Model Complexity and Choice of Model Approaches for Practical Simulations of CO_2 Injection, Migration, Leakage, and Long-term Fate

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Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

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

Benefit to the Program

- Goal: Develop a suite of models, across a broad spectrum of complexity, and determine when simplified models are appropriate for CO_2 sequestration modeling.
- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.

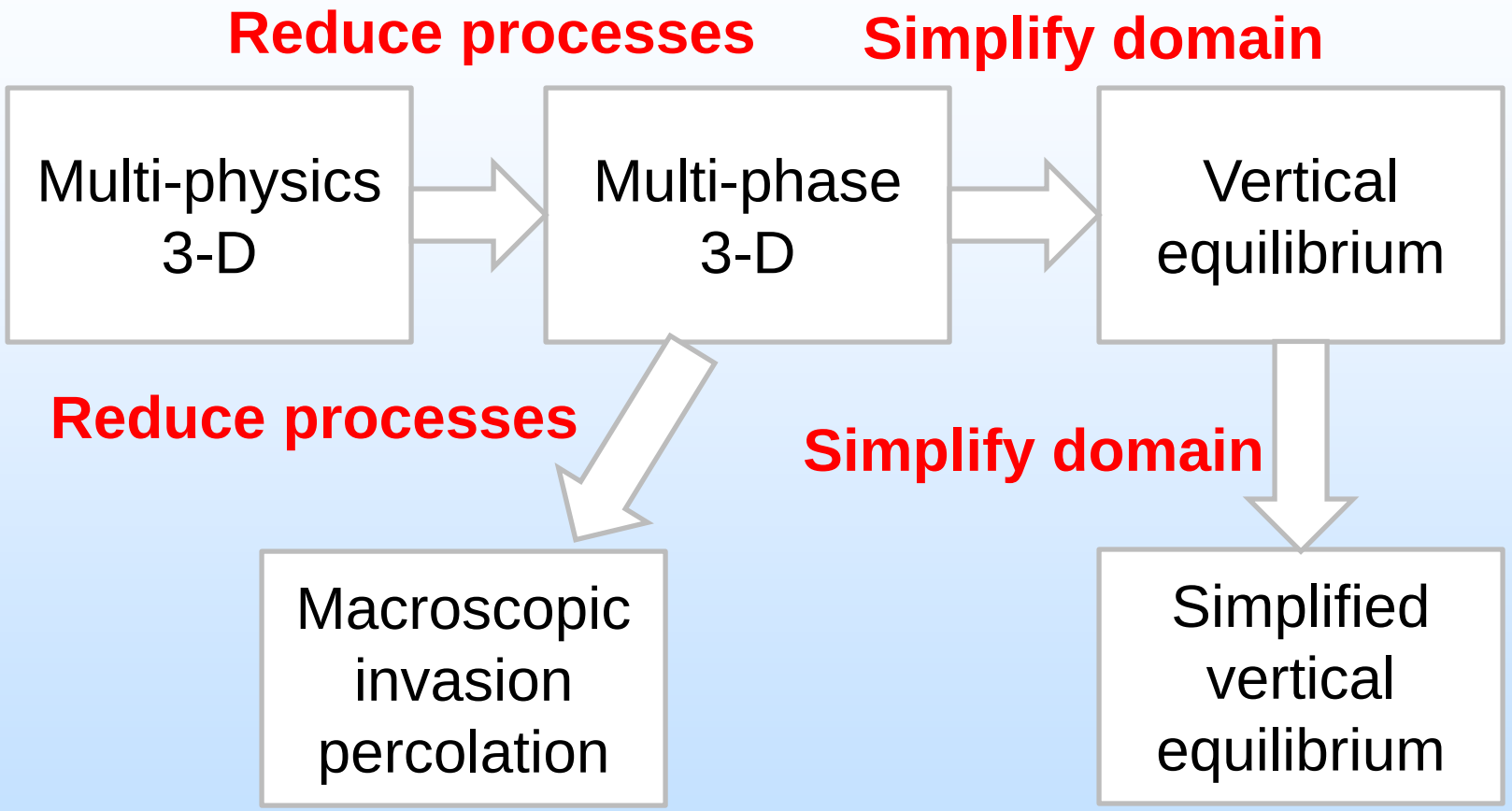
Project Objectives

- Assemble a suite of models across the range of complexity
- Compare the performance of models of different complexity when applied to actual sites
  - forward modeling
  - optimization
- Develop a set of practical criteria that can guide the choice of model complexity

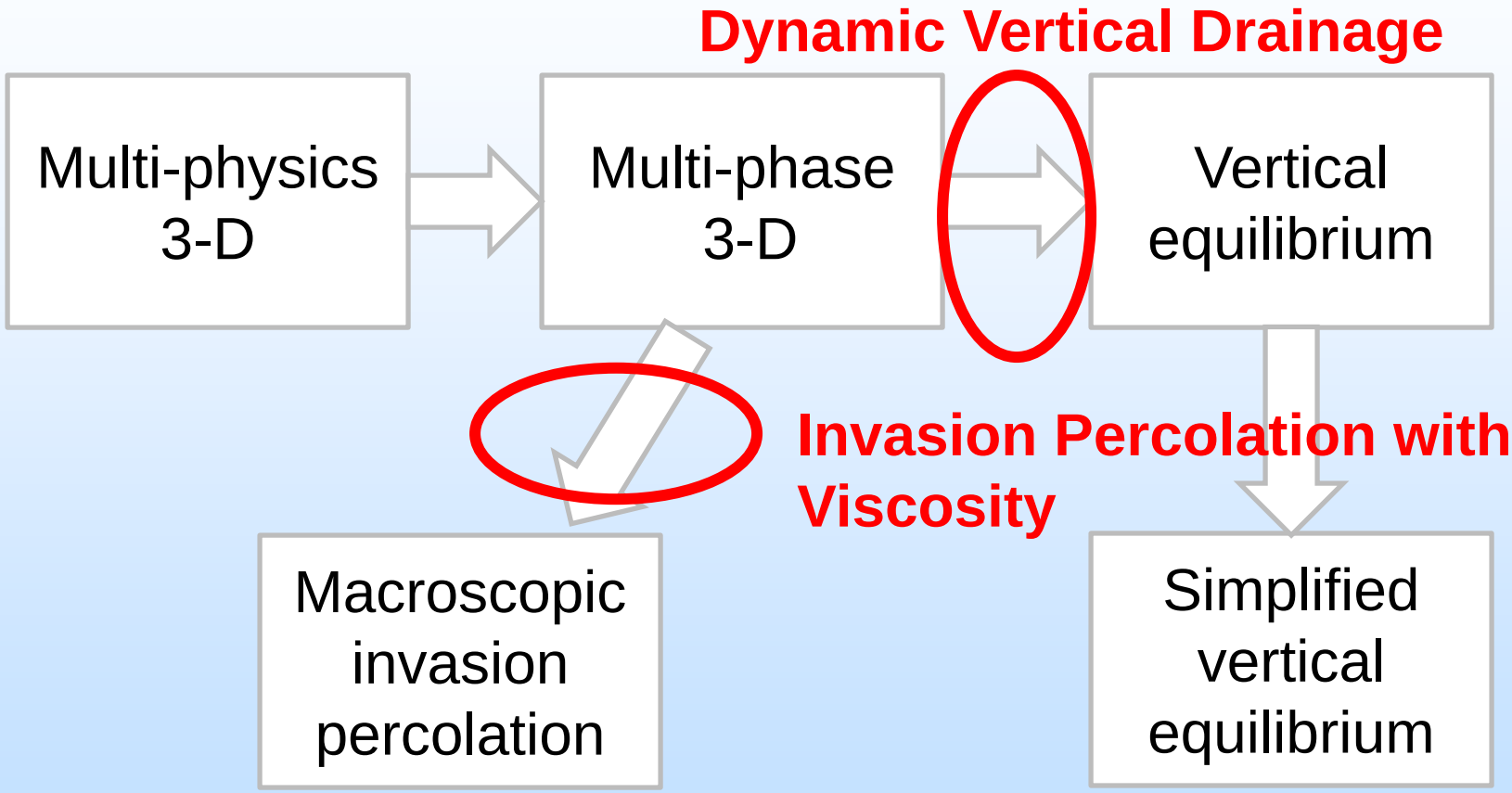
Project Overview

- Spectrum of model complexity
- New algorithm developments
- Model comparison
- Optimization

Model Complexity



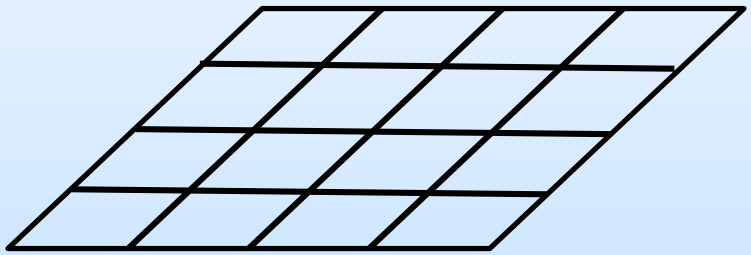
New Algorithms

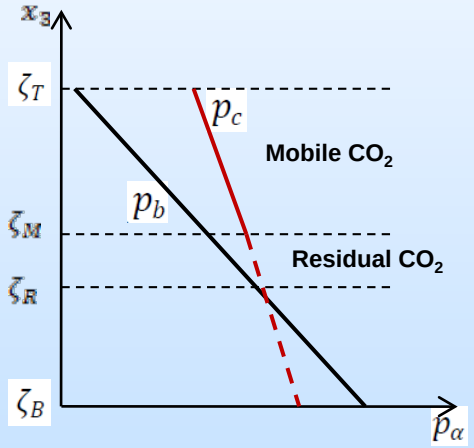


Vertical Equilibrium

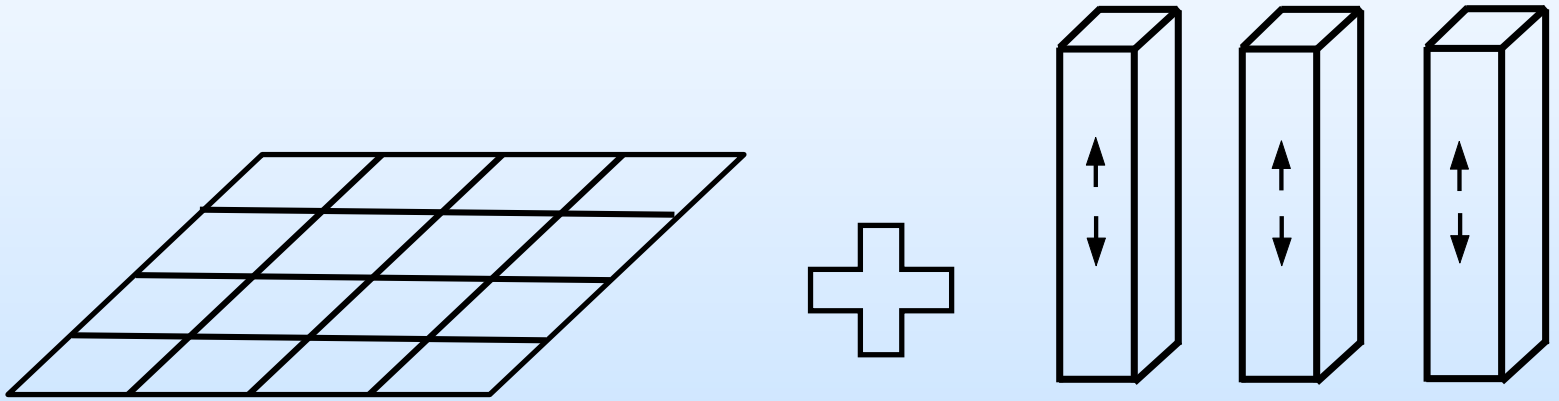
- Integrate 3D governing eqns in vertical direction.
- Solve 2D eqns for integrated saturation and bottom pressure.
- Reconstruct vertical profiles based on equilibrium assumption.

Vertical Equilibrium





Dynamic Reconstruction



Guo et al. (2014) A vertically integrated model with vertical dynamics for CO_2 storage. WRR

Example: homogeneous

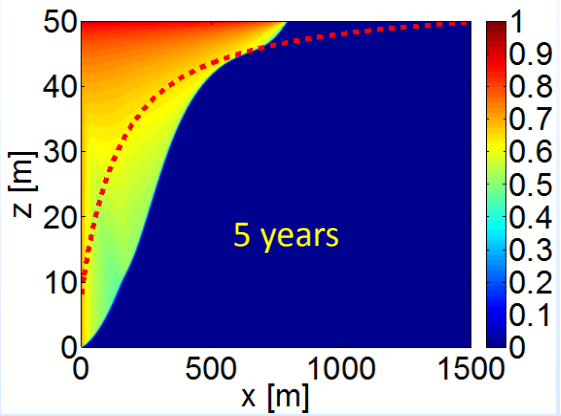
- Homogeneous 2D vertical slice
- Dynamic drainage, vertical equilibrium, full 2D
- 10 mD and 100mD

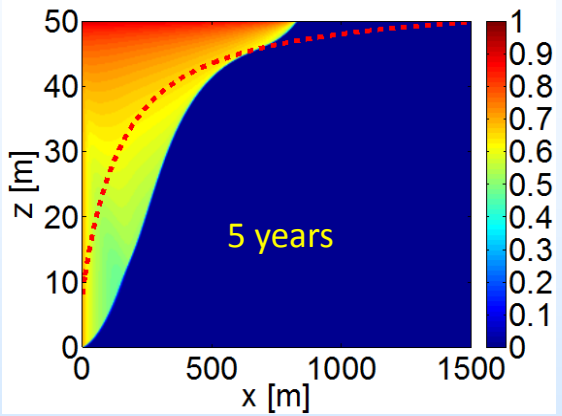
Homogeneous system

Dynamic reconstruction

Full 2D

10 mD

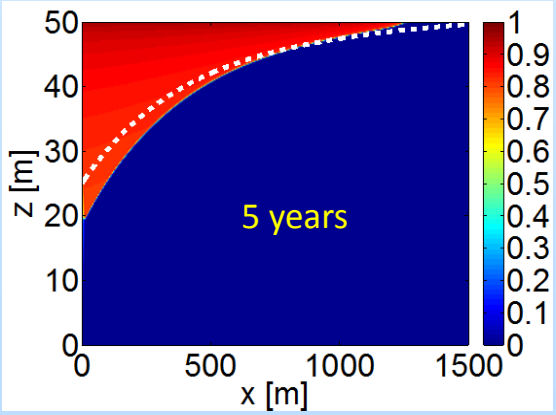


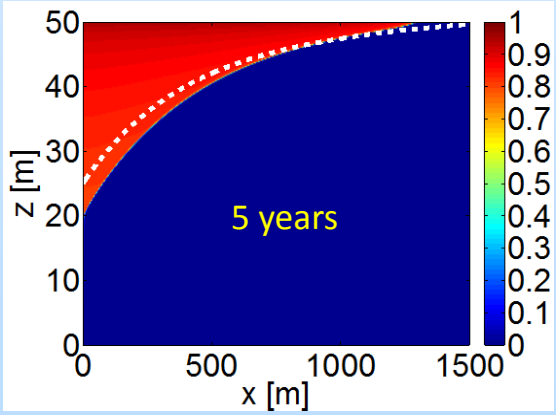


Dynamic reconstruction

Full 2D

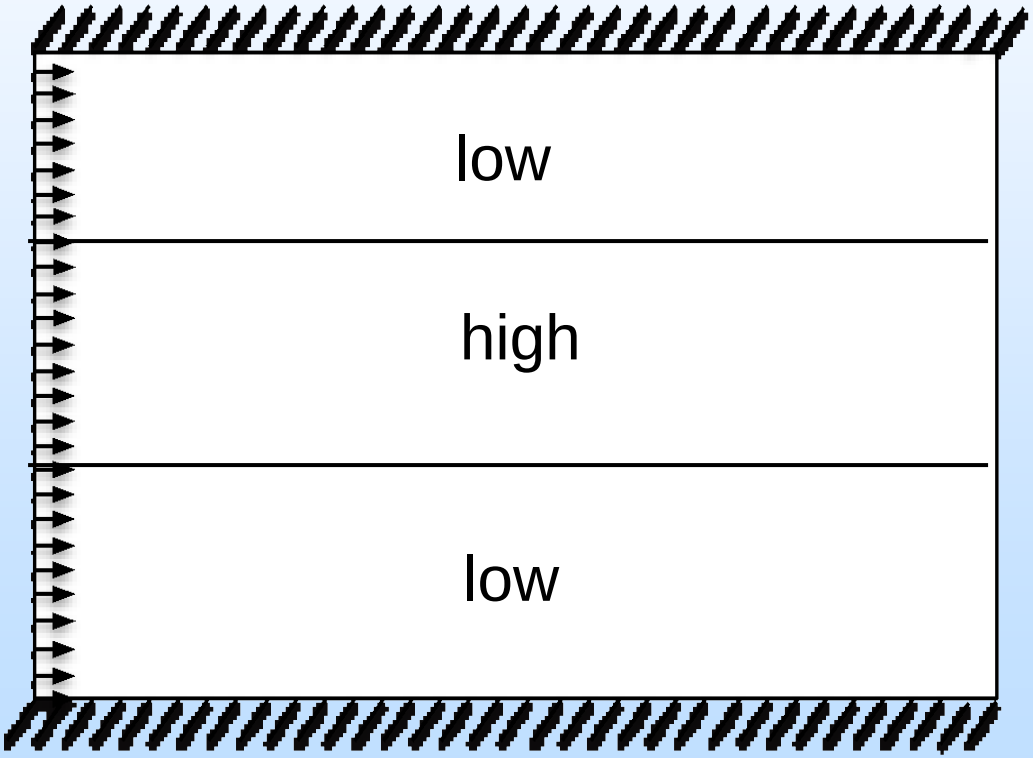
100 mD





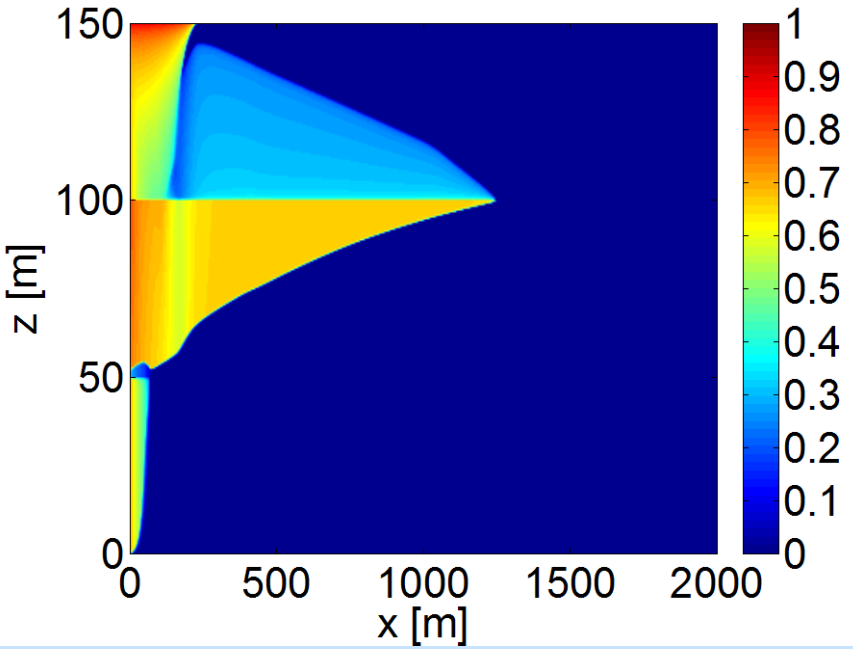
Example: layered system

- Heterogeneity in permeability

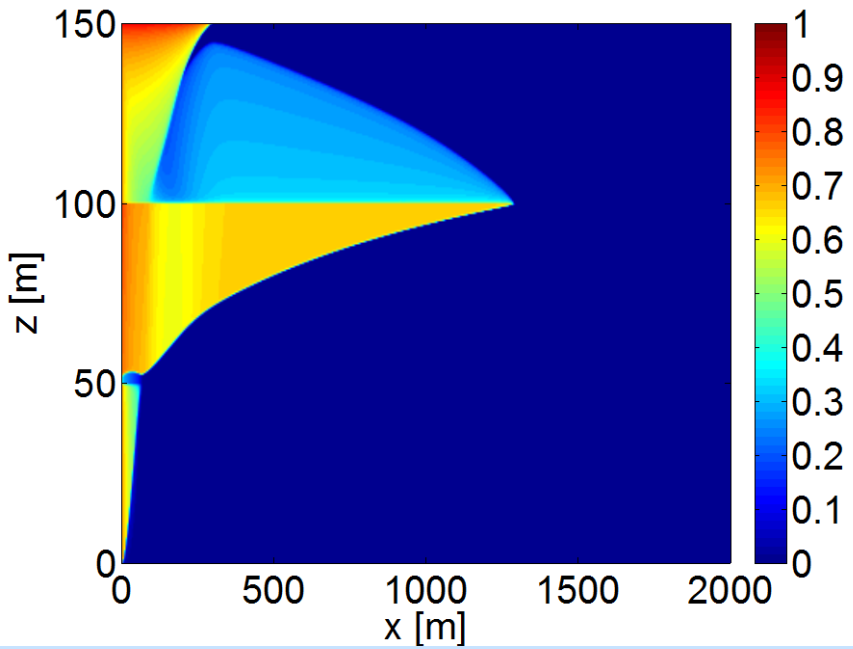


Multi-layer system

Dynamic reconstruction



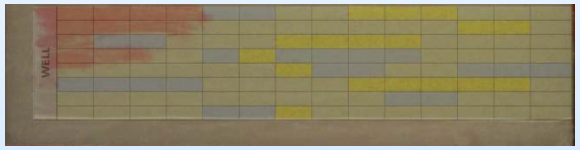
Full 2D



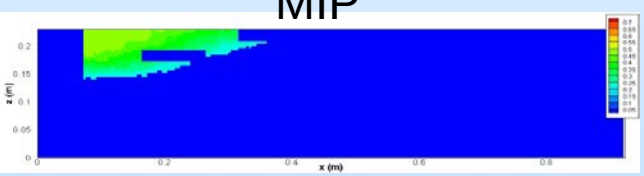
Invasion Percolation

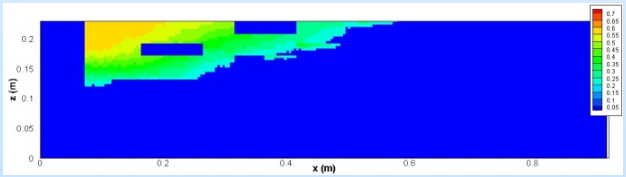
- macroscopic invasion percolation (MIP) model, including buoyant and capillary forces

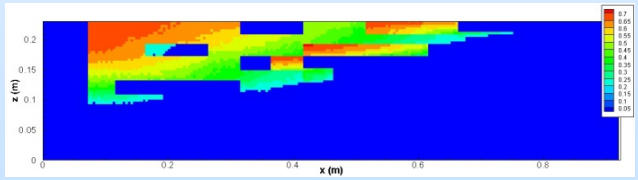
5 hours **10 hours** **20 hours**



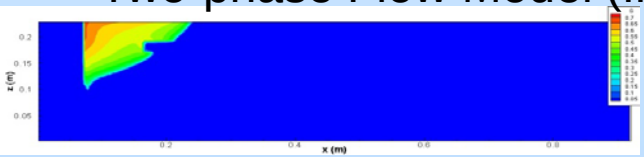
MIP

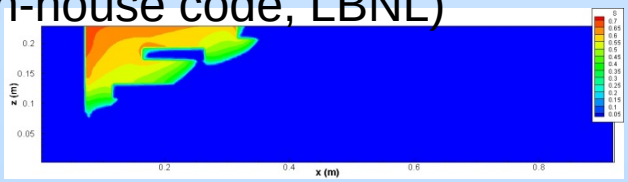


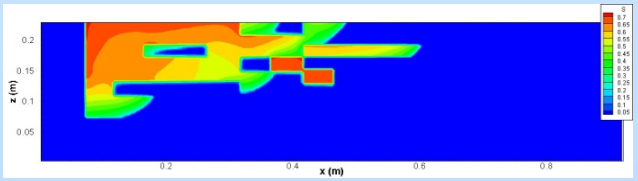




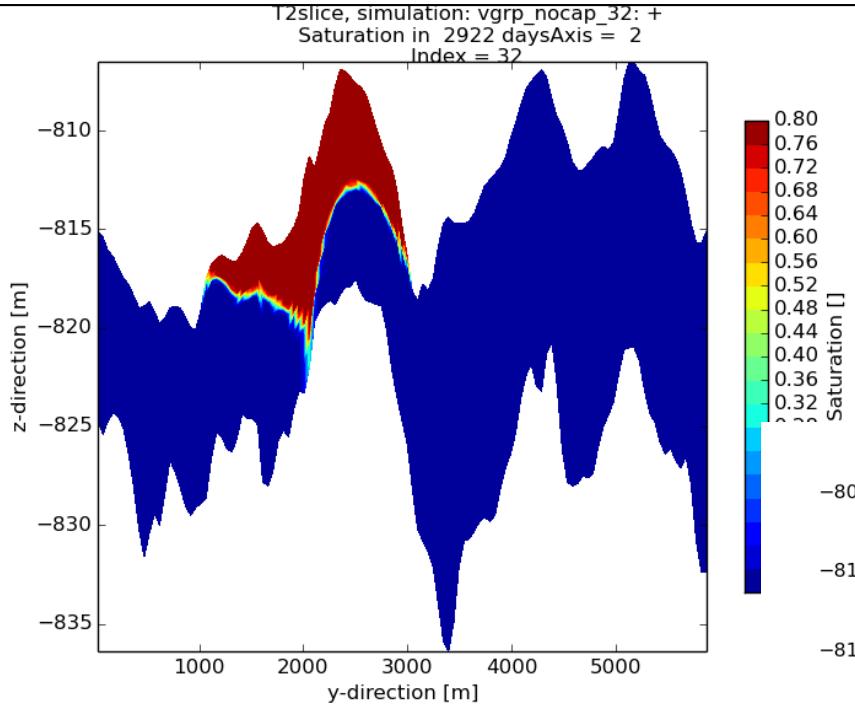
Two-phase Flow Model (In-house code, LBNL)



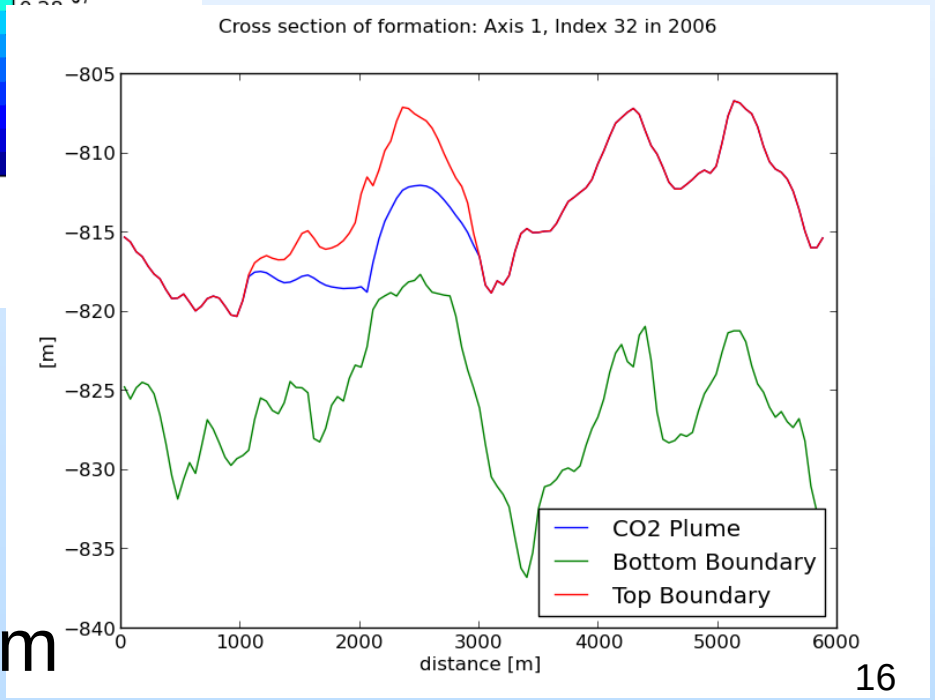




Model comparison: Sleipner



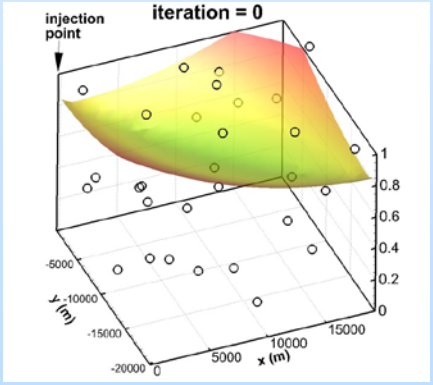
Multi-phase 3D

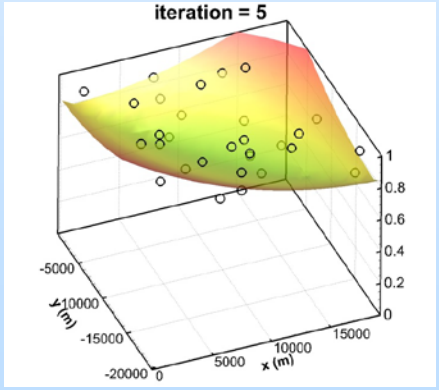


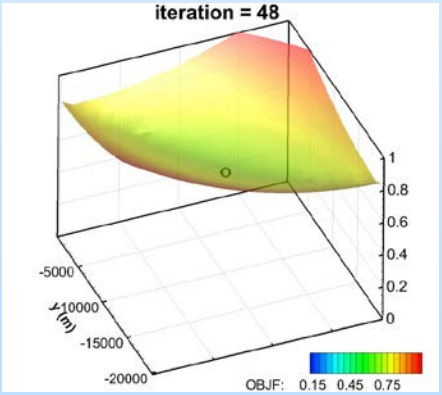
Vertical equilibrium

Optimization

- Constrained differential evolution (CDE) algorithm based on DE algorithm adding constraints
- Apply to models based on example sites







Accomplishments to Date

- Completed review of existing CO_2 sequestration modeling approaches and their application to actual sites.
- Conducted modeling studies at 2 example sites.
- Developed and implemented:
  - vertical drainage dynamics algorithm.
  - algorithm for macroscopic invasion percolation modeling.
  - new constrained optimization algorithm for pressure management applications.

Conclusions

- Vertical drainage dynamics algorithm is able to accurately predict CO_2 plume migration under many practical conditions.
- Single-phase sufficient for basin-scale pressure response, but semi-analytic solutions are likely not sufficient.
- Vertical-equilibrium approach applicable to highly permeable formations such as Sleipner.

Future Plans

- Improve vertical drainage dynamics algorithm
- Improve viscous invasion percolation algorithm
- Model comparison studies for additional sites
- Impact of model complexity on optimization
- Development of best practices guidelines for model complexity choice

THANK YOU!

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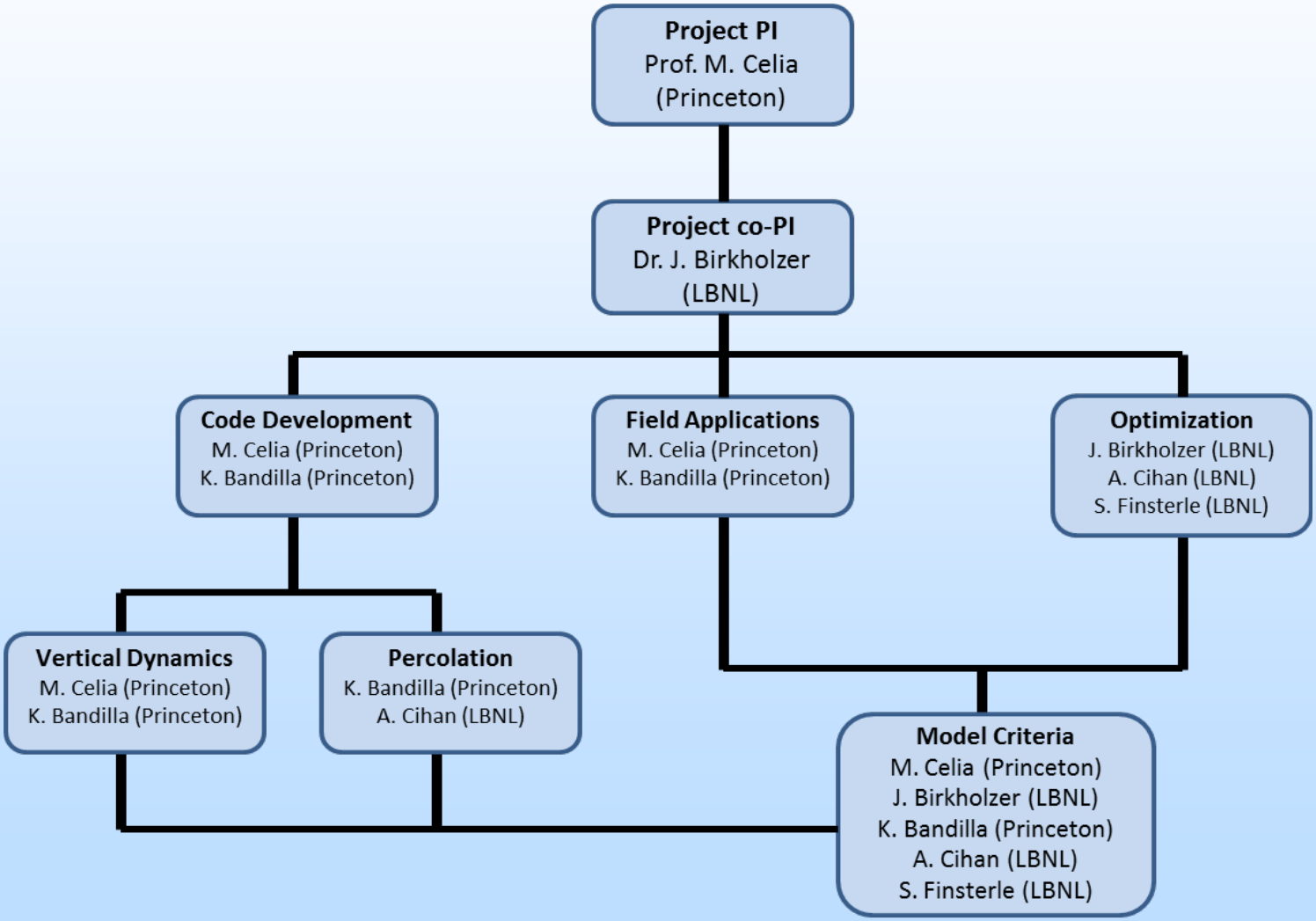
Appendix

Organization Chart



Gantt Chart

	BP1 (2012-2013)				BP2 (2013-2014)				BP3 (2014-2015)			
	1 10/1 -12/31	2 1/1 – 3/31	3 4/1 – 6/30	4 7/1 – 9/30	1 10/1 -12/31	2 1/1 – 3/31	3 4/1 – 6/30	4 7/1 – 9/30	1 10/1 -12/31	2 1/1 – 3/31	3 4/1 – 6/30	4 7/1 – 9/30
Task 1: Proj Mgmt and Planning												
Subtask 1.1: PMP And KickOff	MS											
Subtask 1.2: Project Planning and Reporting												
Task 2: Development Of New Models												
Subtask 2.1: Review And Analyze Existing Models			MS									
Subtask 2.2: Models with Vertical Drainage Dynamics				MS			MS					
Subtask 2.3: New Percolation Model					MS			MS				
Task 3: Model Existing Injection Operations					MS		MS	MS		MS		
Task 4: Optimization Models							MS		MS	MS		
Task 5: Criteria for Model Complexity											MS	

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

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