Multiscale Modeling of Carbon Dioxide Migration and Trapping in Fractured Reservoirs with Validation by Model Comparison and Real-Site Applications

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Transforming Technology through Integration and Collaboration

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Presentation Outline

- Project Benefits, Goals and Objectives
- Project overview
- Accomplishments
- Summary

Project participants

Princeton University

Michael Celia

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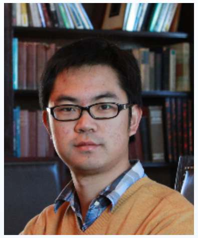

Bo Guo

Lawrence Berkeley National Laboratory

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Benefit to the Program

- Goal: Develop new capabilities for carbon sequestration modeling in fractured reservoirs through improvements in the representation of fracture-matrix flow interactions.

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

Project Objectives

- Develop new model for interactions of fracture and matrix flow
- Incorporate new model into reservoir-scale simulators
- Conduct sensitivity analyses of trapping efficiency and storage capacity using new model
- Apply new model to In Salah site

Project Overview

- Fractured reservoirs
- Dual-porosity models
- Transfer functions
- Hybrid model
- Example

Fractured reservoirs

Carbonate rocks

- 60% of world's remaining oil
- 25% of world's groundwater
- Possibly used for storage of CO_2

Shales and mud-rocks

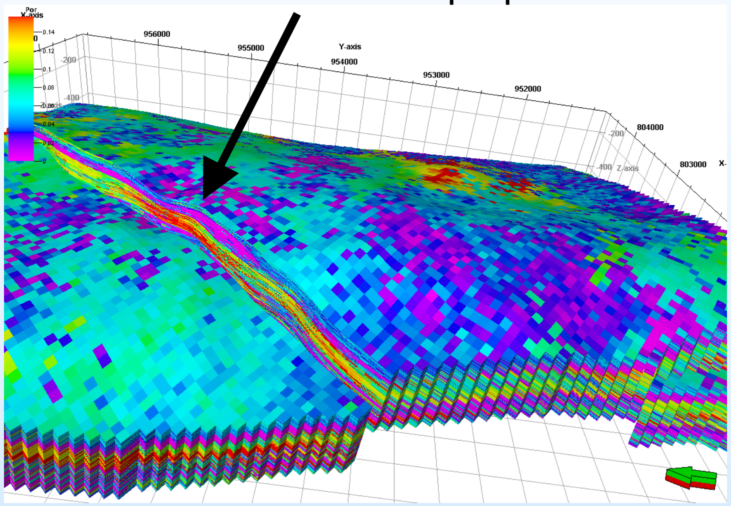
- Unconventional oil and gas
- Leakage through seals and barriers

Crystalline and basement rocks

- Enhanced geothermal systems
- Storage of nuclear waste

Modeling challenges

~ 100 x 100 x 5 m
~ 13,000 t fluid
~ 100,000 t rock
Uniform properties

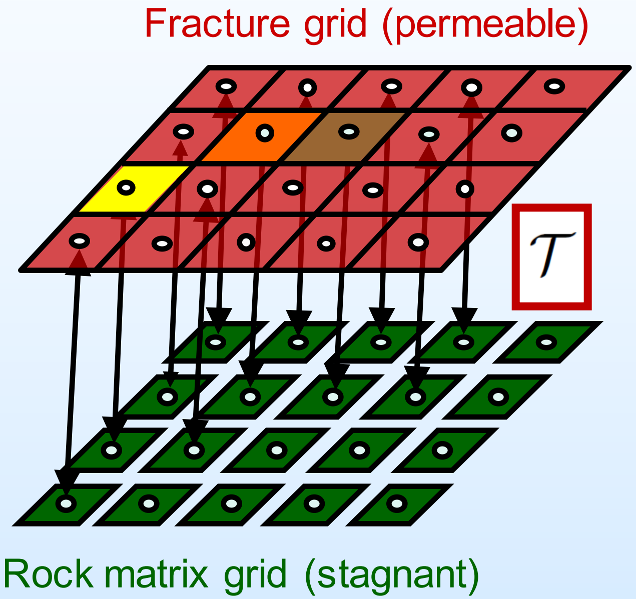


Several km

Dual-porosity models

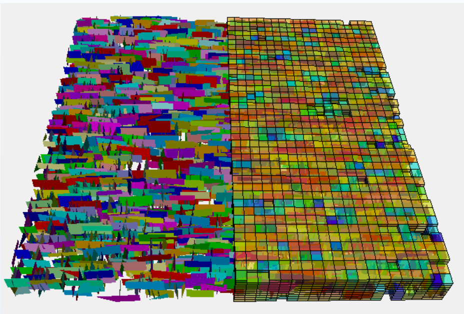
Naturally fractured rock

Conceptual model



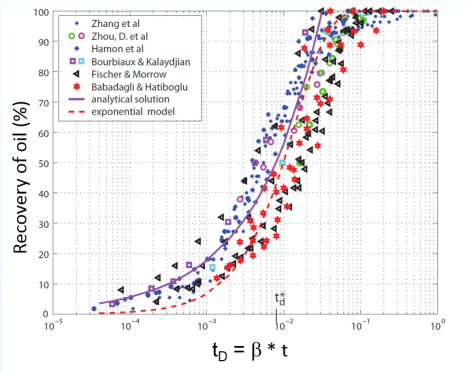
Dual-porosity: ingredients

1. Fracture permeability



2. Matrix properties

3. Transfer function

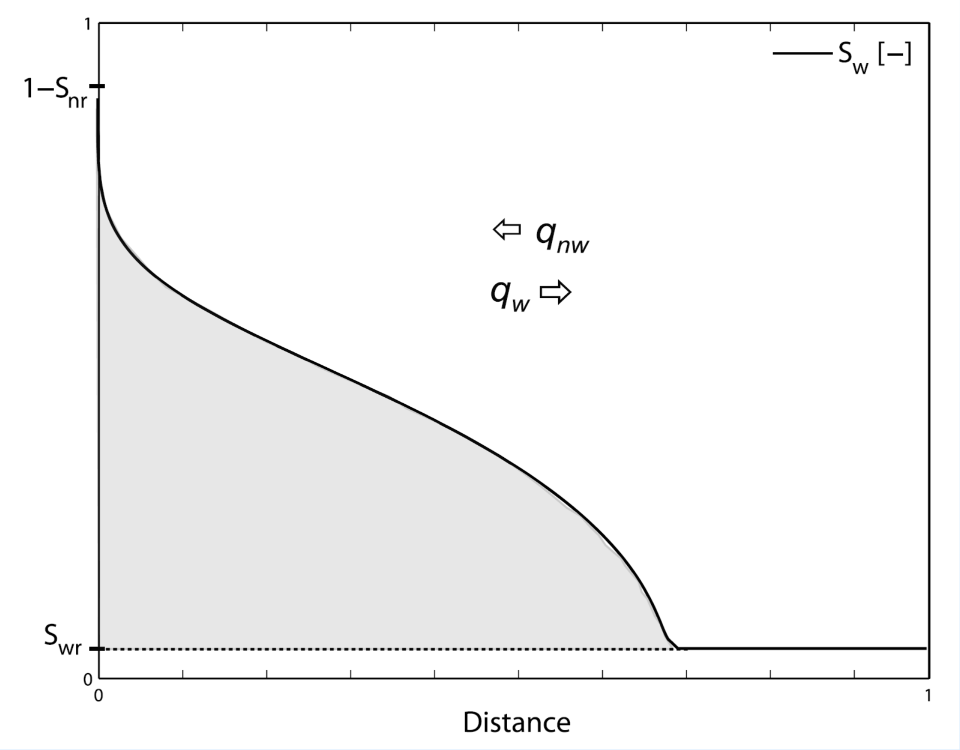


Processes that induce fracture-matrix transfer:

- Forced displacement
- Buoyancy driven displacement
- Spontaneous imbibition

Counter-current spontaneous imbibition

- Driven by capillary forces only
- Wetting fluid displaces the resident non-wetting fluid

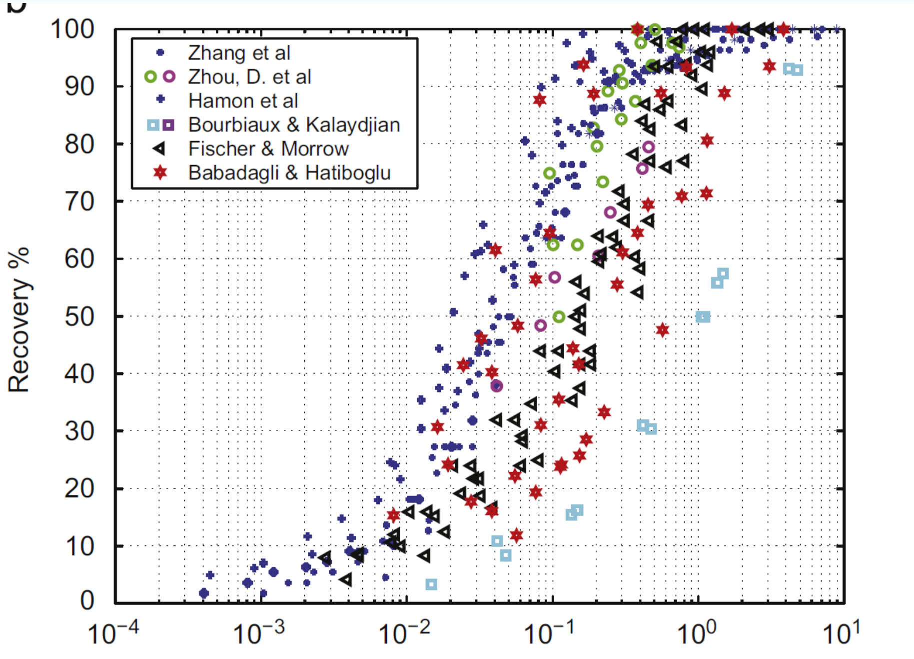


Schmid & Geiger (2012, 2013)

Experimental results

- Experimental values collapse when time is scaled by amount imbibed and effective pore space

- Analytic solution for early time
- First-order rate model

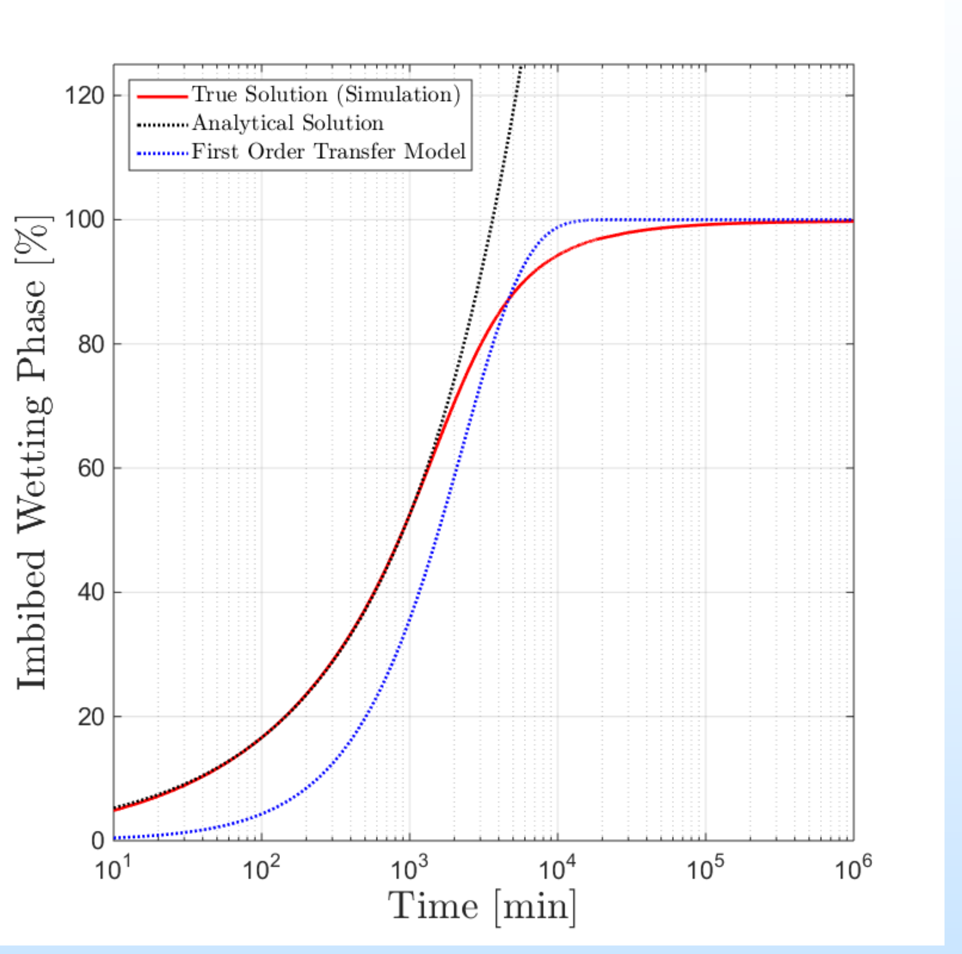


$t_D = \beta * t$

Schmid & Geiger (2012, 2013)

Solution types

- Early time behaves according to self-similar capillary diffusion
- First-order model captures late behavior
- Combine the two solutions to form hybrid model

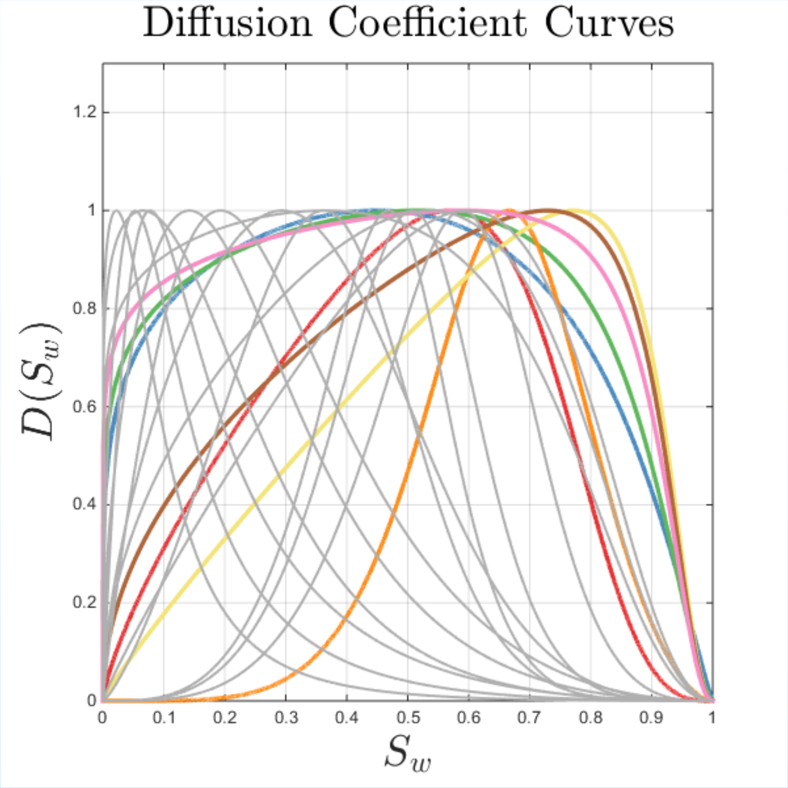


Factors that determine transition time

- Viscosities of fluids
- Capillary pressure
- Relative permeabilities

} Capillary diffusion coefficient

Relevant parameters for CO_2 storage (coloured curves) show substantially different shape in normalized diffusion coefficients.



End of early time regime

- Early time is dominated by counter-current capillary diffusion
- Cumulative diffusion as a measure of the onset to late time recovery
- Transfer at $\hat{t}_{60}$ from early-time to late-time behaviour when 60% of cumulative diffusion has occurred

Illustration of cumulative diffusion

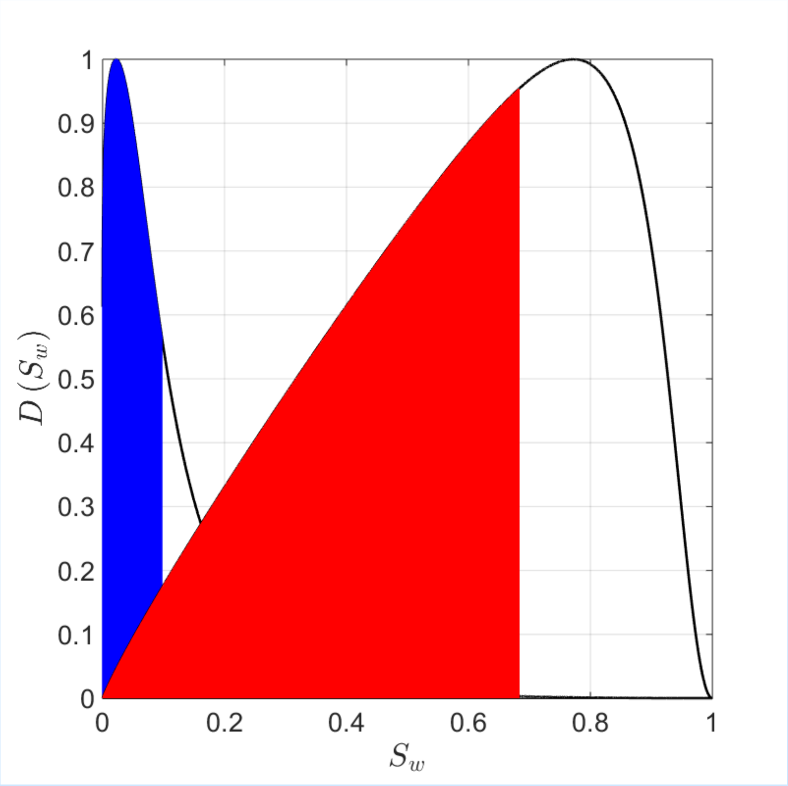
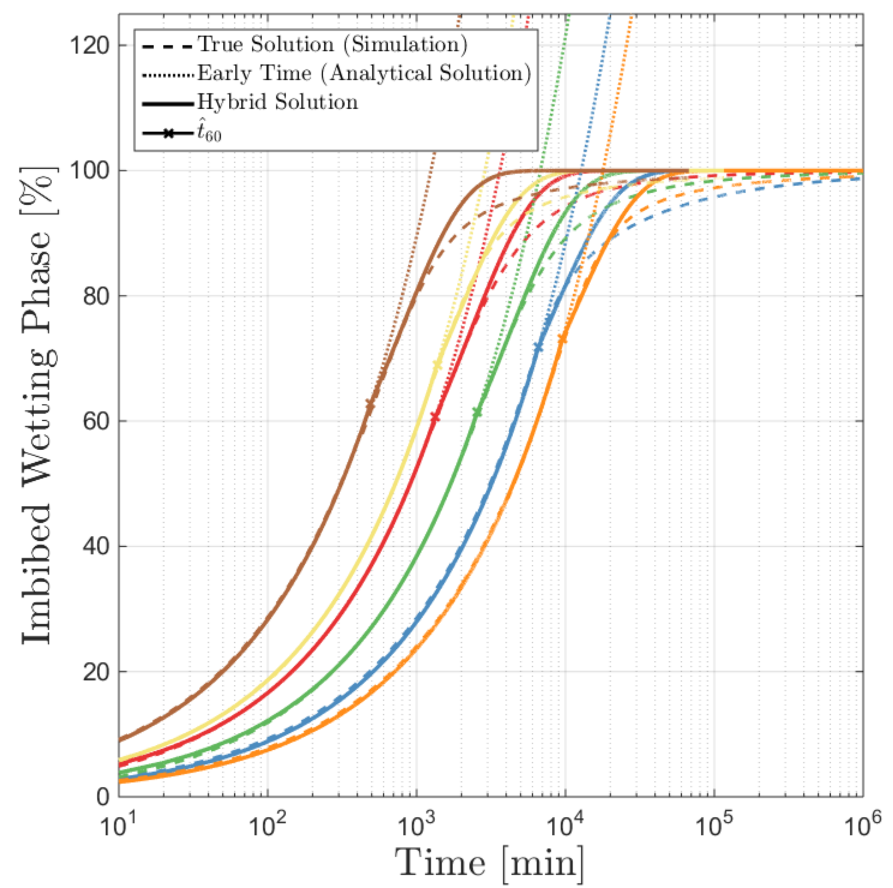


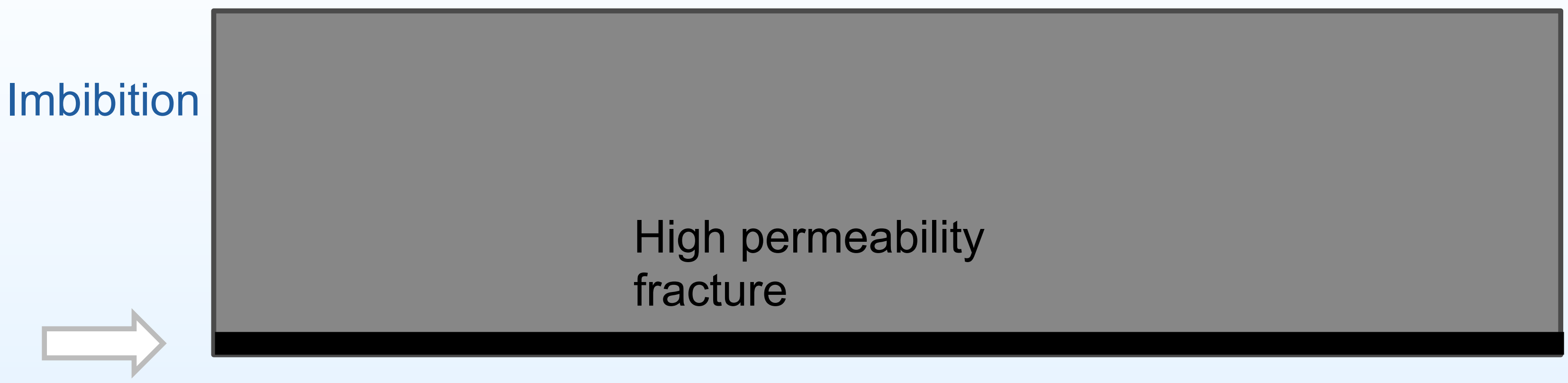
Illustration of hybrid transfer solutions

- Predicted $\hat{t}_{60}$ from diffusion coefficient
- Perfect match for early time through analytical solution
- Approximate match at late time through first-order transfer

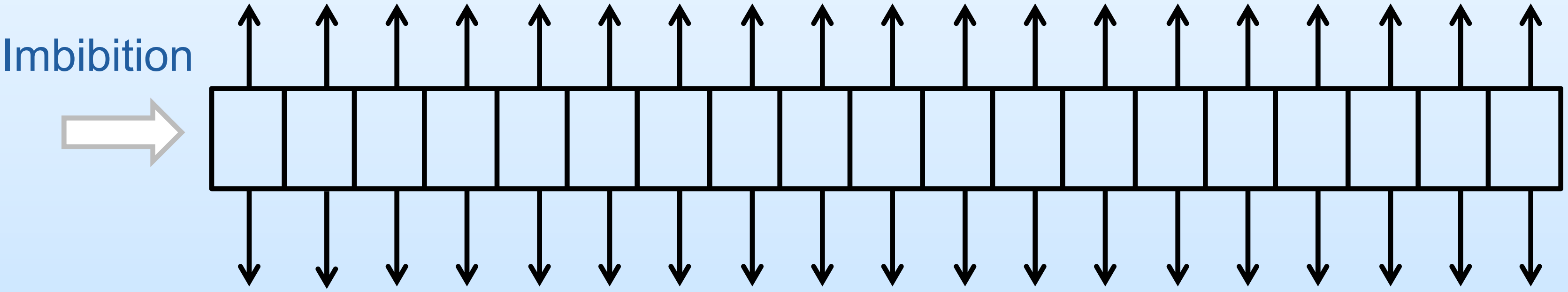


Dual-Porosity Simulation Example Setup

Fully resolved simulation setup

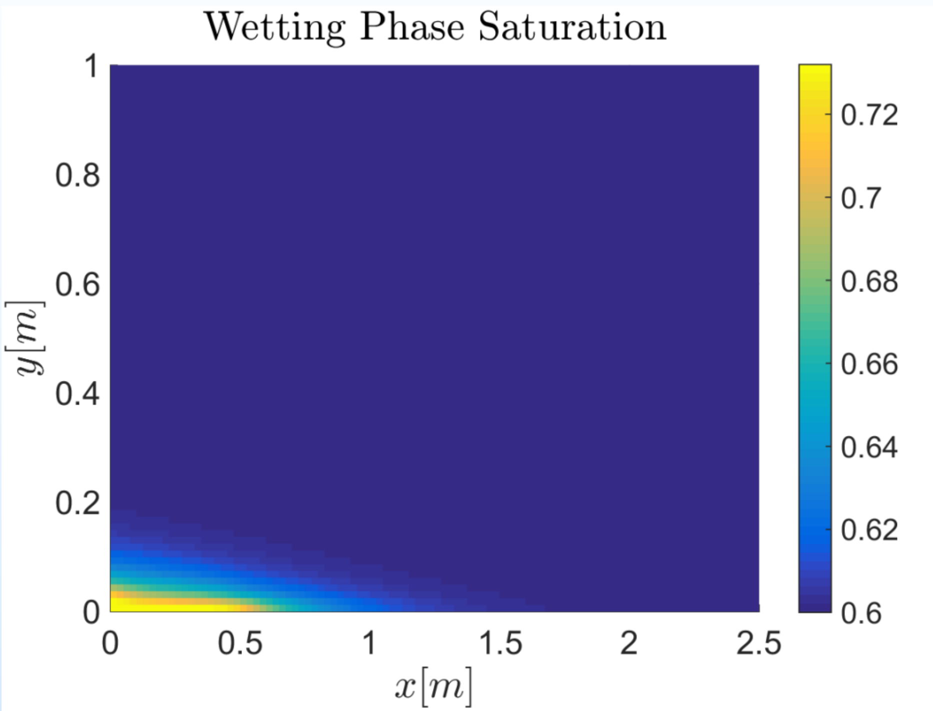


Dual-porosity setup

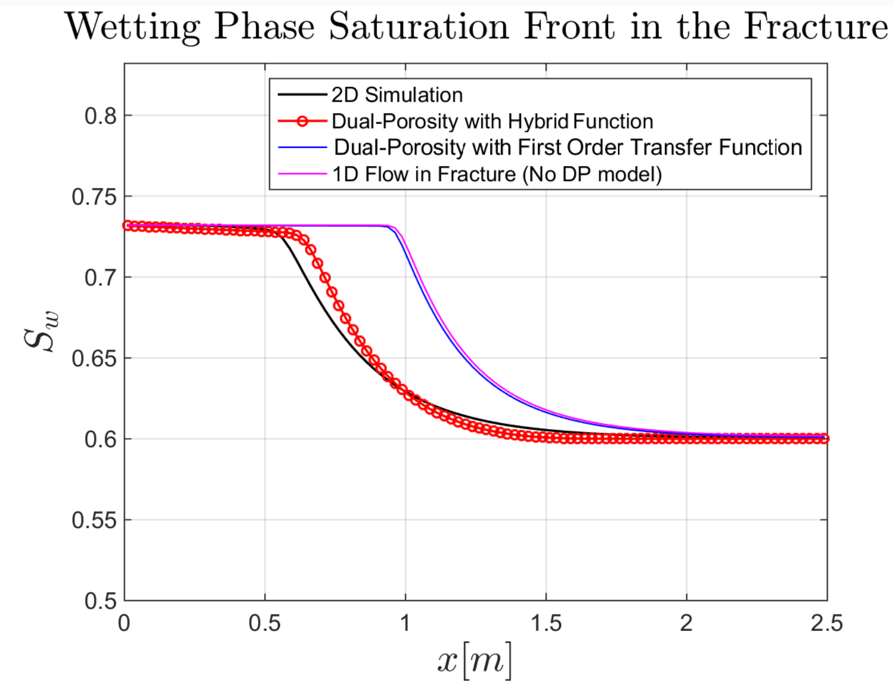


Dual-Porosity Simulation Example Results

Fully resolved simulation



Dual-porosity simulation



Conclusions

- Hybrid transfer functions are able to capture spontaneous imbibition
  - Exactly for early times
  - Approximately for late times
- Transition time can be predicted based on fluid and rock properties

Accomplishments to Date

- Development of hybrid transfer function for dual-porosity model of spontaneous imbibition
- Development of hybrid discrete-continuum model that better represents flow in the rock matrix
- Conversion of In Salah wellhead pressures and temperatures to downhole values
- Continued investigation of applying a vertically-integrated approach to a dual-porosity model

Synergy Opportunities

- The modeling approaches developed in this project should be useful to other projects studying carbon sequestration in fractured formations

Future Plans

- Continue to develop transfer functions
- Continue development of coupling of vertical-equilibrium and non-equilibrium domains to model dual-porosity systems
- Implement the new approach into TOUGH2, MRST and vertically-integrated simulator
- Continue sensitivity analysis of storage efficiency
- Develop model for In Salah site

THANK YOU!

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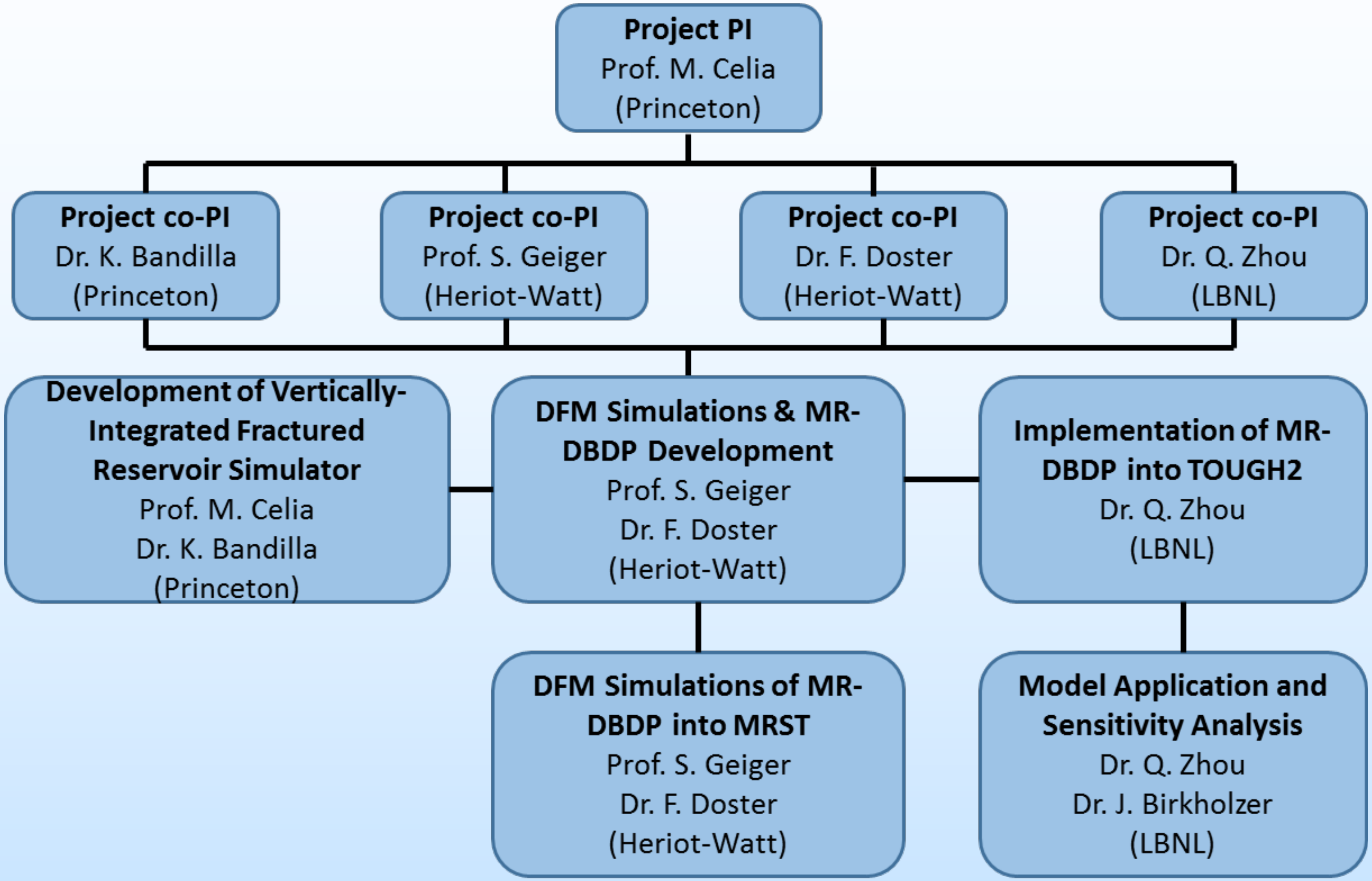
Appendix

Organization Chart



Gantt Chart

light grey: accomplished; dark grey: planned; MS: mile stone

Fiscal Year	BP 1				BP 2				BP 3			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4
Task 1: Project Management, Planning and Reporting												
Subtask 1.1: Updated Project Management Plan	MS											
Subtask 1.2: Kickoff Meeting	MS											
Task 2.0: Detailed DFM modeling of CO2 and brine				MS								
Task 3.0: Development of MR-DBDP model with analytic transfer function						MS						
Task 4.0: Development of new simulator capabilities												
Subtask 4.1: Development of vertically integrated simulator					MS					MS		
Subtask 4.2: incorporate new MR-DBDP into MRST simulator												MS
Subtask 4.3: incorporate new MR-DBDP into TOUGH2						MS						
Task 5.0: Model demonstration and sensitivity analysis												
Subtask 5.1: Investigation of driving forces												
Subtask 5.2: Sensitivity Analysis							MS					
Subtask 5.3: Storage and trapping in heterogeneous reservoir									MS			
Subtask 5.4: Investigation of injection scenarios												
Task 6.0: Simulator application to In Salah												
Subtask 6.1: Site-specific model development										MS		
Subtask 6.2: Migration and Trapping modeling										MS		
Subtask 6.3: Sensitivity analysis												MS

Bibliography

- Nothing to report