Area of Interest 1: Geomechanical Research

Development of Geomechanical Screening Tools to Identify Risk: An Experimental and Modeling Approach for Secure CO_2 Storage

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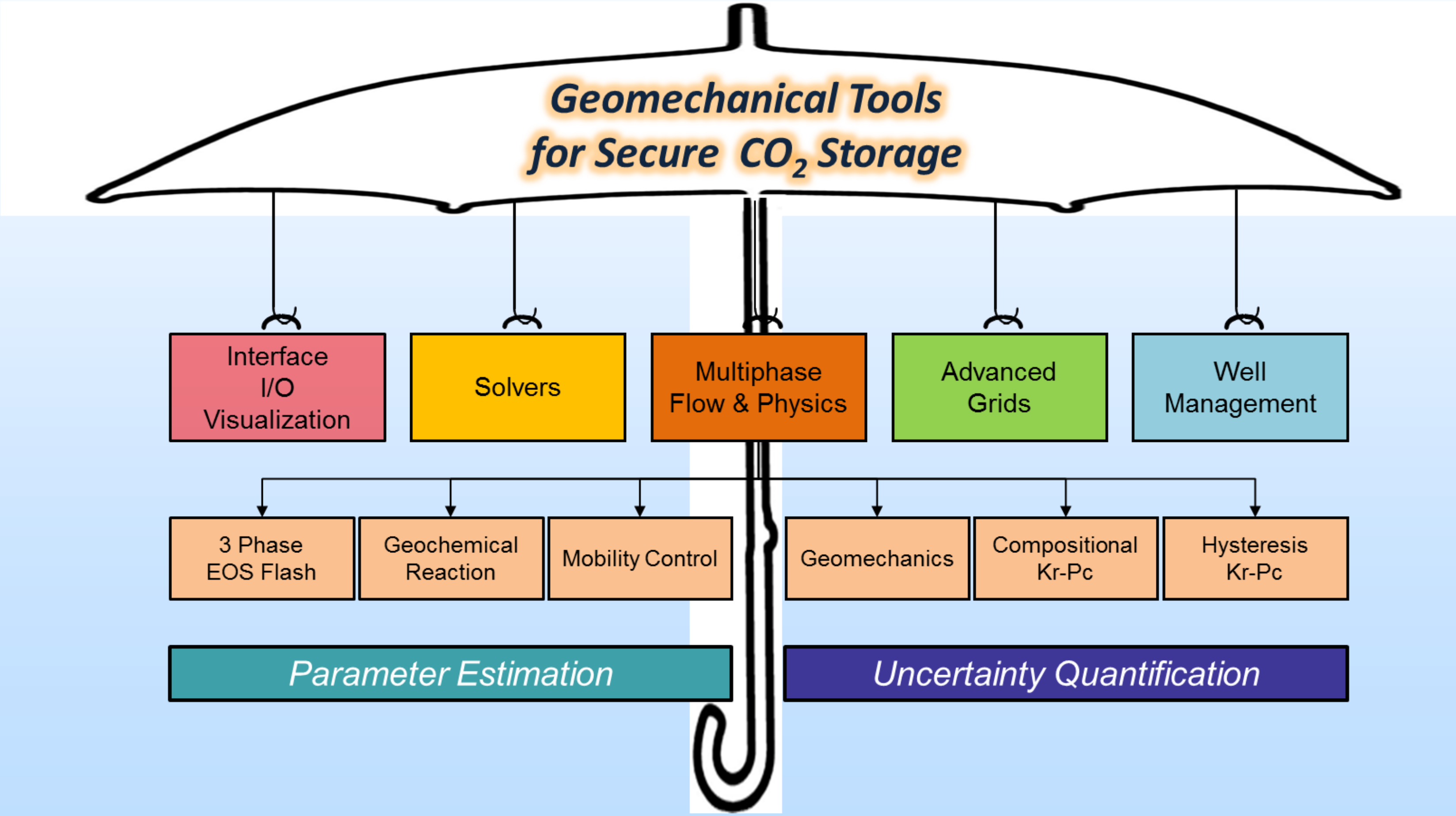
Presentation Outline

1. **Benefit to the Program**
2. **Goals and Objectives**
3. **Technical Status from Tasks 2 to 6**
4. **Accomplishments to Date**
5. **Synergy Opportunities**
6. **Summary**

Benefit to the Program

- Develop a **Geomechanical Screening Tool** to Identify Risk
  - ✓ *Experimental & Modeling Approach for Secure CO_2 Storage*



Project Overview: Goals and Objectives

- **Develop a screening tool** for improved understanding of geomechanical effects associated with CO_2 injection
- Derive a workflow **from experimental and computational** studies conducted for specific CO_2 sites, e.g. Frio, Cranfield

Task 1 Project **management** **(M.F. Wheeler–lead)**

Task 2 Conduct **laboratory experiments** for hydro-mechanical rock properties **(N. Espinoza–lead)**

Task 3 **Upscale** to bridge from laboratory to field scales **(M.F.W.–lead)**

Task 4 Extend **simulator** capability to model CO_2 storage field scale studies **(M. Delshad & B. Ganis–leads)**

Task 5 Perform **parameter estimation** & **uncertainty quantification** **(M.F.W.–lead, S. Srinivasan–consultant)**

Task 6 Integrate results to generate **geomechanical screening tool** / workflow **(M.F.W.–lead, S.S.–consultant)**

Technical Status

Task 2.

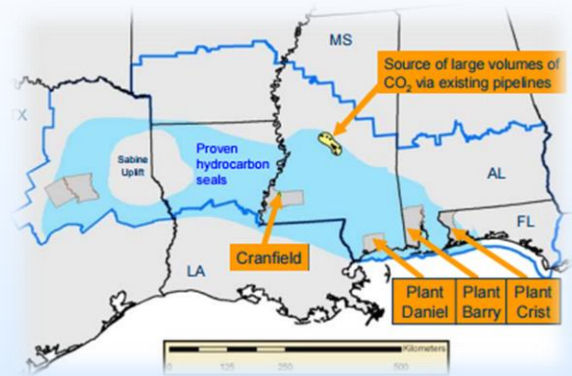
Conduct Laboratory Experiments for Petrophysical & Hydro-mechanical Rock Properties

(N. Espinoza–lead)

Task 2: Laboratory Experiments

Objectives: Complete modeling, perform reservoir simulations, and analyze geological uncertainty for two CO_2 storage field studies (Frio, TX & Cranfield, MS)

- Measure mechanical property from Task 2
- Collect other existing data (seismic, well logs, etc.)
- Measure impact of geochemical alteration on mechanical properties
- Study rock dissolution and its effect on weakening the rocks and creating leakage pathways
- Enhanced simulation for studying and quantifying parameters, e.g. reservoir over pressure, chemical and thermal loading



Site 1: Cranfield, Mississippi

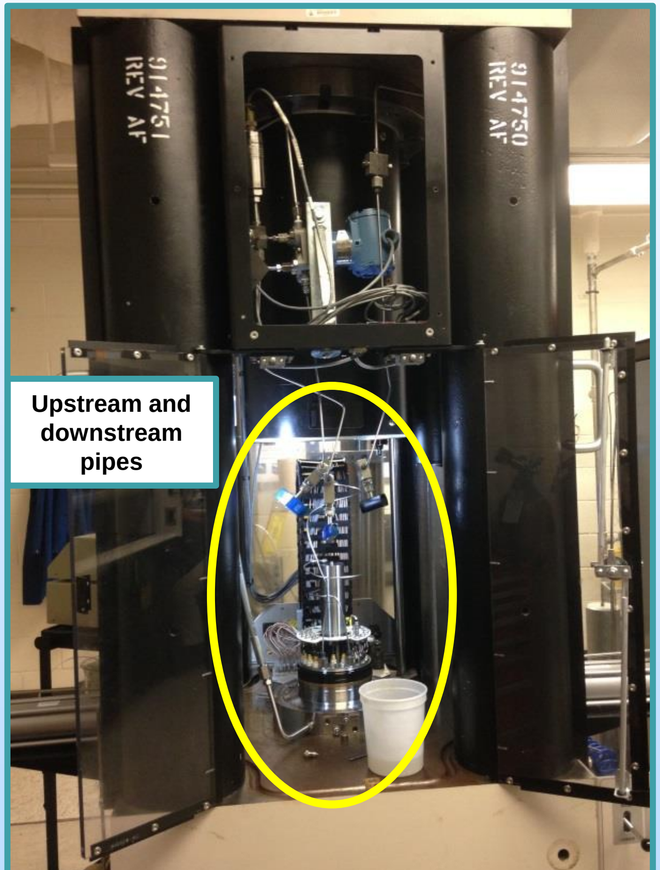
(Source: DOE Cranfield Fact Sheet)

Site 2: Frio pilot study, Texas

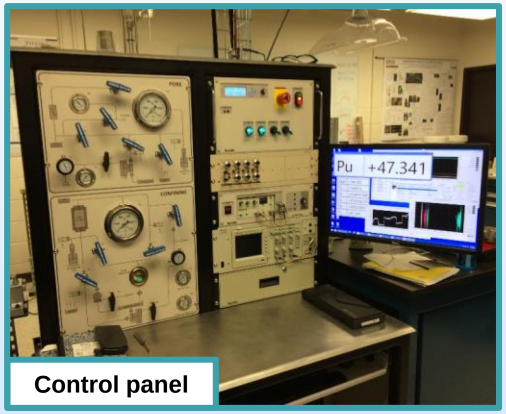
Large Axisymmetric Triaxial Frame Connected to ISCO Pumps for Fluid Injection

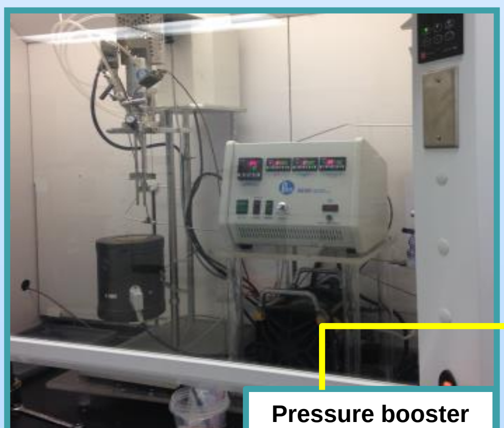
- Experimental setup

1 Sample mounted on the loading frame

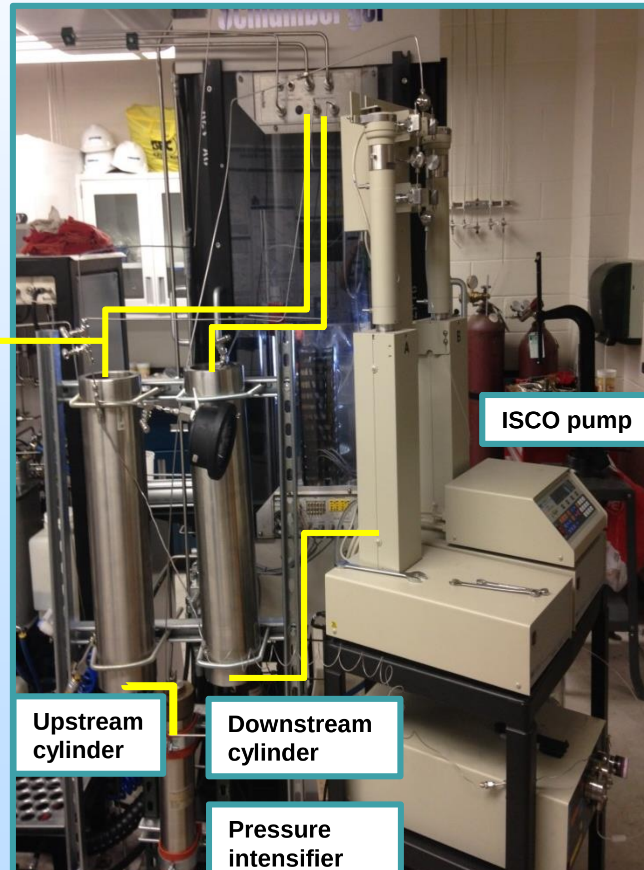


2 Data acquisition



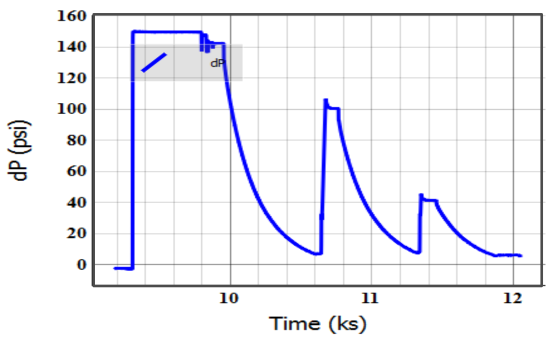
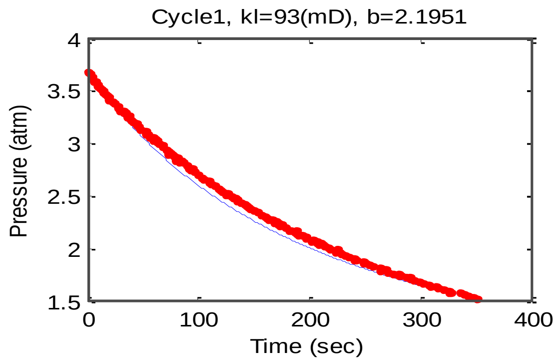
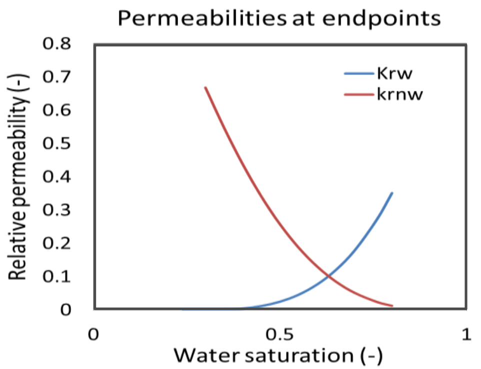


3 Cylinders & pumps for flow system connected to the triaxial cell



Petrophyscial Properties at CO_2 Storage Sites

- Cranfield, MS (Tuscaloosa sandstone): unsteady state gas permeability test

time vs. ΔP	*time* vs. P	S_w vs. k_{rw} , k_{rnw}
		

CO_2 Storage Sites

C-sandstone (Frio, Texas)

- Porosity: ~ 0.36
- Permeability

	k (mD)	k_g at breakthrough (mD)	k_w at S_{gr} (mD)
Vertical	470	184	263

- Capillary pressure measured (porous-plate method and mercury injection capillary pressure method)
- Relative permeability (Brooks-Corey model)

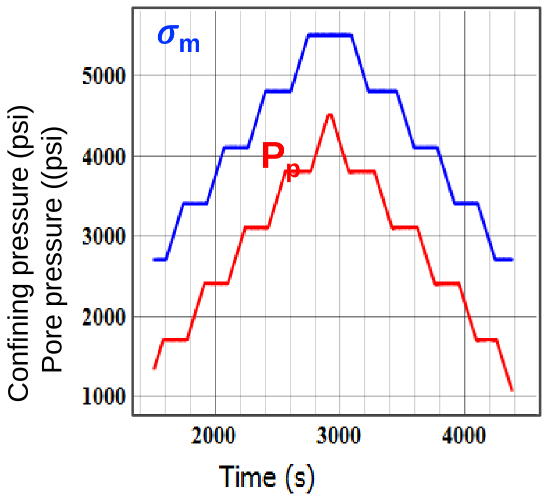
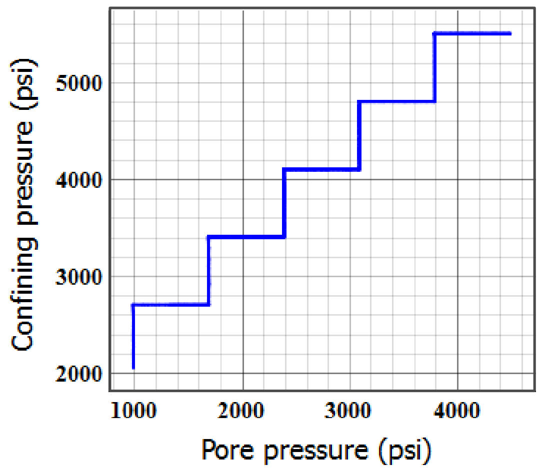
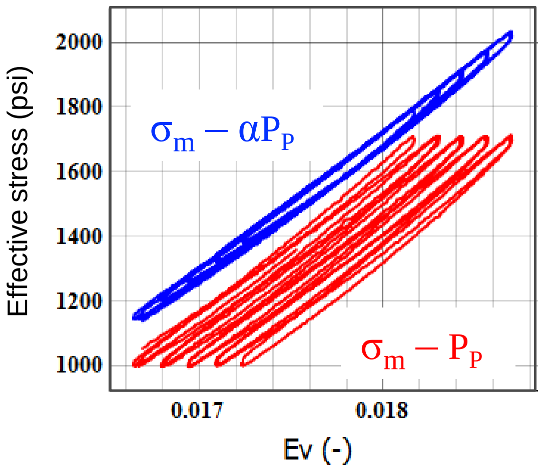
Tuscaloosa Sandstone (Cranfield, Mississippi)

- Porosity : ~ 0.31
- Permeability

	k (mD)	k_g at breakthrough (mD)	k_w at S_{gr} (mD)
Vertical	6.2	1.3	1.43
Horizontal	93	62	37

Mechanical Properties at CO_2 Storage Sites

- Cranfield, MS (Tuscaloosa sandstone): determination of bulk Biot coefficient at in-situ reservoir stress condition

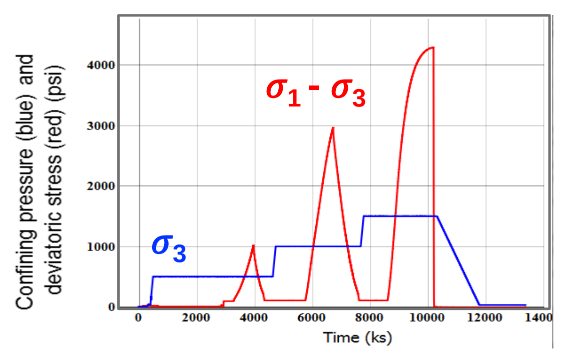
time vs. P_{pore}	P_{pore} vs. $P_{confining}$	ε_v vs. $\sigma_{effective}$
		

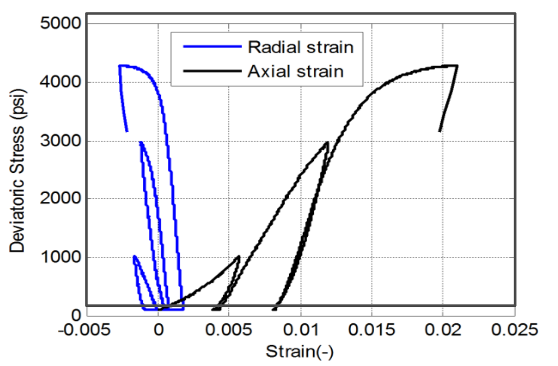
CO_2 Storage Sites	
C-sandstone (Frio, Texas)	Tuscaloosa Sandstone (Cranfield, Mississippi)
• Biot coeffcient (α): 0.96 • Stress condition Axial deviatoric stress : 200 psi Radial effective stress : 400 ~ 600 psi	• Biot coefficient (α): 0.90 ~ 0.915 • Stress condition Axial deviatoric stress : 500 psi Radial effective stress : 1,000 ~ 1,700 psi

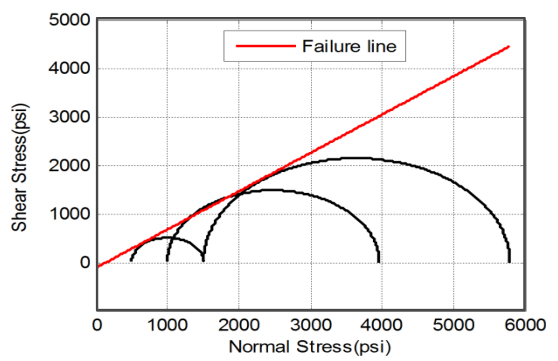
Mechanical Properties at CO_2 Storage Sites

- Frio, Texas (C-sand): multistage triaxial loading test at confining stress 500, 1,000 and 1,500 psi

time vs. σ	ε vs. $\sigma_{deviatoric}$	σ_{normal} vs. σ_{shear}







CO_2 Storage Sites

C-sandstone (Frio, Texas)

- Drained mechanical moduli at reservoir stress condition

	$E_{static\_loading}$ (GPa)	$E_{static\_unloading}$ (GPa)	ν
Vertical	2.74	8.74	0.2 ~ 0.4

- Significant elastic nonlinearity and plastic strains
- Shear strength
  - Friction angle (38˚)
  - Cohesive strength (Zero, Unconsolidated sandstone)
- Remarkable creep measurement at constant stress

Tuscaloosa Sandstone (Cranfield, Mississippi)

- Drained mechanical moduli, Stress anisotropy

	$E_{static\_loading}$ (GPa)	$E_{static\_unloading}$ (GPa)	ν
Vertical	1.9	10.91	0.12 ~ 0.29
Horizontal	1.81	7	0.11 ~ 0.17

- Elastic nonlinearity only beyond the yield cap
- Noticeable creep measurement at constant stress

Technical Status

Task 3.

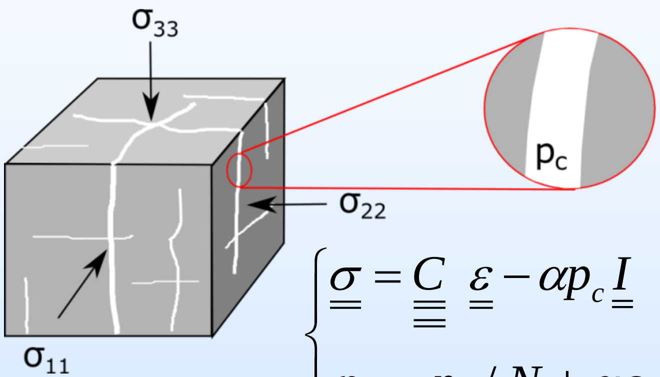
Upscale by Completing Bridge from Laboratory to Field Scales

(M.F. Wheeler–lead)

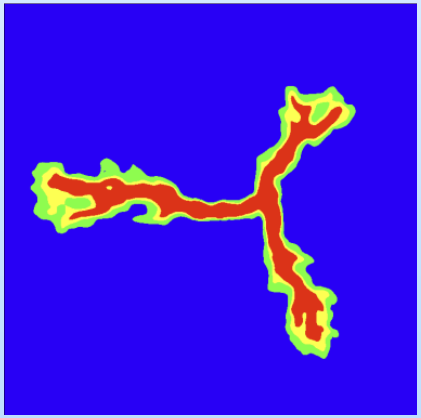
Task 3: Bridge from Laboratory to Field

Objectives: Upscale measured rock properties (fluid flow & geomechanics) to scale relevant to field processes

- Development of **homogenization** schemes combining numerical and analytical approaches
- Particular emphasis will be put on including **natural fractures** in effective properties and localization effects
- Obtain field scale constitutive parameters to perform **coupled fluid flow and geomechanical** numerical simulation



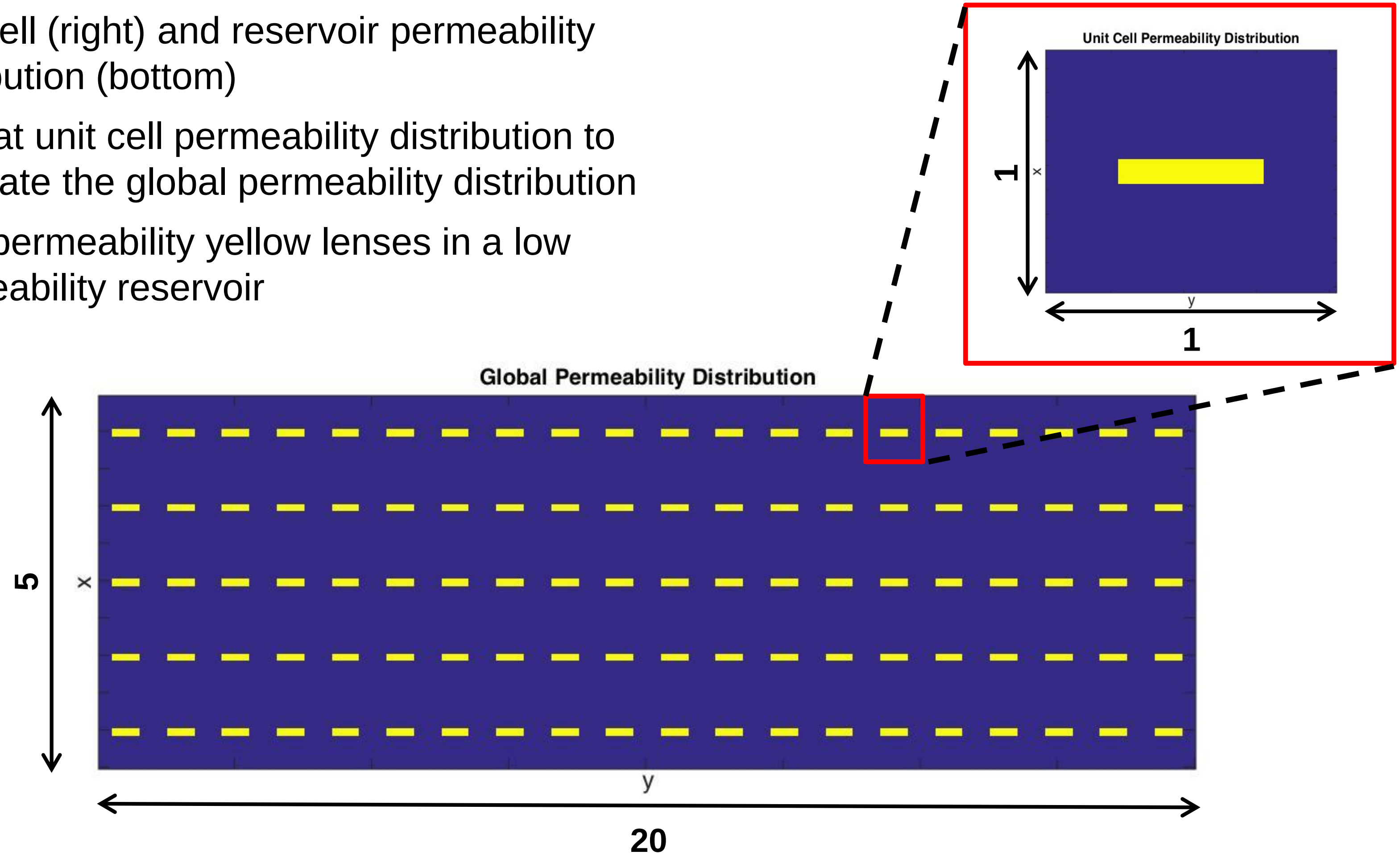
$$\begin{cases} \underline{\underline{\sigma}} = \underline{\underline{\underline{\underline{C}}}}\;\underline{\underline{\varepsilon}} - \alpha p_c \underline{\underline{I}} \\ \varphi = p_c / N + \alpha \varepsilon_V \end{cases}$$



Verification of Homogenization

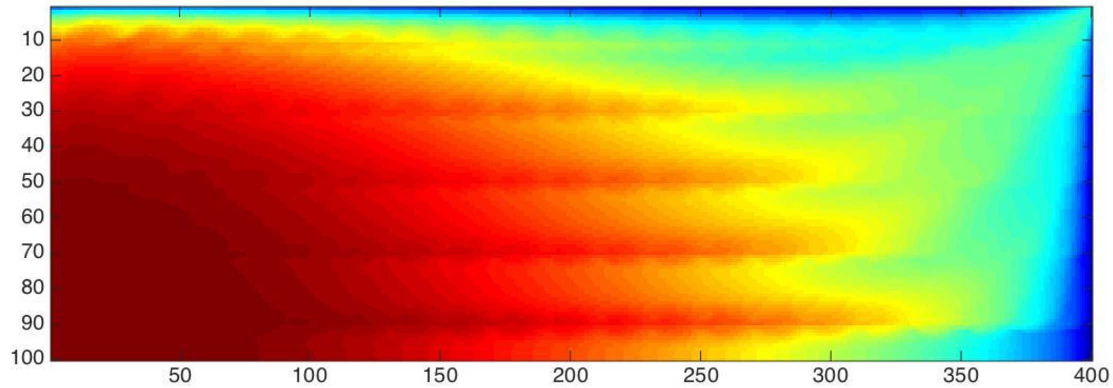
Permeability Distribution of the Reference Field

- Unit cell (right) and reservoir permeability distribution (bottom)
- Repeat unit cell permeability distribution to generate the global permeability distribution
- High permeability yellow lenses in a low permeability reservoir

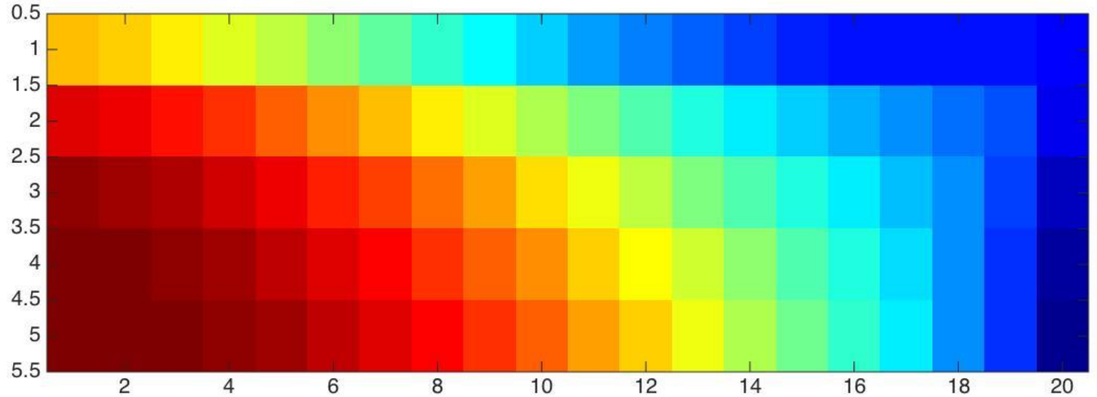


Verification of Homogenization

Concentration on Fine-Scale Gridblocks



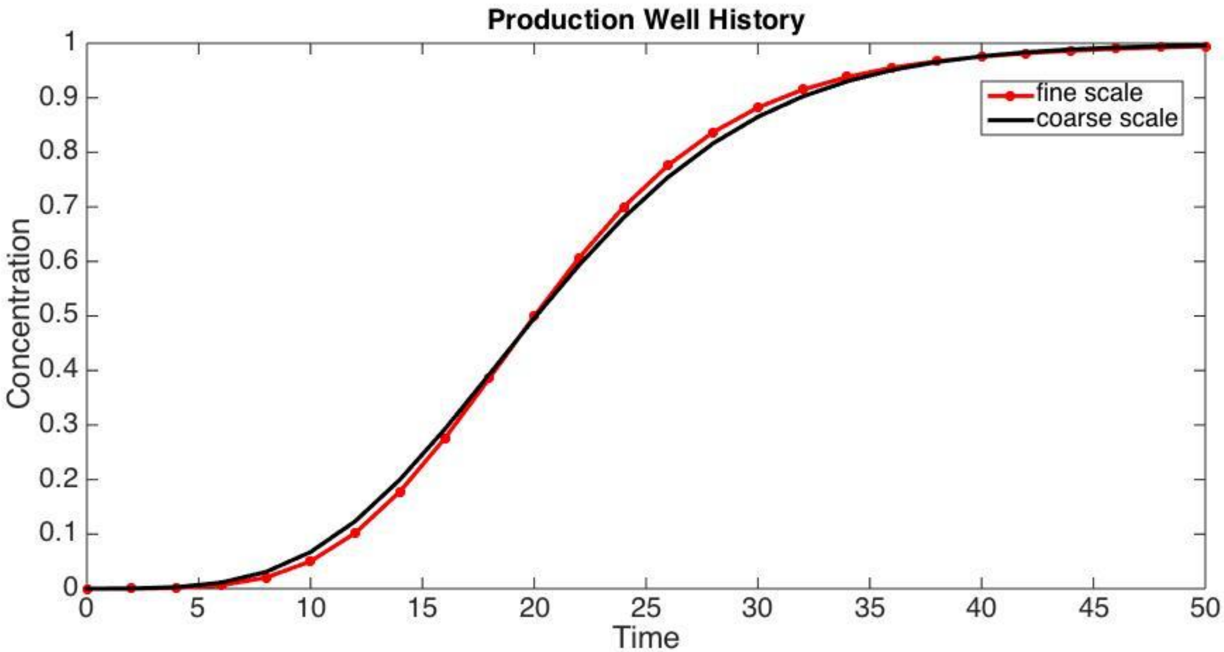
Concentration on Coarse-Scale Gridblocks



Verification of Homogenization

Tracer History at Production Well

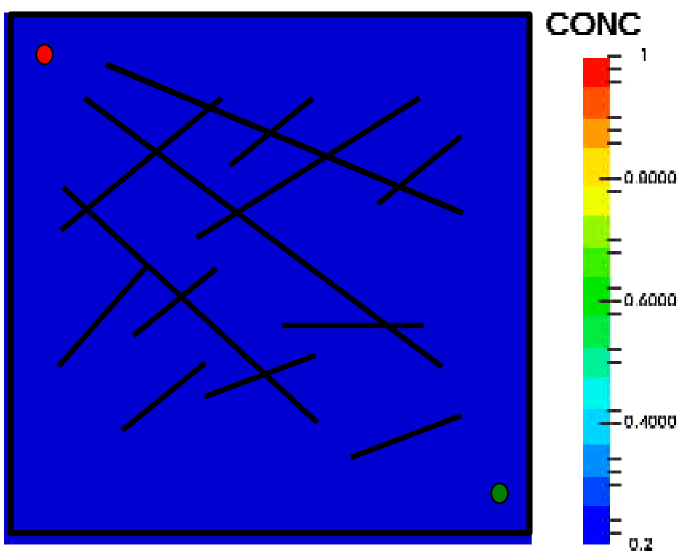
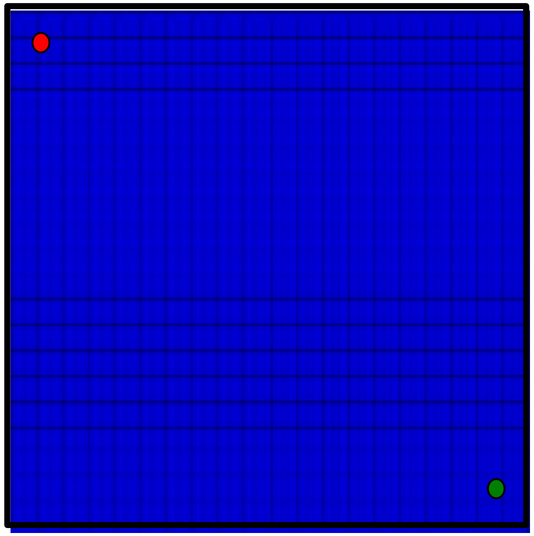
- Multi-well tracer test with continuous injection of tracer
- Single/multi-well tracer tests provide information to validate the upscaled model
- Fine and coarse scale concentration profiles in good agreement
- Validation for single phase flow and transport with ε order diffusion.



Verification of Homogenization

Model Description

- Simple 2D problem
- Easy extension to 3D case
- Effective permeability and dispersion tensor calculation
- Single phase flow with tracer transport

Fine-Scale Gridblocks	Coarse-Scale Gridblocks
	

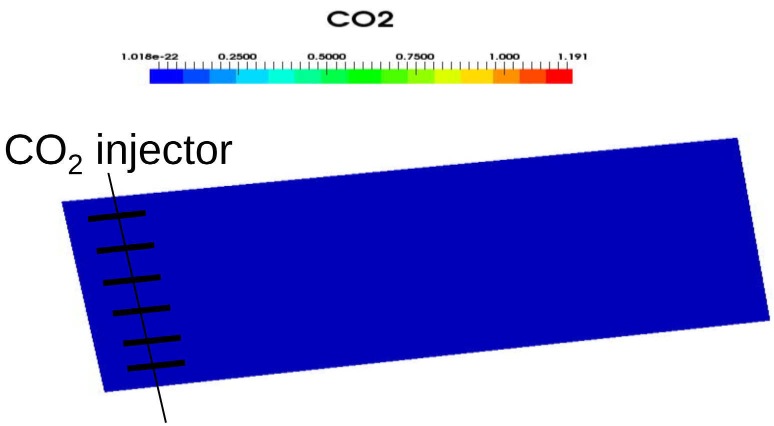
Application to the Frio Field Model

Homogenization of Frio Field Model

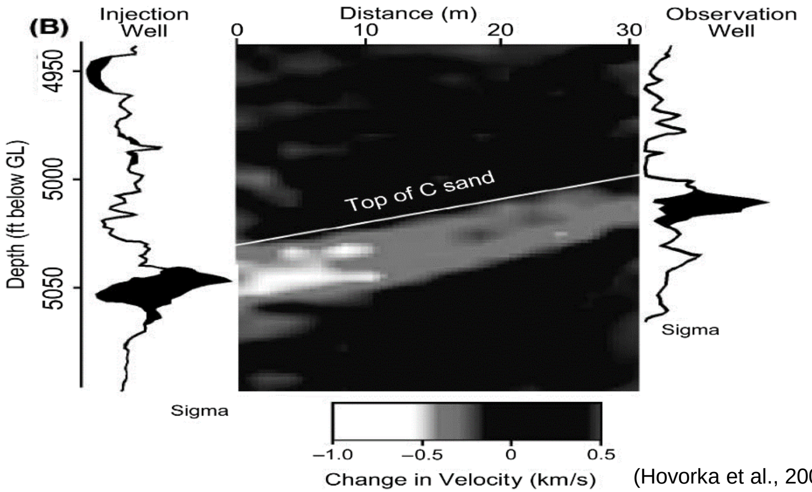
- Running Integrated Parallel Accurate Reservoir Simulator (IPARS)
  - Grid refinement in the region of pilot study: enhanced velocity
  - Upscaling toolset HOMOGEN implemented and verified
- C sand only 20 ft thick
- Only 30 permeability values separated in the vertical direction
- Scale separation (ε) assumption of homogenization does not apply
- Resolving differences in plume migration for fine and coarse scale underway

CO_2 Plume Migration

- Good match with seismic observation



Seismic Observations



(Hovorka et al., 2006)

Technical Status

Task 4.

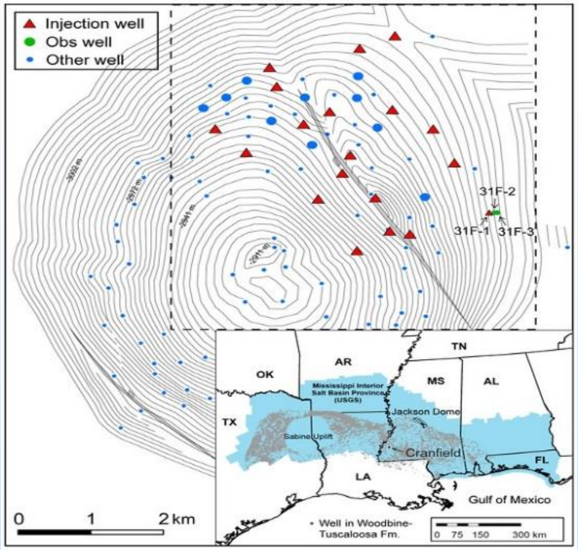
Simulator Development and Modeling CO_2 Storage Field Scale Studies

(M. Delshad and B. Ganis–leads)

Task 4: Simulator Development

Objectives: Complete simulator development with numerical schemes for coupled processes

- Develop computational methods for coupled processes based on multiscale discretization for **flow, geomechanics & hysteresis**
- Development of efficient **solvers & pre-conditioners**
- **Model CO_2 storage field sites** and perform simulations



Multiphase Relative Permeability and Hysteresis Models at a CO_2-EOR Field for CCS Utilization

Gas Mobility Control Methods

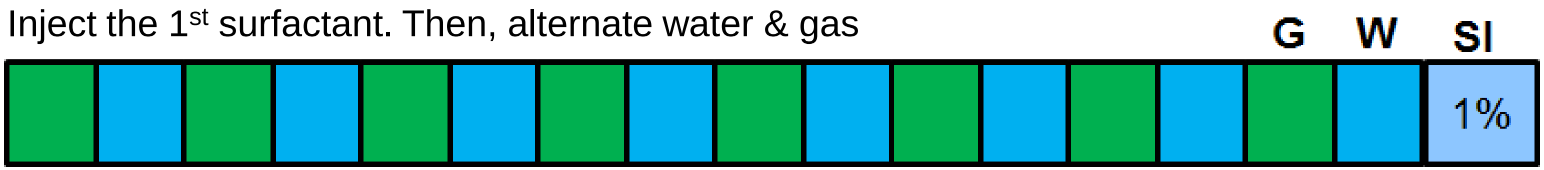
- **Water Alternating Gas (WAG)**
- Simultaneous Water and Gas (CoInj)
- **Surfactant-alternate-gas (SAG)***
  - The 1st surfactant lowers Sor: reducing IFT
  - The 2nd surfactant controls gas mobility: generating foam

(Currently, commercial S/Ws do not implement the injection of two surfactant types.)

- Surfactant dissolved in CO_2 (in-situ foam)
- Polymer Assisted WAG
- Polymer dissolved in CO_2 (viscosifying CO_2)

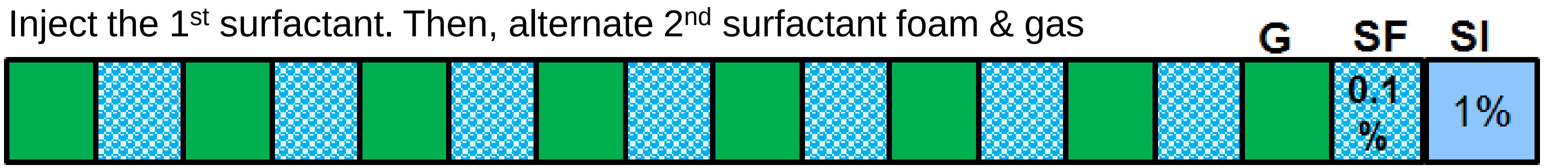
WAG

- Inject the 1st surfactant. Then, alternate water & gas



SAG

- Inject the 1st surfactant. Then, alternate 2nd surfactant foam & gas

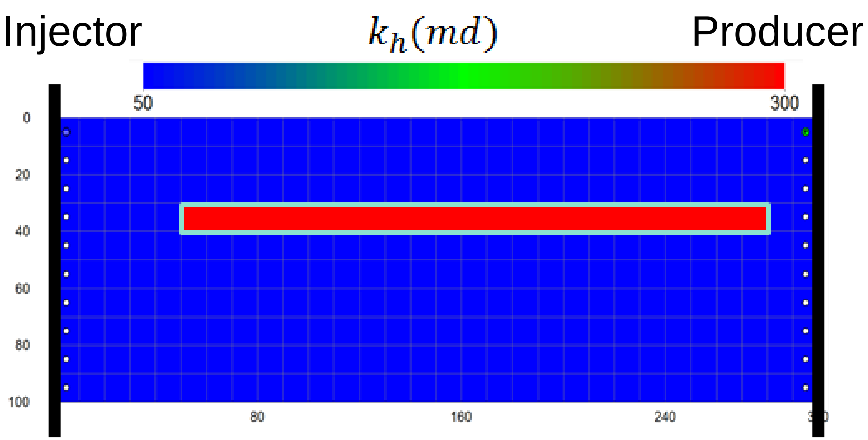


Multiphase Relative Permeability and Hysteresis Models at a CO_2-EOR Field for CCS Utilization

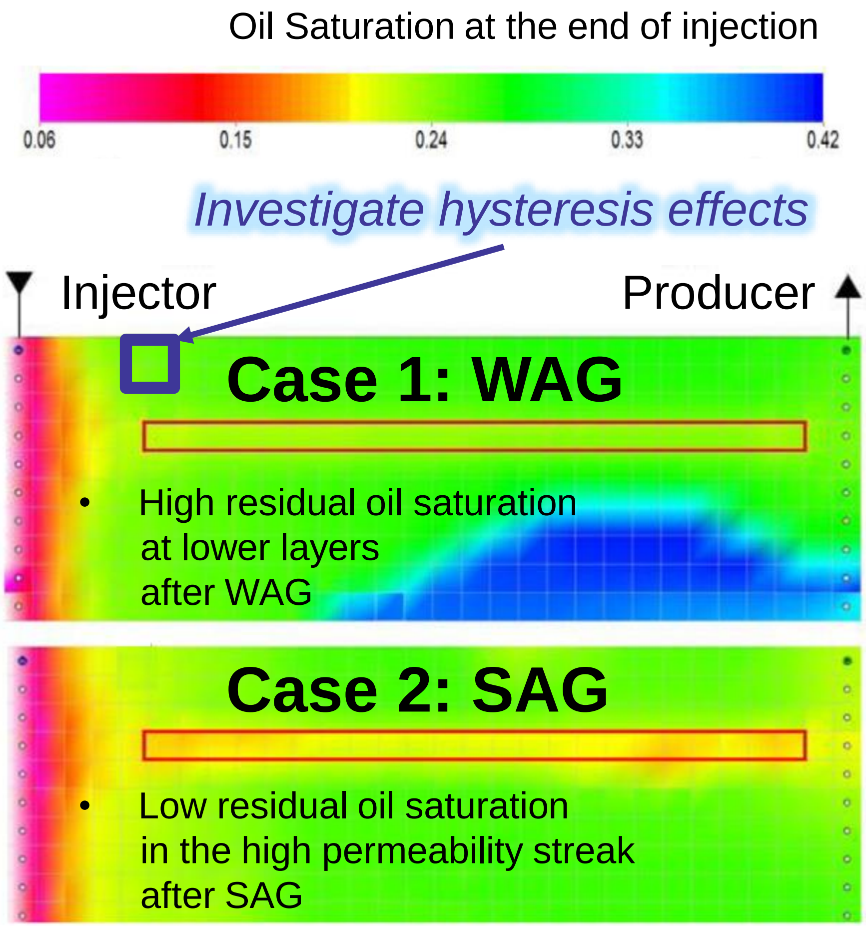
Model Description

- $\Phi = 0.2;\ \frac{k_v}{k_h} = 0.1;\ S_o^{initial} = S_{orw} = 0.35$
- Initial pore volume = 53.4 MSTB
- $T^{initial} = 90°\text{F}\ ;\ P^{initial} = 1{,}500\ psia$
- Initial oil composition:

  C_{10}=30%; C_{15}=40%; C_{20}=30%
- High perm streak in a low perm matrix



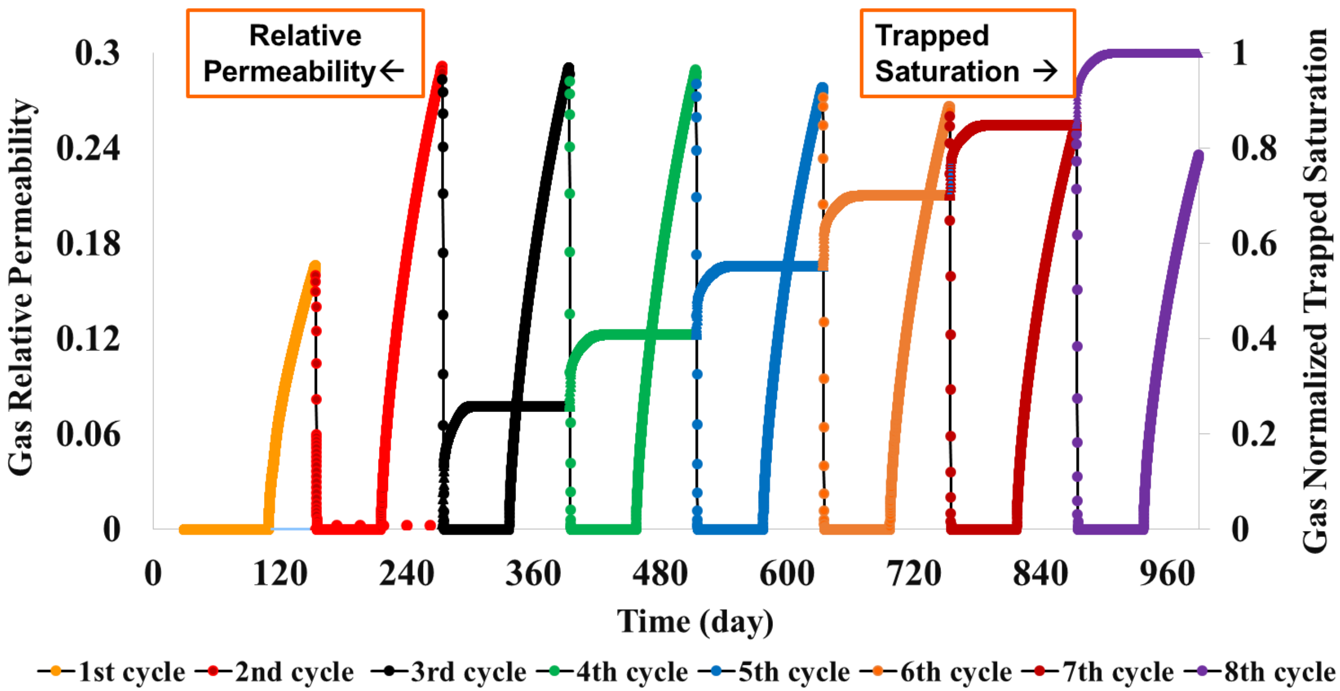
Simulation Results



Multiphase Relative Permeability and Hysteresis Models at a CO_2-EOR Field for CCS Utilization

Cycle-dependent Relative Permeability in Multi-cycle WAG Processes

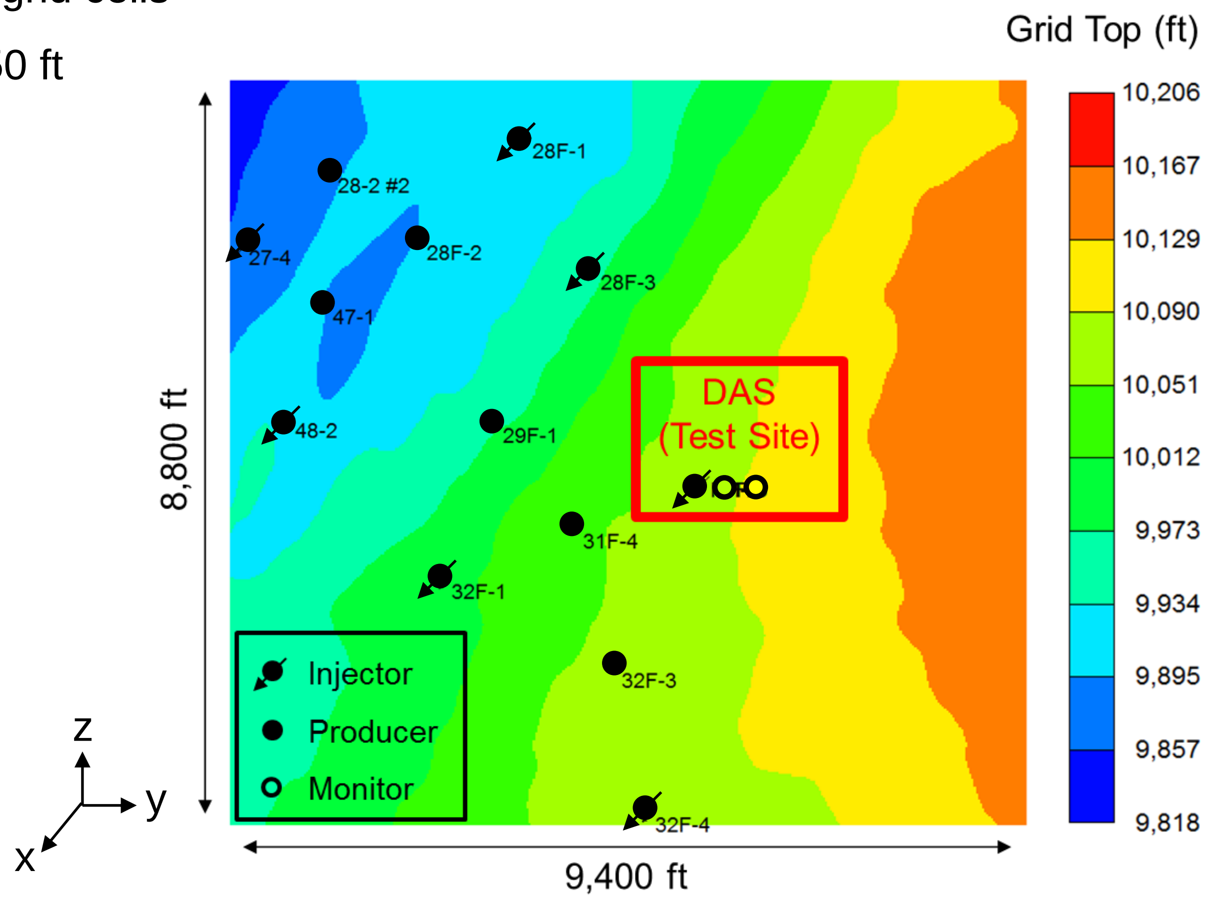
- As the cycle number increases from the 1st to the 8th,
  - Gas relative permeability decreases in time.
  - Gas normalized trapped saturation increases monotonically.
    : due to hysteresis !



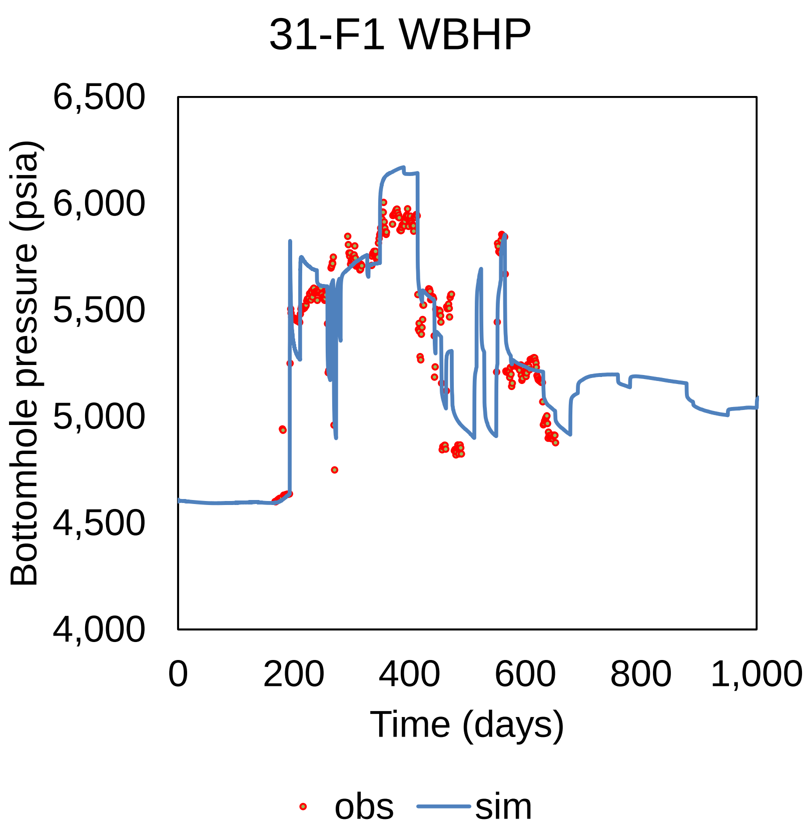
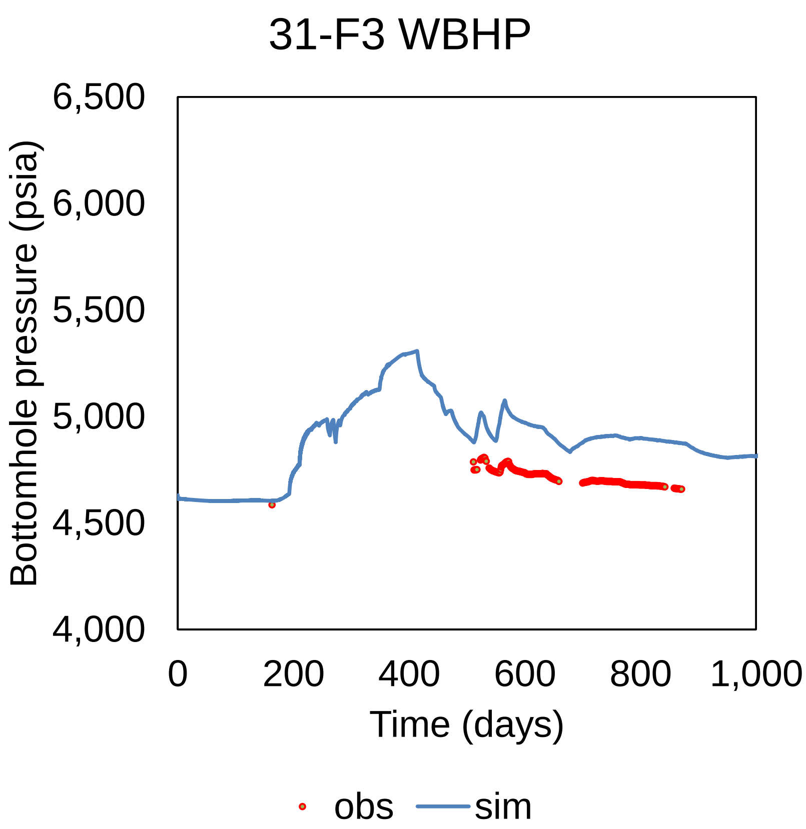
Compositional Simulation for the CO_2-EOR field: Cranfield, MS

Reservoir Model of Cranfield, MS

- 661,760 = 20x188x176 grid cells
- Grid size: 4 ft x 50 ft x 50 ft
- 6 oil producers
- 7 CO_2 injectors
- 2 monitoring wells



Compositional Simulation for the CO_2-EOR field: Cranfield, MS

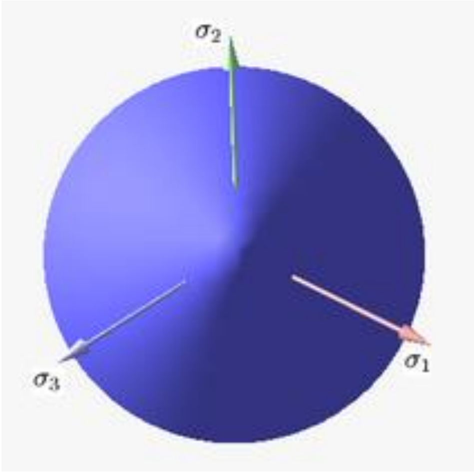
31F-1 (CO_2 injection well)	31F-3 (monitoring well)
	

(* Special thanks to Sun, A. and Hovorka, S. This work was collaborated with Bureau of Economic Geology.)

Geomechanical Effects of CO_2 Injection with a Poro-plasticity Model

Fluid Flow	$\frac{\partial(\rho(\phi_0 + \alpha\varepsilon_v + \frac{1}{M}(p - p_0)))}{\partial t} + \nabla \cdot \left(\rho\frac{K}{\mu}(\nabla p - \rho g \nabla h)\right) - q = 0$
Stress Equilibrium	$\nabla \cdot (\sigma'' + \sigma_o - \alpha(p - p_0)I) + f = 0$
Hooke's law	$\sigma'' = D^e : (\varepsilon - \varepsilon^p)$
Strain-Displacement Relation	$\varepsilon = \frac{1}{2}(\nabla u + \nabla^T u)$
Plastic Strain Evolution	$\dot{\varepsilon}^p = \lambda\frac{\partial F(\sigma'')}{\partial \sigma''}, \quad \text{at } Y(\sigma'') = 0$ $\dot{\varepsilon}^p = 0, \quad \text{at } Y(\sigma'') < 0$
Yield and Flow Functions	$Y = q + \theta\sigma_m - \tau_0$ $F = q + \gamma\sigma_m - \tau_0$

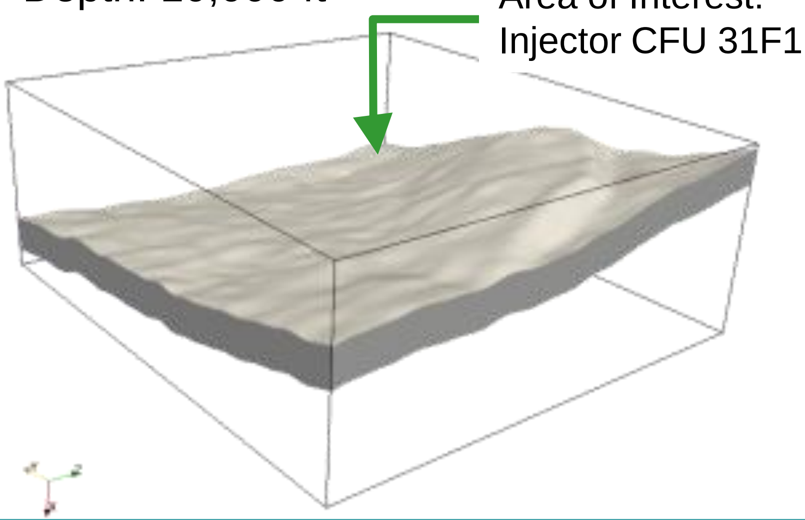
Druker-Prager Yield Surface



Poro-plasticity Simulation for the CO_2-EOR Field: Cranfield, MS

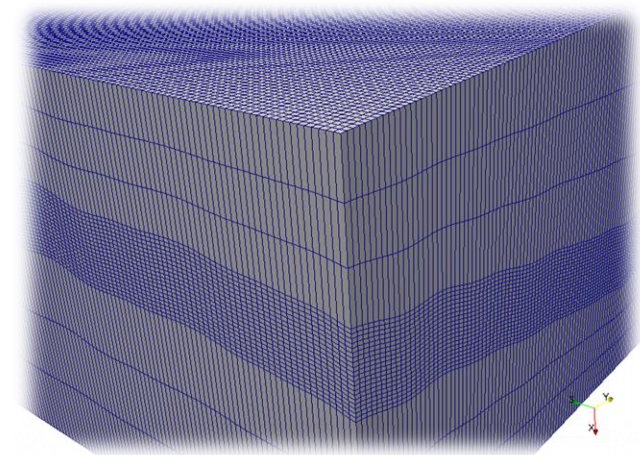
Reservoir Model Description

- Latest Cranfield numerical experiments:
  - Fully compositional multiphase flow
  - Druker-Prager poro-elasto-plasticity
  - Stress-dependent permeability
  - 4 injection wells / 2 production wells
- Domain size: 150 x 1,000 x 1,000 ft^3
- Simulation time: 595 days
- Depth: 10,000 ft



Hexahedral Geometry

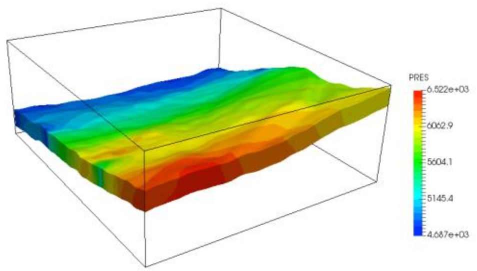
- Grid Resolution:
  - 26 x 188 x 176 = 860,288 hexahedral finite elements

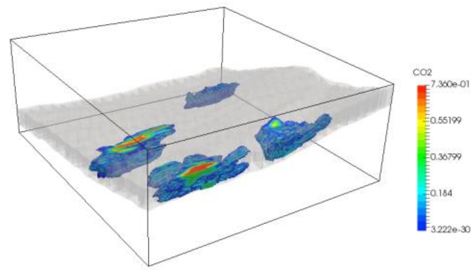


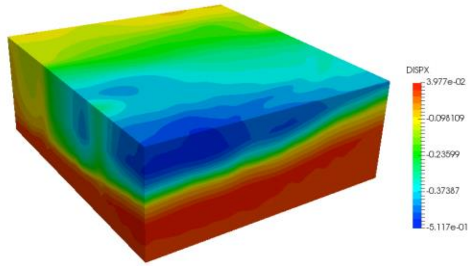
- Computer Used:
  - Stampede at TACC
  - Parallel simulation using 512 cores
  - Runtime of 34 hours

Poro-plasticity Simulation for the CO_2-EOR Field: Cranfield, MS

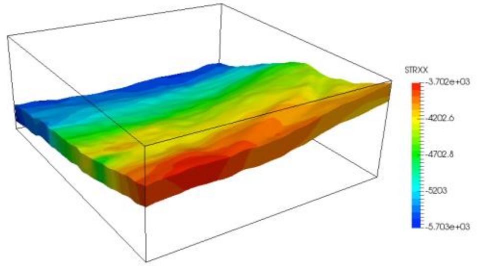
Reference Phase Pressure	CO_2 Concentration	Vertical Displacement

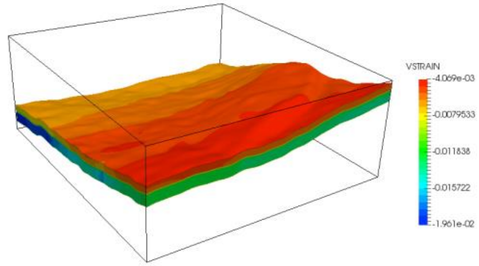


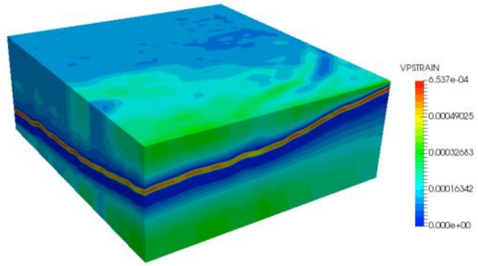




σ_{xx} Stress Component	Volumetric Strain	Volumetric Plastic Strain



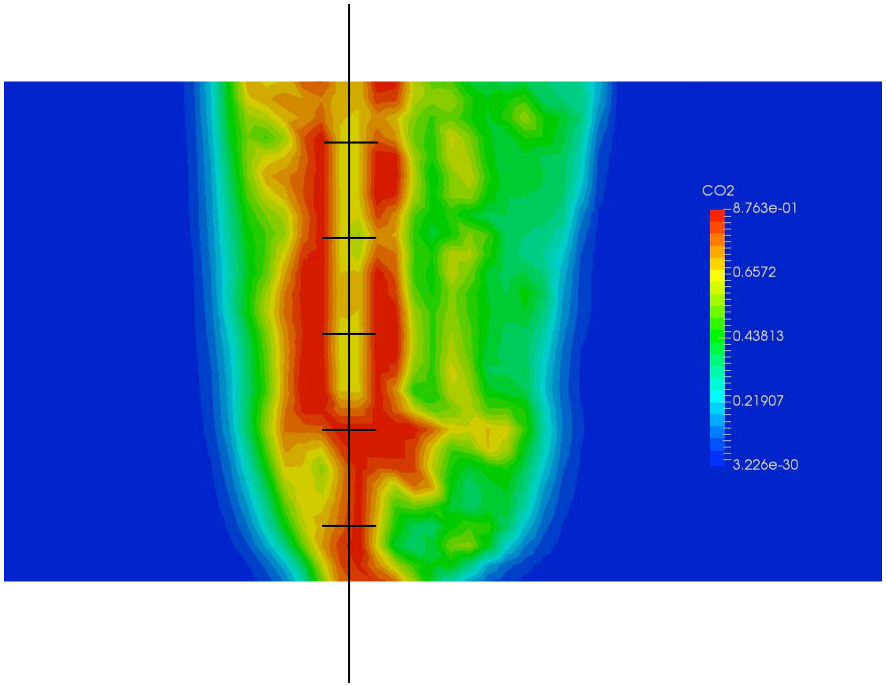




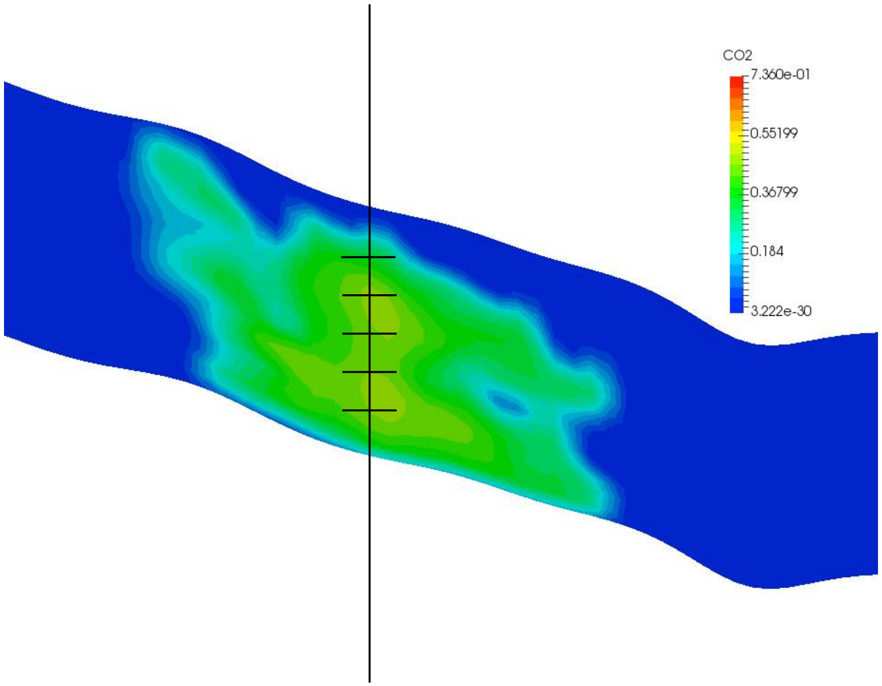
Shape of CO_2 Plume at the Injector CFU-31F1 at Cranfield, MS

Brick Geometry Model	Hexahedral Geometry Model

CO_2 injection well



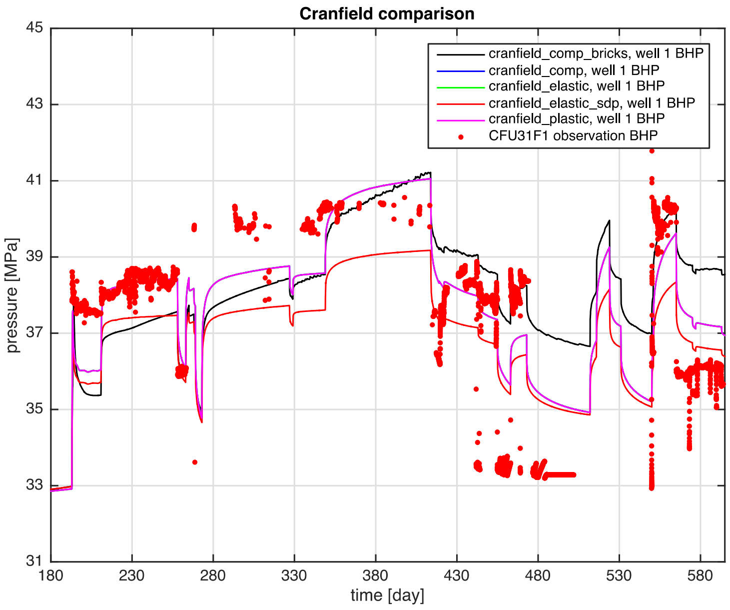
CO_2 injection well



Shape of CO_2 Plume at the Injector CFU-31F1 at Cranfield, MS

Effects of Poro-elasticity, Poro-plasticity, & Stress-dependent Permeability

- Hexahedral geometry and gravity had positive impacts on BHP results.
- Mechanics allows computation of displacements, stresses, & plastic strain.
- Either linear or nonlinear mechanics did not significantly impact well BHP.
- Stress-dependent permeability (SDP) had a noticeable effect on well BHP, but calibration is needed.
- Not yet history-matched using a compositional-geomechanics module



Future Works

- Perform history matching using the coupled compositional-geomechanical model w/ SDP
- Incorporate local grids and time stepping with more accurate well information
- Perform near-wellbore studies with discretely meshed well for better plastic effects

Task 5.

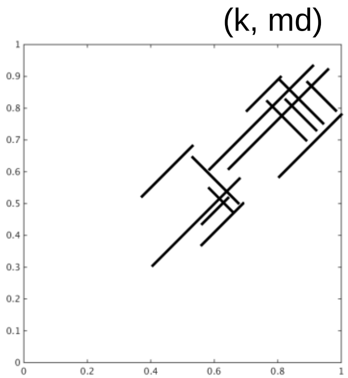
Parameter Estimation & Uncertainty Quantification

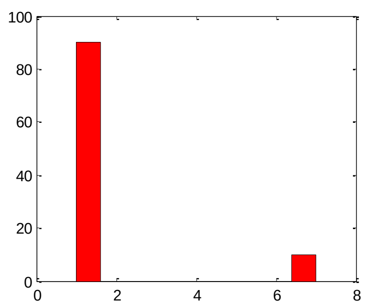
(M.F.W.–lead, S. Srinivasan–consultant)

Task 5: Uncertainty Quantification

Objectives	Update input parameters for numerical models, e.g. simulated responses match observations

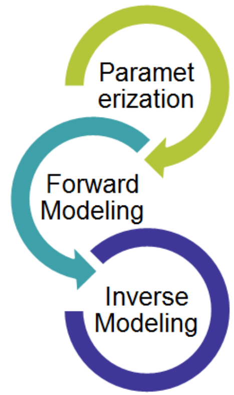
A Priori Model

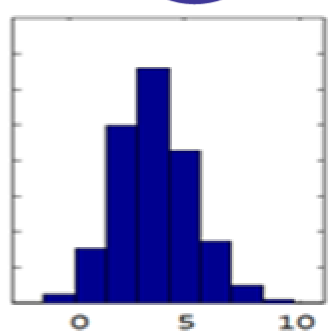




Multi-modal histogram of permeability

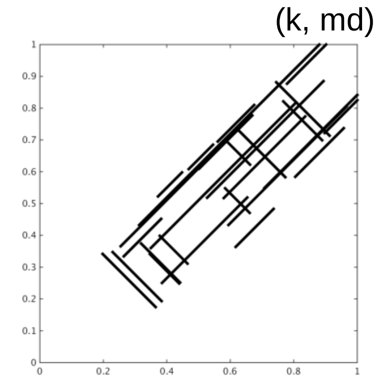
History Matching

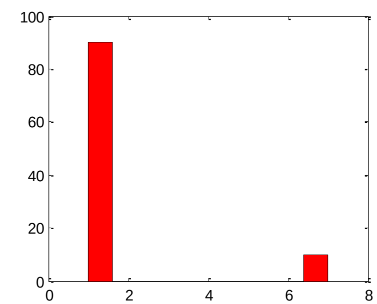




Gaussian histogram of Level-set parameters

A Posteriori Model



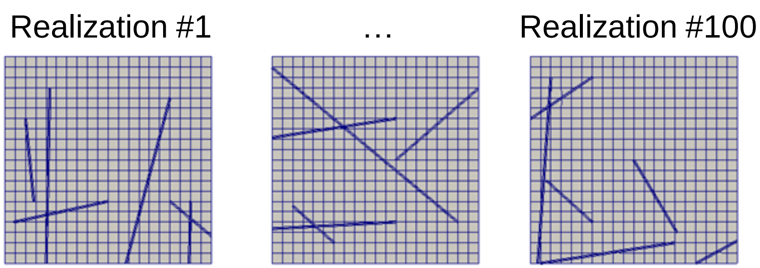


Multi-modal histogram of permeability

History Matching Coupled with Level-Set Parameterization, MFDFrac, and EnKF

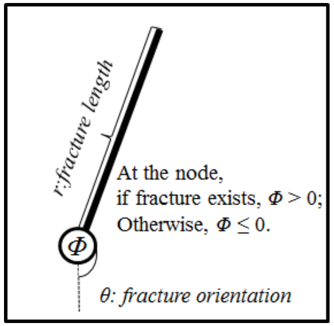
1 Initialization

- Generate initial fractured realizations



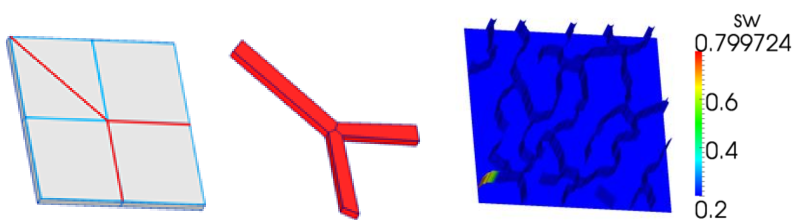
2 Level-Set Parameterization

- Convert non-Gaussian to Gaussian parameters
- Φ: level set at the node
- r: fracture length
- θ: fracture orientation



3 Simulation using MFDFrac

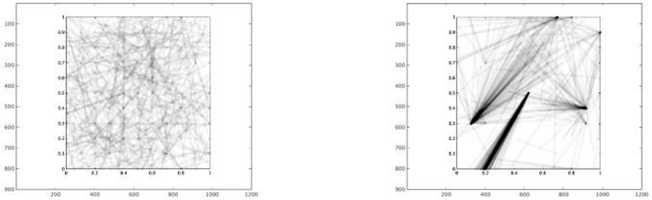
- Mimetic Difference Approach



Internal Fracture Boundaries | Intersecting Fractures | Flow

4 Inverse Modeling using EnKF

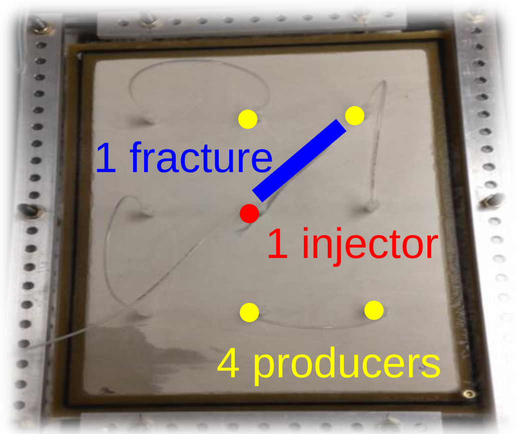
- EnKF for updating Gaussian parameters



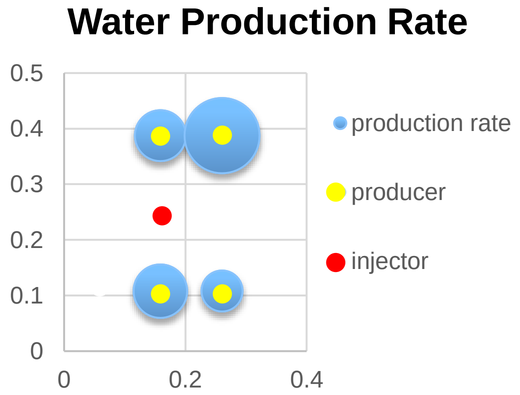
Ensemble mean of initial fracture realizations | Ensemble mean of final fracture realizations

History Matching Coupled with Level-Set Parameterization, MFDFrac, and EnKF

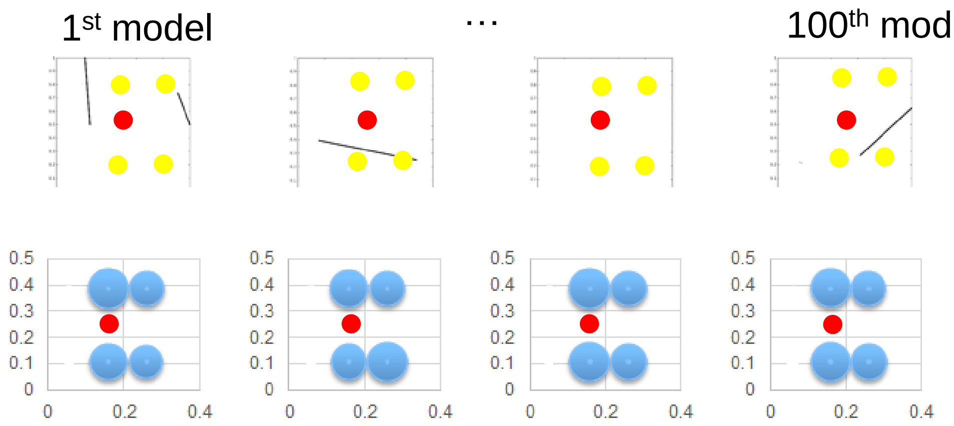
1 Lab-scale Sandpack



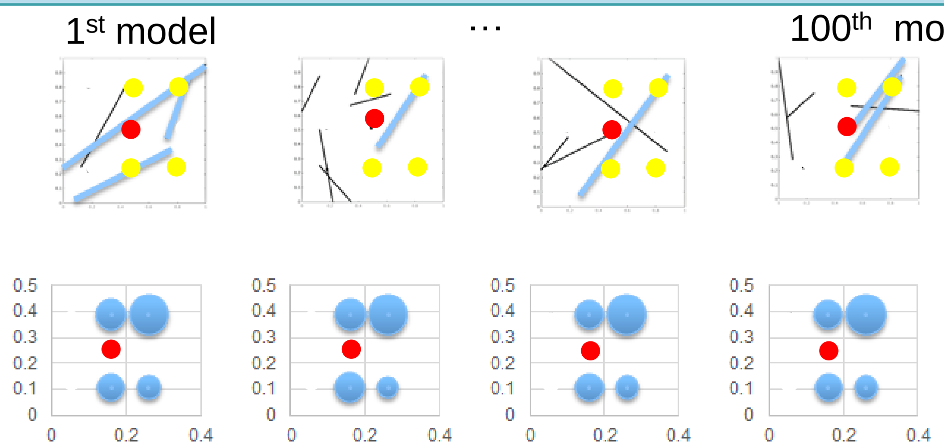
2 Observed Lab Data



3 100 Prior Models (before history matching)



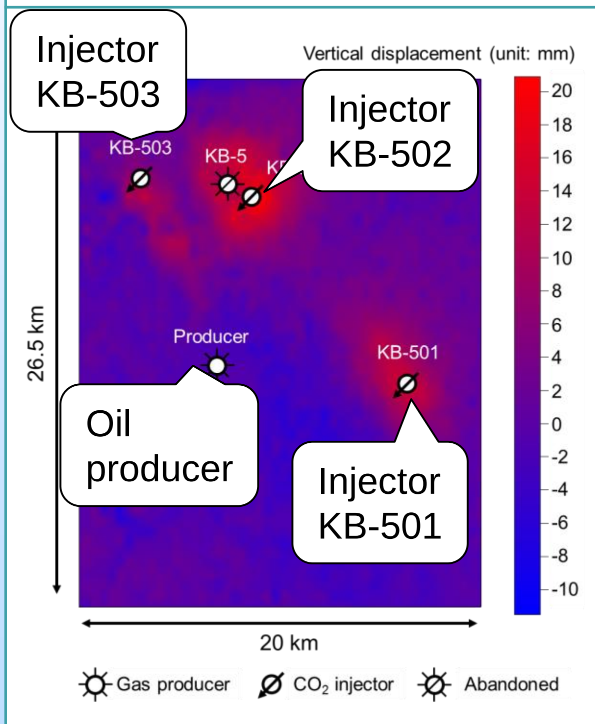
4 100 Posterior Models (History-matched)

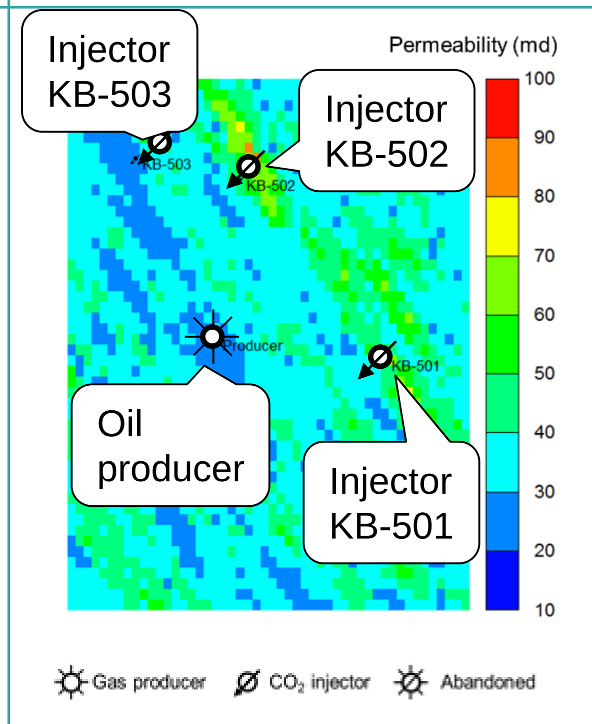


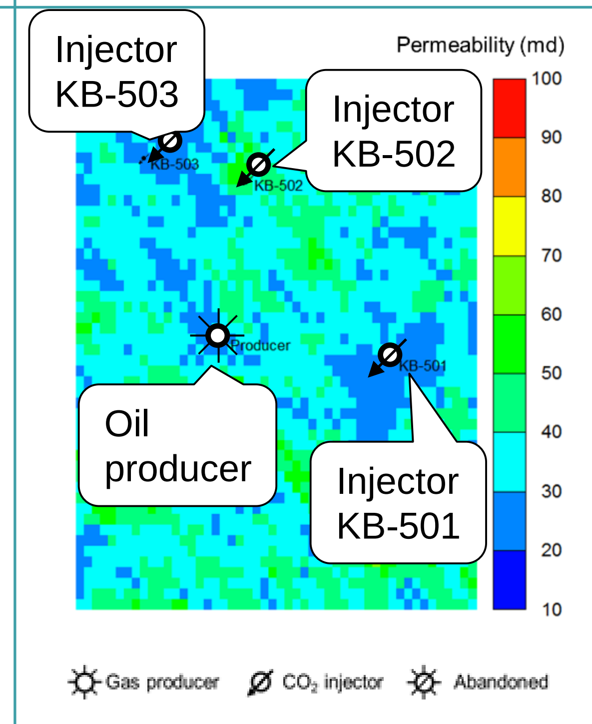
(Jing et al., 2016)

History Matching of a Fractured Reservoir : at the Well KB-503 in the In Salah CCS Field

Vertical Displacement	Global-Objective Optimization	Multi-Objective Optimization
• Observed data = InSAR (vertical displacement resulting from CO_2 injection) • Simulator: CMG-GEM	• After history matching, high permeability regions were obtained near all three CO_2 injection wells.	• After 4-objective history matching, permeability values were lowered near KB-501 and KB-503 wells .



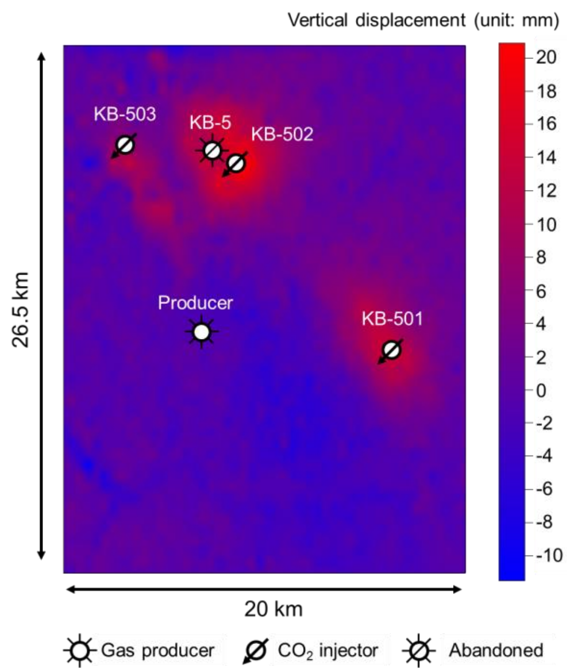


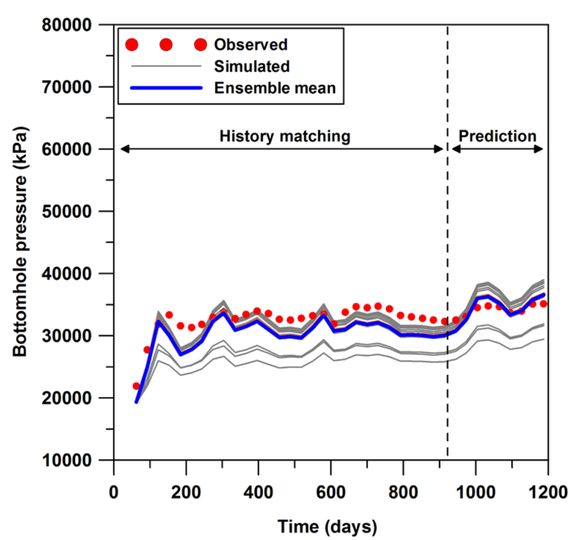


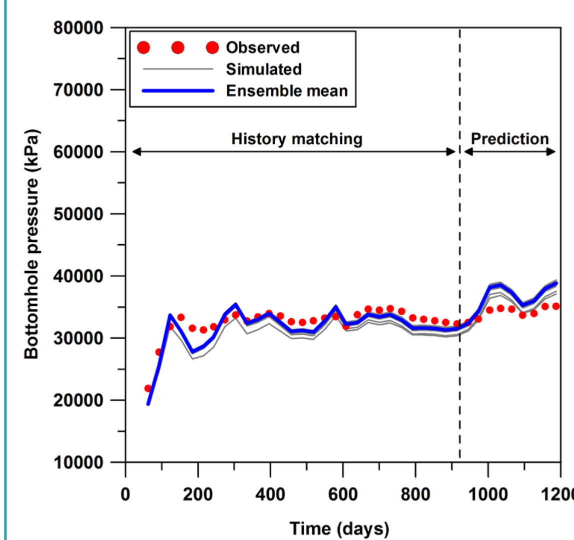
(Nwachukwu et al., 2016; Min et al., 2016)

History Matching of a Fractured Reservoir
: at the Well KB-503 in the In Salah CCS Field

Vertical Displacement	Global-Objective Optimization	Multi-Objective Optimization
• InSAR: satellite measured vertical displacement resulting from CO_2 injection • Simulator: CMG-GEM	• High permeability near the KB-503 well yielded underestimated BHP compared to observed BHP.	• Low permeability near the KB-503 well improved the matching quality of BHP.







(Nwachukwu et al., 2016; Min et al., 2016)

Technical Status

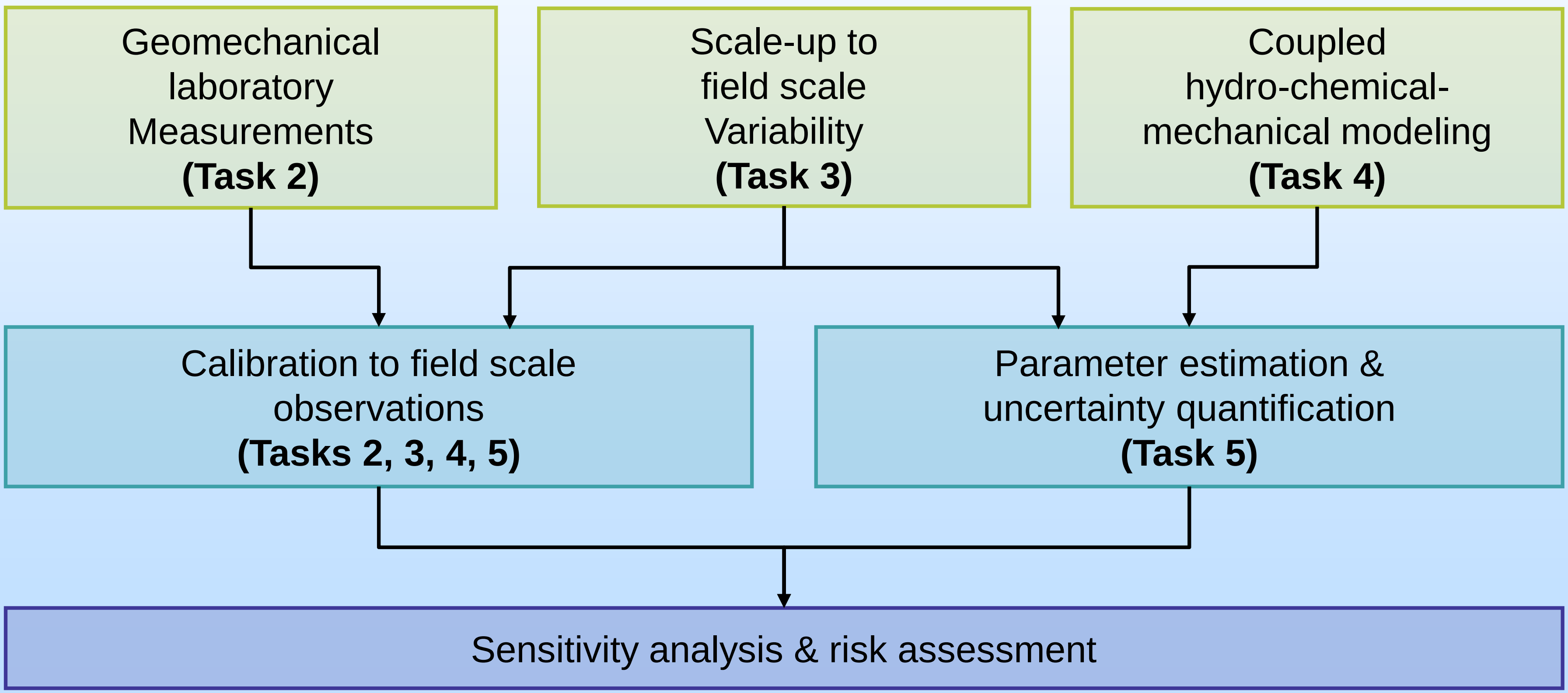
Task 6.

Integrate Results to Generate Geomechanical Screening Tool/Workflow

(M.F.W.–lead)

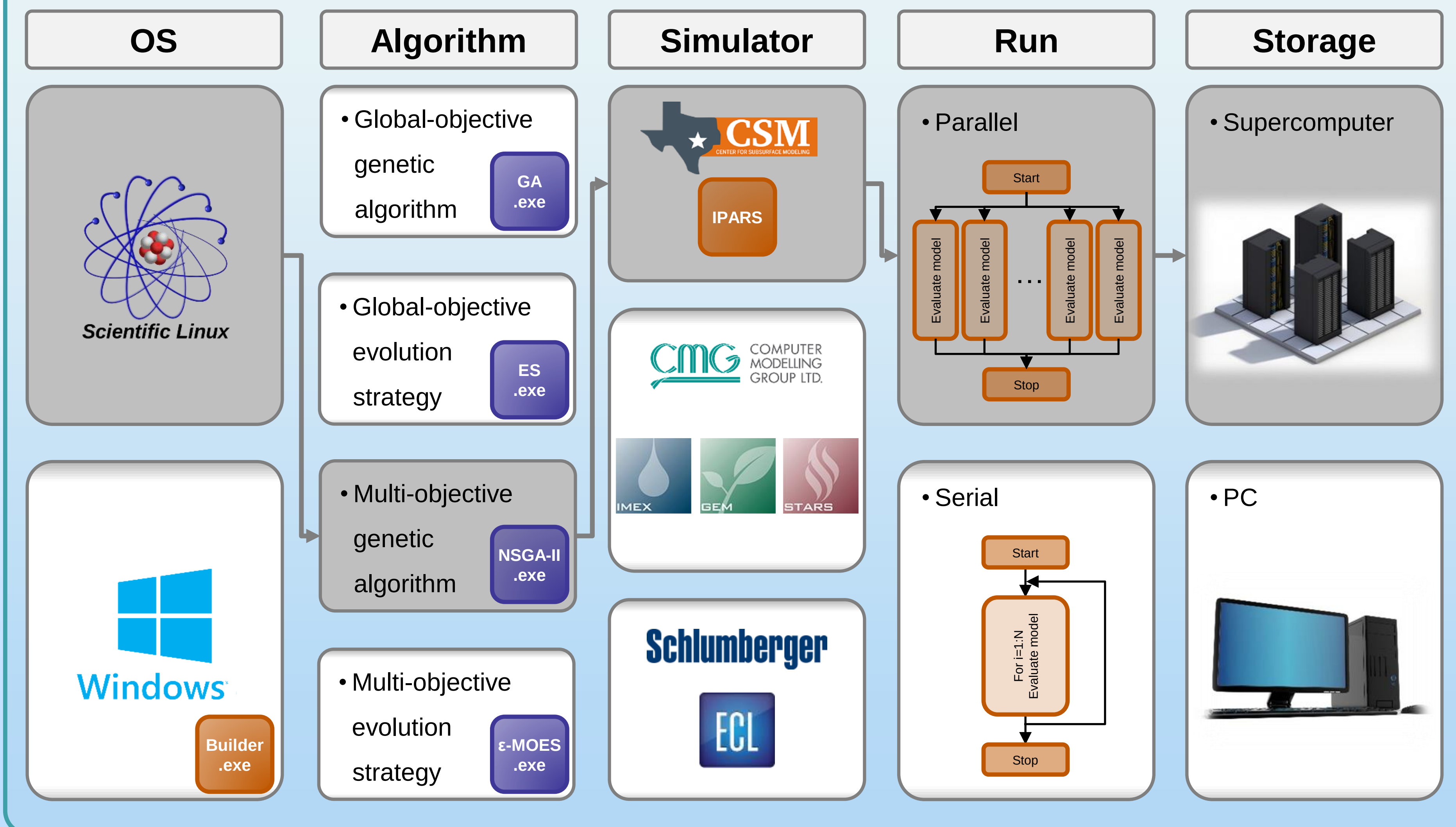
Task 6: Geomechanical Screening Tool

Objectives	Derive a workflow based on project tasks performed - experimental and numerical investigation of geomechanical processes, effects, & conditions related to CO_2 storage and analysis of two CO_2 storage field case studies



Development of a Multiple Model Optimizer : IRMS (Integrated Reservoir Management S/W)

All products of the tasks are being integrated with CSM's IPARS for Subsurface Modeling



Accomplishments to Date

Integrated Geomechanical Screening Tool / Workflow (T6)

❑ Lab-scale Experiments (T2)

- Experimental setup (1st year)
- Non-destructive test (1st & 2nd years)
  - ➢ Flow properties
    k, kr (for T3 & T4)
  - ➢ Mechanical properties
    λ, μ, α (for T3 & T4)
- Destructive test (3rd year)
  - ➢ Strong acid to accelerate fractures for geochemical reaction (for T3)
  - ➢ Effect of hysteresis (for T4)

❑ Development of Forward Models (T3 & T4)

- Enhanced velocity for LGR (T3)
- Compositional (T4)
- MFMFE (T4)
- Homogenization (T3)
- Poro-plasticity (T4)
- Gas-mobility control (T4)
- Time stepping (T3)
- Hysteresis (T4)

❑ Development of Inverse Models (T5)

- Level-set (T5)
- EnKF (T5)
- Multi-objective optimization (T5)

❑ Field Observations (T2 to T5)

- Frio (T3)
  Tracer w/ minimal chemical reaction
- Cranfield (T4 & T5)
  No chemical reaction
  Few core data
  History matching w/ Mechanics and Hysteresis
- Castlegate (T2 & T3)
  Outcrop sandstone for destructive test

Legend

Tasks during the 1st year
Tasks during the 2nd year
Tasks during the 3rd year

Synergy Opportunities

Assistance in Decision Making

- Assist in selection of suitable sites for safe CO_2 storage using generalized S/Ws based on a posteriori knowledge

Interdisciplinary Collaboration

- Enhance understanding of the effects of CO_2 migration on open and closed faults and fractures

Training & Education

- Support training and education of students who will take part in an interdisciplinary work, e.g. IPARS tutorial

Contribution to Identifying Geological Risk for Secure CO_2 Storage!

Outreach

Annual Affiliates Meeting	UTPREP4
• The annual two-day event presents opportunities for our industrial partners to hear about latest developments in timely and critical areas of technology (November 3-4, 2015)	• The Role of Computation in Protecting the Environment: A Workshop for High School Students on Energy and the Environment (July 13-14, 2016)

Summary

- We have measured fluid and geomechanical properties such as relative permeability, Biot Coefficients, for Frio and Cranfield sites through lab-scale non-destructive experiments.
- We have imported the experimental data into numerical models of Frio and Cranfield and calibrated the CCS models using EnKF with level-set and multi-objective optimization methods.
- We have developed advanced flow & geomechanics modules, which are not yet well-implemented in commercial software: Homogenization, Hysteresis, Capillary-trapping, Poro-elasticity, Poro-plasticity, parameterized EnKF, Multi-objective optimization
- Achieved ahead of milestone

Acknowledgements

Thank you for your attention

Contact: mfw@ices.utexas.edu

Organization Chart

Project Director M.F. Wheeler					
Task 1 Management	**Task 2** Laboratory Program	**Task 3** Bridging between Laboratory and Field Scales	**Task 4** Modeling and Field Studies	**Task 5** Uncertainty Quantification and Parameter Estimation	**Task 6** Integrate Results to Generate Geomechanical Screening Tool / Workflow
Task Leader M.F. Wheeler	**Task Leader** N. Espinoza	**Task Leader** M.F. Wheeler	**Task Leader** M. Delshad	**Task Leader** M.F. Wheeler	**Task Leader** M.F. Wheeler
Key Personnel M. Delshad S. Srinivasan N. Espinoza	**Key Personnel** M.F. Wheeler M. Delshad ½ Postdoc 1 Student (Y 1&2)	**Key Personnel** S. Srinivasan N. Espinoza ½ Postdoc 1 Student	**Key Personnel** M.F. Wheeler N. Espinoza ½ Postdoc 1 Student (Y 3)	**Key Personnel** M. Delshad M.F. Wheeler 1 Student S. Srinivasan (Consultant)	**Key Personnel** M. Delshad S. Srinivasan N. Espinoza Postdoc Student

Gantt Chart

#	Task	Sep. 2014 - Aug. 2015 Q1	Q2	Q3	Q4	Sep. 2015 - Aug. 2016 Q1	Q2	Q3	Q4	Sep. 2016 - Aug. 2017 Q1	Q2	Q3	Q4
1	Management	A, B											
2	Laboratory Experiment			C	D		E		F	G			
3	Upscale from Lab. to Field								H		I		
4	Simulator Development				J				K	L		M	
5	Uncertainty Quantification								N				O
6	Integrated Geo-Screening Tool												P

A to P : Milestones   Scheduled   Accomplished

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  - Min, B., Nwachukwu, A., Srinivasan, S., and Wheeler, M.F. 2016, Selection of geologic models based on Pareto-optimality using surface deformation and CO_2 injection data for the In Salah gas sequestration project. SPE Journal (submitted). Nwachukwu, A., Min, B., and Srinivasan, S. 2016, Model selection for CO_2 sequestration using surface deformation and injection data. International Journal of Greenhouse Gas Control (submitted).
  - Liu, R., Ganis, B., White, D., and Wheeler, M.F. Implementation of a Drucker-Prager plasticity model in a reservoir simulator using a fixed-stress iterative coupling scheme. (In preparation).
  - White, D., Ganis, B., Liu, R., and Wheeler, M.F. Simulation of the Cranfield CO_2 injection site with a Drucker-Prager plasticity model. (In preparation).
  - White, D., Ganis, B., Liu, R., and Wheeler, M.F. A near-wellbore study with a Drucker-Prager plasticity model coupled with a parallel compositional Reservoir simulator. (In preparation).
  - Dewers, T. et al. 2016, Control of process for subsurface science and engineering: examples from geologic carbon storage. (Submitted).

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- Conference:

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  - Min, B., Wheeler, M.F, Sun. A. 2016. Multi-objective optimization of pulse testing results using parallel compositional simulations for reservoir characterization of a CO_2-EOR field in Mississippi. AGU Fall Meeting, San Francisco, California, 12–16 Dec. (submitted).
  - Min, B., Wheeler, M.F, and Sun. A. 2017. Parallel multiobjective optimization for the coupled compositional/geomechanical modeling of pulse testing. SPE Reservoir Simulation Conference, Montgomery, Texas, 20–22 Feb. (accepted).
  - Ping, J., Al-Hinai, O., Srinivasan, S. and Wheeler, M.F., 2016, History matching for fractured reservoirs using mimetic finite differences and ensemble Kalman filter. AGU Fall Meeting, San Francisco, California, 12–16 Dec. (submitted).
  - Wheeler, M.F., Amanbek, Y., and Singh, G. 2016. Upscaling reservoir properties using single well tracer test, Computational Method in Water Resources, Toronto, Canada, 21–24 Jun.