Numerical Simulations For CO2 Storage in Saline Aquifer

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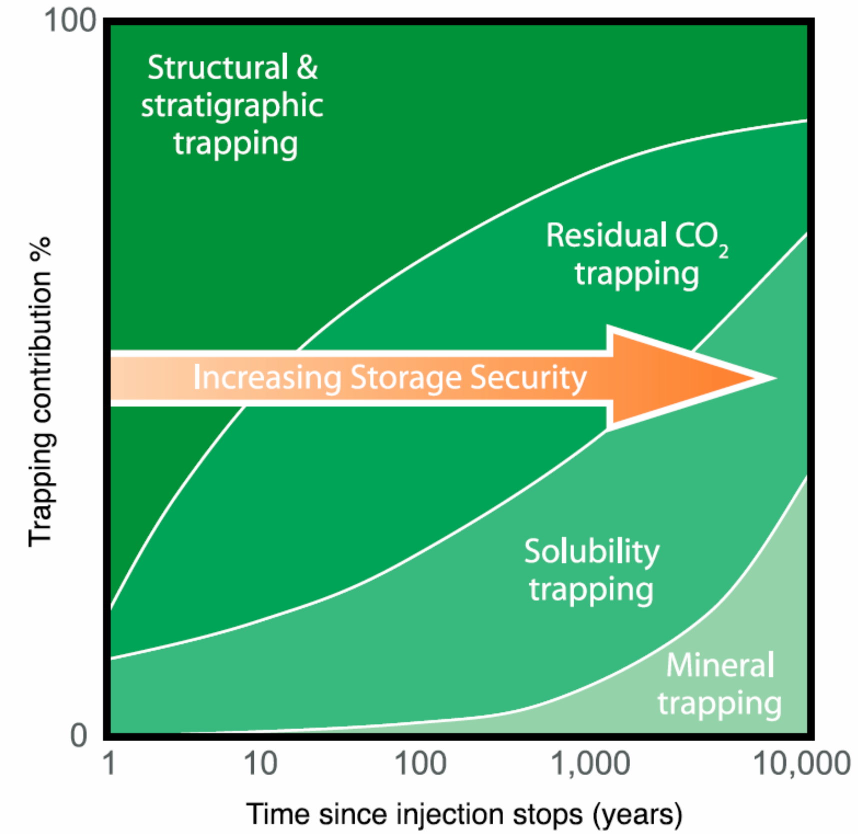
Long-Term Fate of Stored CO_2



Different Storage Modes

1. free gas
2. trapped gas
3. dissolved in brine
4. sequestered as solid minerals

1, 2, and 3 can be simulated with multiphase flow simulator; 4 can be simulated by reactive transport model.

Source: *2005 IPCC Special Report on Carbon Dioxide Capture and Storage;* http://www.ipcc.ch/activity/srccs/index.htm

The simulation technology needed to solve these problems(1)

✓How do the relative proportions of CO_2 in these different storage modes change over time?

✓How does the evolution of CO_2 leaks depend on coupling of chemical, mechanical, and thermal effects? What is the fate of leaking?

✓What fraction of subsurface volume can be accessed by CO_2 ?

✓How is the utilization of subsurface space affected by viscous instability, gravity override and formation heterogeneities?

The simulation technology needed to solve these problems(2)

✓Can CO_2 leaks self-seal or self-enhance?

✓What is the role of relative permeability and capillary pressure effects in CO_2 containment and leakage?

✓What is the role of different phase compositions and phase changes in CO_2 leakage?(supercritical, liquid ,gaseous CO_2 , dissolved in water)？

✓What is the pressure build up and CO2 plume distribution after CO2 injection？

✓Help for design and analysis of tests.

……

Simulators for CO_2 Storage in Saline Aquifers

- ECLIPSE
- FEHM
- GEM
- GPRS
- TOUGH2
- STOMP
- Other simulators :COORES, DuMu, IPARS-CO2, MUETE, RockFlow, RTAFF2

TOUGH Family Code For CO_2 Sequestration

Fluid dynamics: TOUGH2/ECO2N

- Multiphase flows of water/CO_2/NaCl mixtures
- Applications to studies of reservoir dynamics, storage capacity, CO_2 leakage

Geochemistry: TOUGHREACT/ECO2N

- Reactions between gas-aqueous-solid phases
- Study mineral trapping, caprock integrity, natural CO_2 reservoirs

Geomechanics: TOUGH-FLAC

- TOUGH2 coupled to commercial FLAC3D geomechanics code
- Stress-strain: analyze leakage through caprock and faults

Large Scale Simulations: TOUGH2-MP/ECO2N

Computation Challenging

✓Site characterization needs basin-scale model

✓Refined grids are needed for catching CO2 convection

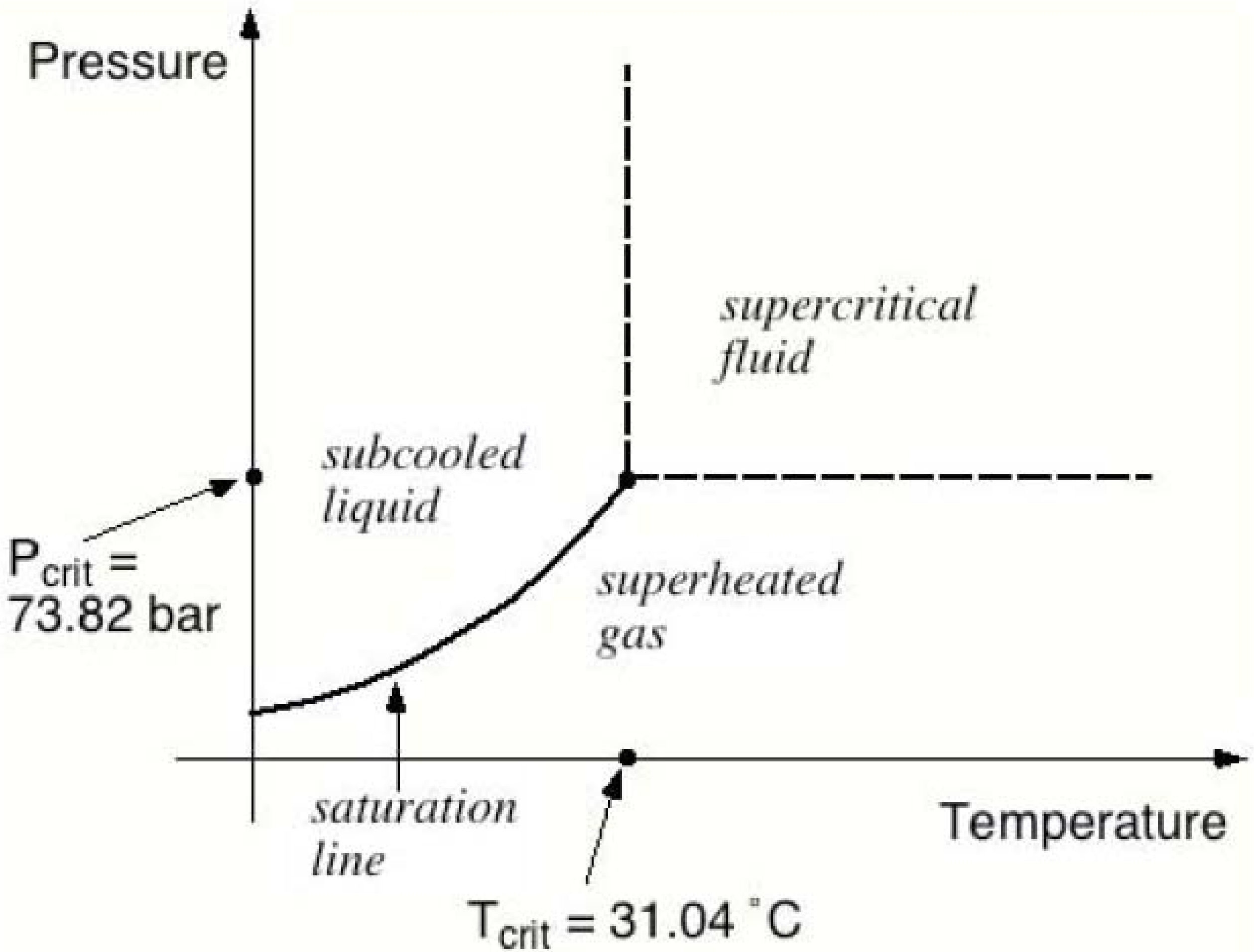
✓Multi-Scale, multiphase flow

✓Complex geochemical reaction and mechanical processes

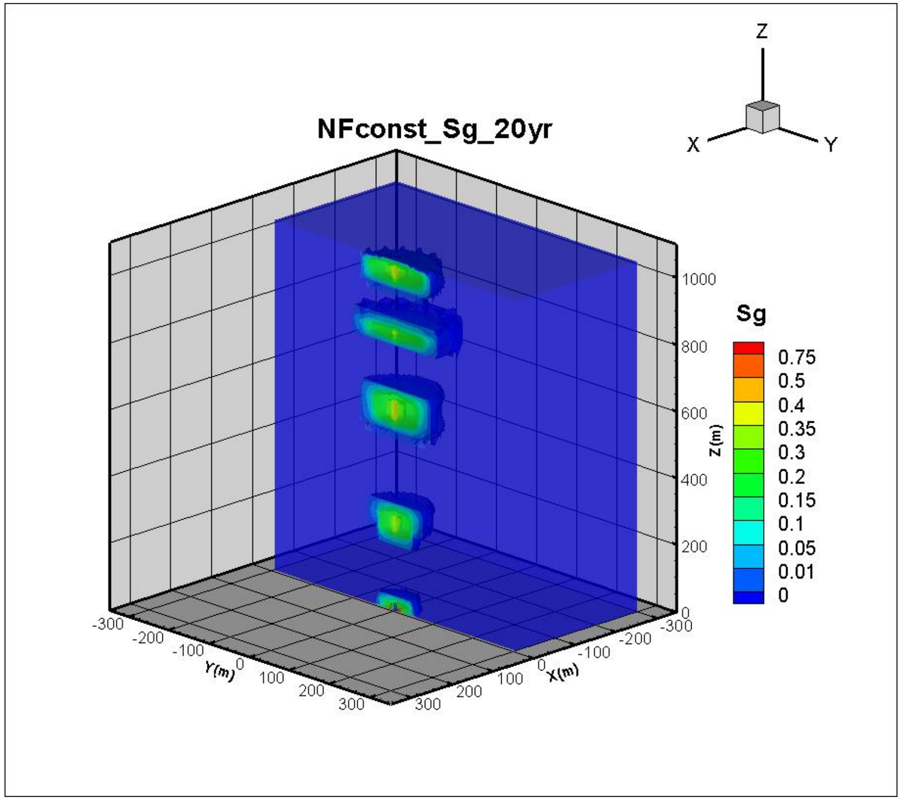
✓Leakage of CO2 through boreholes, faults, and other high permeability paths (may be non-Darcy flow)

✓THMC coupling simulations

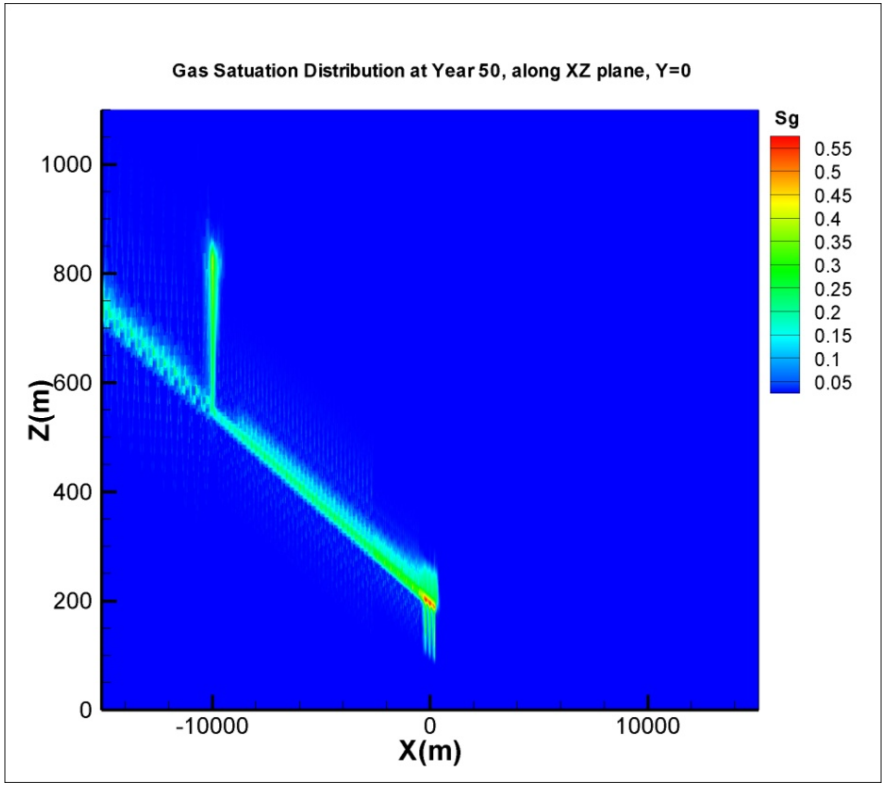
Phase Diagram of CO2 for Numerical Simulations



Examples for permeability influences on CO2 storage



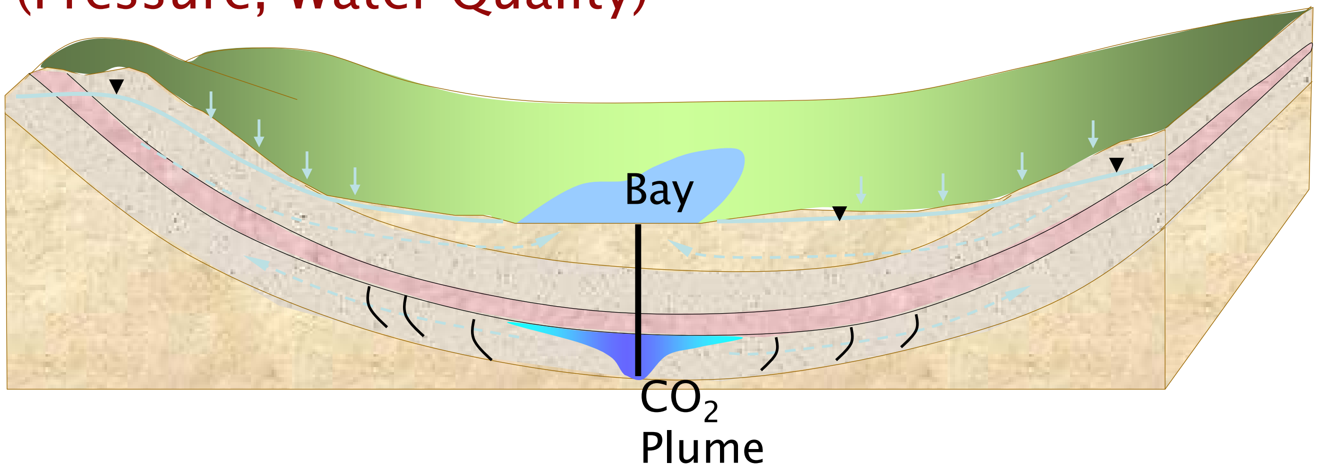
Simulation results for a storage site in Western China



Simulation results for a storage site in Eastern China

Example 1: Tokyo Bay Model
(from Hajime, Zhang et al. 2008)

- Large-scale injection (several $MtCO_2$/yr) into virgin aquifers would:
  - Push large volume of water out of the aquifers.
  - Potentially affect subsurface groundwater environment (Pressure, Water Quality)



Lithofacies Analysis

Age			Ma	Group/Formation				Thickness Ratio	Lithofacies West/East
Quarternay	Horocene			fluvial/river terrace sediments				–	–
Quarternay	Pleistocene	Late		Shimosa Group				–	–
Quarternay	Pleistocene	Middle		Kazusa Group	Upper	Kongochi		35%	sandy
Quarternay	Pleistocene	Middle		Kazusa Group	Upper	Upper Kasamori			muddy / sandy
Quarternay	Pleistocene	Middle	0.6	Kazusa Group	Upper	Lower Kasamori			gravelly
Quarternay	Pleistocene	Middle		Kazusa Group	Upper	Chonan		20%	sandy
Quarternay	Pleistocene	Middle		Kazusa Group	Upper	Ichijyuku		5%	gravelly / sandy
Quarternay	Pleistocene	Early	0.8	Kazusa Group	Upper	Kokumoto		15%	muddy
Quarternay	Pleistocene	Early		Kazusa Group	Upper	Umegase		25%	sandy
Quarternay	Pleistocene	Early	1.0	Kazusa Group	Upper	Higashi Higasa			gravelly
Quarternay	Pleistocene	Early	1.2	Kazusa Group	Lower	Otadai		20%	muddy
Quarternay	Pleistocene	Early	1.7	Kazusa Group	Lower	Kiwada		10%	muddy
Neocene	Pleiocene			Kazusa Group	Lower	Tomiya	Tomiya	20%	muddy
Neocene	Pleiocene			Kazusa Group	Lower	Tomiya	Ohara		muddy
Neocene	Pleiocene			Kazusa Group	Lower	Tomiya	Namihana	20%	muddy
Neocene	Pleiocene			Kazusa Group	Lower	Tomiya	Katsuura	30%	muddy
Neocene	Pleiocene			Kazusa Group	Lower	Kurotaki			gravelly
Neocene	Miocene			Awa Group				–	– / –

Simplified

Model

Model	
fluvial/river terrace	Sand
Shimosa	Mud
Upper Kazusa	Sand
Middle Kazusa	Sand
Middle Kazusa	Mud
Middle Kazusa	Sand
Lower Kazusa	Mud
Lower Kazusa	Sand
Lower Kazusa	–

Shallow Seal layer

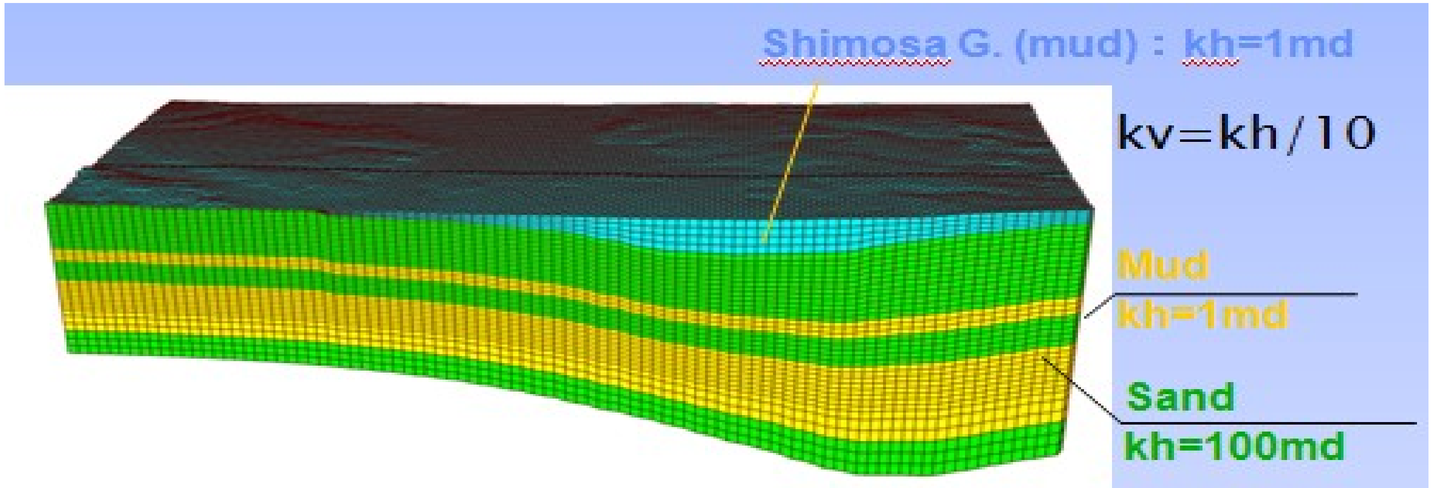
Deep Seal layer

Storage Aquifer

Hydrogeological Model(1)

Continuous Layer Model

Assume perfect lateral continuity



Base Case   Rock compressibility 10^{-9} 1/Pa
Porosity   40%

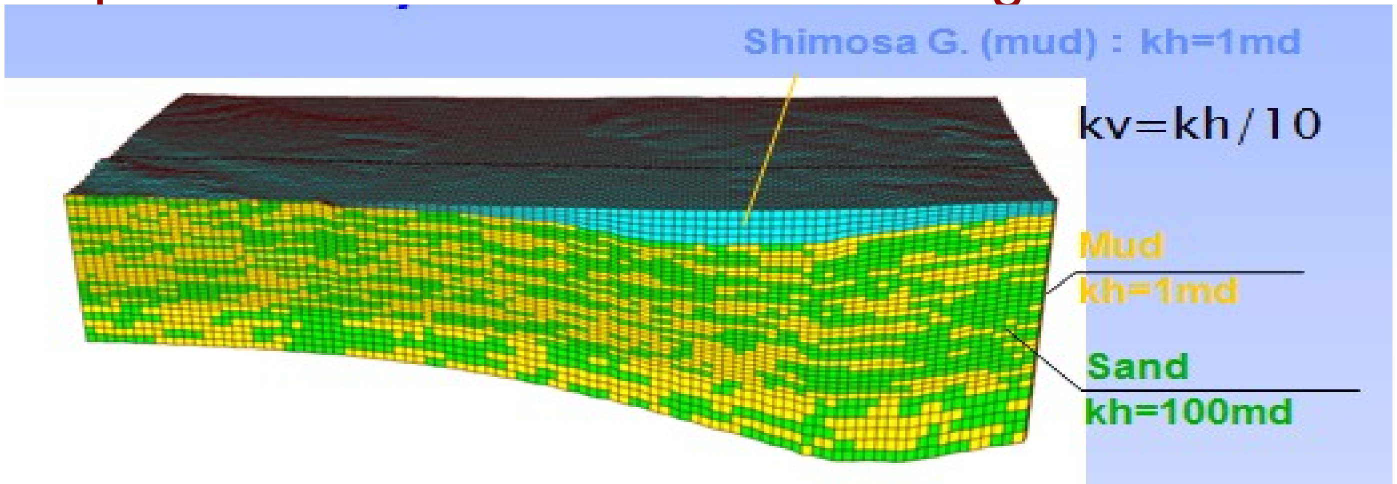
Sensitivity cases

1. Rock compressibility $10^{-9} \rightarrow 10^{-8}$ 1/Pa
2. Permeability of mud layers $1 \rightarrow 10$ md

Hydrogeological Model(2)

Discontinuous Layer Model

Represents lateral lithofacies changes



- Geostatistical Unconditional Simulation(10 realizations)
  - Lateral lithofacies changes
  - Continuity of layers

5km (horizontal)

20m (vertical)

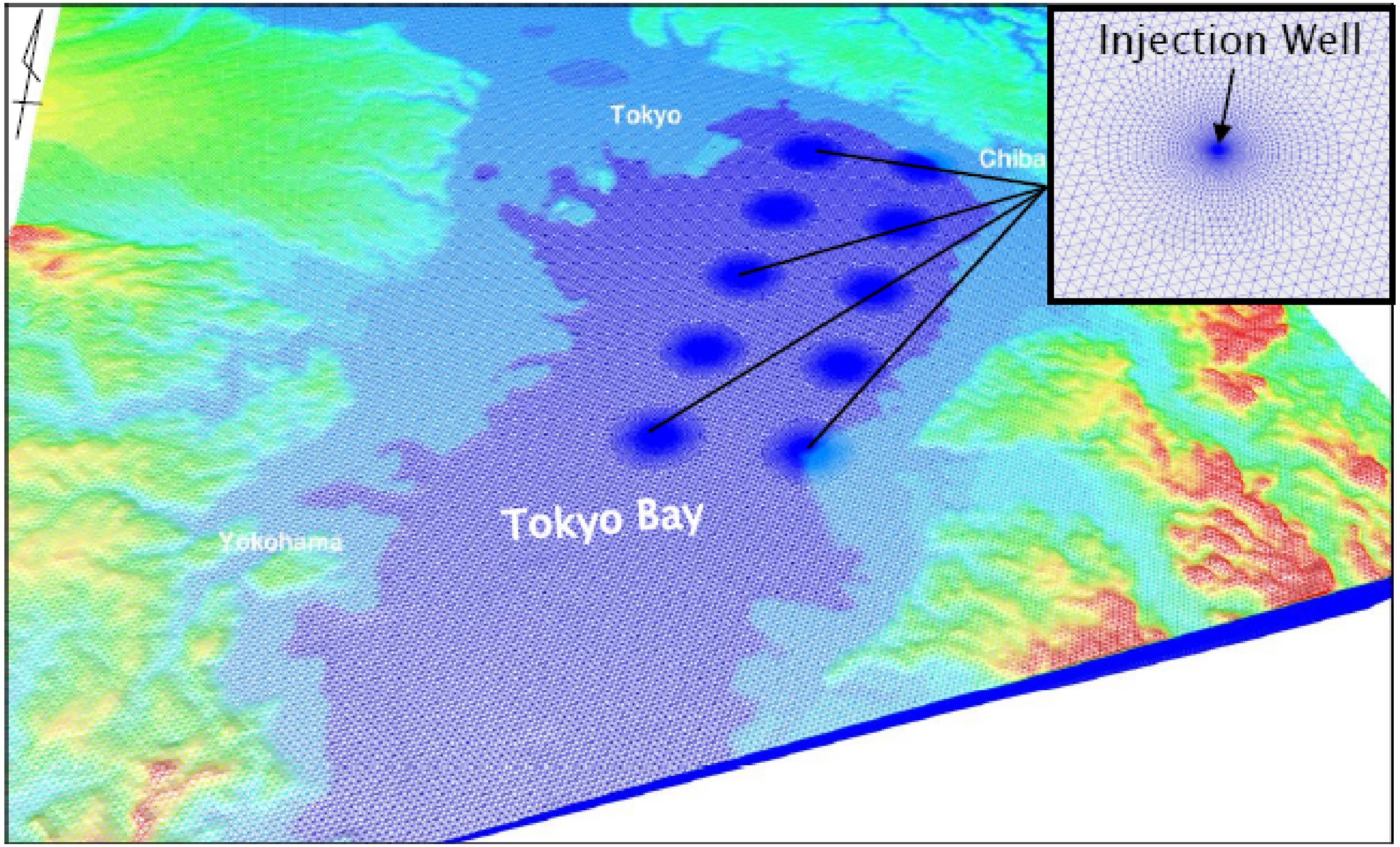
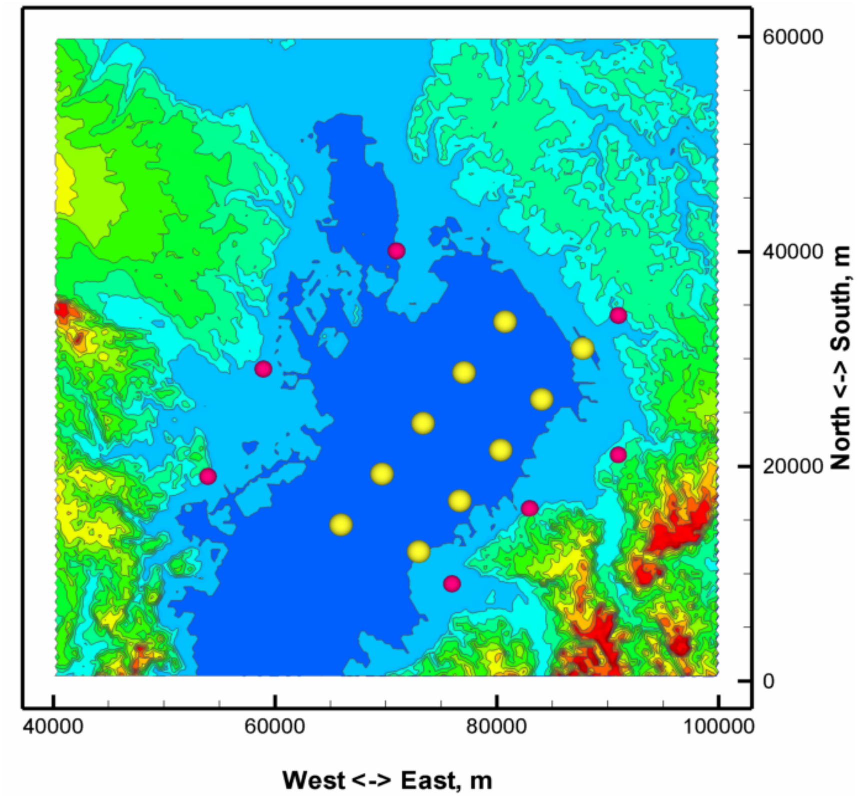
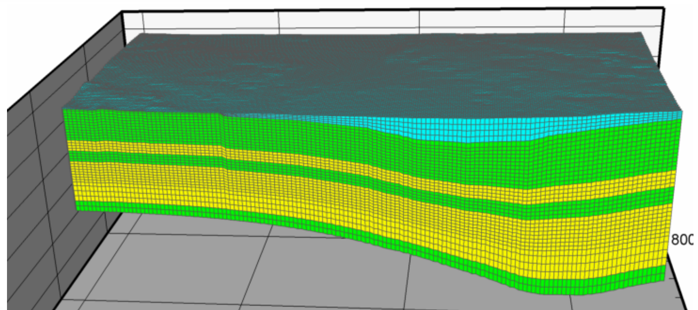


Figure 1. 3D grid system (about 10 million gridblocks, only connections are shown)

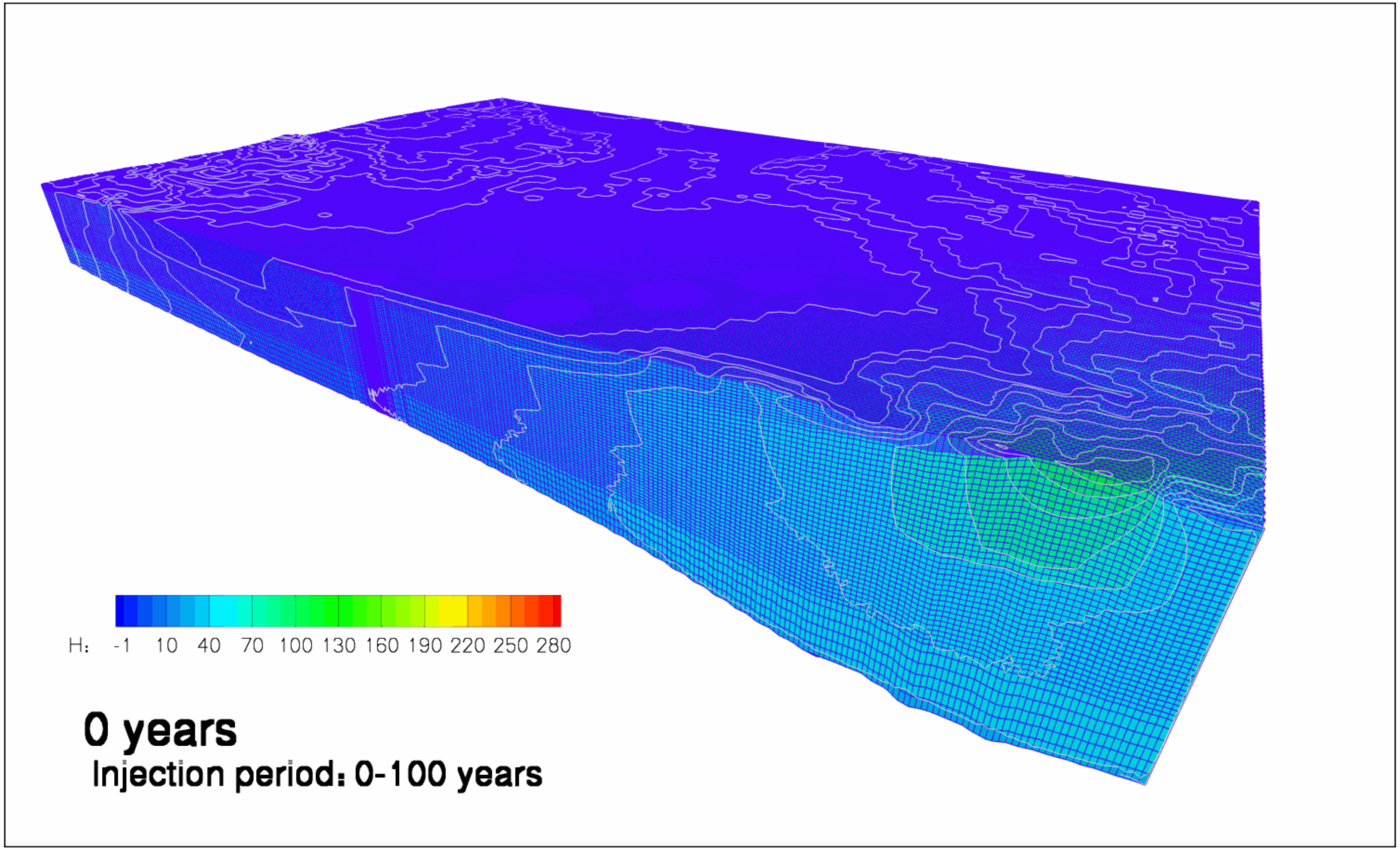
Hypothetical CO_2 Injection

- Target aquifer:
  - Middle Kazusa Group
  - Depth = 800 to 1000m
- Supercritical CO_2
  e.g.,Density ~ 0.56 t/m^3
  (at P=10MPa, T=40 °C)
- Injection rate:
  1Mt/year/hole × 10 holes
  = 10 Mt/year
- Assume CO_2 injection over a period of 100 years.
- Simulation is performed until 1000 years

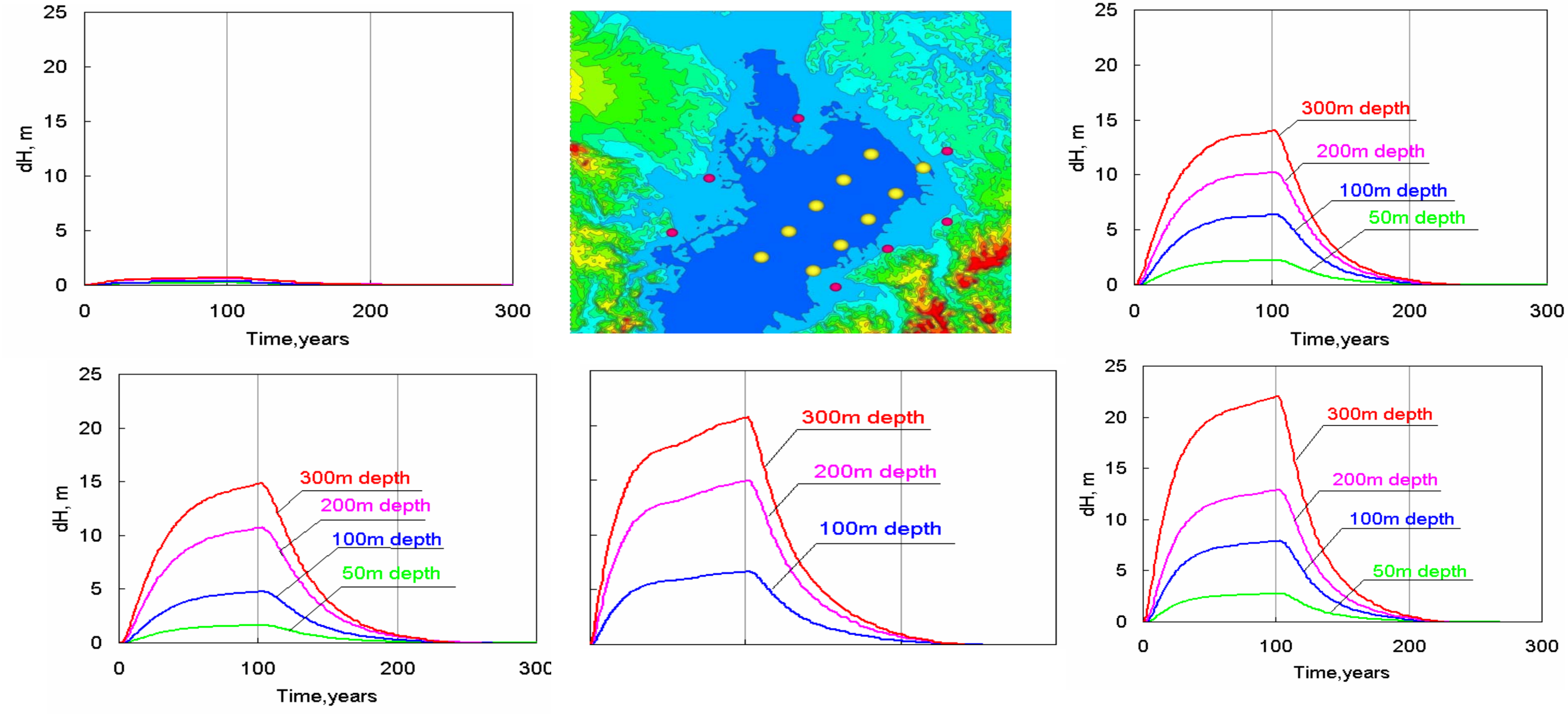




Results –CO_2 migration-



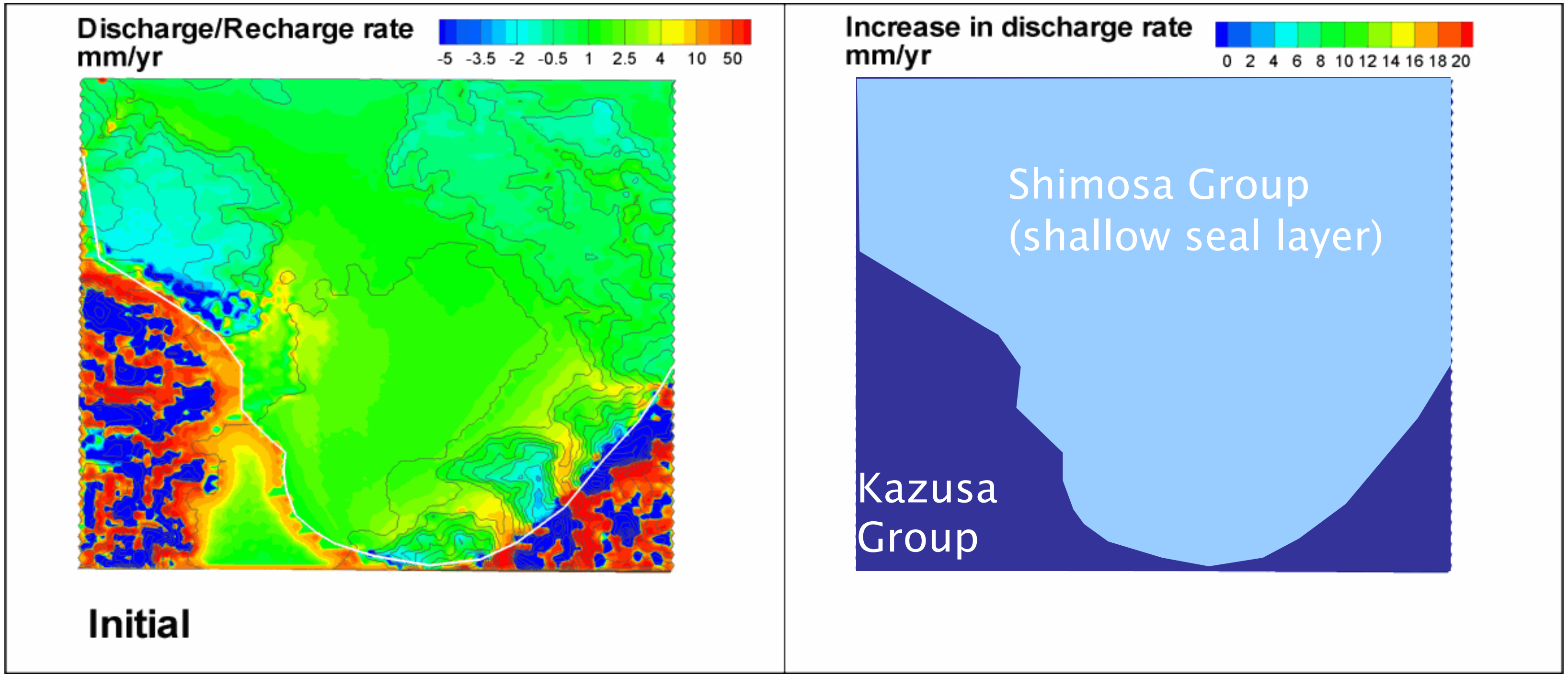
Results –Head Build-up (1)-
Change in head with time at urban inlands



Base Case (Continuous Layer Model)

Results –Surface Discharge –

How much water pushed out is discharged at the surface



Base Case

Discharge occurs in the sea floor and under the boundary of Shimosa/Kazusa G.

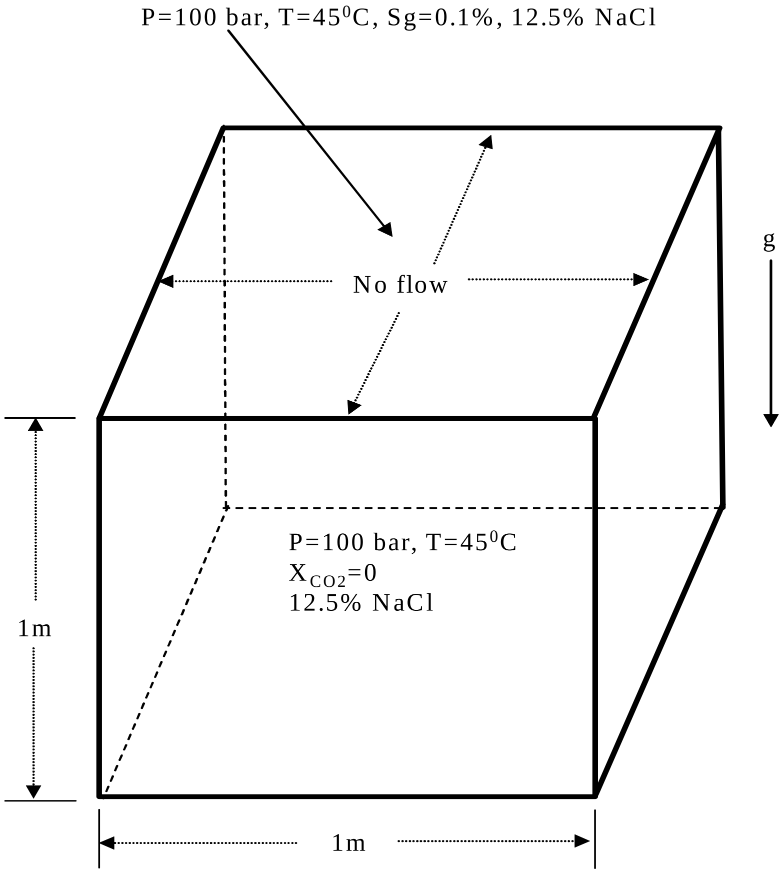
Example 2: Dissolution-Diffusion-Convection Process(Zhang and Pruess 2007)

✓Role of irregular features (geometry, heterogeneity) and 3-Deffects in “real” systems?

✓Growth of dissolved CO_2 inventory.

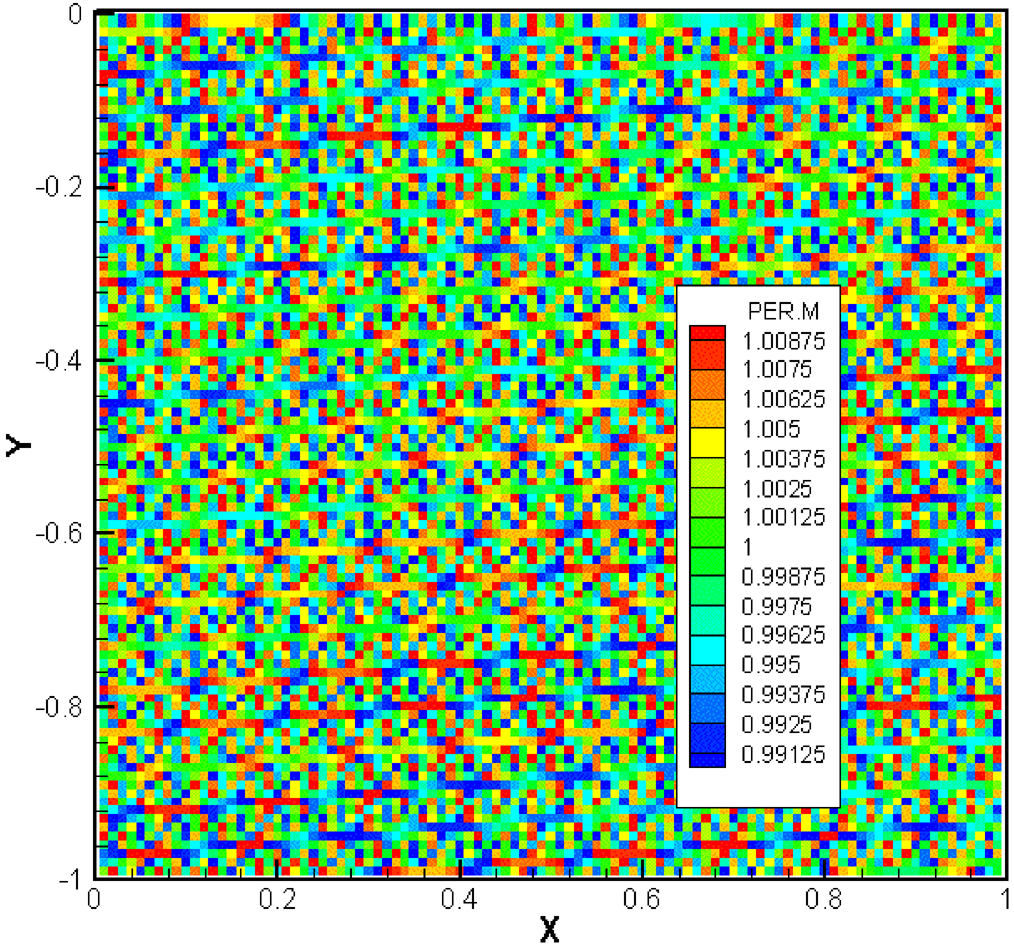
✓How can the multi-scale nature of the dissolution-diffusion-convection process be captured in field-scale simulations?

3D Model



3-D domain for simulating brine convection induced by CO2 dissolution and associated increase in aqueous phase density. (Xco2=0.0493 at top boundary)

Random Heterogeneity Field for Triggering Brine Convection



Characterizing DDC Processes

✓Constant dissolved concentration at the interface

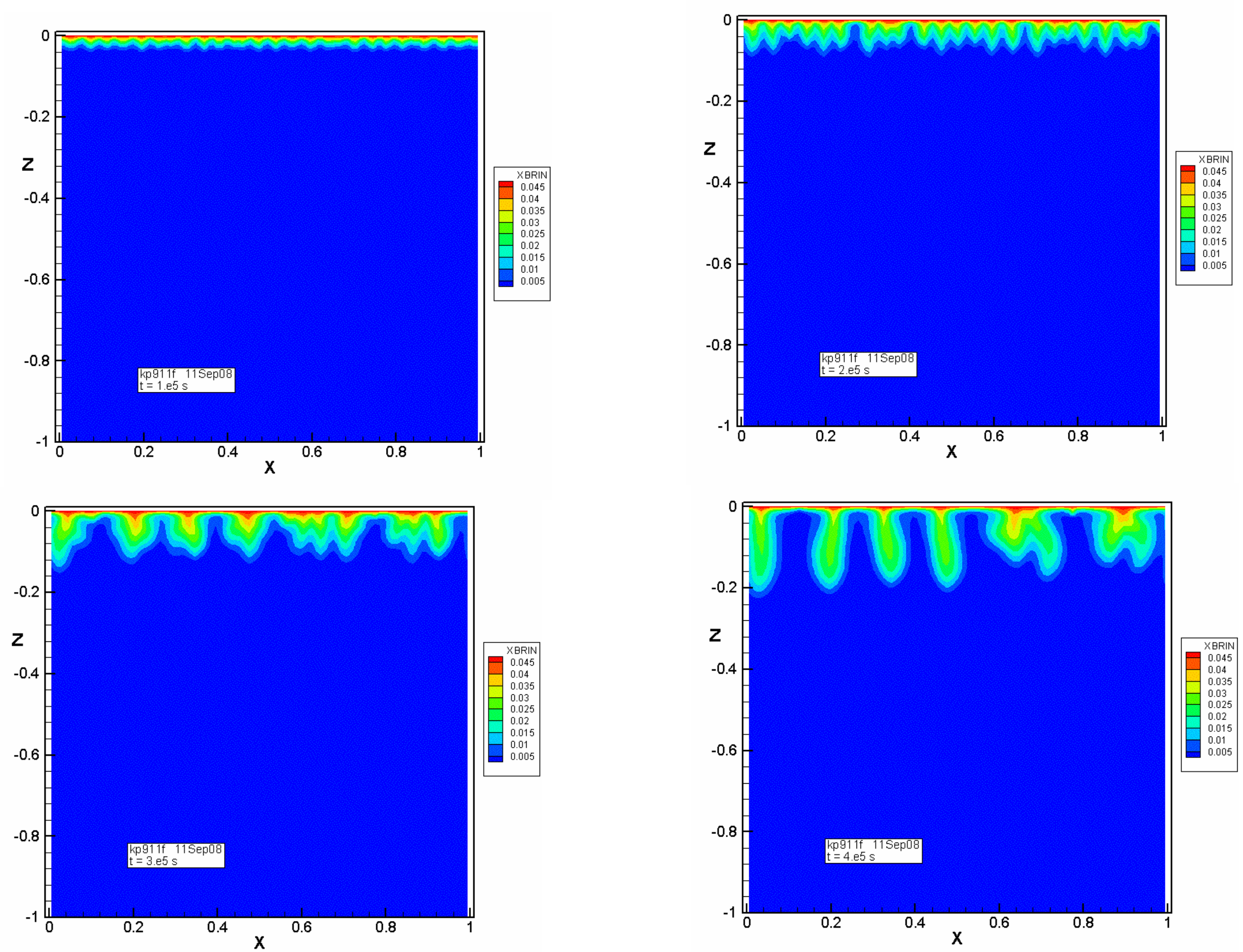
✓The rate of CO_2 entering the system equals to its dissolution rate at the top boundary.

✓The growth of total dissolved CO_2 inventory over time

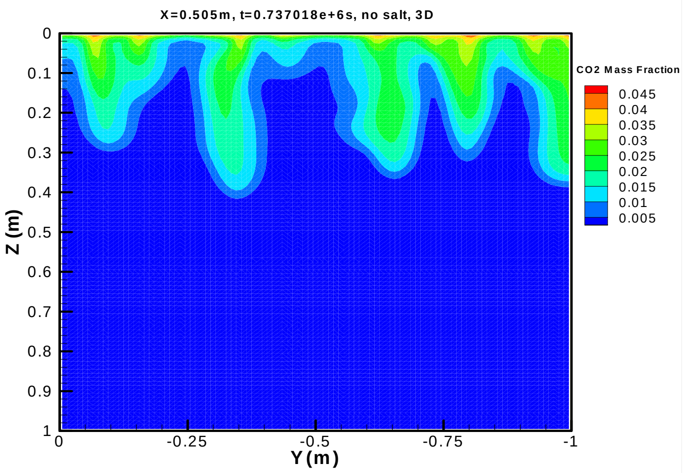
✓Comparison with the case without convection

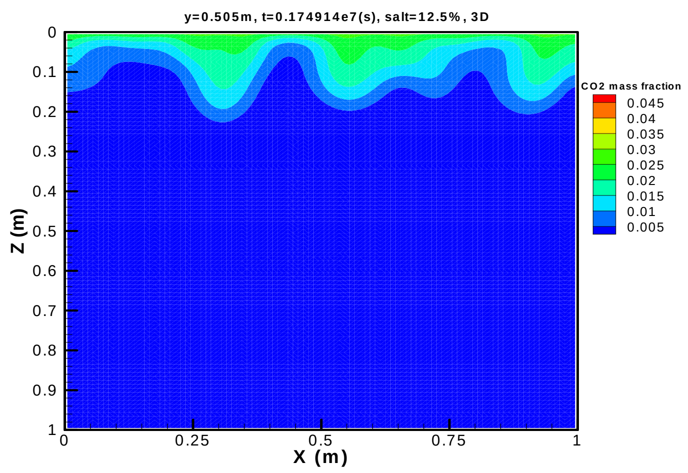
✓Investigating different random seeds

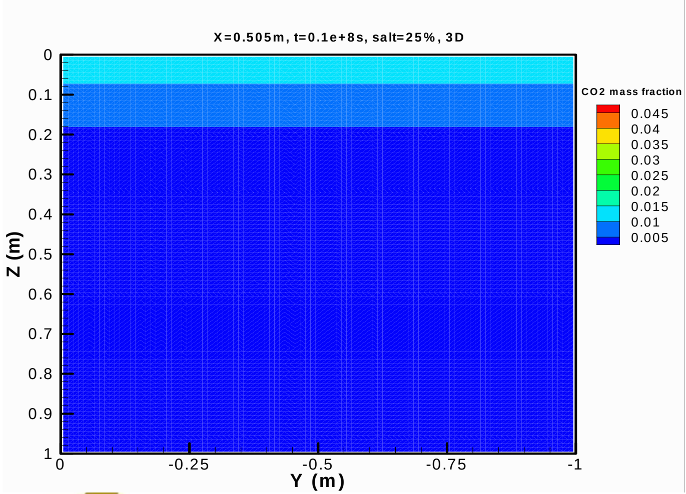
Dissolved CO2 concentrations at different times

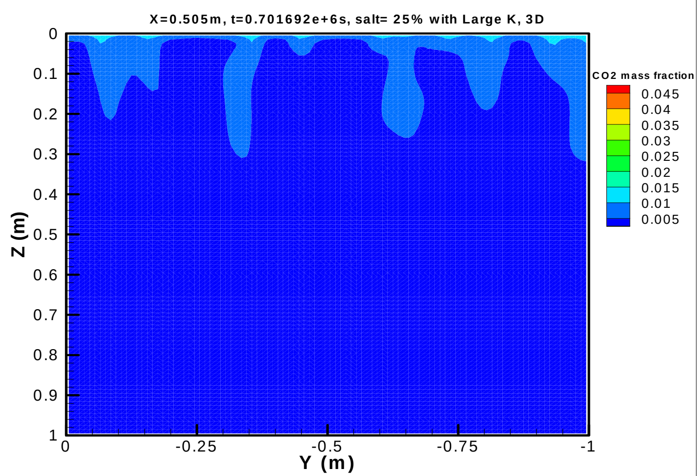


3D Model results

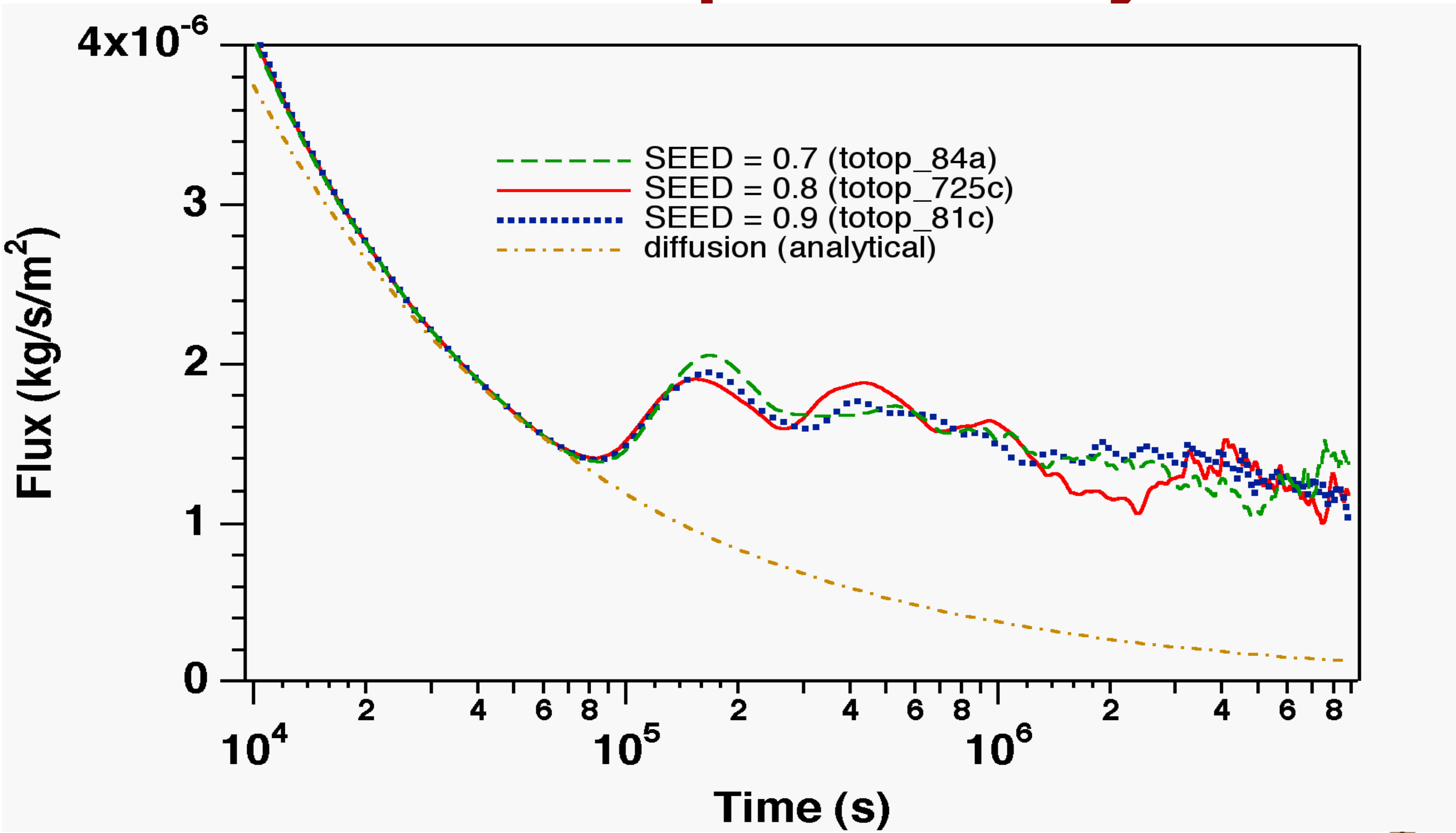








Random permeability influence on CO2 flux at top boundary



Thank you