Hydrological, Geochemical, Geophysical and Geomechanical Modeling for CO_2 Sequestration

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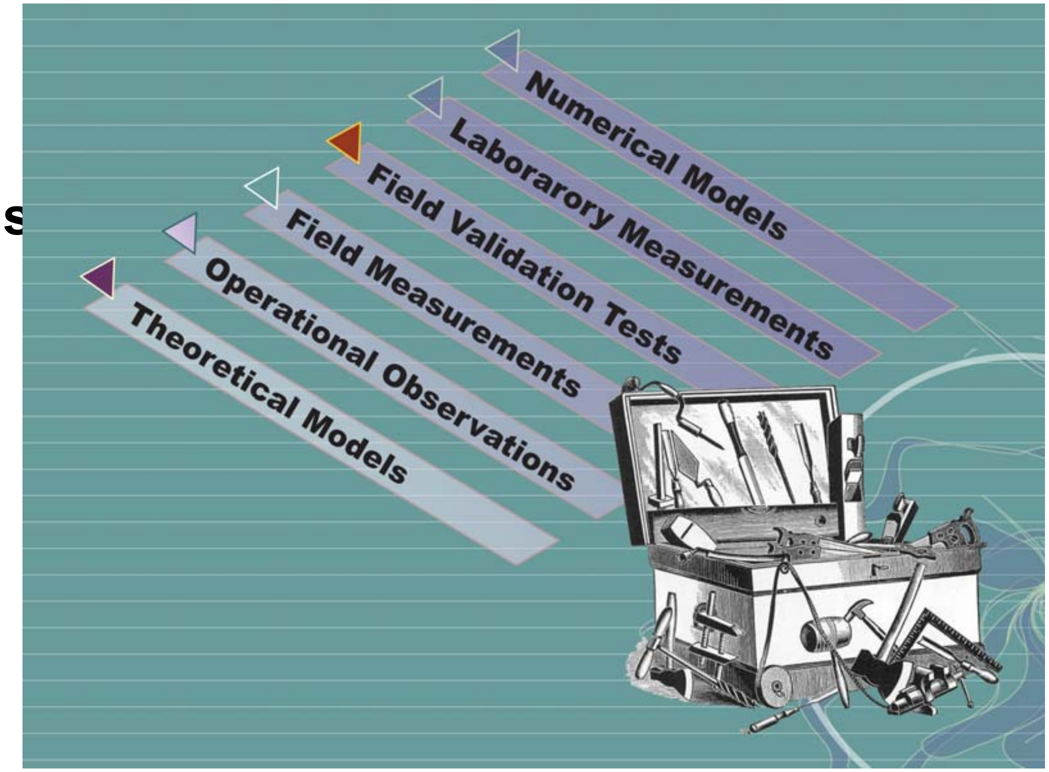
Numerical Modeling is One Important Component of the Toolbox

- **CCS technology requires multiple tools**
- **Level of detail/sophistication is application dependent**
  - **R&D**
  - **Technology development/deployment**
  - **Regulation**

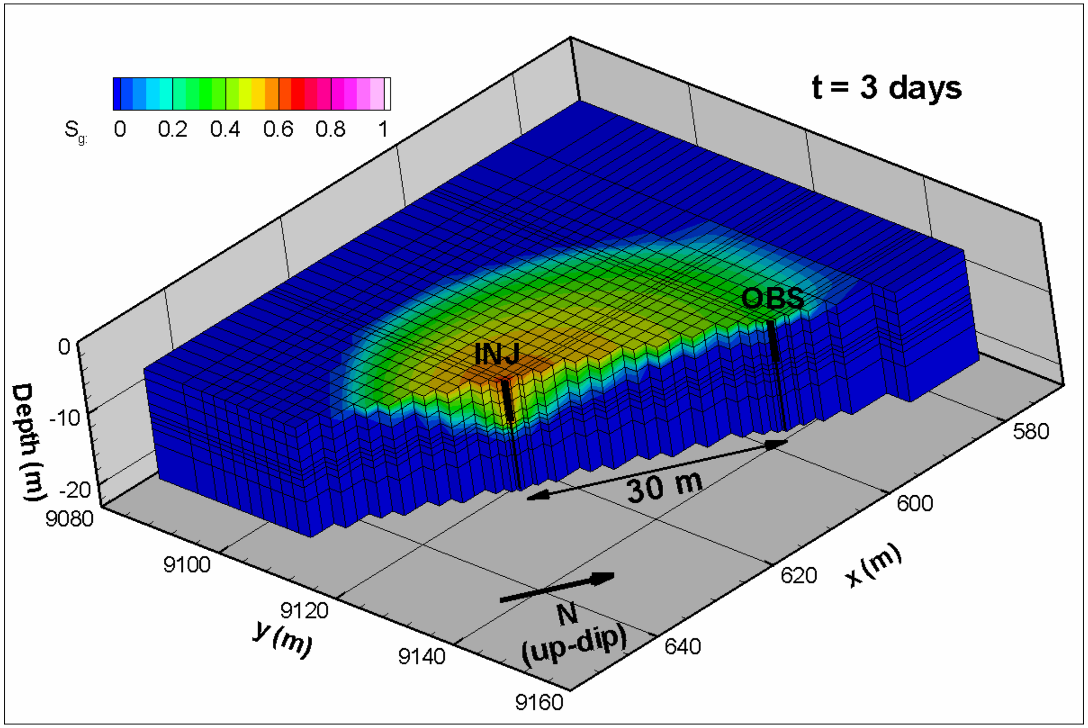


Categories of Models

- Forward models
  - —Input properties, output “behavior”
  - —Hydrological, geophysical modeling
- Coupled models
  - —Reactive geochemical transport models
  - —Hydro-geomechanical models
- Inverse models
  - —Input measurements of behavior, output properties
  - —Geophysical, hydro-geomechanical models
- Integration of models

Flow and Transport Modeling

- **Models address core issues**
  - **Plume size and shape**
  - **Plume movement**
  - **Storage mechanisms**
  - **Capacity**
  - **Assessing leakage risk**
  - **Impact of leakage**

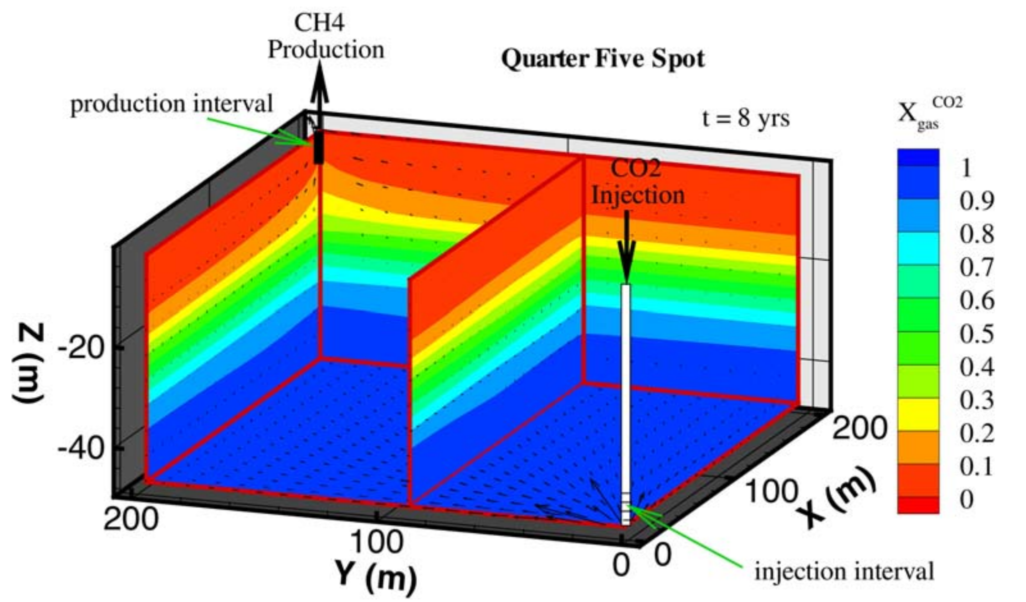


Predicted CO_2 plume, Frio pilot

Source: C Doughty, LBNL

Models Differ by Formation Type

- Oil reservoir simulators
  - Focus on details of oil-CO_2 interactions
- Coal bed reservoir simulators
  - Incorporate surface sorption processes
  - Coal swelling
- Gas reservoir simulators
  - Focus on CO_2 – CH_4 interactions over broad P and T conditions
- Saline formation simulators
  - Focus on CO_2 – H_2O interactions over broad P and T conditions

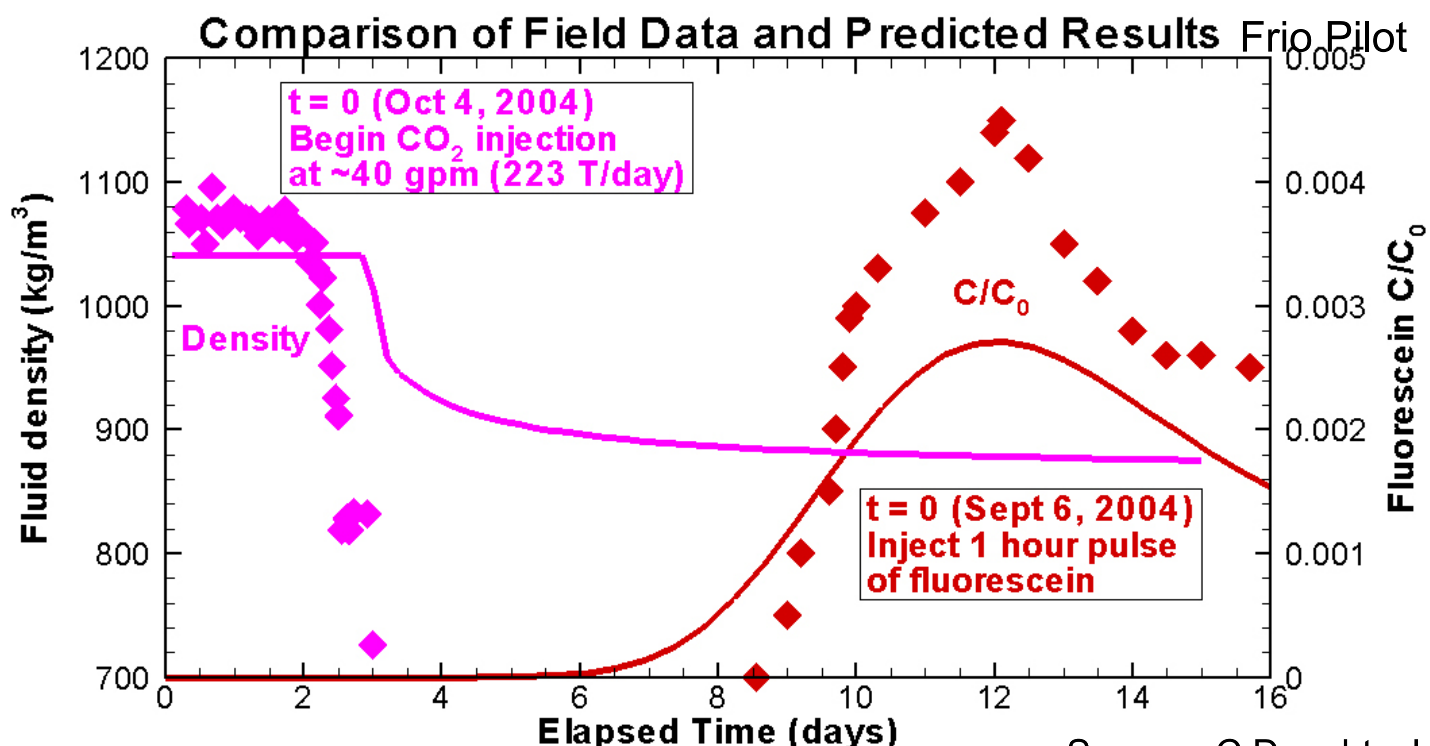


Gas reservoir simulation

Source: C Oldenburg, LBNL

How Good Are the Models?

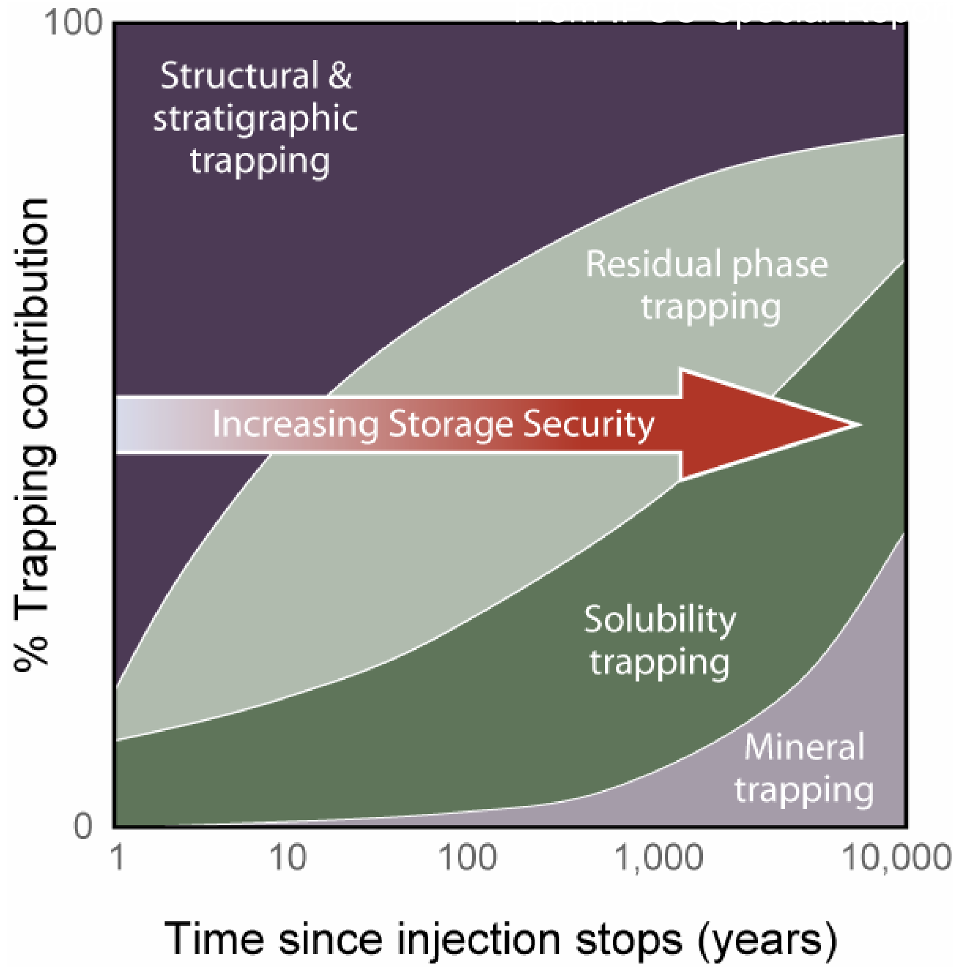
- Large body of experience in flow and transport modeling
- Model intercomparison studies and initial field studies indicate that important CO_2 flow and transport processes are well simulated



Source: C Doughty, LBNL

Reactive Geochemical Transport Models

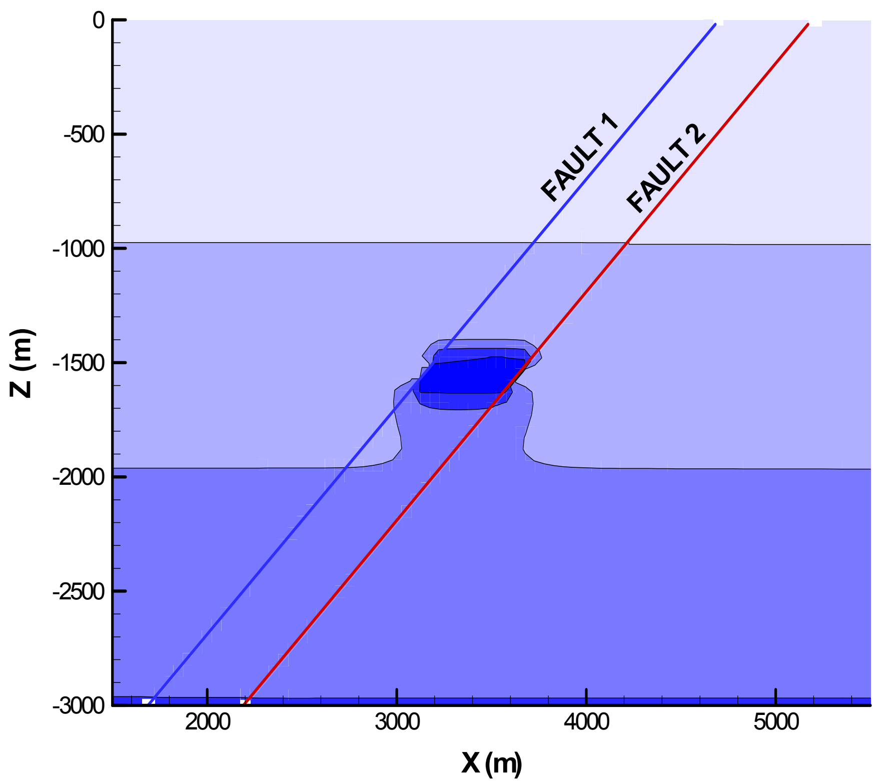
- **Coupling of rock-water interactions with flow and transport modeling**
- **Models address storage security, formation alteration, impacts of leakage**
- **Near term focus of sequestration requires that kinetics be included**
- **Weakness: long term kinetics and coupling between dissolution/precipitation and permeability**

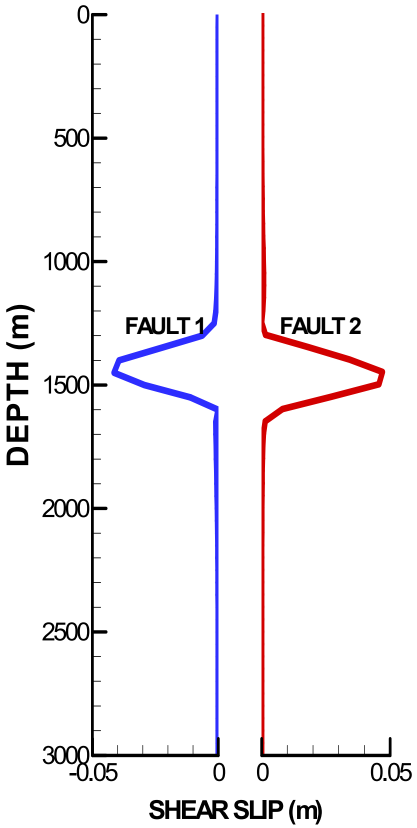


Source; S Benson, LBNL

Hydrogeomechanical Modeling

- Coupling of flow and stress/strain modeling
- Assess interaction of pore pressures with in-situ stresses
- Relatively small body of experience



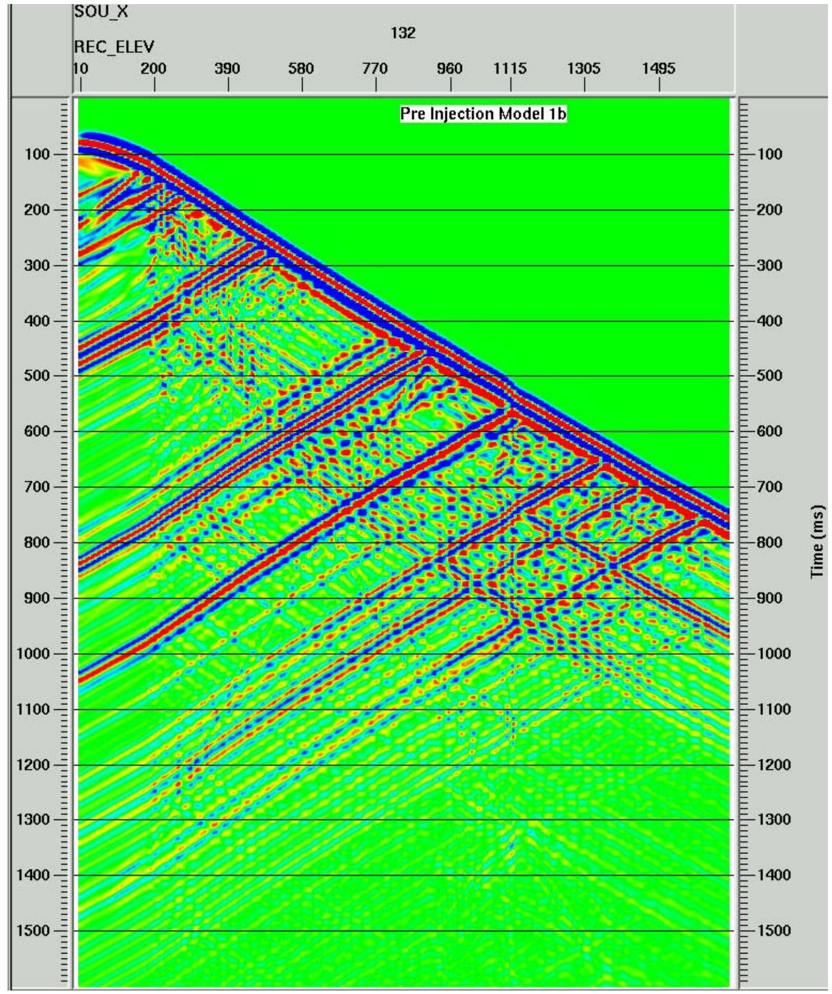


Fault displacements due to pore pressure increases

Source: J Rudquist, LBNL

Geophysical Modeling

- **Forward modeling predicts the results of geophysical measurements**
- **Site characterization and monitoring applications**

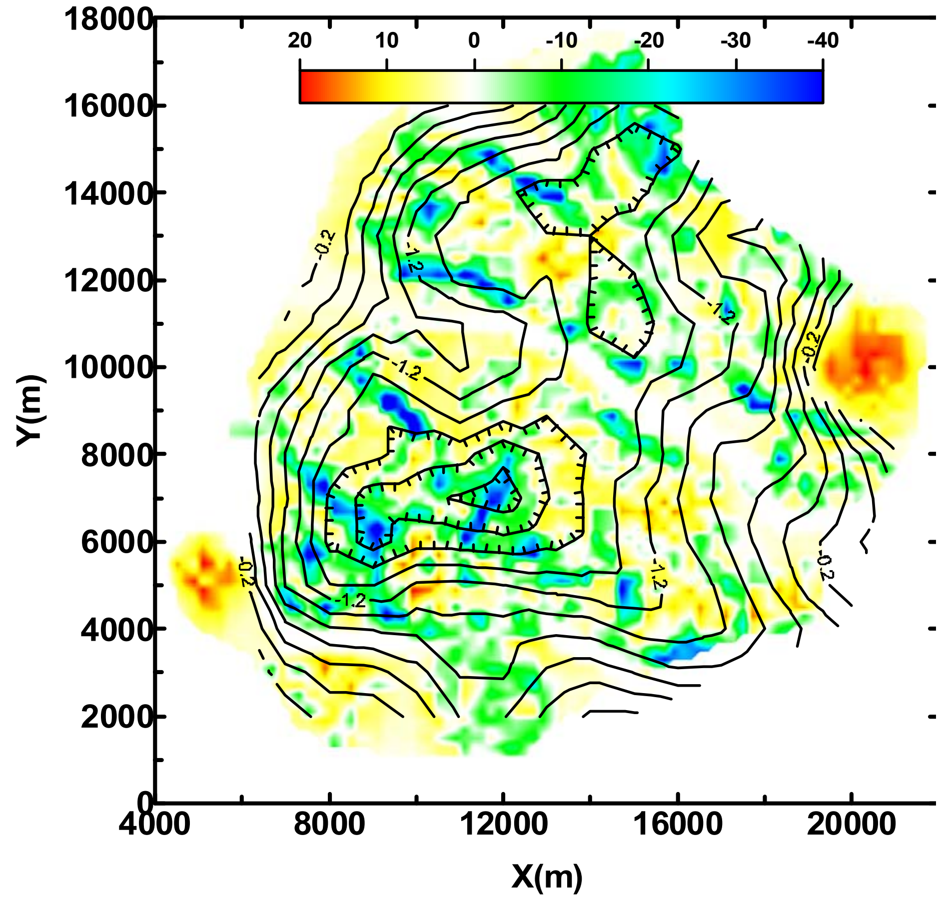


Prediction of Frio pilot VSP

Source: T Daley. LBNL

Geophysical Models Vary by Method

- **Seismic**
  - —CO_2 affects velocities
- **Electromagnetic**
  - —CO_2 affects resistivity
- **Gravity**
  - —CO_2 affects density
- **Current models are highly sophisticated**

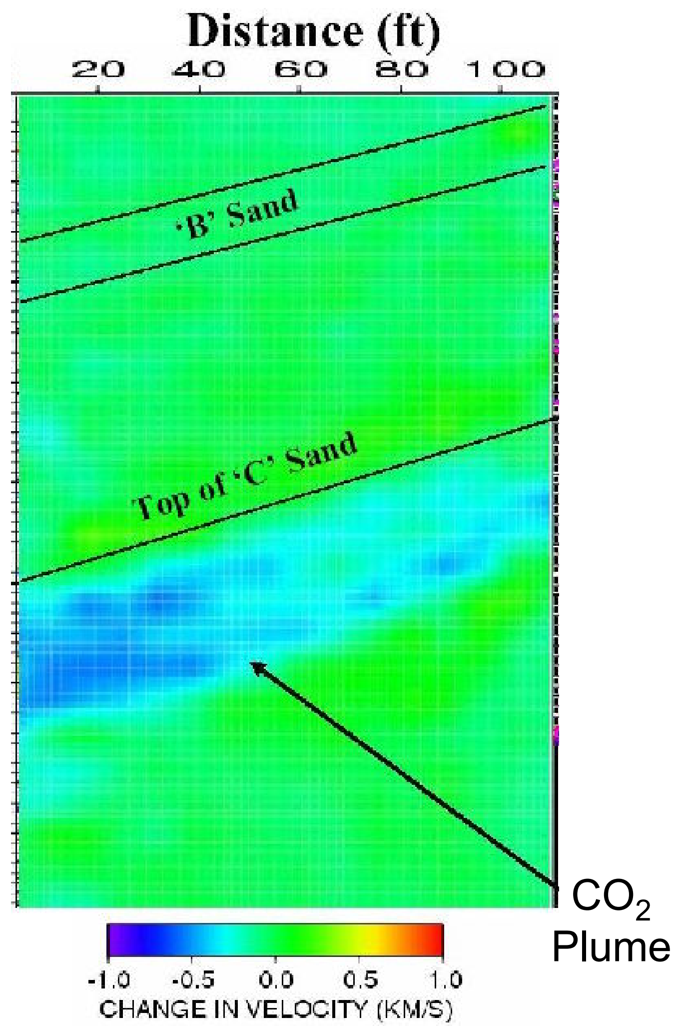


Predicted contours of gravity response due to CO_2 injection

Source: M Hoversten, LBNL

Inversion Models

- **Geophysical measurements are inverted to give subsurface distribution of properties**
  - **Velocity distribution from seismic data**
  - **Conductivity distribution from electrical data**
- **Rock-physics models used to get CO_2 saturation**
- **Weakness: non-uniqueness, realism of rock-physics models, resolution of non-seismic**

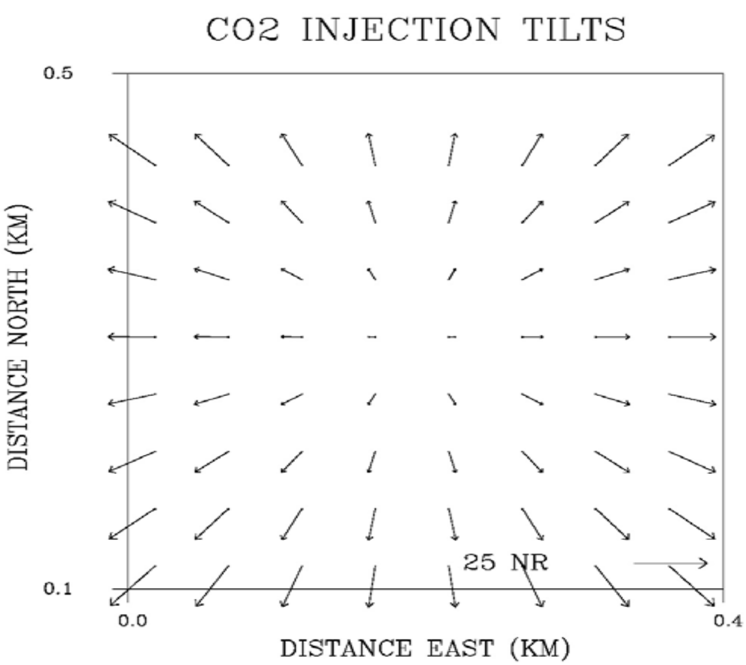


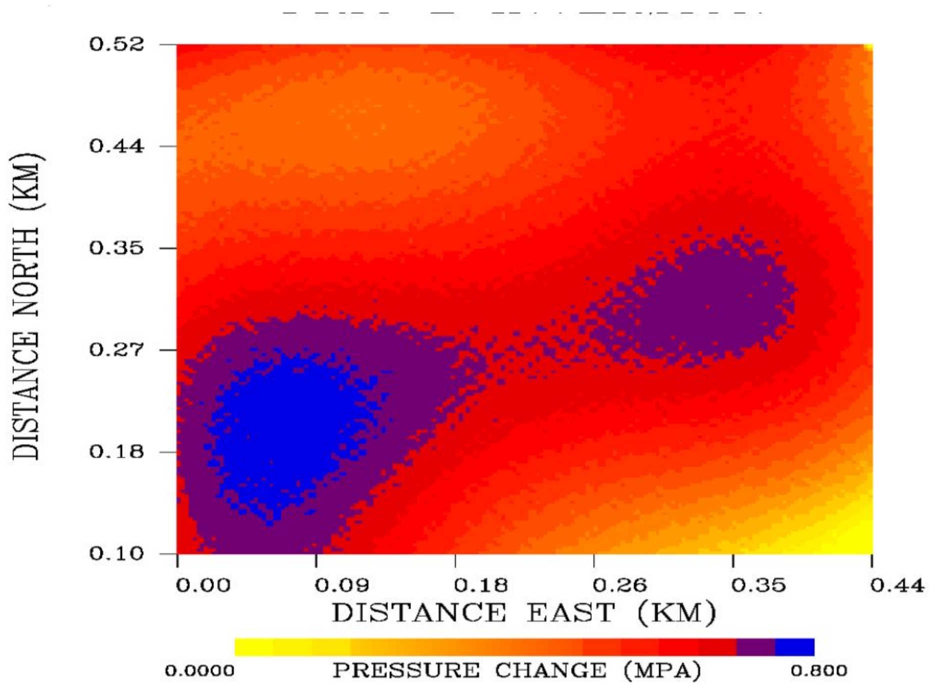
Crosswell seismic inversion, Frio pilot

Source: T Daley, LBNL

Inversion Applied to Hydrologic and Geomechanical Measurements

- Low resolution
- Active research area



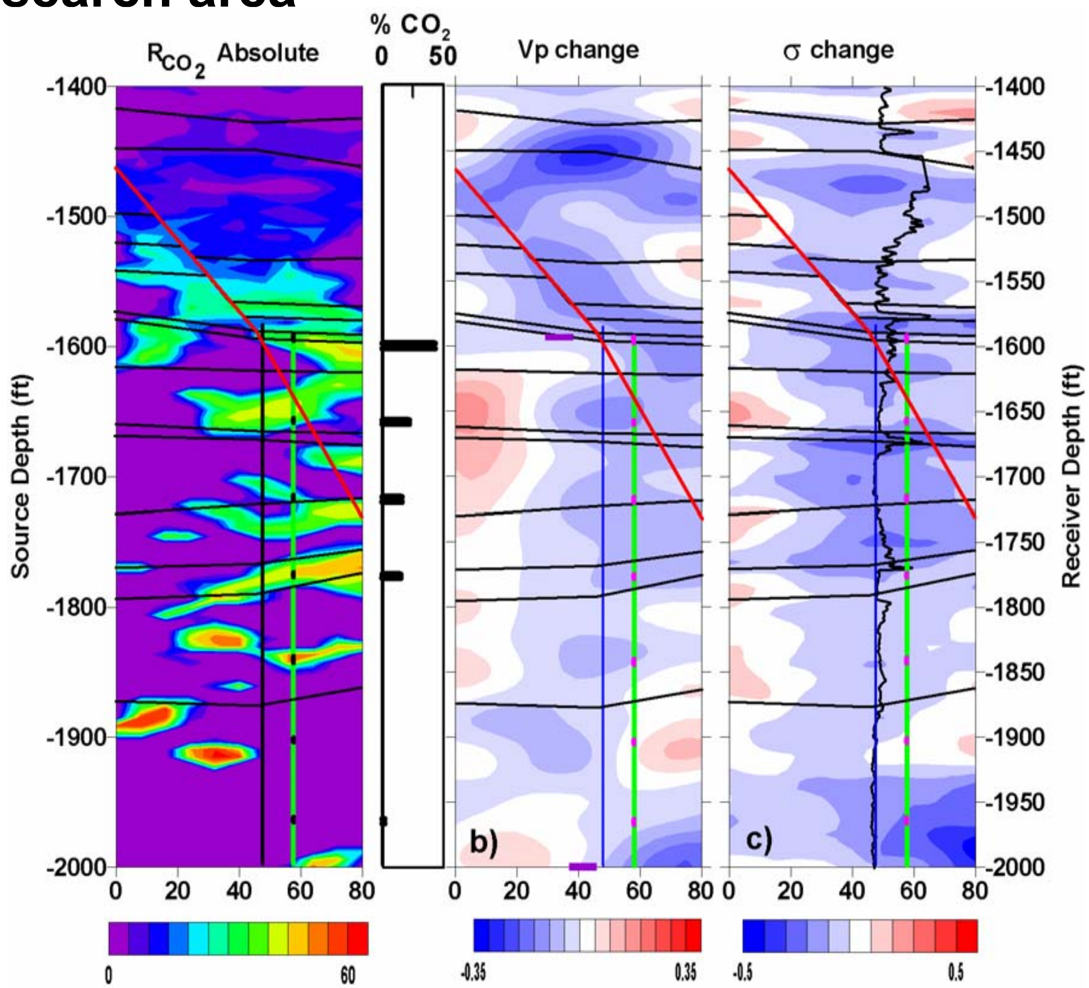


Inversion of surface tilt for subsurface pore pressures

Source: D Vasco, LBNL

Joint Inversion Reduces Non-uniqueness

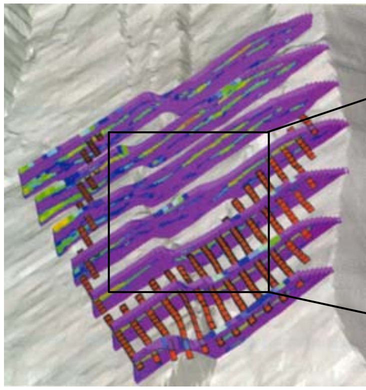
- **Active research area**



Joint inversion of crosswell seismic and EM, Lost Hills CO_2 pilot

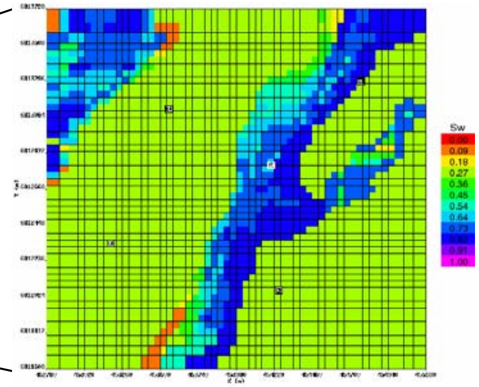
Source: M Hoversten, LBNL

Platforms for Combining Models are Being Developed

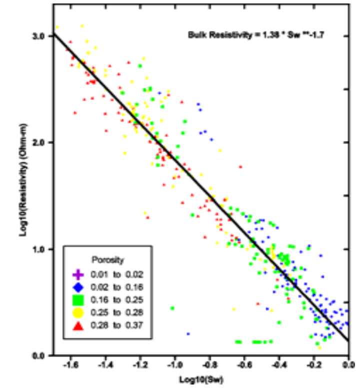


3D reservoir Simulation

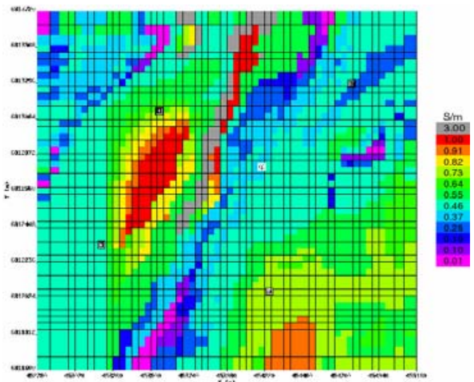
Horizontal Section at 2340m depth



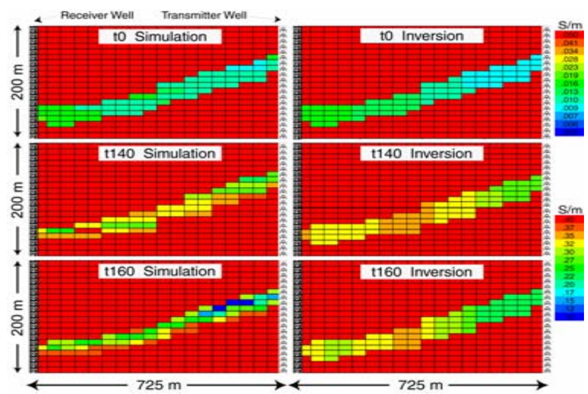
Reservoir Properties (e.g. Water saturation Sw)



Saturation - Resistivity from log data

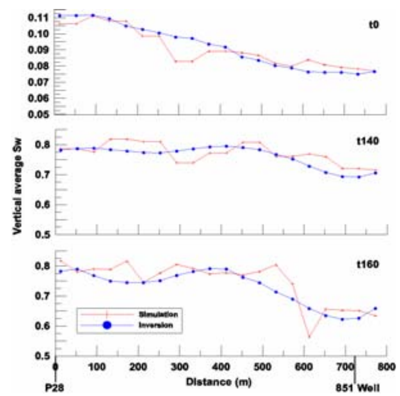


Electrical Conductivity (Finite Difference Grid)



Vertical cross sections at Time Steps during water flood

Inversion Images of Reservoir at Time Steps



Predicted Vertical Average Sw in Reservoir

Source: M Hoversten, LBNL

Conclusions

- Models exist for simulation of important physical processes in CO_2 sequestration
- Model improvements continue; particularly significant impact on monitoring
- Field pilot testing essential for model validation
- Realism, relevance of simulations depends on quality of input data