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

Project Number DE-FE0009563

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Princeton University

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
August 18-20, 2015

Presentation Outline

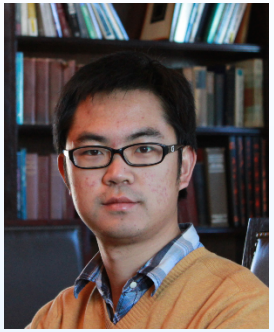
- Project Benefits, Goals and Objectives
- Project overview
- Accomplishments
- Summary

Project participants

Princeton University

Michael Celia

Karl Bandilla



Bo Guo

Lawrence Berkeley National Laboratory

Jens Birkholzer

Abdullah Cihan

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.

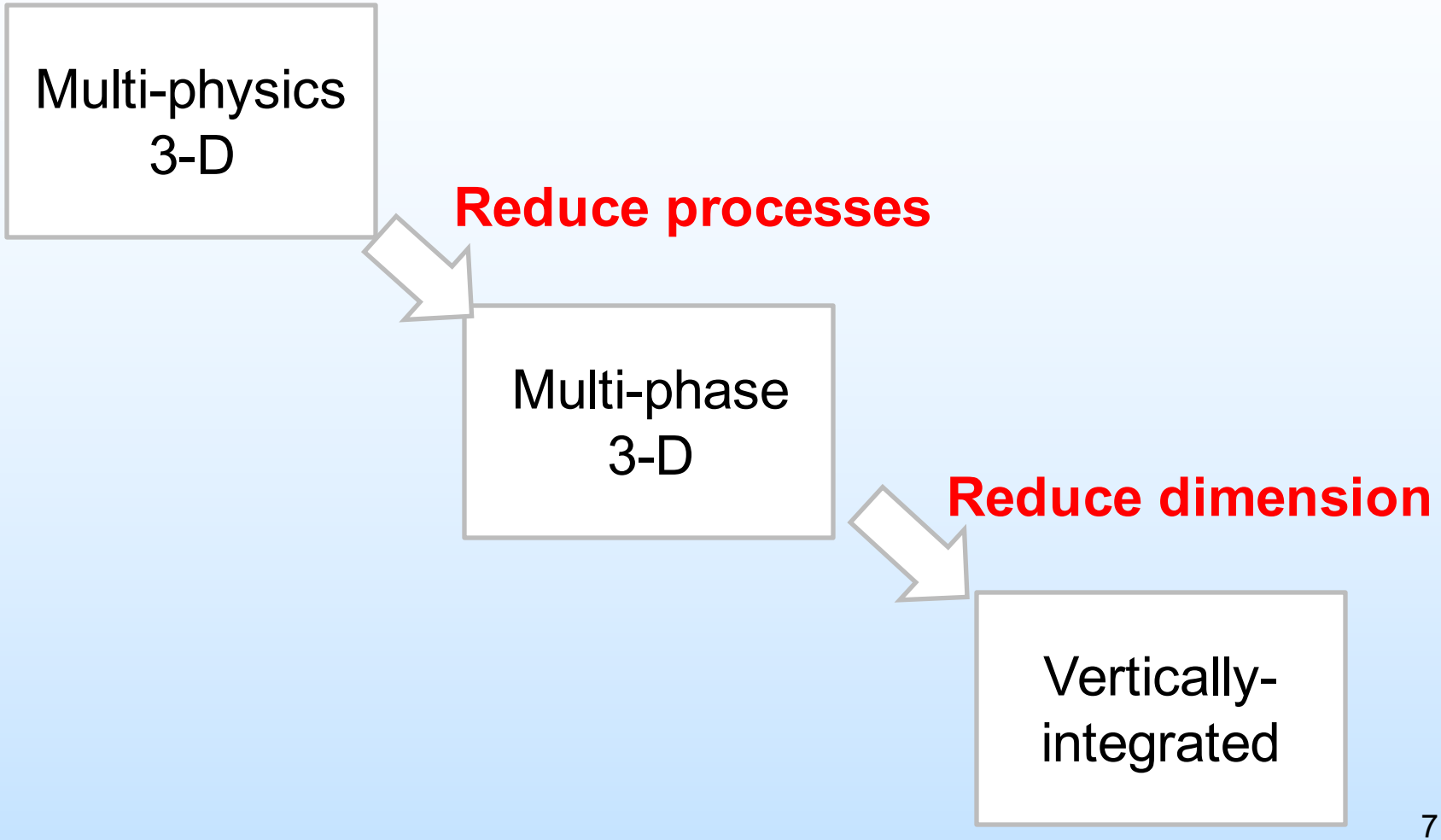
Project Objectives

- 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

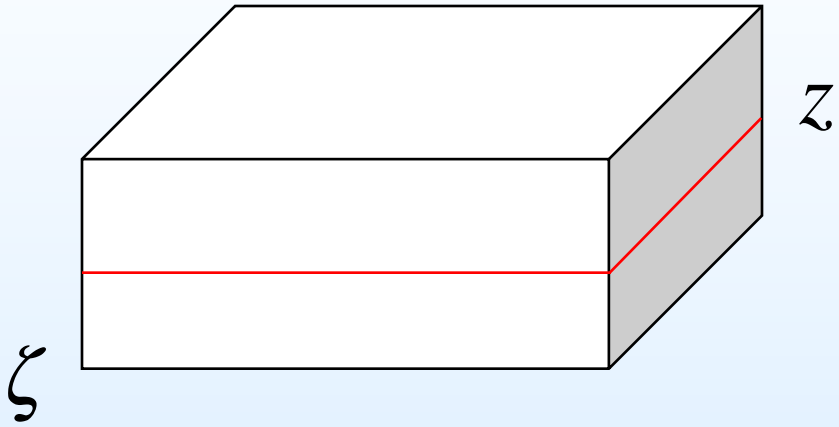
- Spectrum of model complexity
- Vertically-integrated models
  - Model comparison
  - Optimization
  - Vertical dynamic reconstruction

Model Complexity

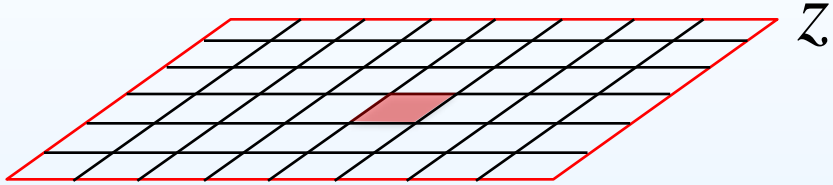


Vertical integration

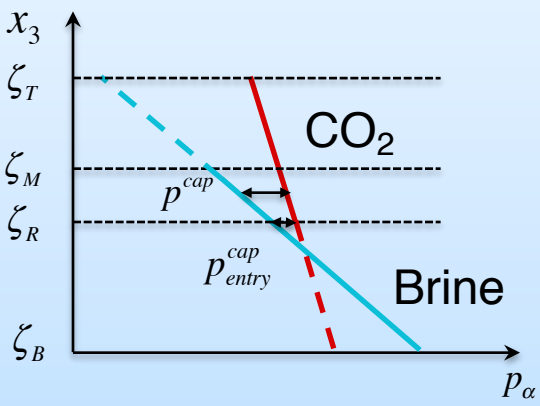
Full multi-dimensional system

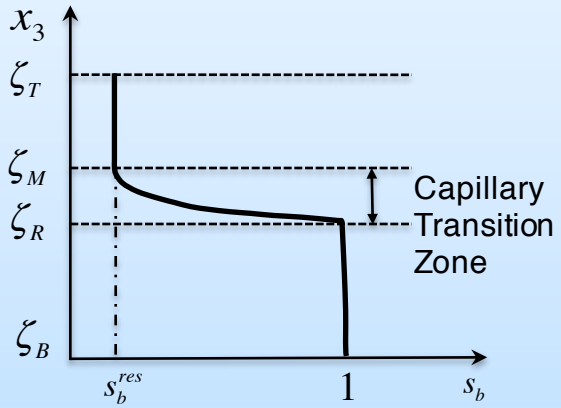


Coarse Scale



Fine Scale

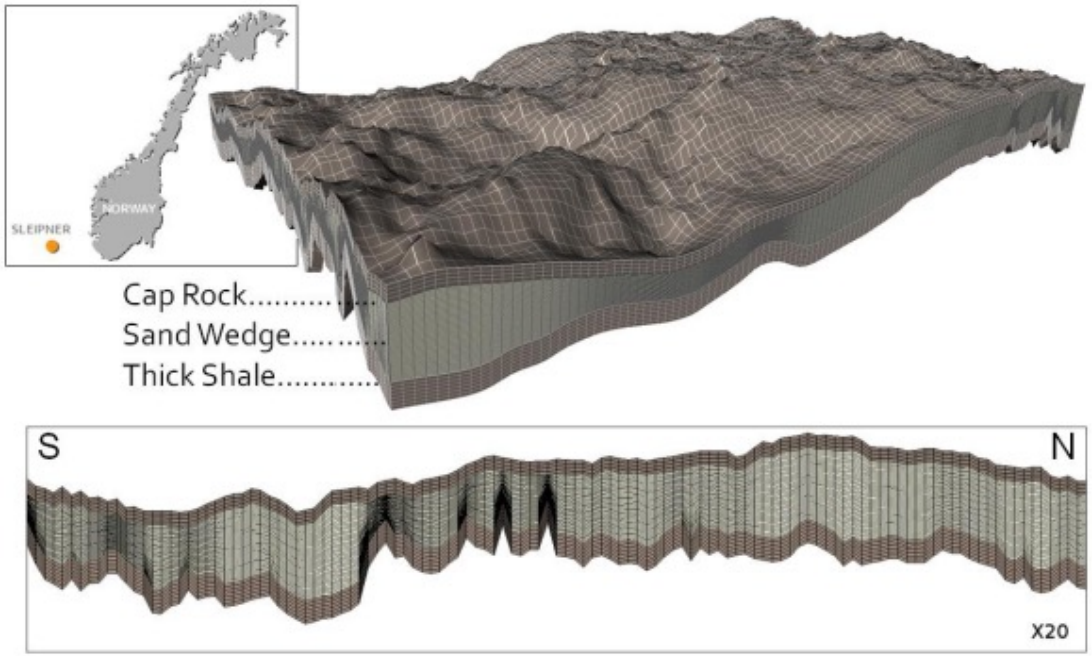




Model application

- 9th layer of Utsira (Sleipner)
- Optimization of injection rate at Kimberlina

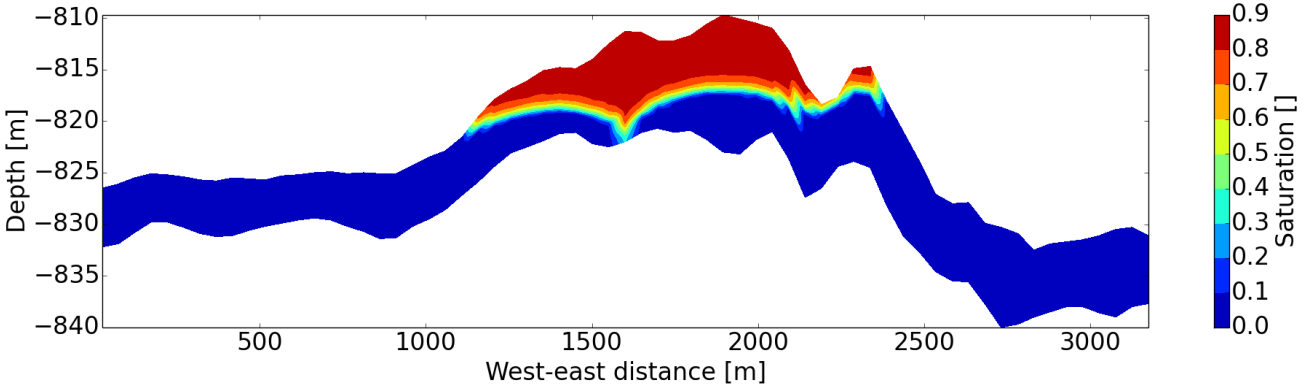
Sleipner: model



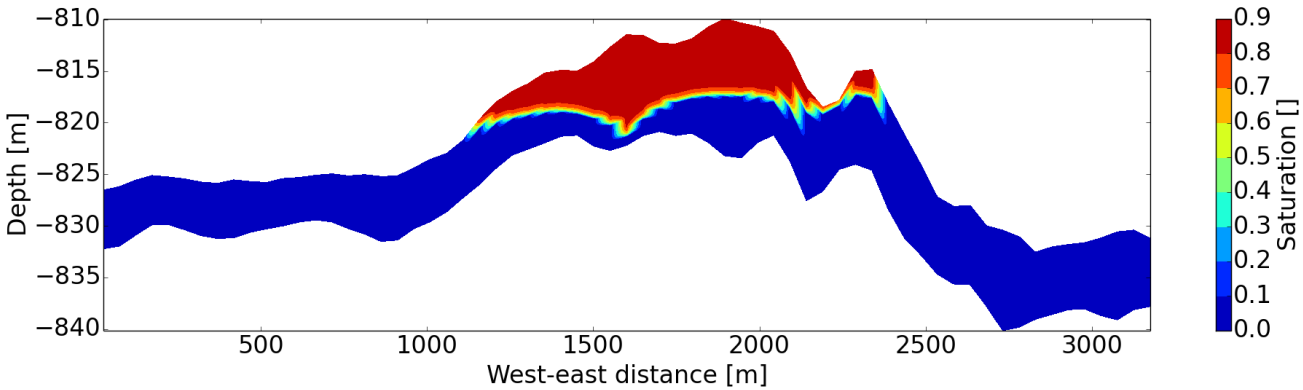
area	3 x 6 km	Permeability	2000 mD
thickness	5 – 30 m	Injection rate	0.14 Mt/yr
porosity	0.35	Entry pressure	2.5 kPa
Residual brine saturation	0.1	Brooks-Corey parameter	2.8

Sleipner: cross-section

Full 3D

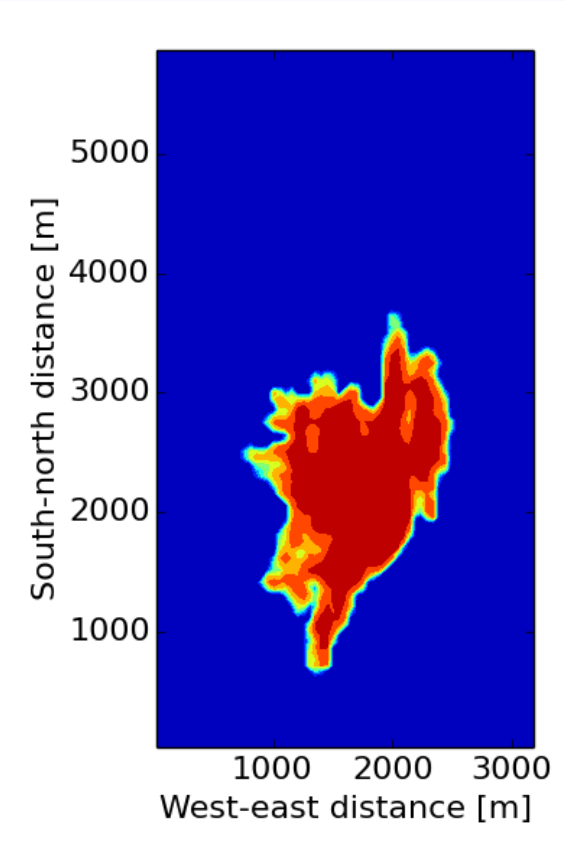


Vertical-equilibrium

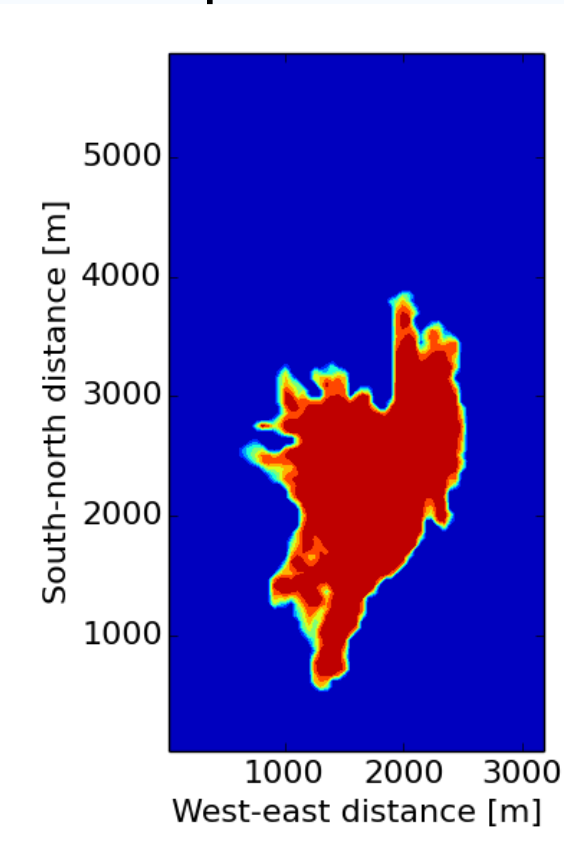


Sleipner: plume

Full three-dimensional

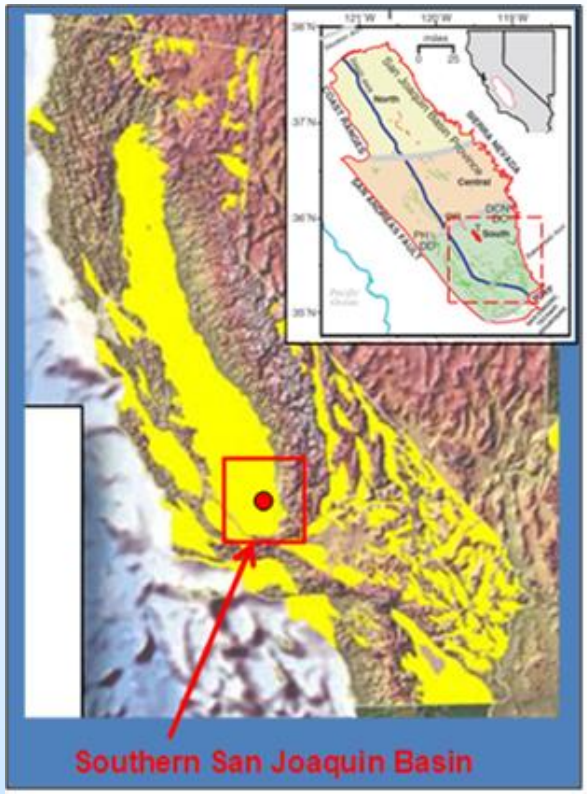


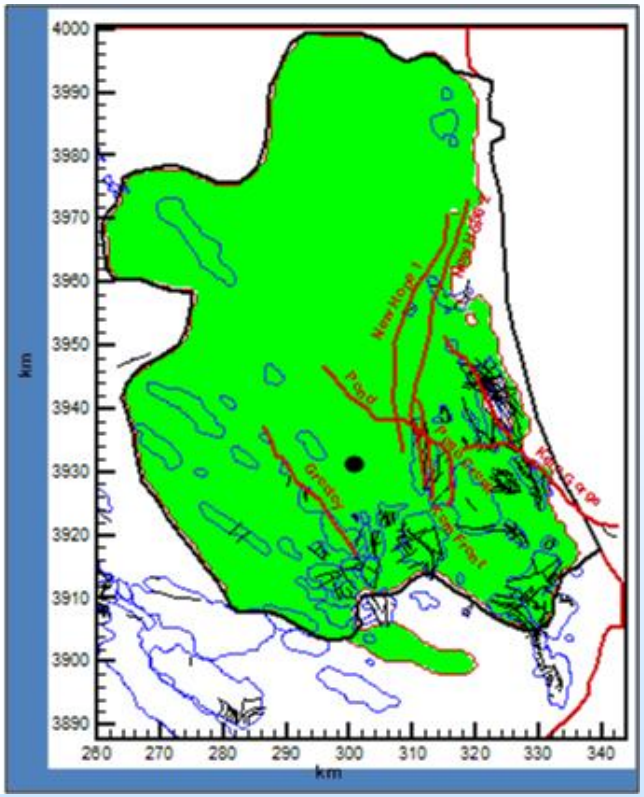
Vertical equilibrium



seismic

Optimization: Kimberlina

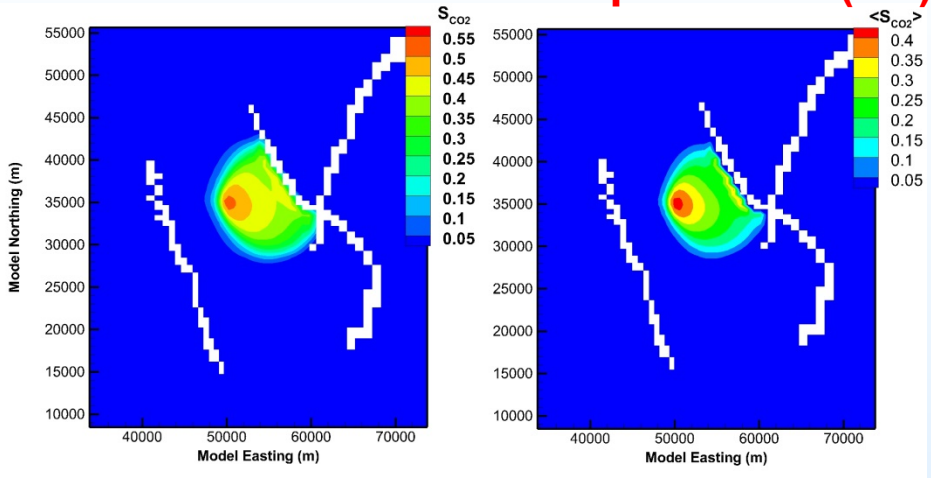




Optimized injection rate

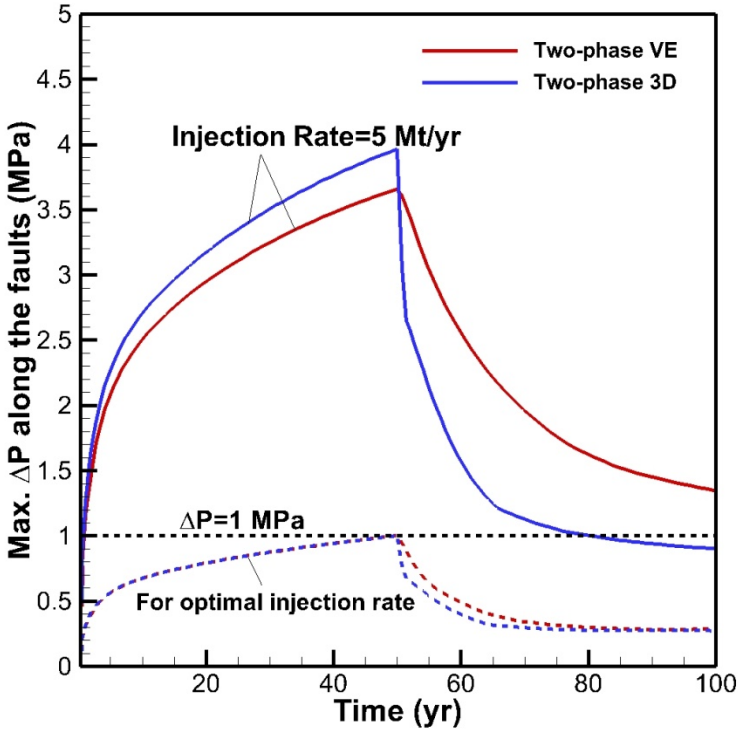
Two-phase Flow in 3D

Two-phase Vertical-Equilibrium (VE)

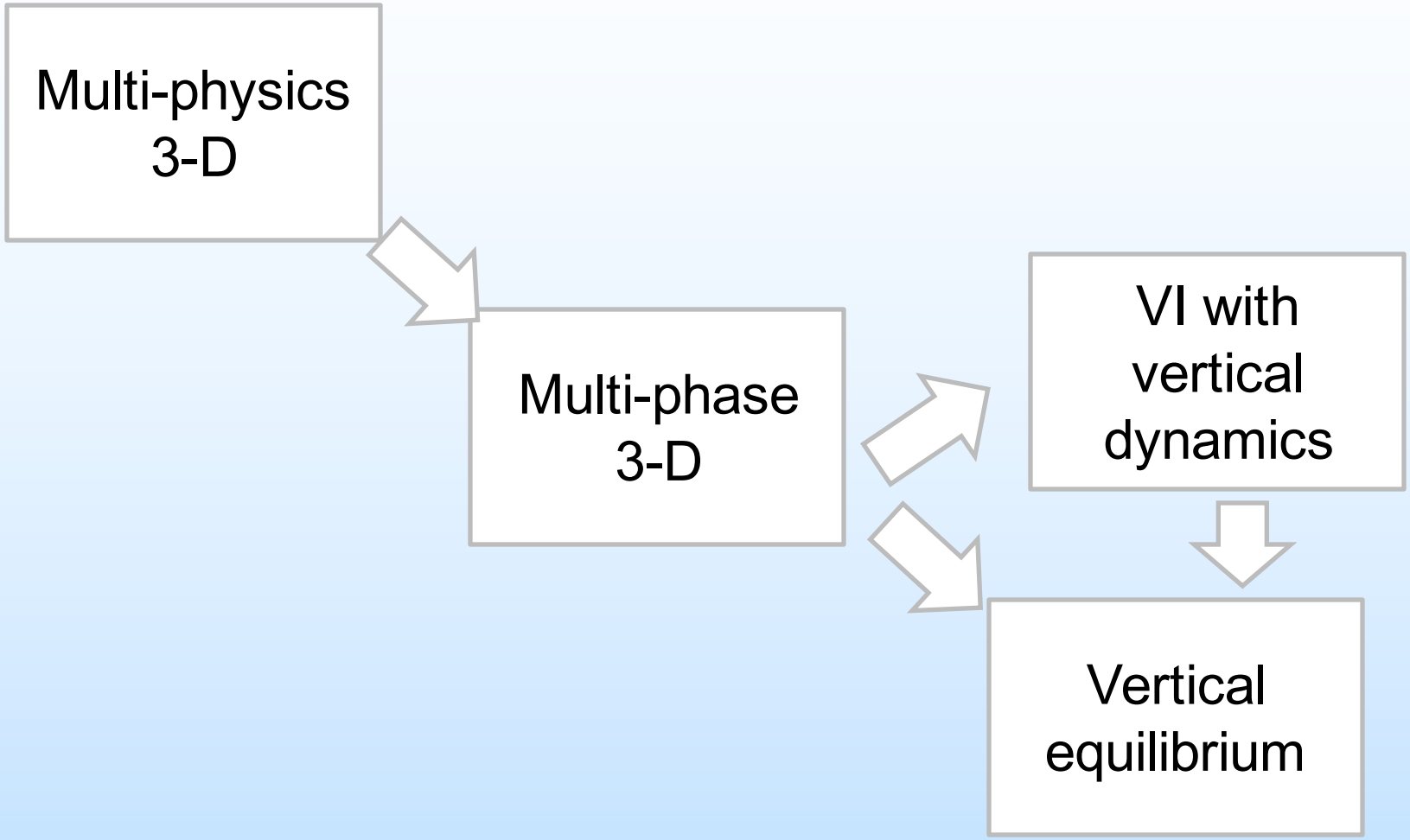


(Saturation distribution at the top layer, vertical resolution~5m, average thickness~100m)

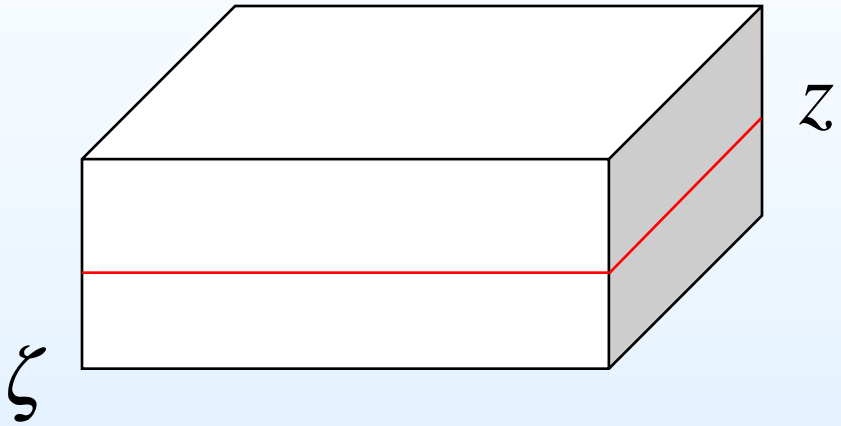
Model Type	Optimal Injection Rates without Brine Extraction for ΔP_{max}=1MPa along the Faults
Two-phase 3D	0.051 Mt/yr
Two-phase VE	0.048 Mt/yr



Model Complexity

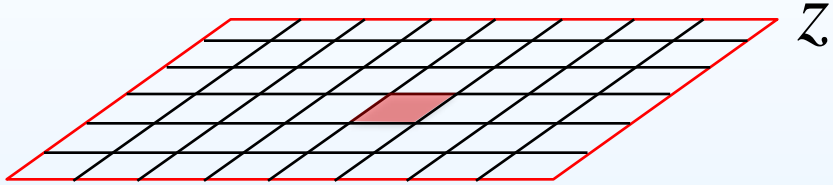


Single-layer Dynamic Reconstruction (DR)

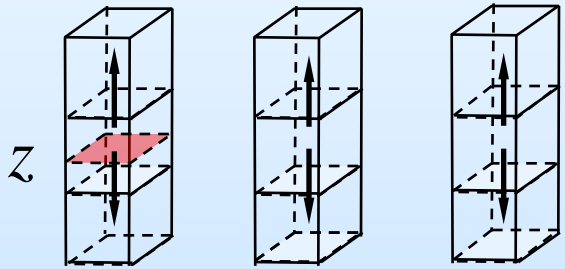


Full multi-dimensional system

Coarse Scale

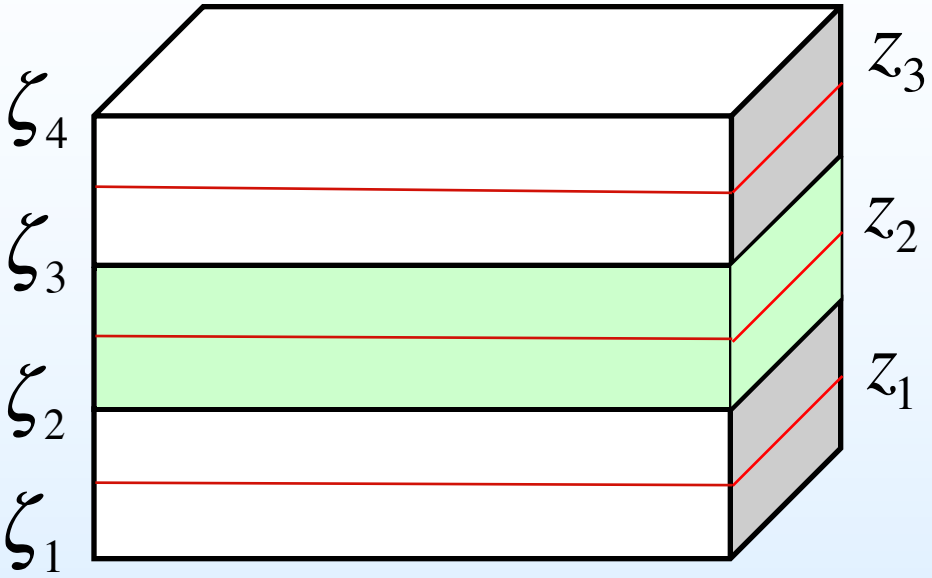


Fine Scale



Guo et al., *WRR*, 2014

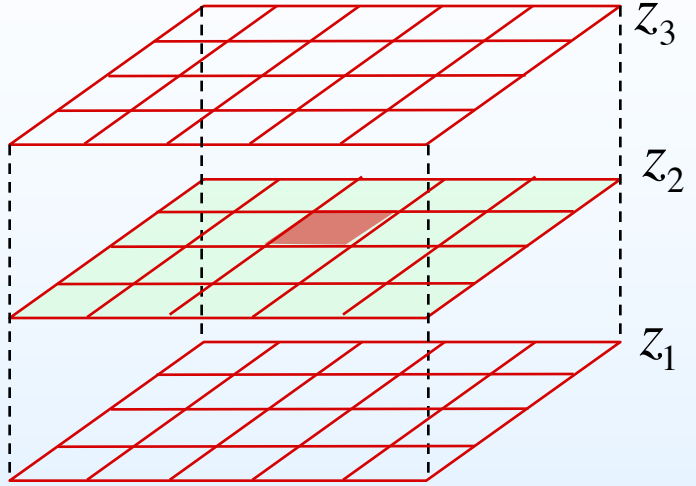
Multi-layer Dynamic Reconstruction (DR)



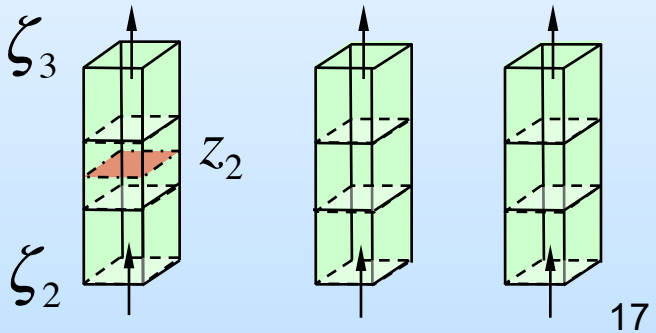
Full multi-dimensional system

(layered geological heterogeneity)

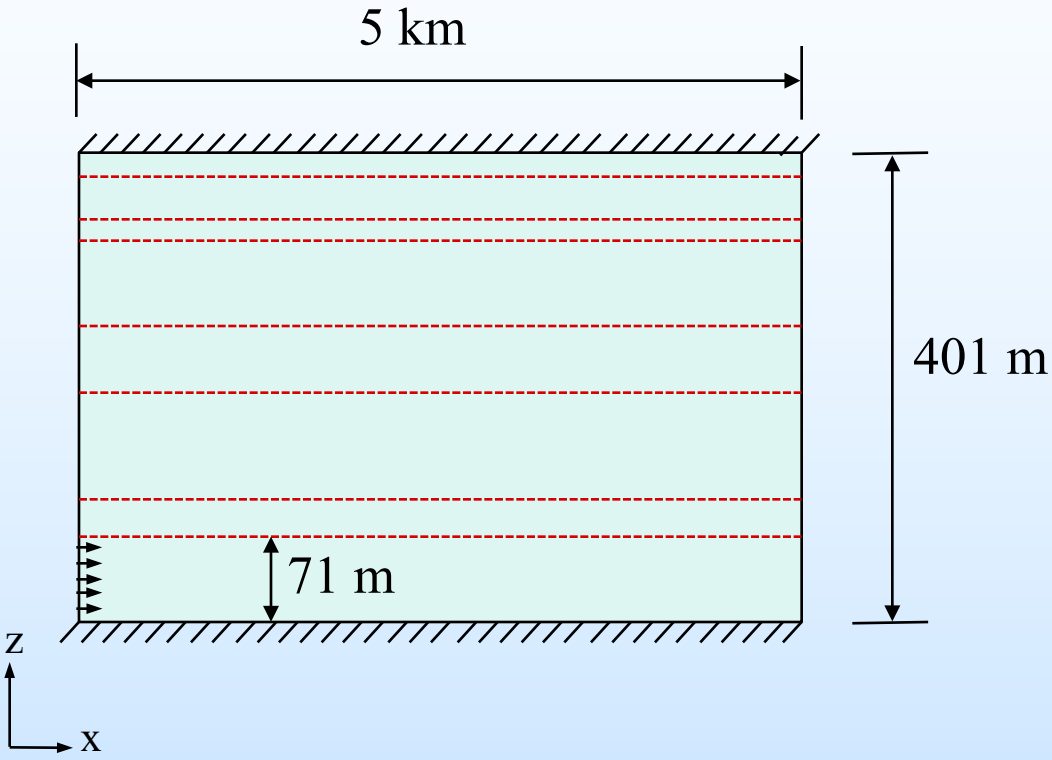
Coarse Scale



Fine Scale



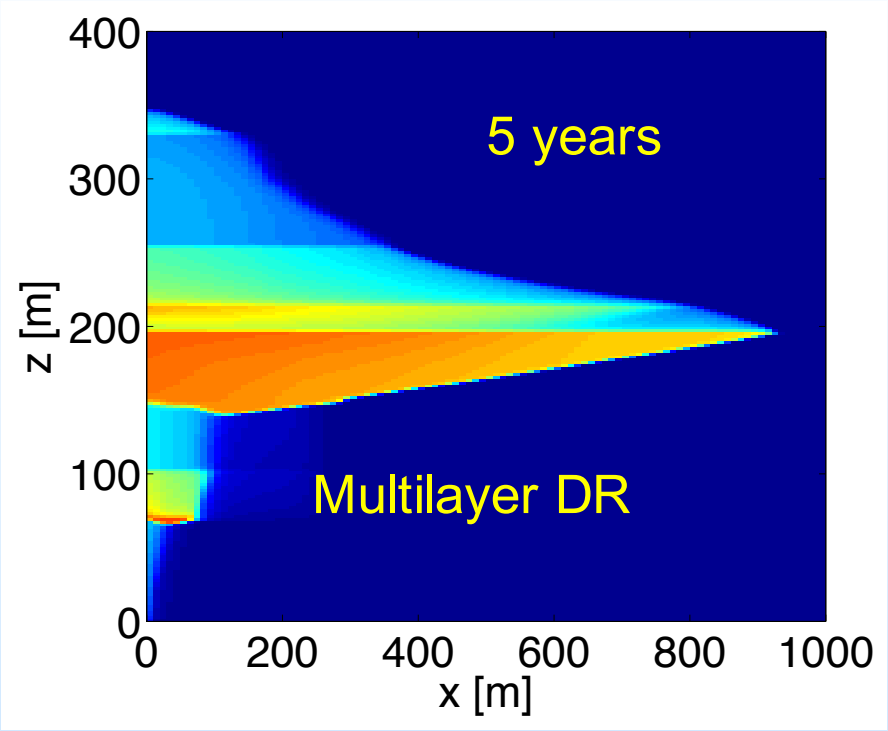
Example: Mt. Simon

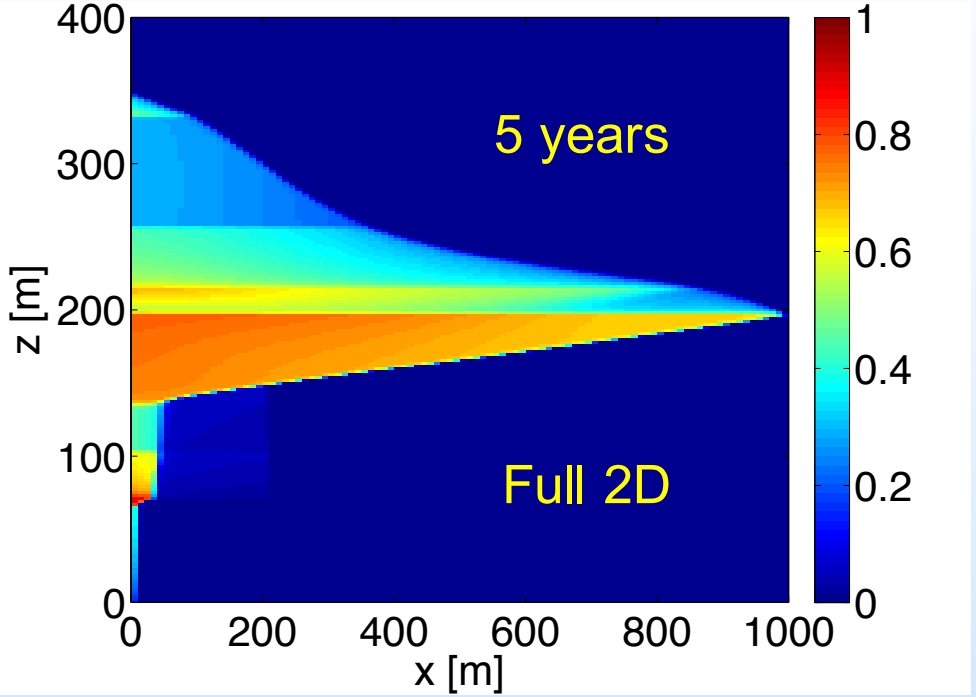


- **Relative per. / Capillary pres.**
  Brooks-Corey curves, λ=2
  capillary pressure neglected
- **Fluid properties**
  brine density = 1100 kg/m^3
  CO_2 density = 900 kg/m^3
  brine viscosity = 3.0E-4 Pa s
  CO_2 viscosity = 4.25E-5 Pa s
- **CO_2 Injection rate**
  $Q_{CO2} \approx 2$ Mt/year/km

Example results

CO_2 plume after 5 years injection





Conclusions

- Vertical drainage dynamics algorithm is able to accurately predict CO_2 plume migration under many practical conditions.
- Vertical-equilibrium approach applicable to highly permeable formations such as Sleipner.
- Vertical-equilibrium models can be efficient tools for CO_2 sequestration related optimization problems

Accomplishments to Date

- Completed review of existing CO_2 sequestration modeling approaches and their application to actual sites.
- Conducted modeling studies at 3 example sites.
- Developed and implemented:
  - vertical drainage dynamics algorithm while taking into account layered heterogeneity.
  - algorithm for macroscopic invasion percolation modeling.
  - new constrained optimization algorithm for pressure management applications.

Synergy Opportunities

- Criteria developed in this project may guide model approaches used in other projects

Future Plans

- Improve vertical drainage dynamics algorithm with layered heterogeneity
- 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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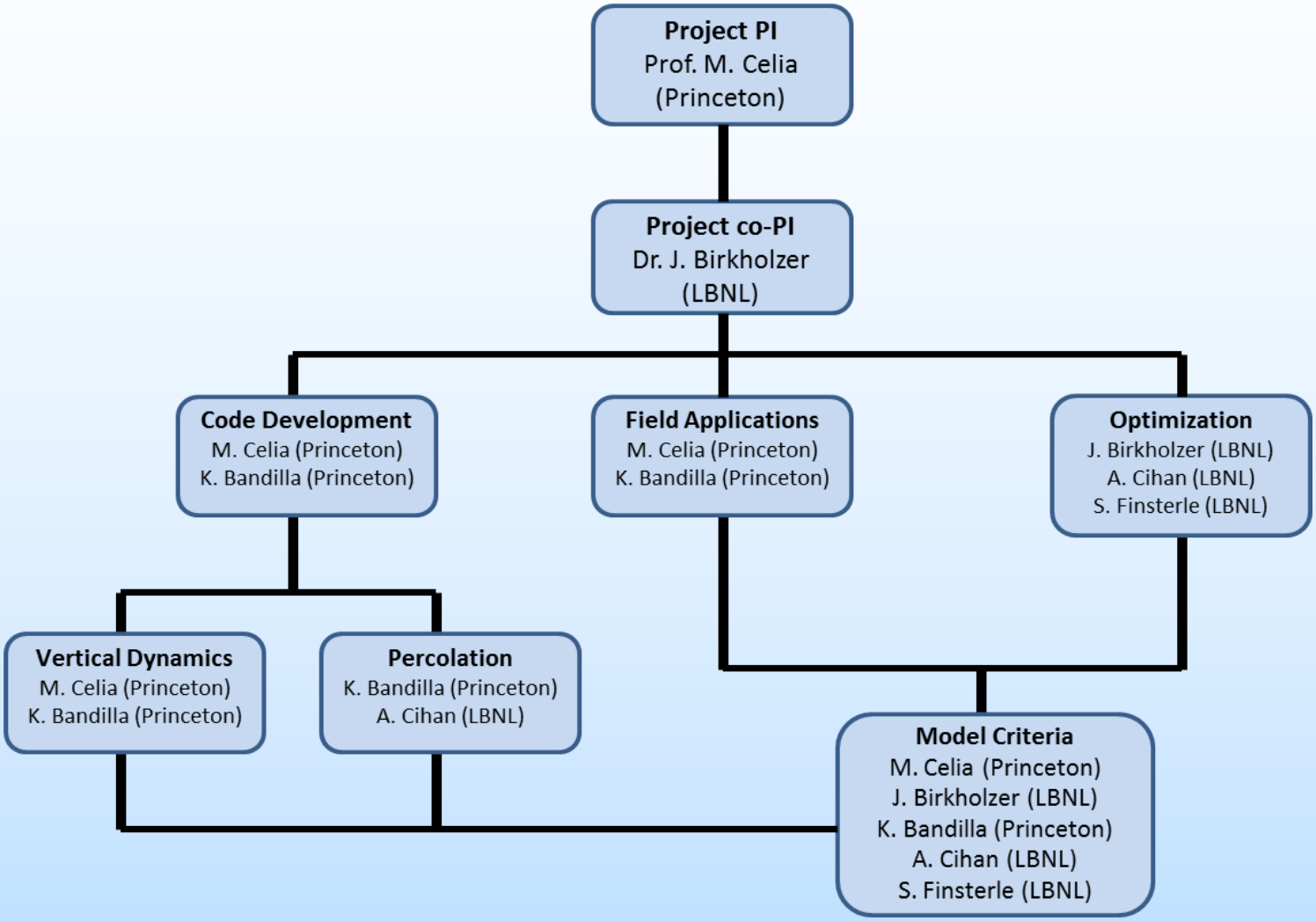
Appendix


BERKELEY LAB
Lawrence Berkeley National Laboratory

Organization Chart



Gantt Chart

	BP1 (2012-2013)				BP2 (2013-2014)				BP3 (2014-2015)				BP4 (2015-2016)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
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		MS

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

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