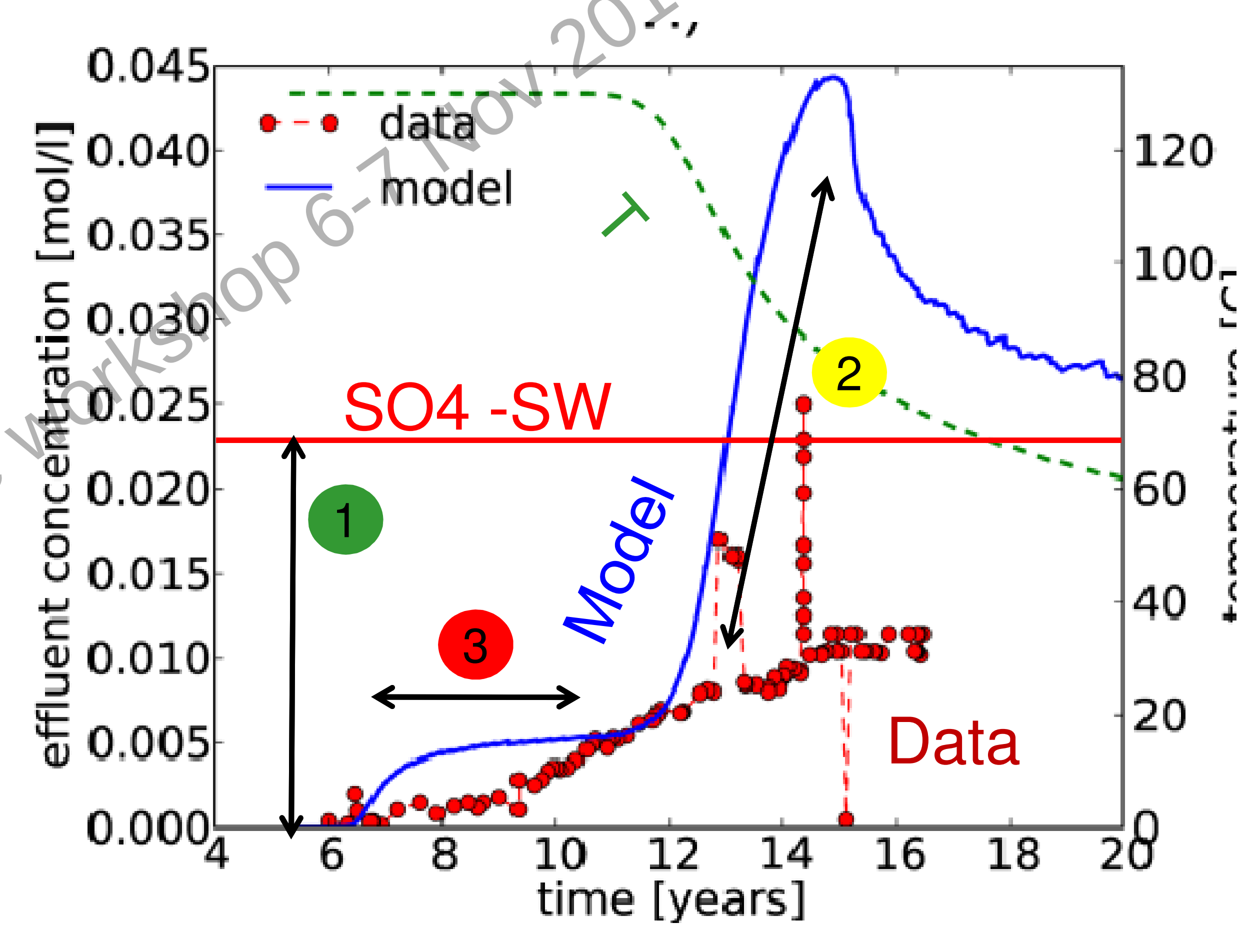
SO4 - Produced water

1. Net loss – precipitation of anhydrite

2. Sensitive to T profile – improve T model

3. Lag in sulphate – adsorption in reservoir



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Summary

- Similar behavior observed in lab and field
  - Ca-gain (dissolution?), Mg-and SO4 loss (precipitation?)
- Ion profile sensitive to reservoir T model
  - Used as a tool to constrain T-model?
- Pore water composition changes from injector to producer
  - Important for optimal EOR performance
- Similar approach on complex streamlines

Conclusion

- Important to model mechanism
  - Predictions, optimization
- Core to field program needed
  - E.g. water X gives Y amount of oil
  - Missing opportunities?
- Standard reservoir models not suited for water chemistry
  - Stream line approach?