Simulating Transport of Perfluorocarbon Tracers in the Cranfield Geological Carbon Sequestration Project

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Objectives

- Simulation of multiphase flow of CO_2-brine and perfluorocarbon (PFC) tracer for Cranfield detailed area of study (DAS)
- Evaluating breakthrough curves (BTCs) and breakthrough times (BTs) for PFCs (PMCP, PMCH, PTCH, and PECH/PDCH) and SF_6 tracers co-injected with CO_2
- Study how combination of PFC pulses & simulation results help in constraining heterogeneity & flow paths development over time

Reservoir Simulator

- Multi-phase compositional *compressible* flow
- Thermodynamic equilibrium: equality of fugacities of components in each phase
- Cubic-plus-association (CPA) EOS
- Darcy & pressure equations by Mixed Hybrid FE (MHFE)
- 2^{nd} order discontinuous Galerkin (DG) for transport equation

Numerical Set-up

- DAS within Cranfield (Figure 1 & 2)
- Petrophysical properties from *The University of Texas at Austin, Bureau of Economic Geology* (see Figure 3)
- Aquifer temperature: 128°C
- Initial pressure at bottom: 32 MPa
- CPA-EOS parameters tuned to match Cranfield data
- Brooks-Corey relative permeabilities

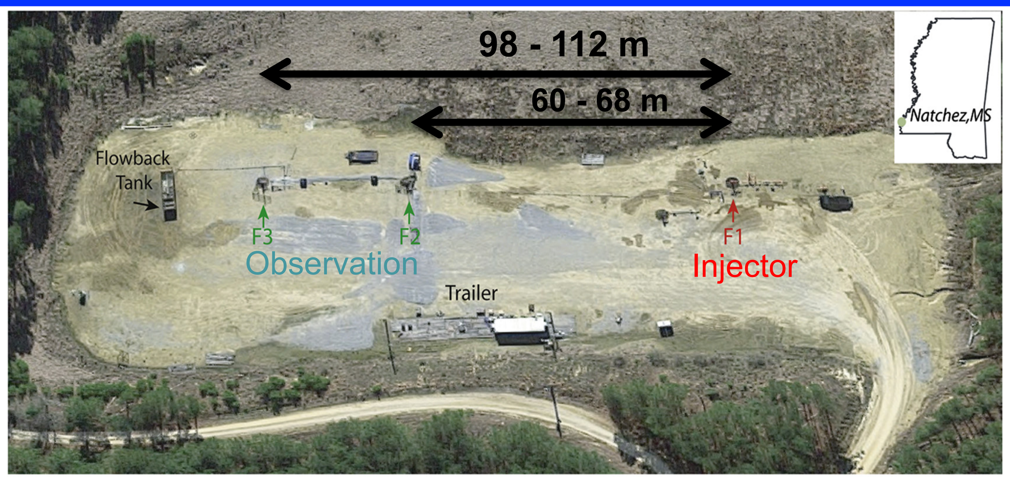


Figure 1
DAS with an injector (F1) and observation wells F2 and F3

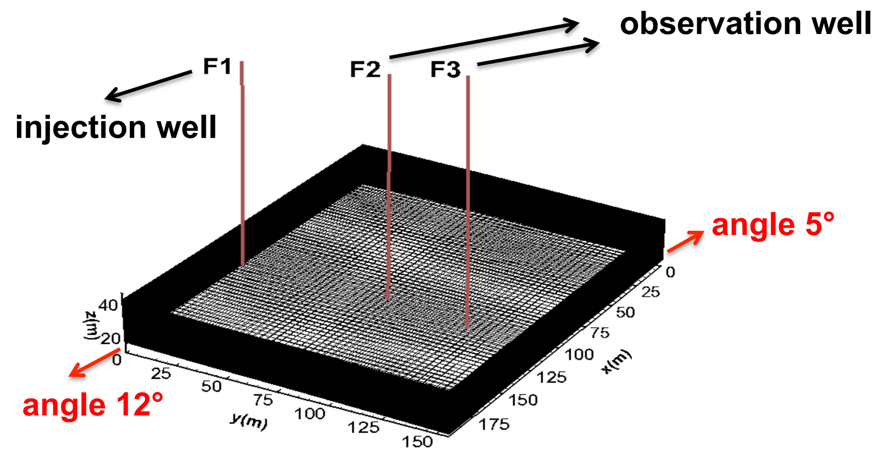


Figure 2
Numerical grid for DAS. The grid is 155 × 195 × 24 m^3, with 257,856 hexahedral elements. Grid block size of 3 × 3 × 0.3 m^3

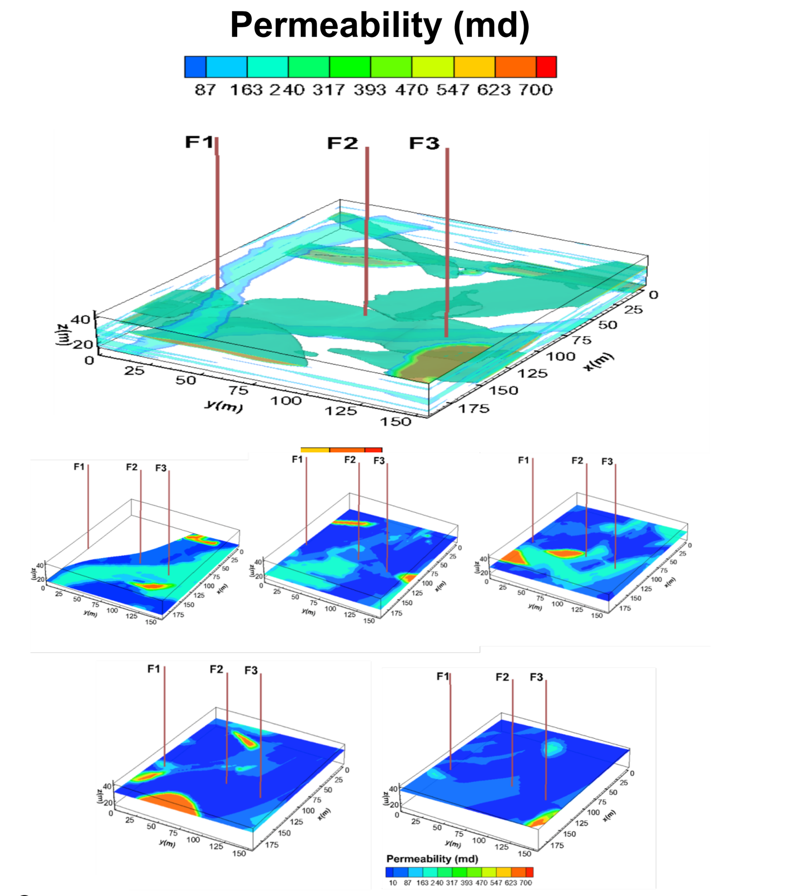


Figure 3
Formation permeability shows modeled fluvial channels

Figure 4 Injection rate

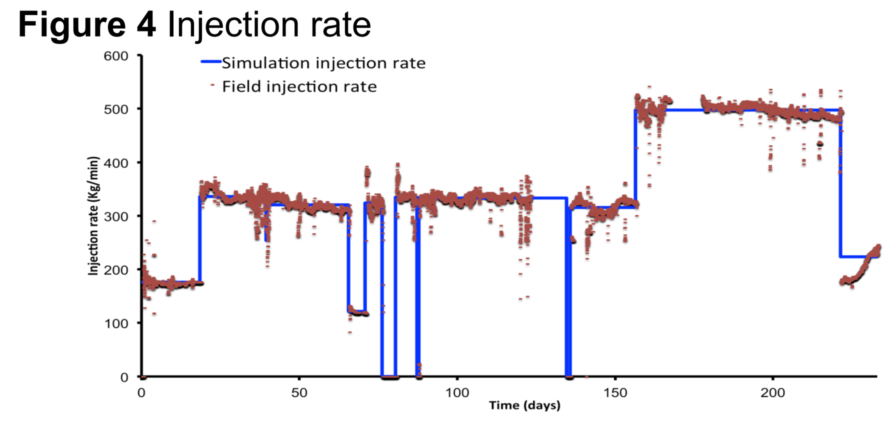


Figure 5 Bottom-hole pressure

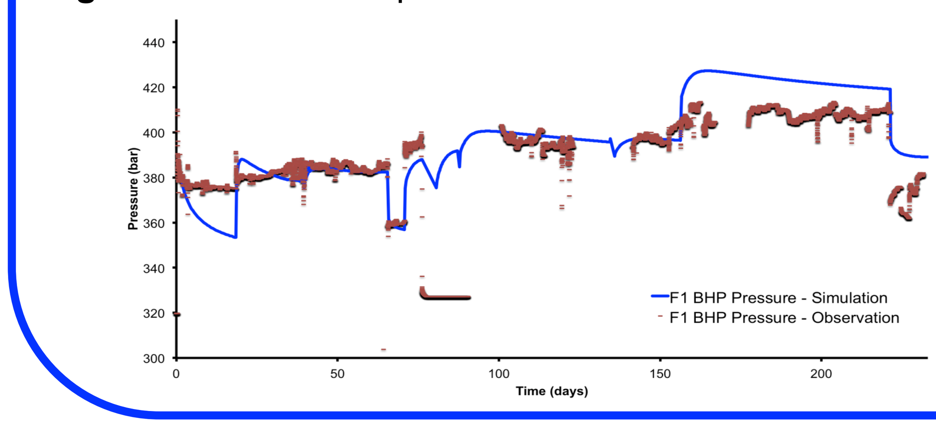


Figure 6
2009 and BTCs for 20 individual grid cells throughout the observation wells (F2 and F3) perforated intervals. It is clear that multiple channels of the PMCH tracer reach the observation wells at different times and depths

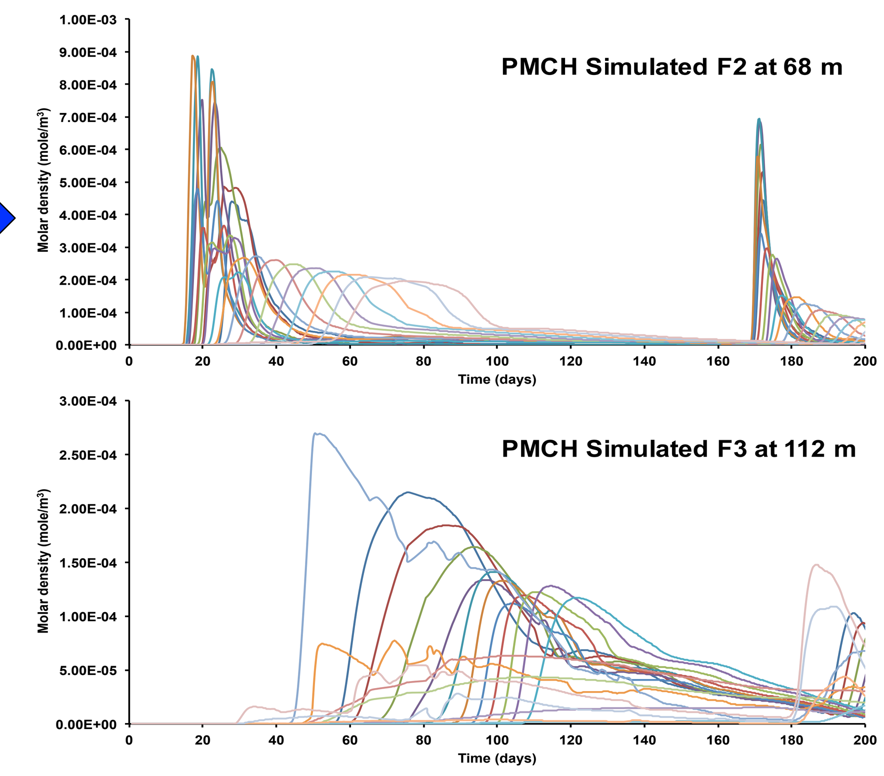


Figure 7
2009 and 2010 BTCs for PFCs and SF_6 for F2 (left column) and F3 (right column). Blue circles for times < 50 days correspond to measured data in the 2009 campaign. The 2010 measurements are located around 150 days

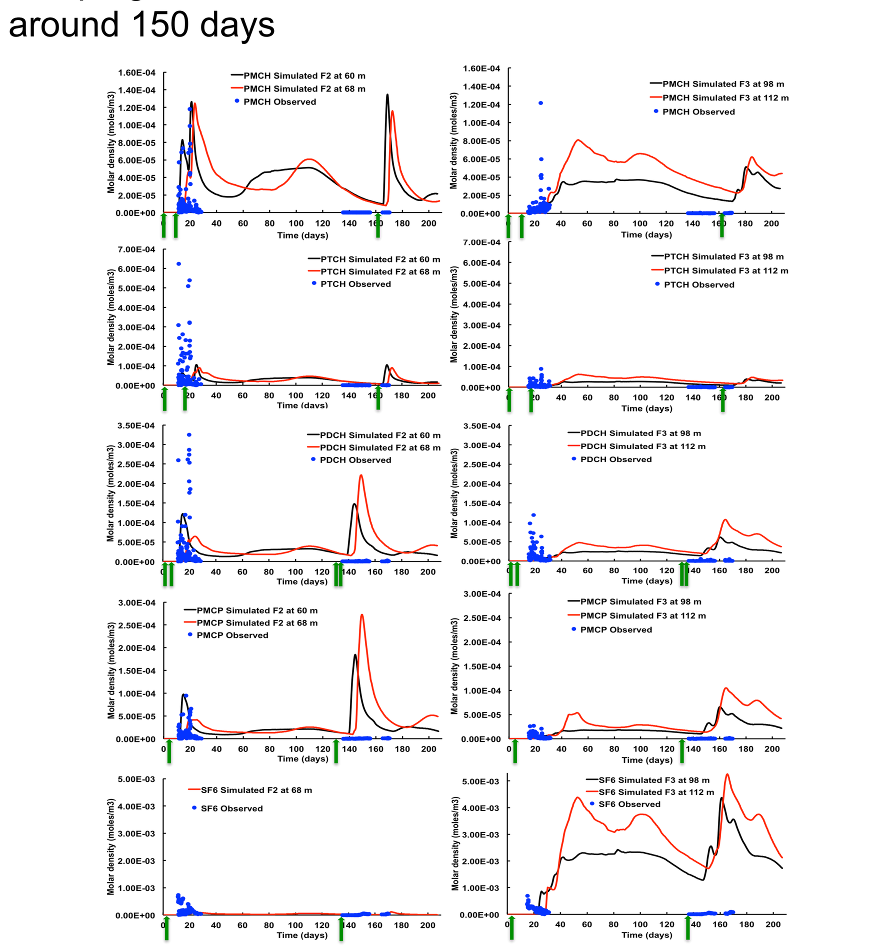
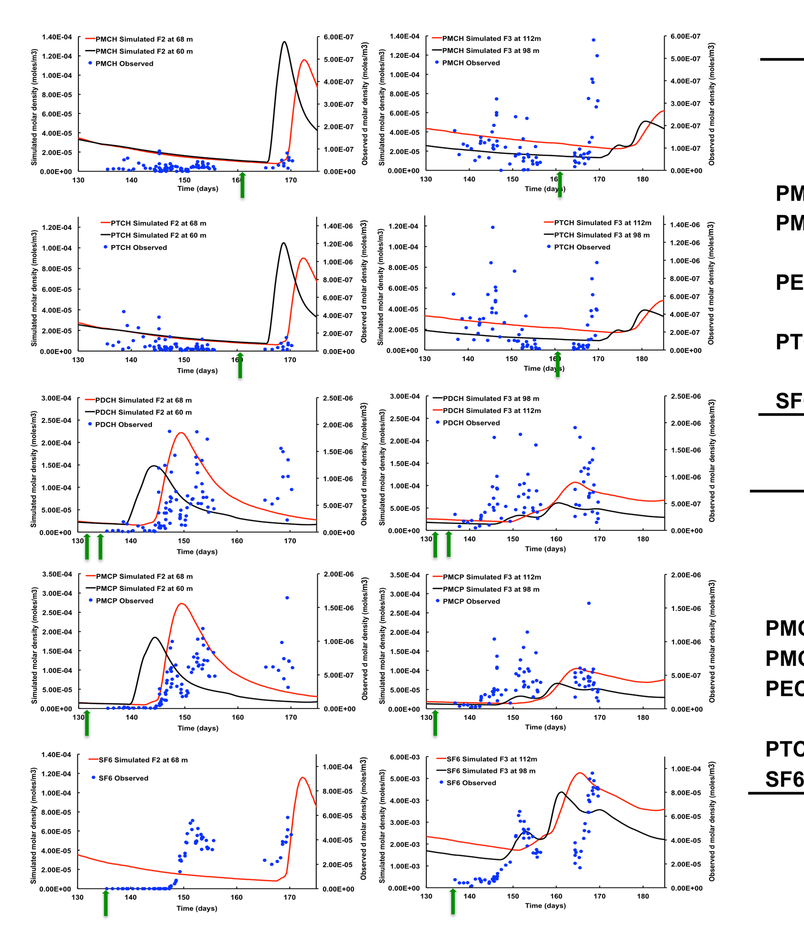


Figure 8
2010 BTCs for PFCs and SF_6 for observation wells F2 (left column) and F3 (right column). Measured data are shown on a different scale (right axis)



Injected mass, injection schedule, observed, and simulated BTs

2009 campaign

	Injected		Breakthrough time (days)			
			Observed		Simulated	
	Mass (kg)	Time (days)	F2	F3	F2	F3
PMCP	0.6	3.125	13.7	15.6	11	23.2
PMCH	1.1	0	11.6	17.2	10	23.2
	0.6	11.2	-	23.7	-	31
PECH	0.6	1.3	11.4	15.6	10.2	23.2
	0.6	3.125	-	17.0	-	31.5
PTCH	1.1	0.25	11.1	16.5	10.4	23.5
	0.6	18.5	-	29.6	-	29
SF6	40.4	2.5	12.0	14.8	10.8	23.2

2010 campaign

	Injected		Breakthrough time (days)			
			Observed		Simulated	
	Mass (kg)	Time (days)	F2	F3	F2	F3
PMCP	1.4	132.6	148.8	145.9	139.5	145.5
PMCH	1.0	161.5	-	168.5	165.5	170.5
PECH	1.3	132.7	146.3	145.5	139	144.5
	0.5	134.7	-	-	142	165.0
PTCH	1	161.5	-	168.5	165.5	170
SF6	31.75	135	153.1	147.0	141	147

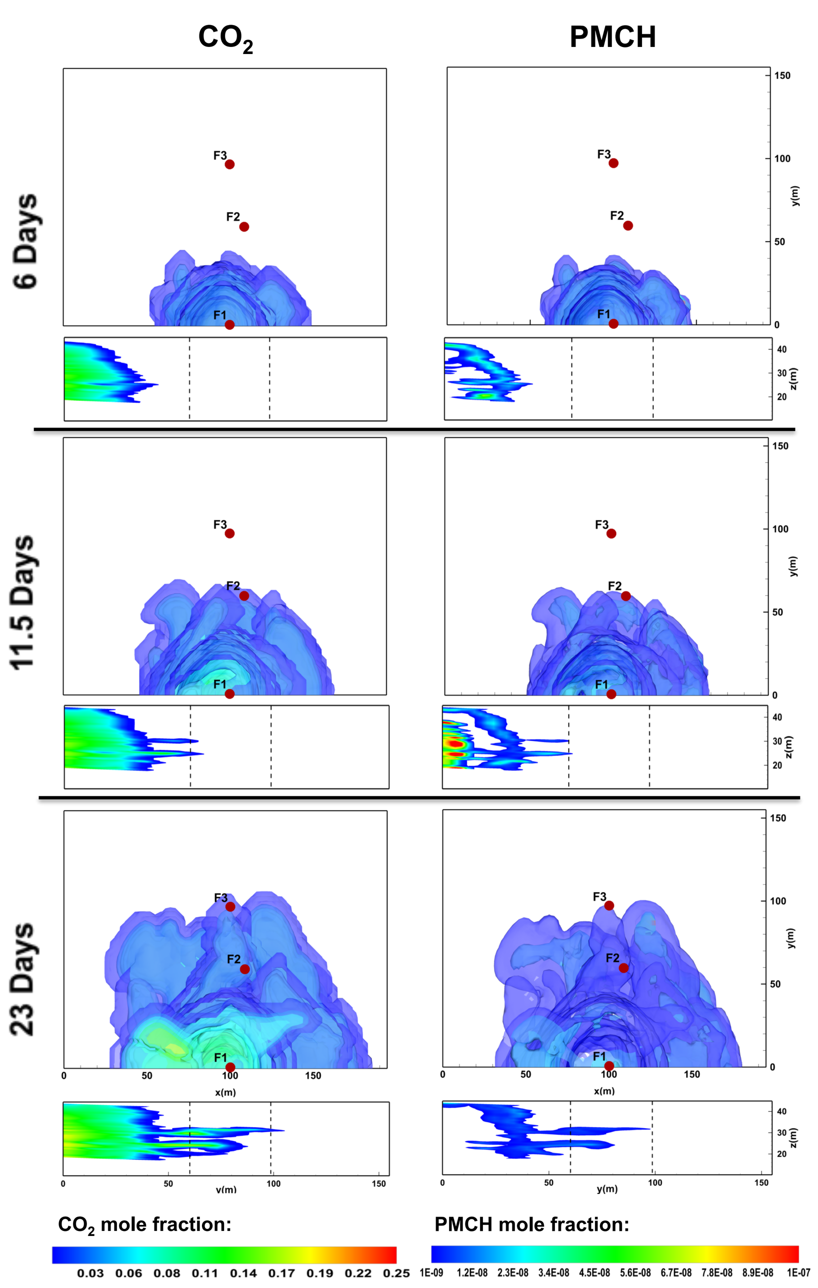
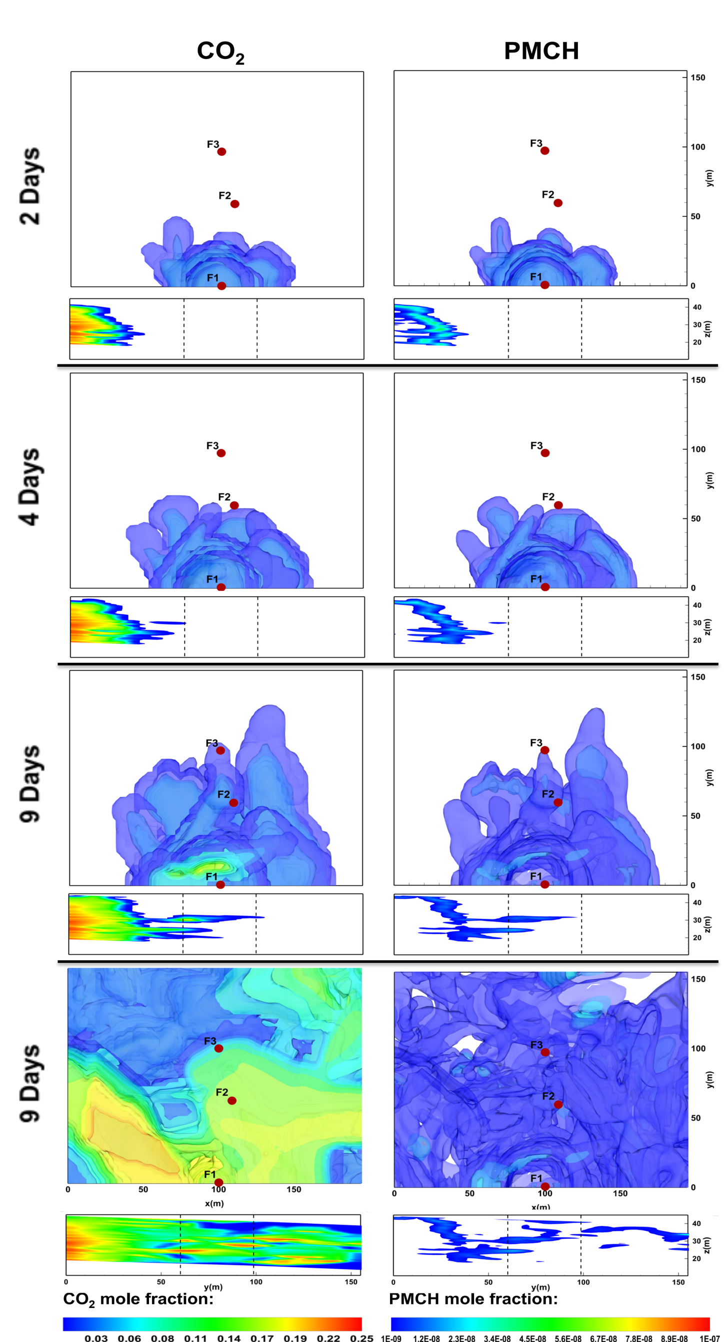


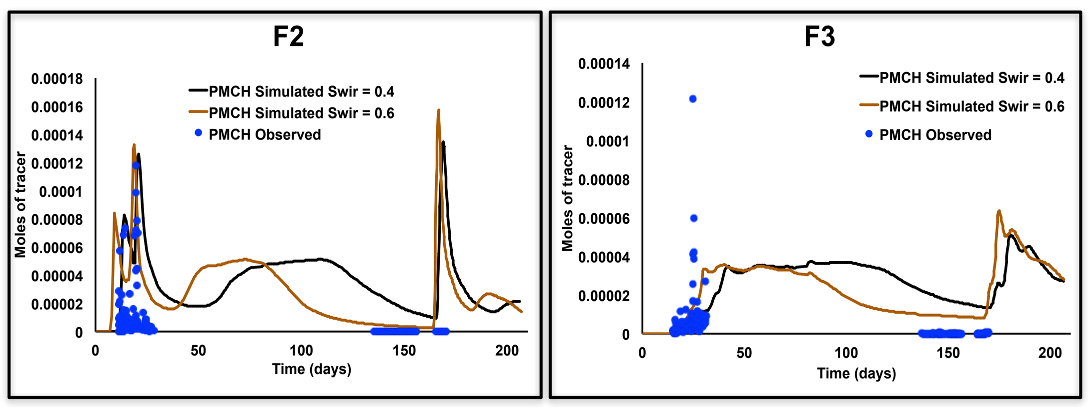
Figure 9
Contours of CO_2 and PMCH mole fraction after 6, 11.5, and 23 days of CO_2 injection (**2009 campaign**). PMCH injected at time zero and 11.5 days. Vertical cross sections in the middle of the computational domain are also shown. The dotted lines show the locations of F2 and F3 at 60 m and 98 m, respectively. BTs of PMCH and CO_2 in F2 and F3 are nearly the same, confirming that the PMCH follows CO_2 transport pathways

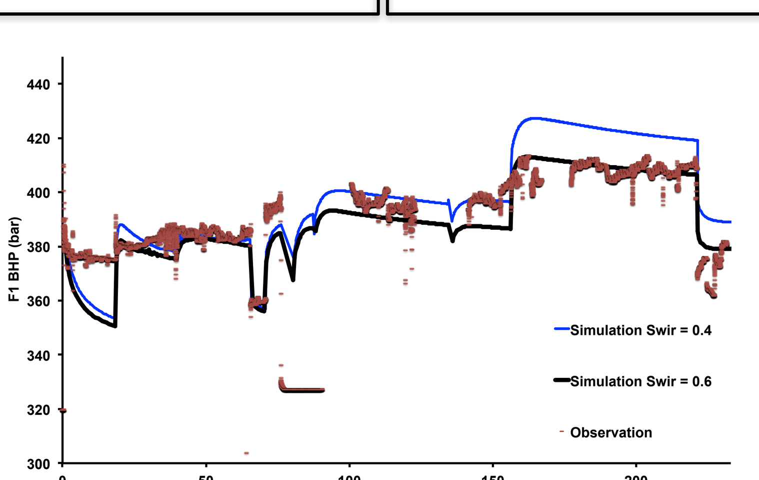
Figure 10
Contours of CO_2 and PMCH mole fraction after 2,4, and 9 days of CO_2 and PMCH injection starting at time 161.5 days (**2010 campaign**). The top 3 rows of panels only show '**new**' CO_2 and PMCH, whereas the bottom row shows cumulative concentrations (2009 and 2010 combined)



Residual brine saturation

- Residual water saturation of 0.6 provides a better results for BTCs curves and pressure responses, especially at later times





Conclusions

- Simulations match the field data remarkably well over relatively short time-scales
- Larger discrepancy at later times due to the growing complexity of developing flow paths and tracer transport
- Perfluorocarbon tracers offers a powerful tool to interrogate the subsurface *in-situ*
- Tracer BTCs + simulations can constrain reservoir properties (e.g., distribution of fluvial depositional features) and physical processes (e.g., advection and diffusion) are

Acknowledgements

This work was supported by the U.S. Department of Energy's (DOE) Office of Fossil Energy funding to Oak Ridge National Laboratory (ORNL) under project FEAA-045. ORNL is managed by UT-Battelle for the U.S. DOE under Contract DE-AC05-00OR22725.

References

1. Soltanian *et al.* 2016. Simulating the Cranfield geological carbon sequestration project with high-resolution static models and an accurate equation of state. IJGGC, 54, 282-296.
2. Soltanian *et al.* Simulating transport of Perflurocarbon tracers in the Cranfield geological carbon sequestration project. IJGGC, *in review*.