Monitoring of Geological CO_2 Sequestration Using Isotopes and Perfluorocarbon Tracers

Project Number FEAA-045

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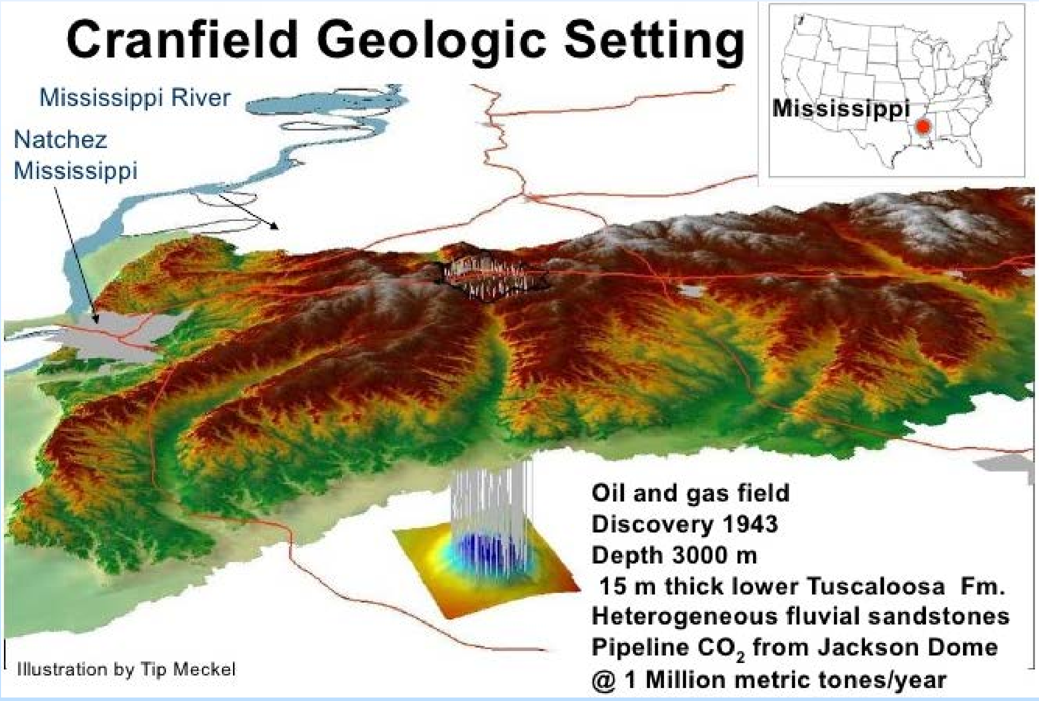
National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

- Motivation & Objectives
- Summary of perfluorocarbon tracer data
- Reservoir simulations for Cranfield project
- Conclusions
- Future work



Modified from
slideshare.net/globalccs/cranfield-large-scale-co2-injection-usa

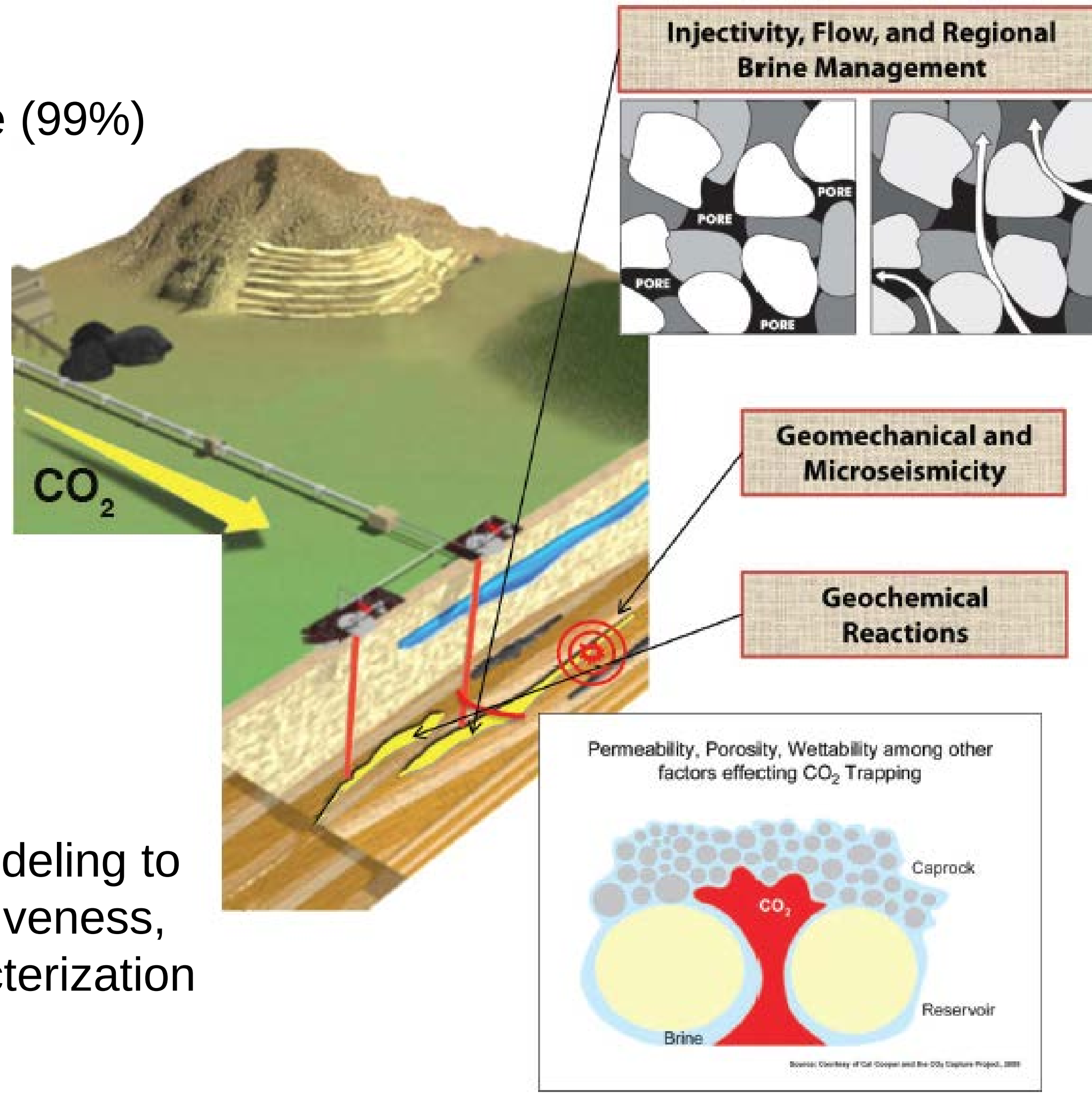
Benefit to Program

Use tracers to monitor & validate (99%) CO_2 **storage permanence**

New subsurface signal to monitor physical & chemical processes that can affect **storage efficiency:**

- Alter porosity & permeability, e.g., fracturing
- Control fluid flow, e.g., diffusion, mixing, advection, capillarity, and reaction

Couple tracers with reservoir modeling to predict storage capacity & effectiveness, aid future site selection & characterization



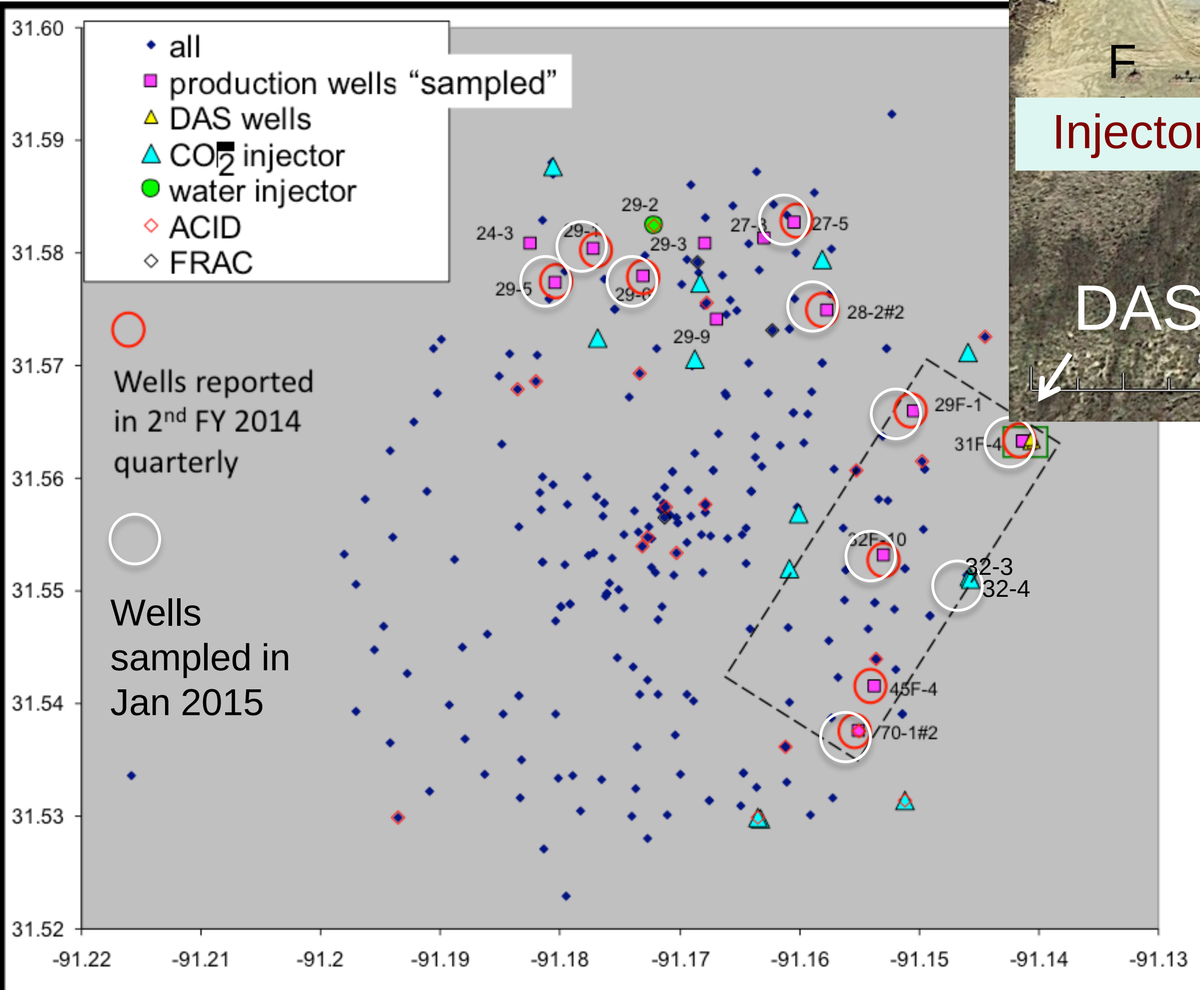
Modified from NETL Carbon Storage GSRA Technology Research Areas Illustration

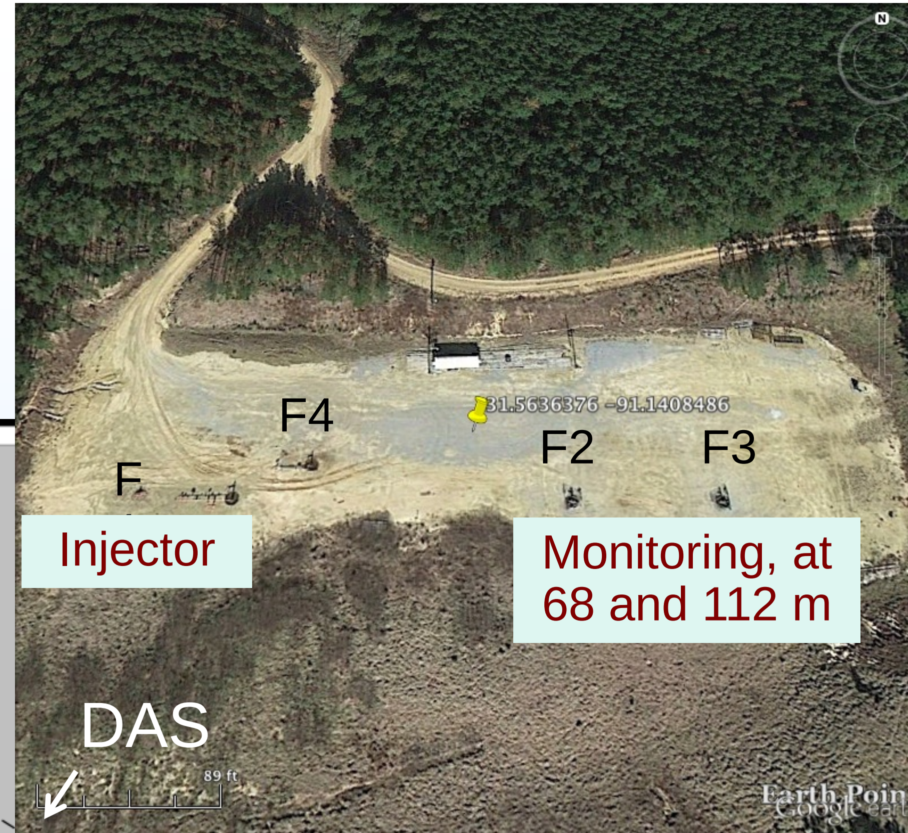
Project Overview

Develop complementary tracer methods to interrogate sub-surface for improved CO_2 storage efficiency & permanence

- Complete geochemical and PFT analysis from 5-year Cranfield, Mississippi storage project
- Improve ultra-trace detection methods for PFT mixtures
- Integrate geochemical, isotope and PFT results into an advanced reservoir simulator for improved predictions
    - Step 1: Develop high-resolution petrophysical model & reproduce earlier simulations for pressure & CO_2
    - Step 2: Incorporate natural (isotopic) and introduced (PFTs, SF_6) tracer data in simulations
- Transfer technology to storage project partners

Cranfield, MS, DAS: Detailed Area of Study





Thanks to:

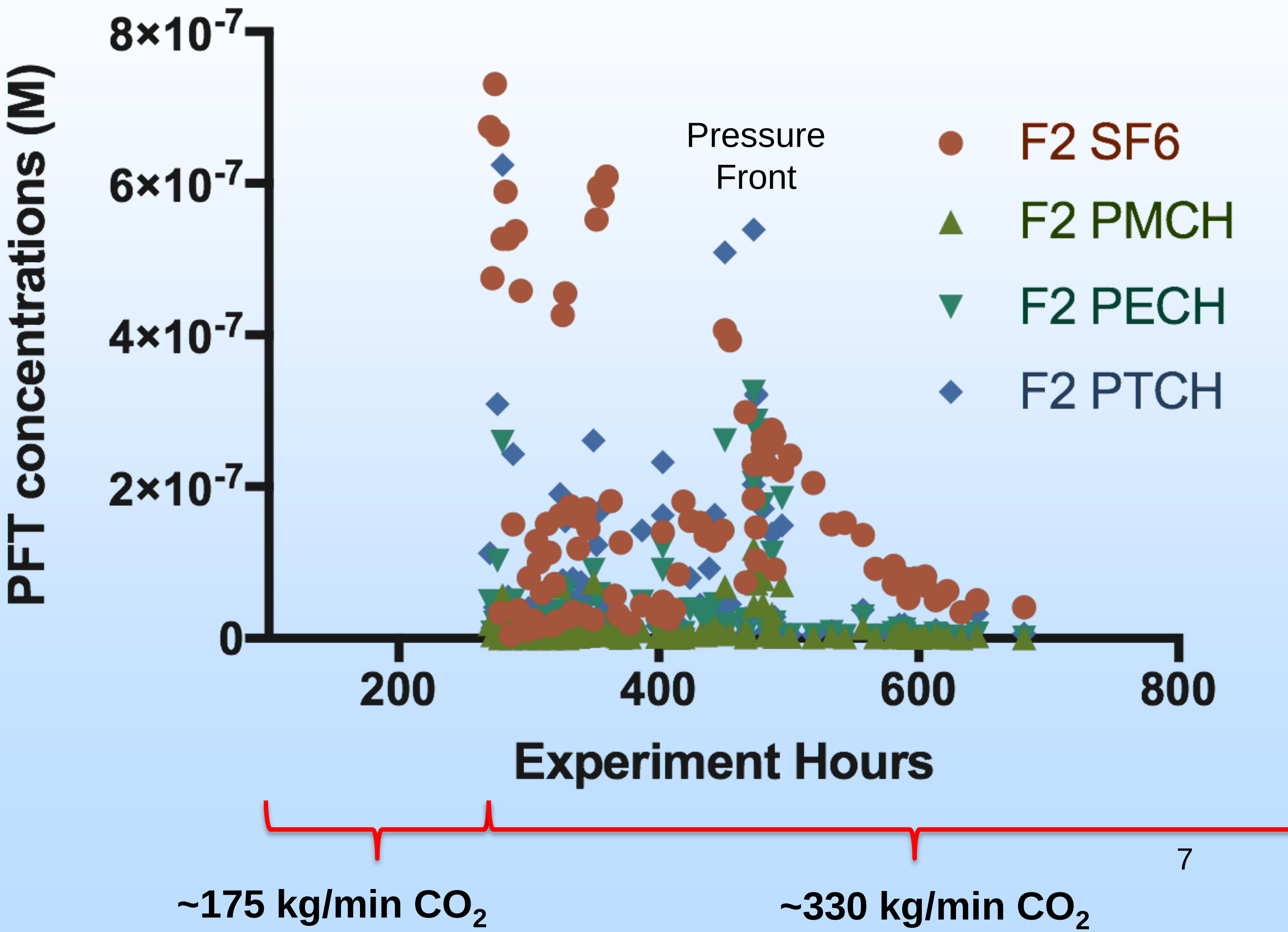
- SECARB
- TBEG
- LBNL
- Sandia Technology
- Denbury Resources

SUMMARY OF TRACER ANALYSES

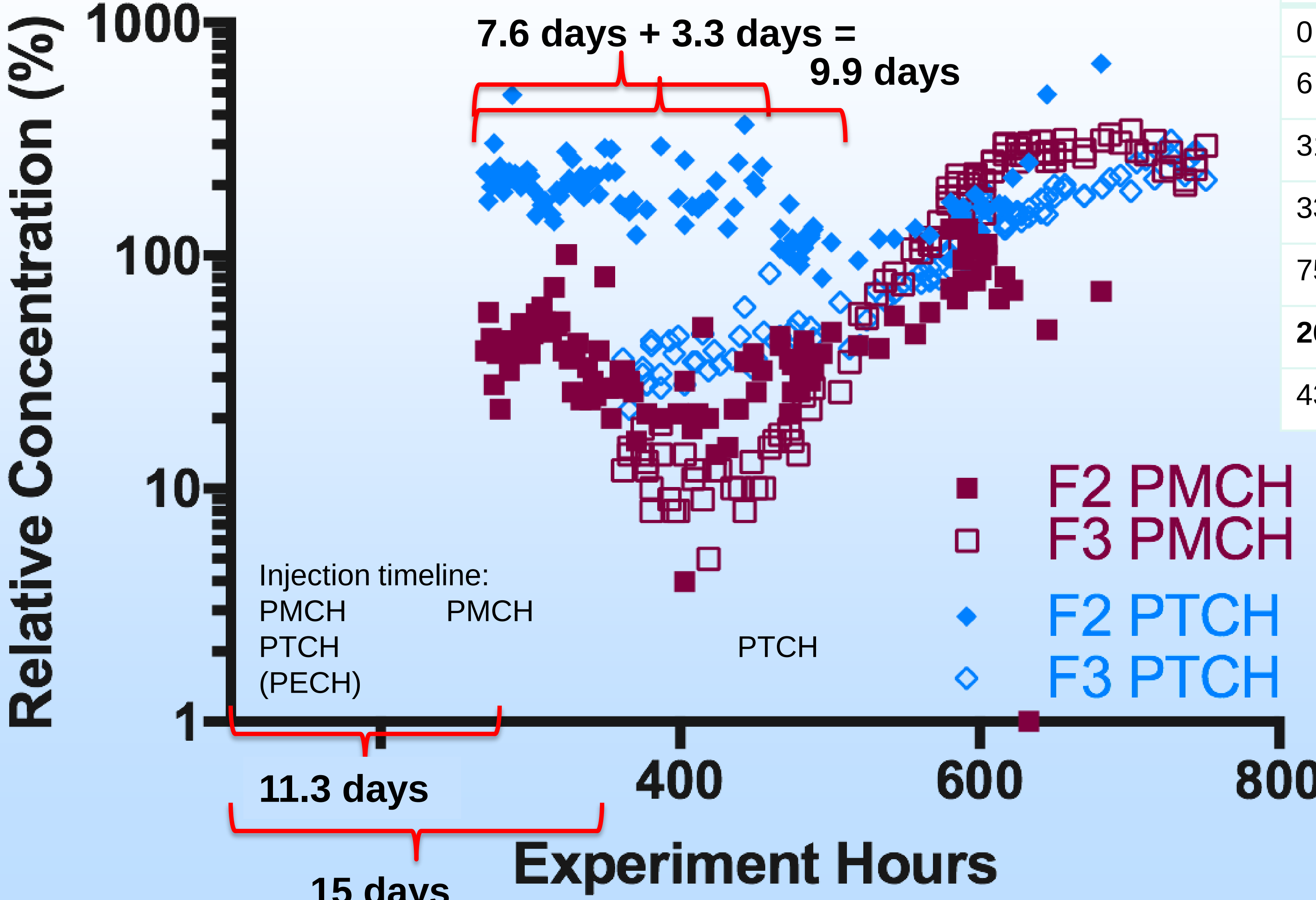
2009 Campaign PFTs at F2

Injections

Time	PFT
0	PMCH
6	PTCH
31	PECH
33	SF_6
75	PDCH
269	PMCH
436	PTCH



2009 Campaign PFTs Relative to PECH



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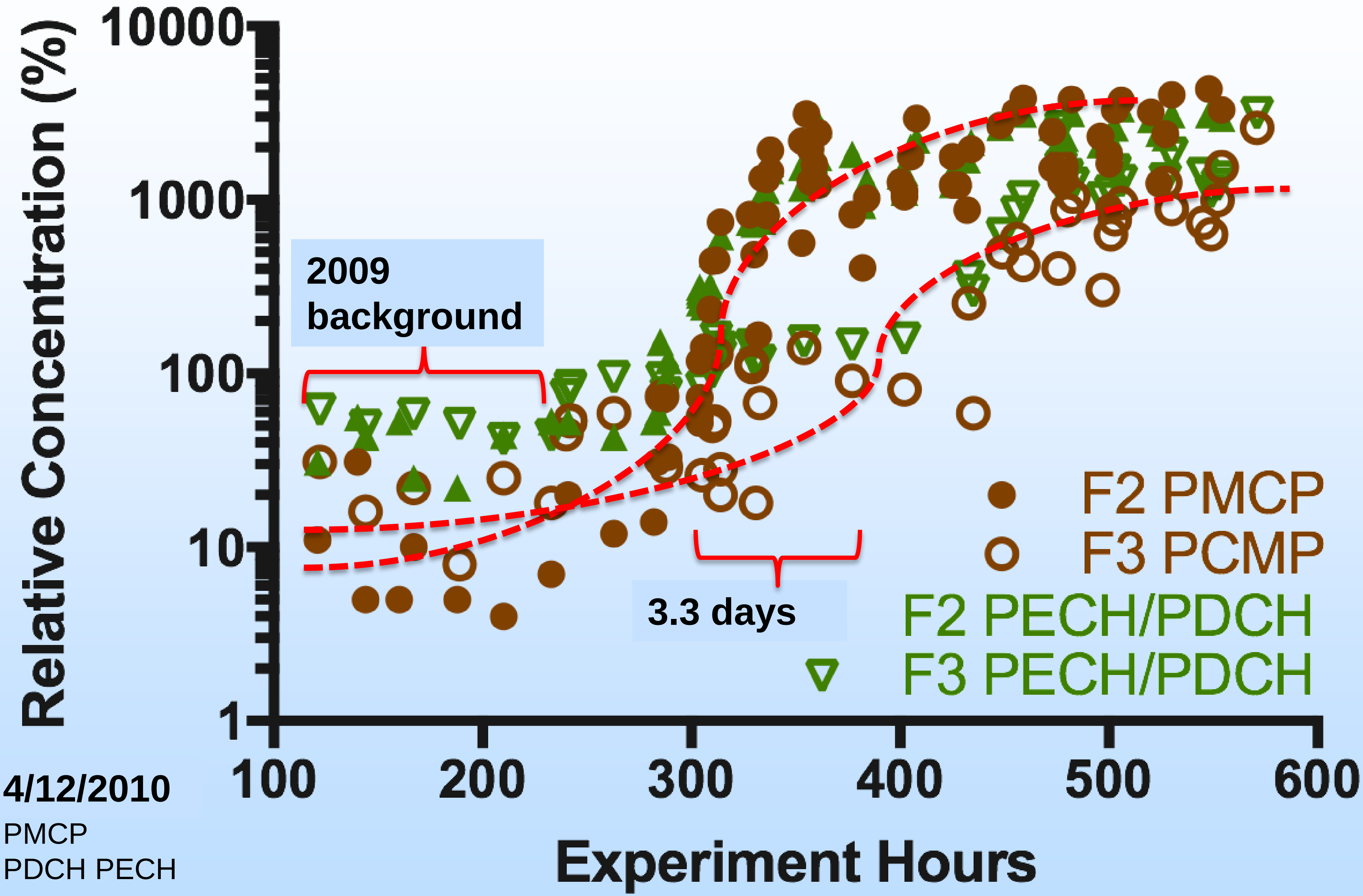
2010 Campaign PFTs Relative to PTCH



4/12/2010

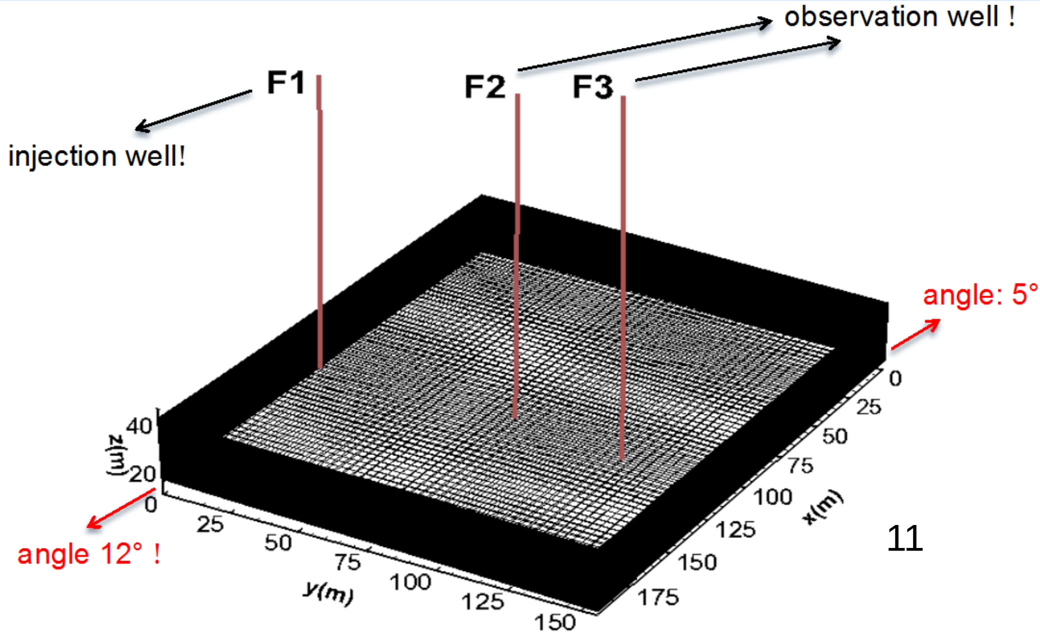
PMCP

PDCH PECH

RESERVOIR MODELING

Static Model

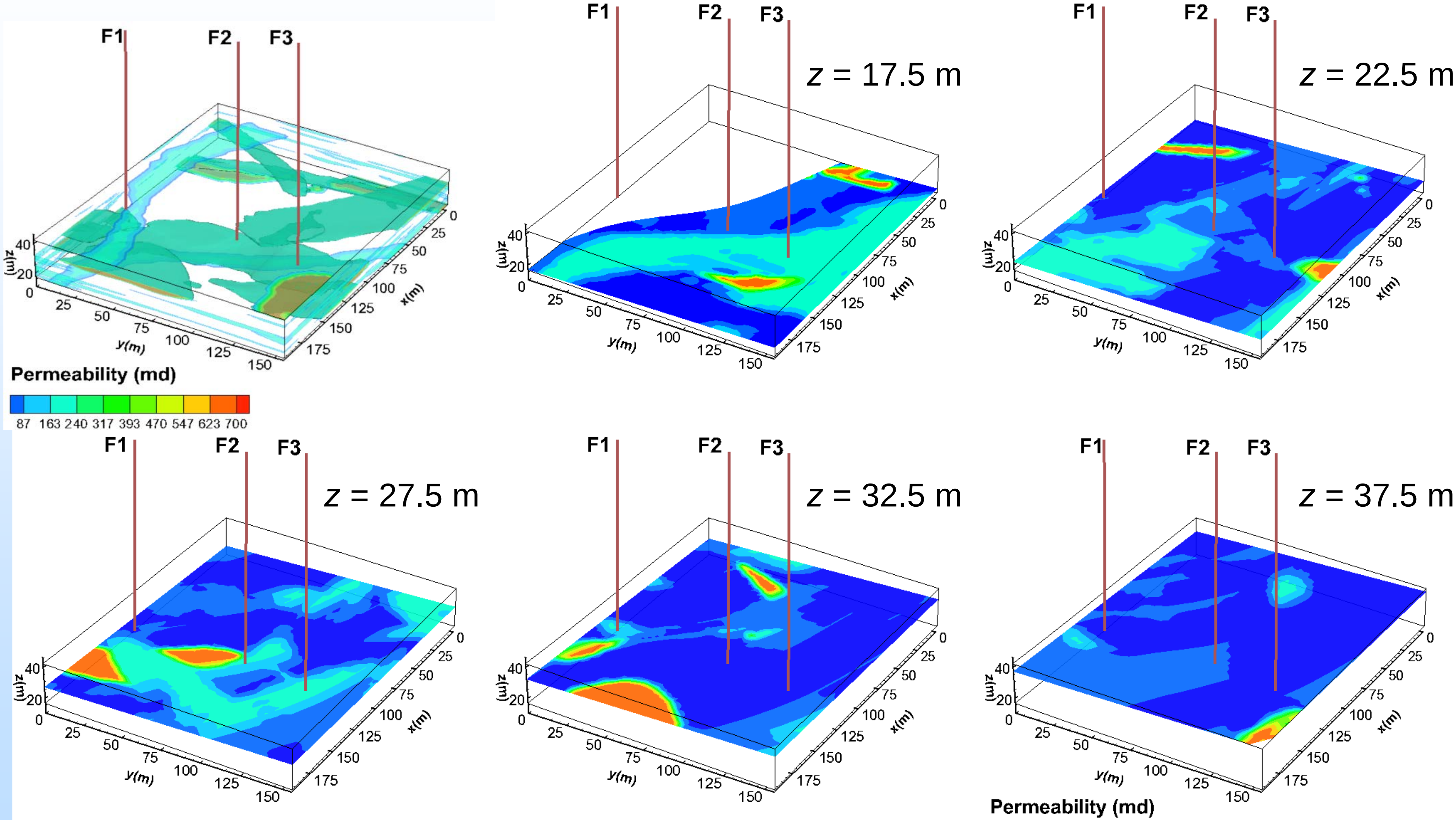
- DAS extracted from > 60 million element Cranfield model[1]
- DAS is 155 × 195 × 24 m^3, inclined in *x* and *y*
- 64 × 51 × 79 = 257,856 grid cells, i.e. 1 ft vertical resolution
- History-matched petro-physical properties for 8 facies
- Earlier studies[2] considered *up-scaled* models for entire field



[1]Developed by TBEG team
Hosseini et al., IJGCC (2013)

[2]Delshad et al., IJGCC (2013)
LBNL, PNNL SimSeq models in
Mukhopadhyay et al., TPM (2015)

Permeability



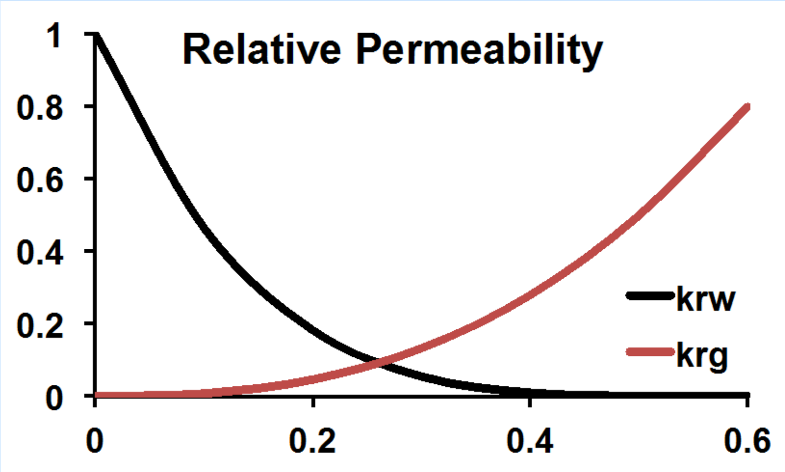
Fluvial depositional features: high permeability channels & tight shales

Osures Reservoir Simulator

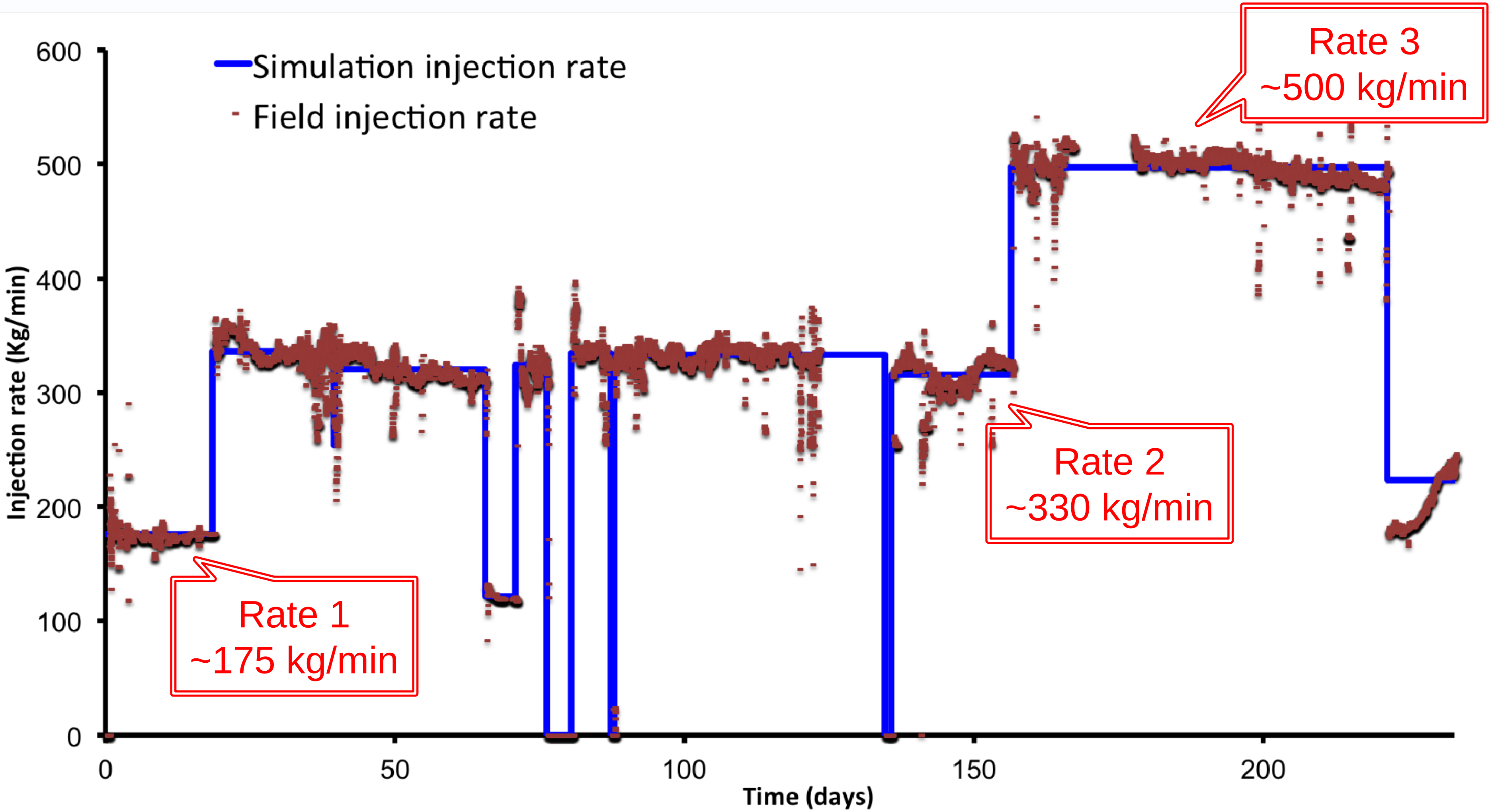
- Higher-order finite elements for flow and transport
- EOS-based phase-split computations
- Cubic-Plus-Association (CPA) EOS for water-CO_2 mixtures

- Fickian diffusion, mechanical dispersion, capillarity
- Brooks-Corey relative permeabilities with S_{wir} = 40%

- No-flow top and bottom (shale), constant pressure on outflow boundaries in *x* and *y*

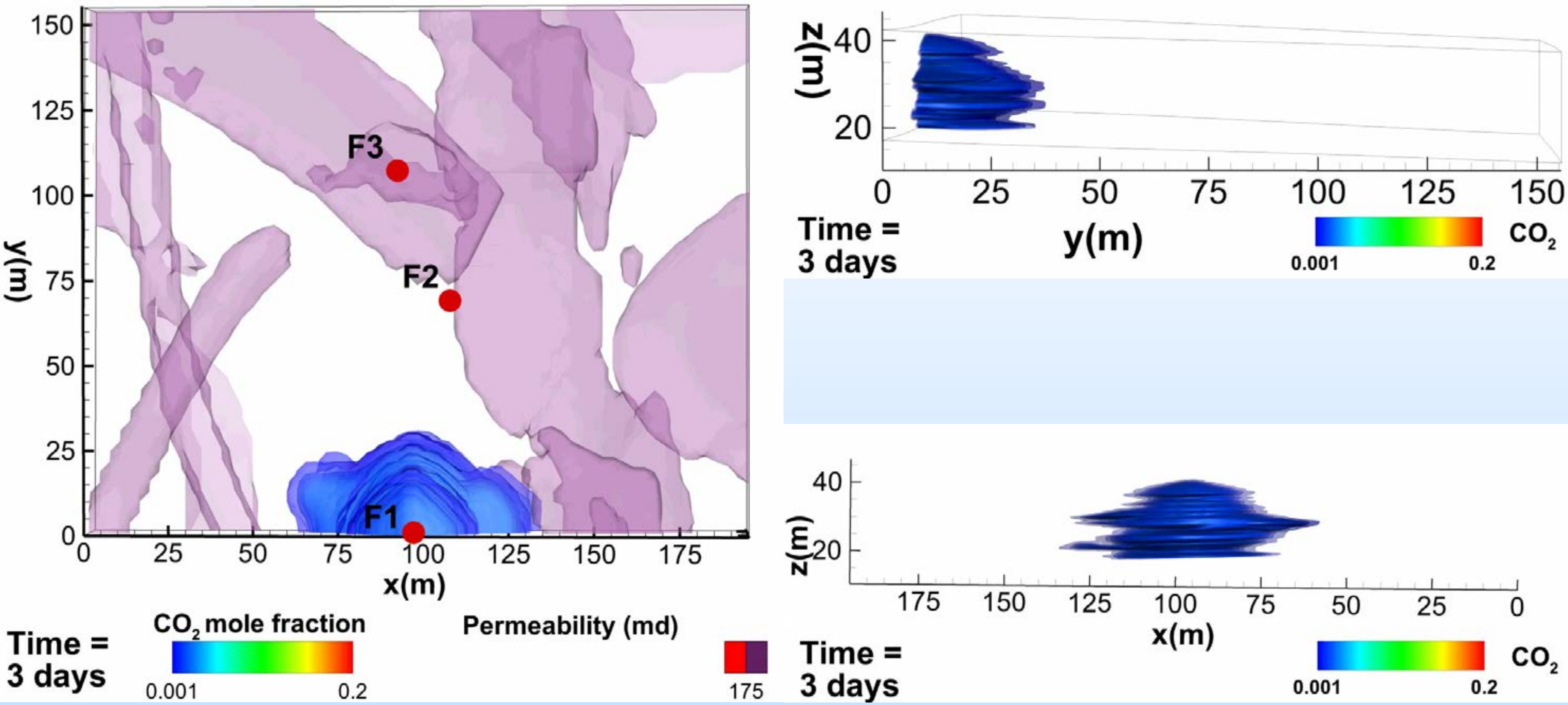


Injection Schedule



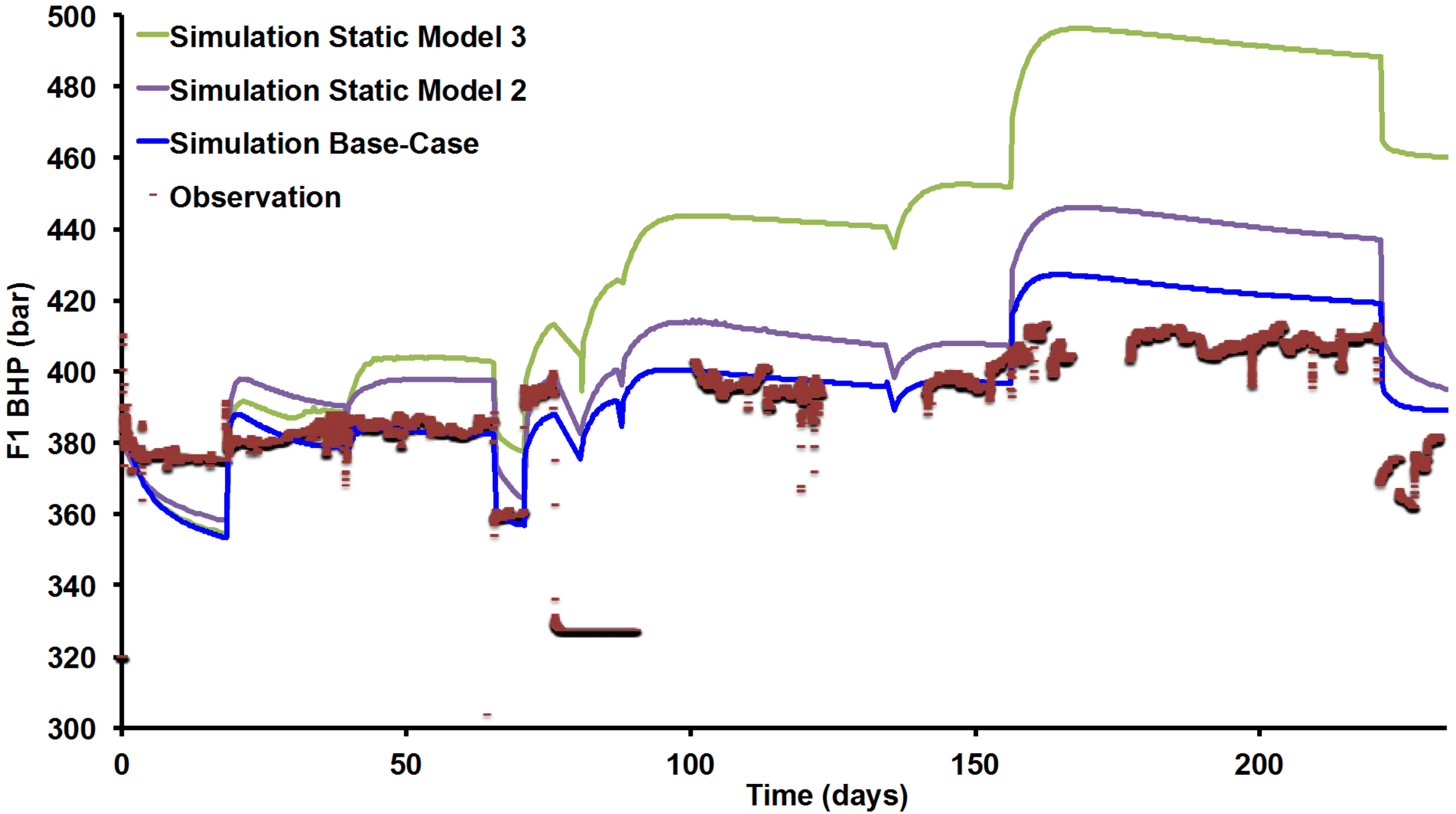
Hosseini et al., IJGCC (2013)

Results



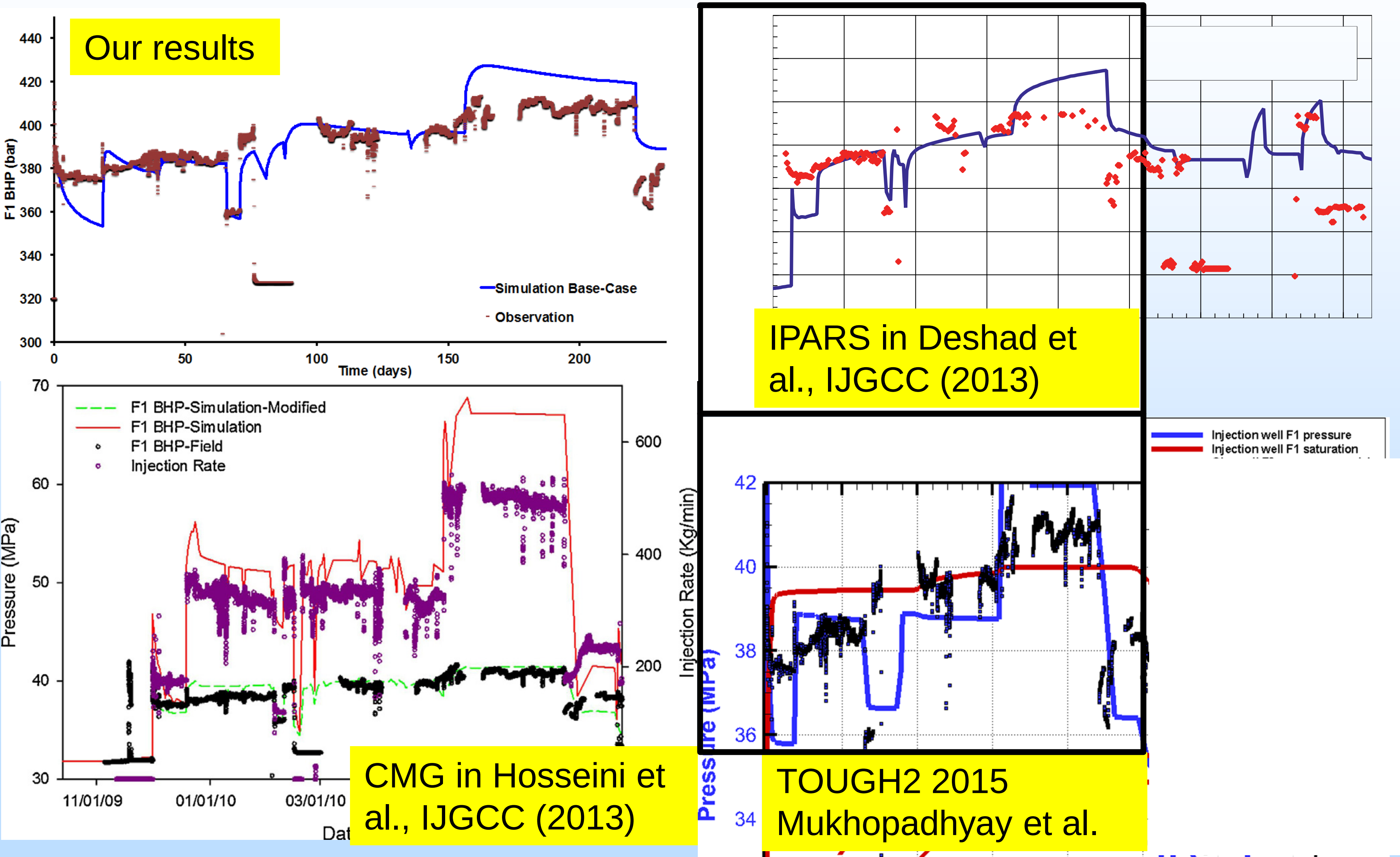
F3
F2
F1
y(m)
x(m)
Time = 3 days
CO$_2$ mole fraction
0.001
0.2
Permeability (md)
175
z(m)
y(m)
Time = 3 days
CO$_2$
0.001
0.2
z(m)
x(m)
Time = 3 days
CO$_2$
0.001
0.2

Pressure Response in F1

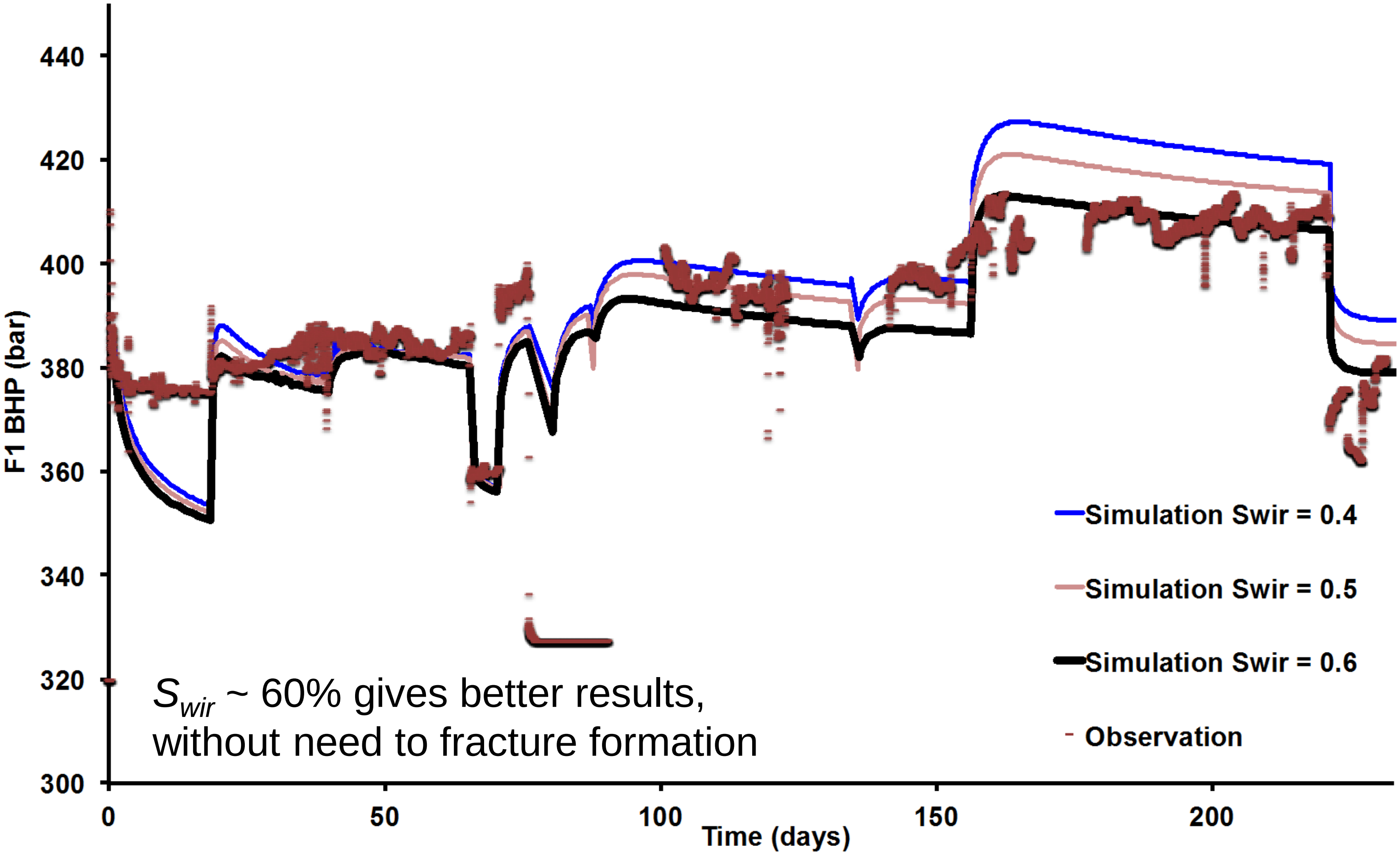


3 detailed TBEG static models. Model selected in Hosseini et al. (2013) and Delshad et al. (2013) (blue) also shows best agreement with our simulations

Compared to IPARS, CMG, TOUGH2



Sensitivity to S_{wir}



S_{wir} ~ 60% gives better results, without need to fracture formation

CO_2 Breakthrough Times

Unit = days	**F2**	**F3**	**#cells from F1-F3**
Observed	**11**	**16**	
Our simulations	**9.3 – 13.2**	**20.8 – 26.3**	**37**
IPARS: Delshad et al. (2013)	13	90	7
CMG: Hosseini et al. (2013)	7, 13, 28, 16	21, 28, 33, 46	7
TOUGH2: LBNL model (Mukhopadhyay et al., 2015)	19	53	<7
STOMP: PNNL model (Mukhopadhyay et al., 2015)	8-14	19-53	<7

Conclusions from Simulations

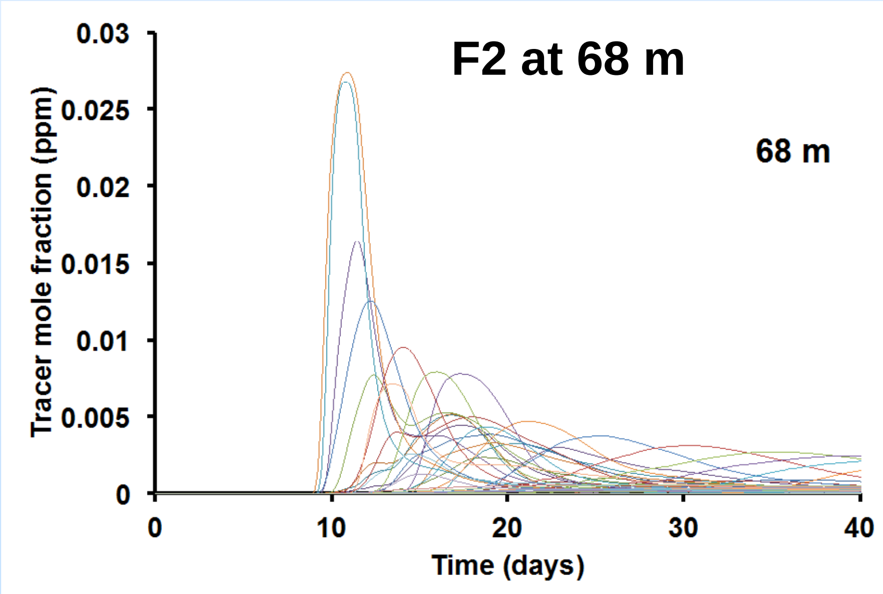
- Qualitative agreement with previous studies, but closer to field data due to high-resolution static model, higher-order FE methods, and robust physics
- Agreement (mostly) on static model and wettability
- However, pressures at highest rate and CO_2 breakthrough in F3 overestimated in all models
- Most likely cause: missing fluvial conduits of flow

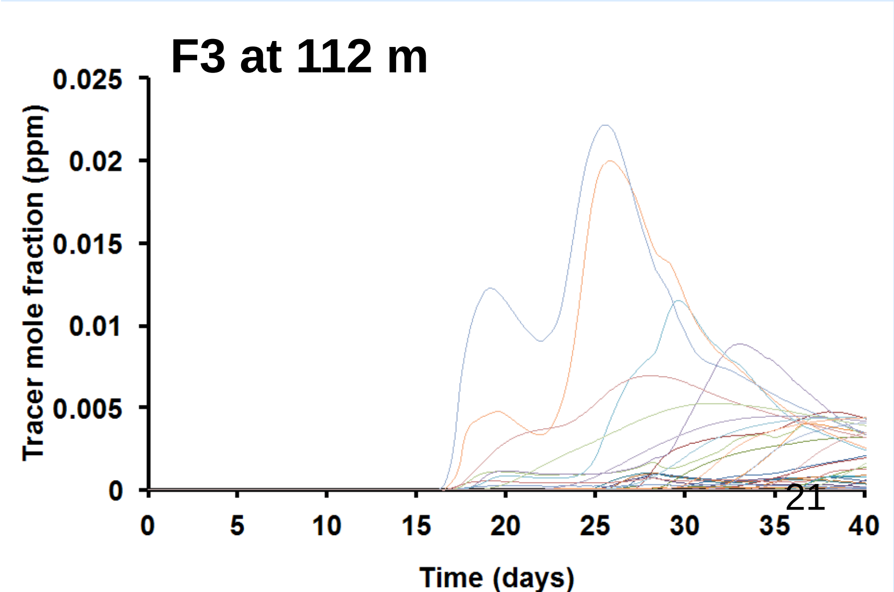
- Next step: can we further constrain heterogeneity by modeling tracer experiment?

Future Work

- PFT tracers will initially be modeled as conservative species
- Phase behavior from critical properties, provided by manufacturer
- Isotope data are less comprehensive, but will be considered to distinguish injected and natural CO_2 sources

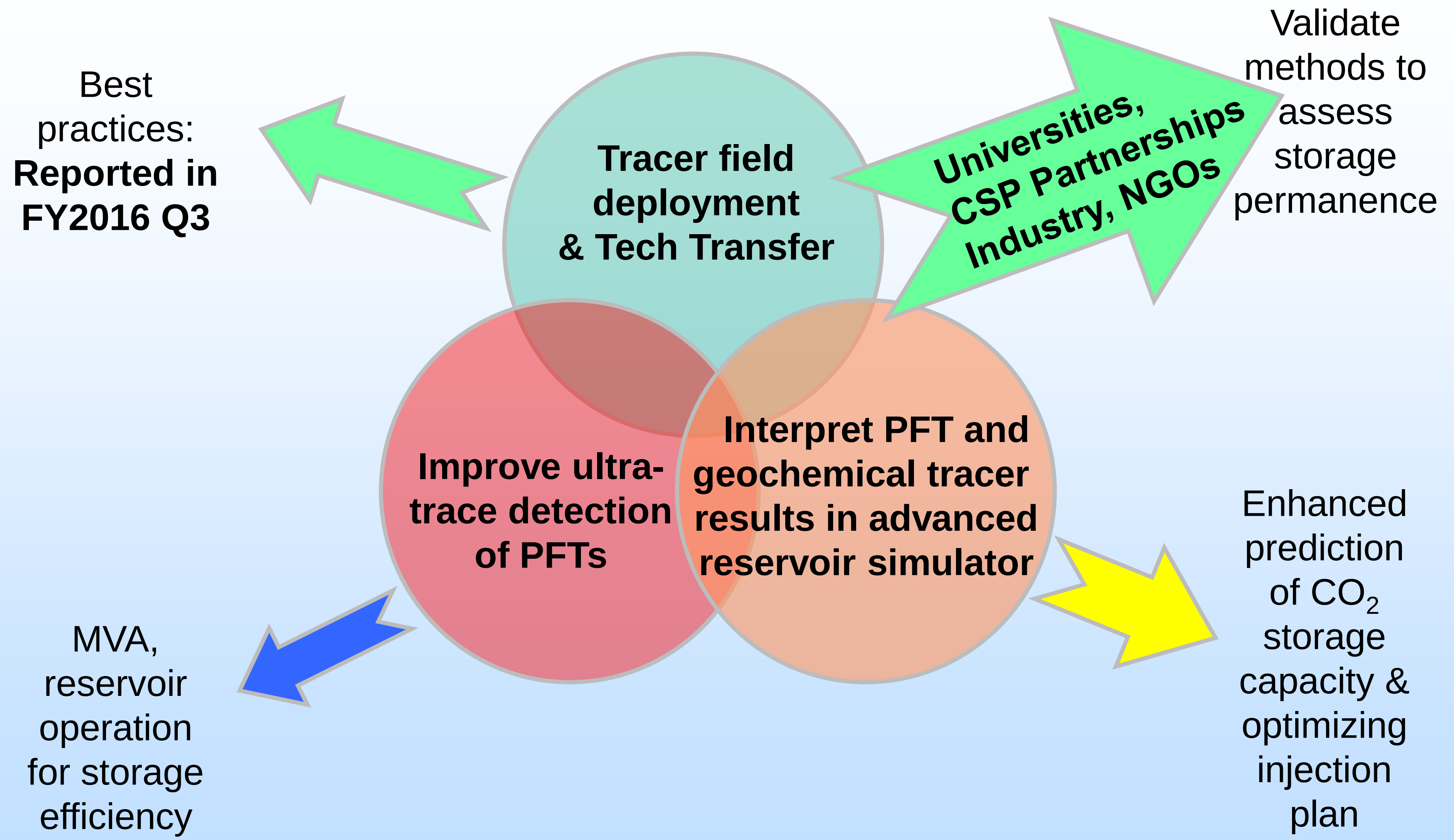
Preliminary results for 0.6 kg PMCH tracer injection
Each curve corresponds to different depth in observation well





Appendix

Future Plans & Synergies



Project Organization

David Graham, PI

Tommy Phelps
Susan Pfiffner

David Cole
M. R. Soltanian
J. Moortgat

Collaborators:

RCSPs

Gantt Chart

Task Description	2015				2016				2017			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Sampling plan	■											
Initial gas-brine isotope model	■	■										
PFT comparison		■	■									
Geochem comparison		■	■	■								
Tech transfer update			■	■								
Technology survey				■	■							
Static reservoir model Cranfield DAS				■	■	■						
Annotated tracer dataset				■	■	■						
Plan for PFT assessment in HCs						■	■					
Simulate Cranfield CO_2 flow & transp.						■	■	■				
Tech transfer update							■	■				
Prelim. simulation of PFTs							■	■	■	■		
Best practices for PFT analysis in HCs									■	■	■	
Combined CO_2 and tracer simulation										■	■	■
Tech transfer update											■	■

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Accomplishments and Benefits to Program

- Accomplishments
- **Assessing water-mineral-CO_2 interactions using geochemical modeling and isotopic signatures in baseline, during and post injection for multiple sites and campaigns.**
- **Determine behavior of perfluorocarbon tracer suites, breakthrough, development of reservoir storage over time at multiple sites.**
- **Delineate CO_2 fronts with PFT's, isotopes and on-line sensors (T, pH, Cond.).**
- **Established methods, proven successful, inexpensive, ongoing collaborations.**
- **Developed high-resolution Cranfield model to investigate CO_2 and tracer transport**
- ***Procedures for monitoring, verification and accounting (MVA) as tech transfer for larger sequestration demonstrations complementing other sites/partnerships.***

- Benefits,
- **Fate, Breakthroughs, Transport, Interactions, MVA, and Technology Transfer.**
- **Established, successful, inexpensive, Technology Transfer collaborations.**
- **Lessons Learned of baseline needs and multiple natural and added tracers.**
- **Publications: 13 journal/book articles, a dozen proceedings papers.**
- **Education: 4 Students and 2 postgraduates.**

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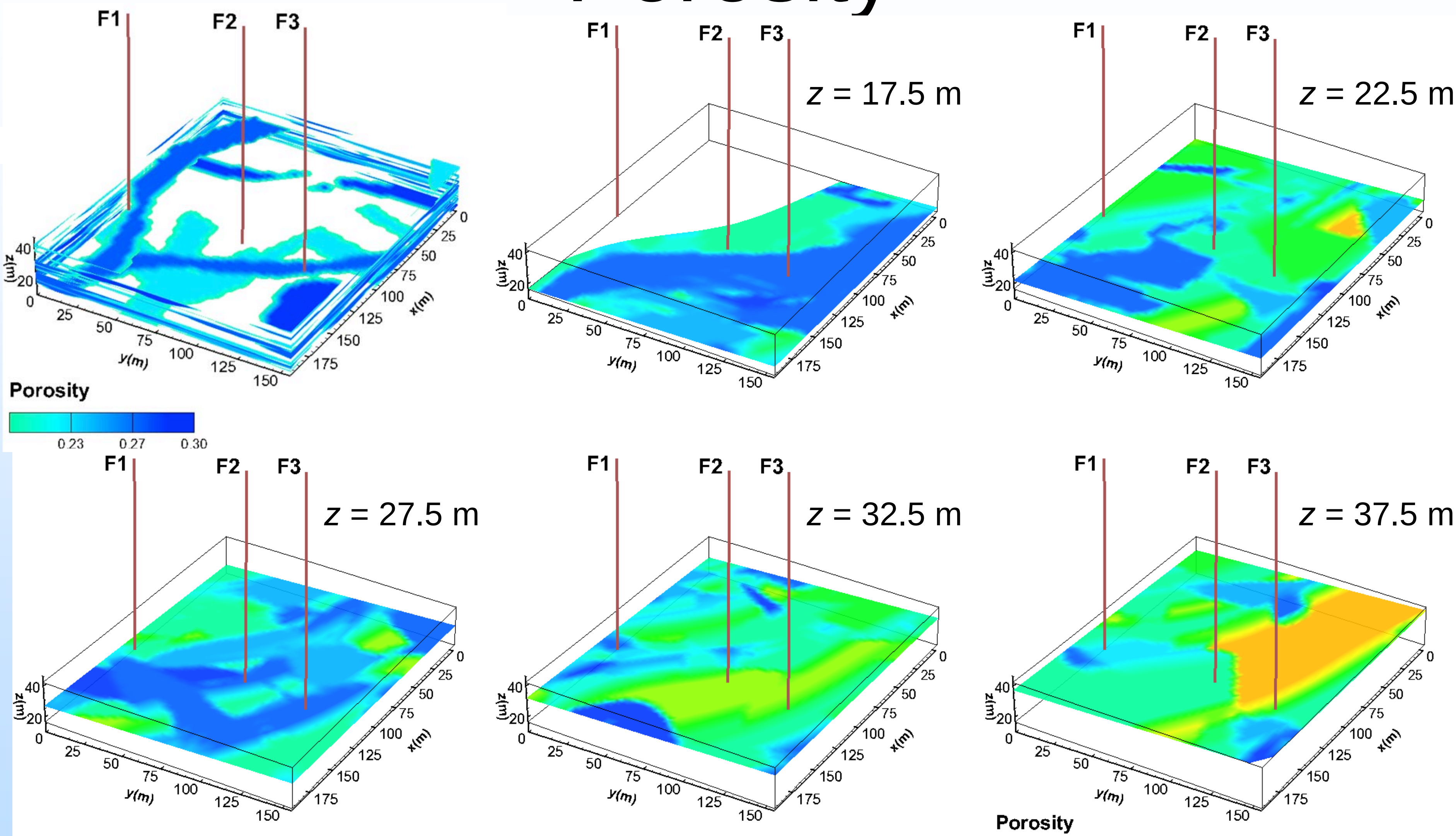
Porosity



Fluvial depositional features: high permeability channels & tight shales

Sensitivity Analyses II/II