Basin-scale Modeling of CO_2 Sequestration in the Illinois Basin—Progress Report

Midwest Carbon Sequestration Science Conference
Champaign, IL
September 18, 2012

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Acknowledgments--

This material is based upon work supported by the U.S. Department of Energy under award number DE-FC26-05NT42588.

US DOE project manager: Darin Damiani, NETL

This work used the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation grant number OCI-1053575.

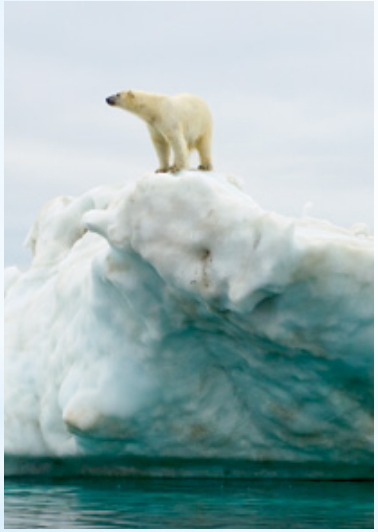
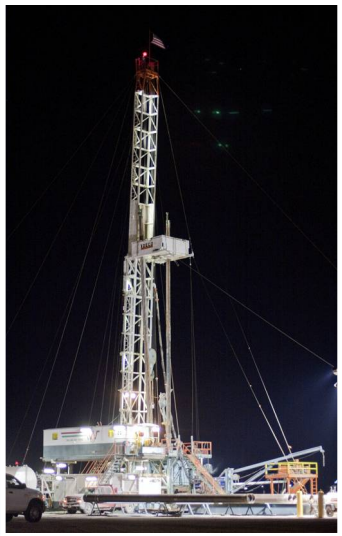
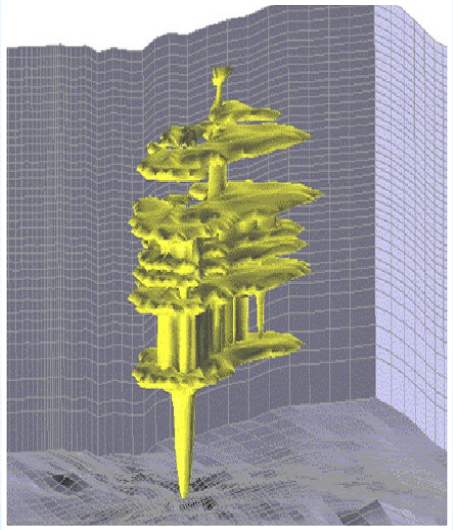
This research is partially supported with funds from a USEPA STAR grant 488220.
Project Manager: Barbara Klieforth

Lawrence Berkeley National Lab– Quanlin Zhou & Jens Birkholzer contributed to the development of the model discussed.

Natural gas storage companies (Ameren Illinois, Nicor, Peoples Gas, Panhandle Energy) have provided useful data.

Outline

- Background
- Modeling approach
- Modeling results

Background/GCS in Illinois Basin

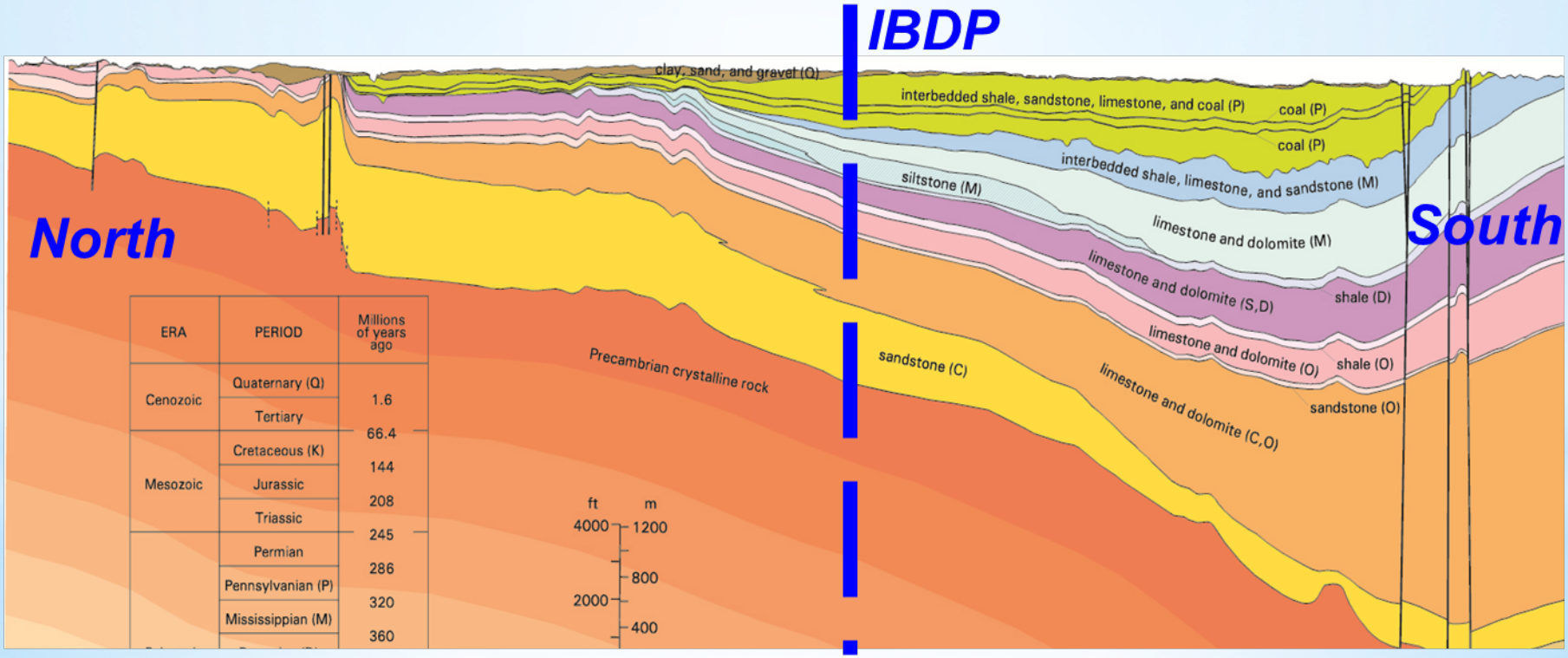
- Illinois Basin estimates
  - Emissions: 291 million metric tons/yr
  - Storage resource
- Why is the Mt. Simon being modeled?

	Resource (Metric ton= 1,000 kg)	
	Million metric tons	years
EOR	140-440	0.5-1.5
Deep Coal	1,600-3,200	5.5-11.0
Mt. Simon	11,000-150,000	38-515

Source: The United States 2012 Carbon Utilization and Storage Atlas" 4th Ed, Nov 2012

Background/ Geology

- Mt. Simon– open reservoir, extensive, 3 layers

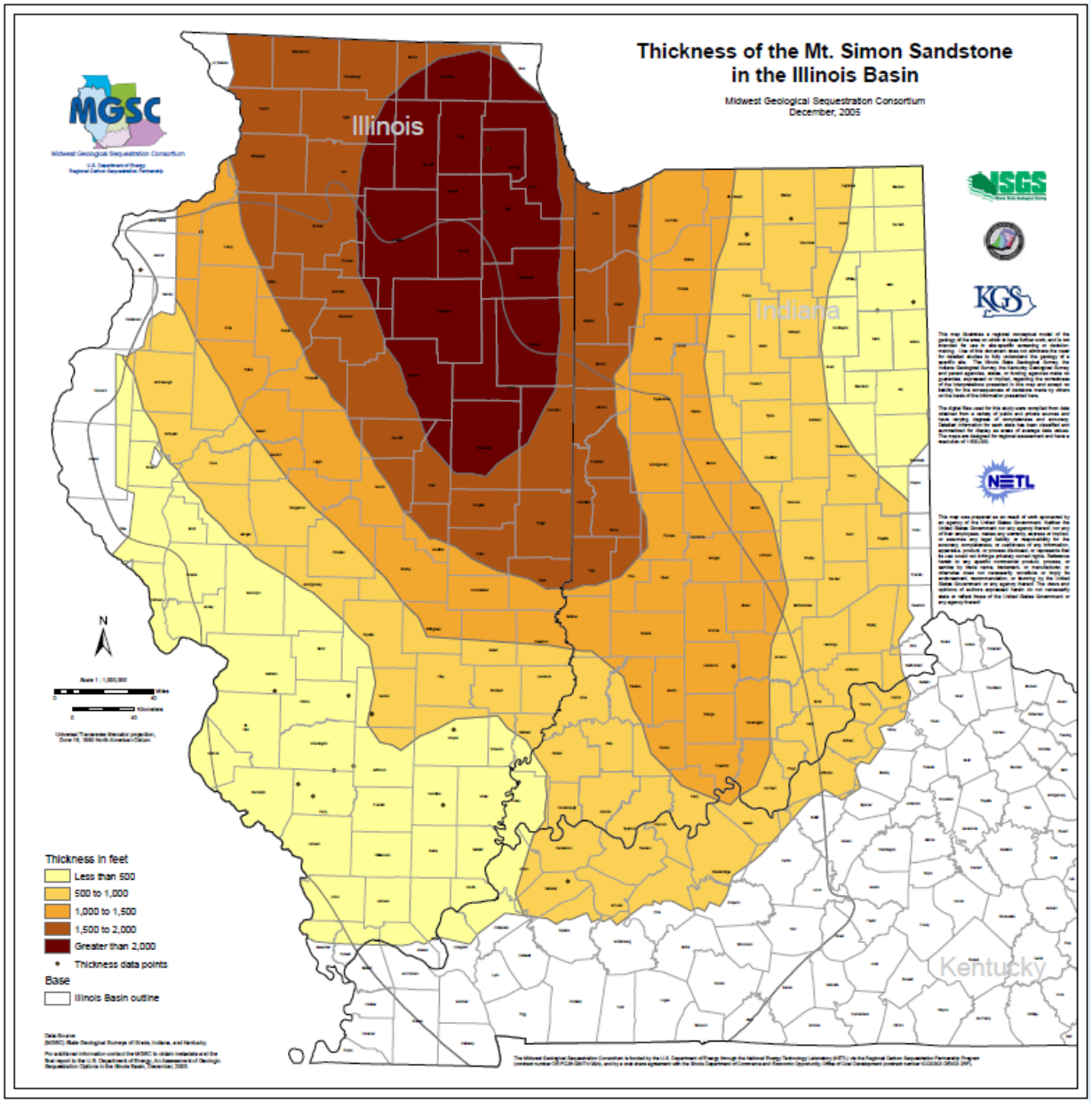


Background/ Geology

- Thickness (ft) of Mt. Simon

Thickness in feet

- Less than 500
- 500 to 1,000
- 1,000 to 1,500
- 1,500 to 2,000
- Greater than 2,000
- Thickness data points

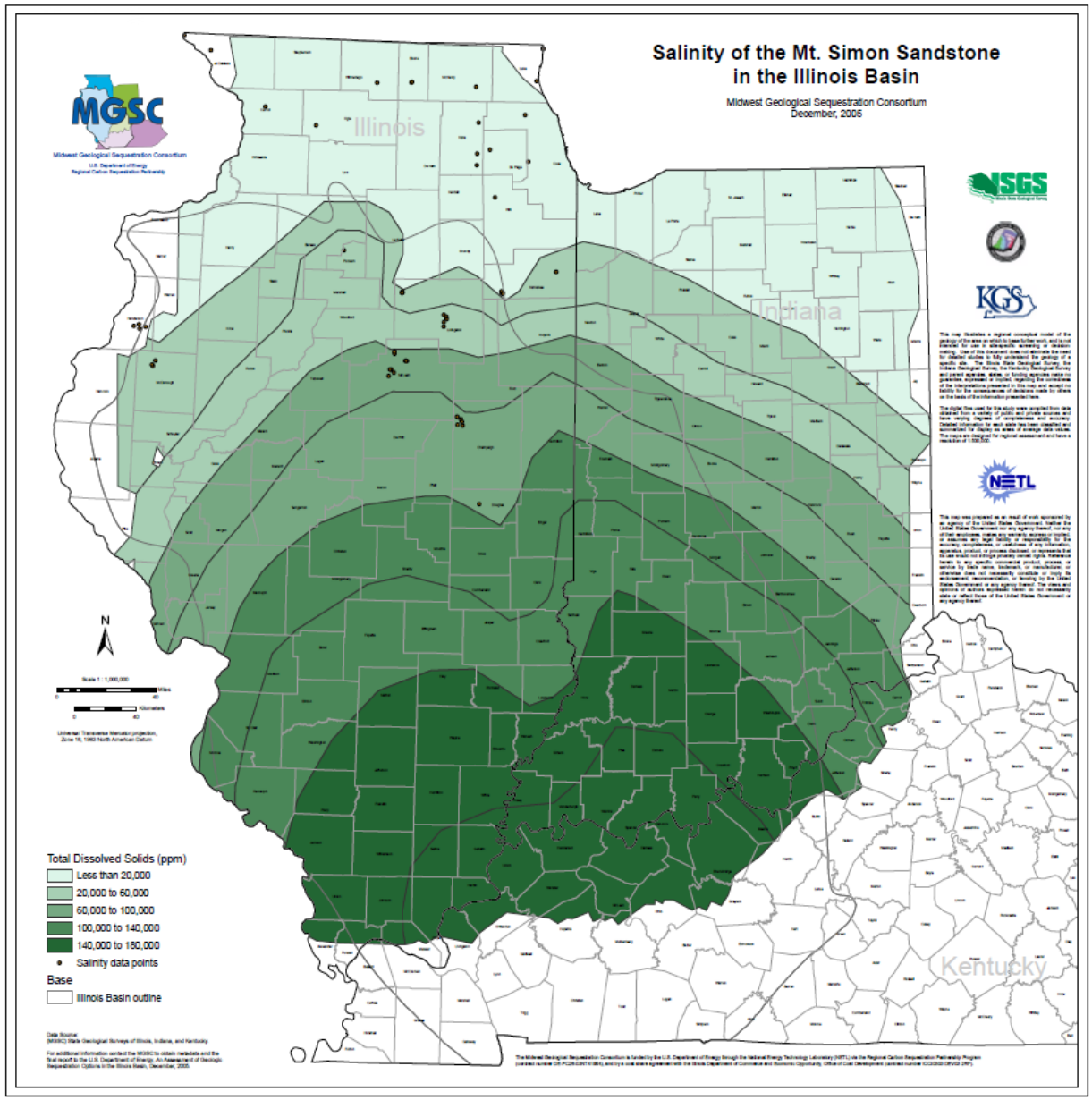


Background/ Geology

- TDS of Mt. Simon brine

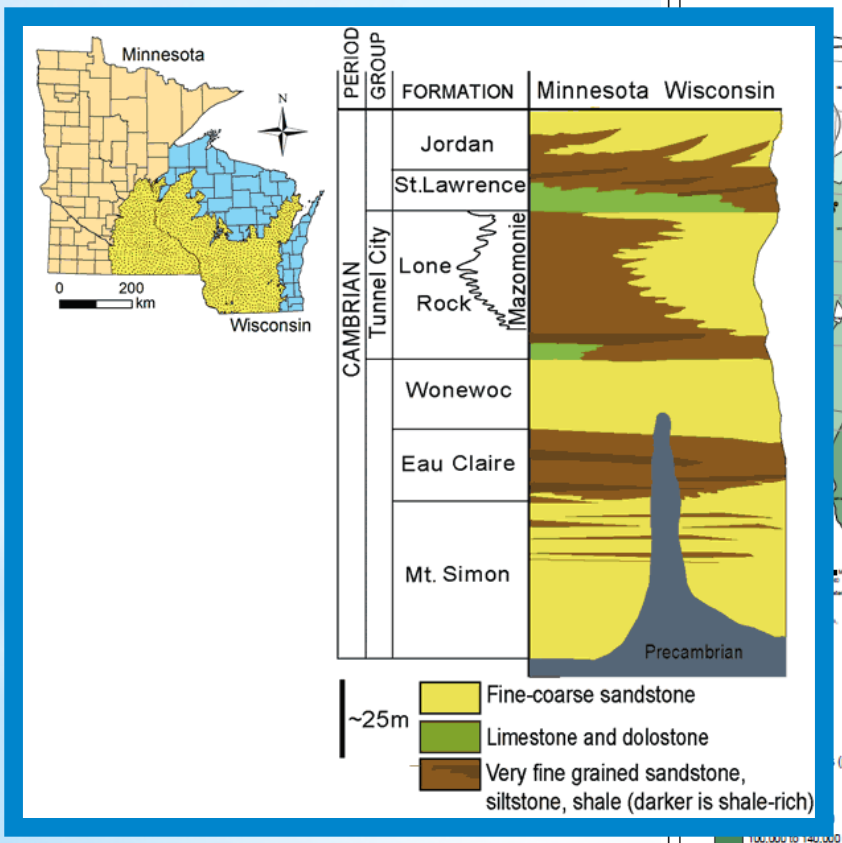
Total Dissolved Solids (ppm)

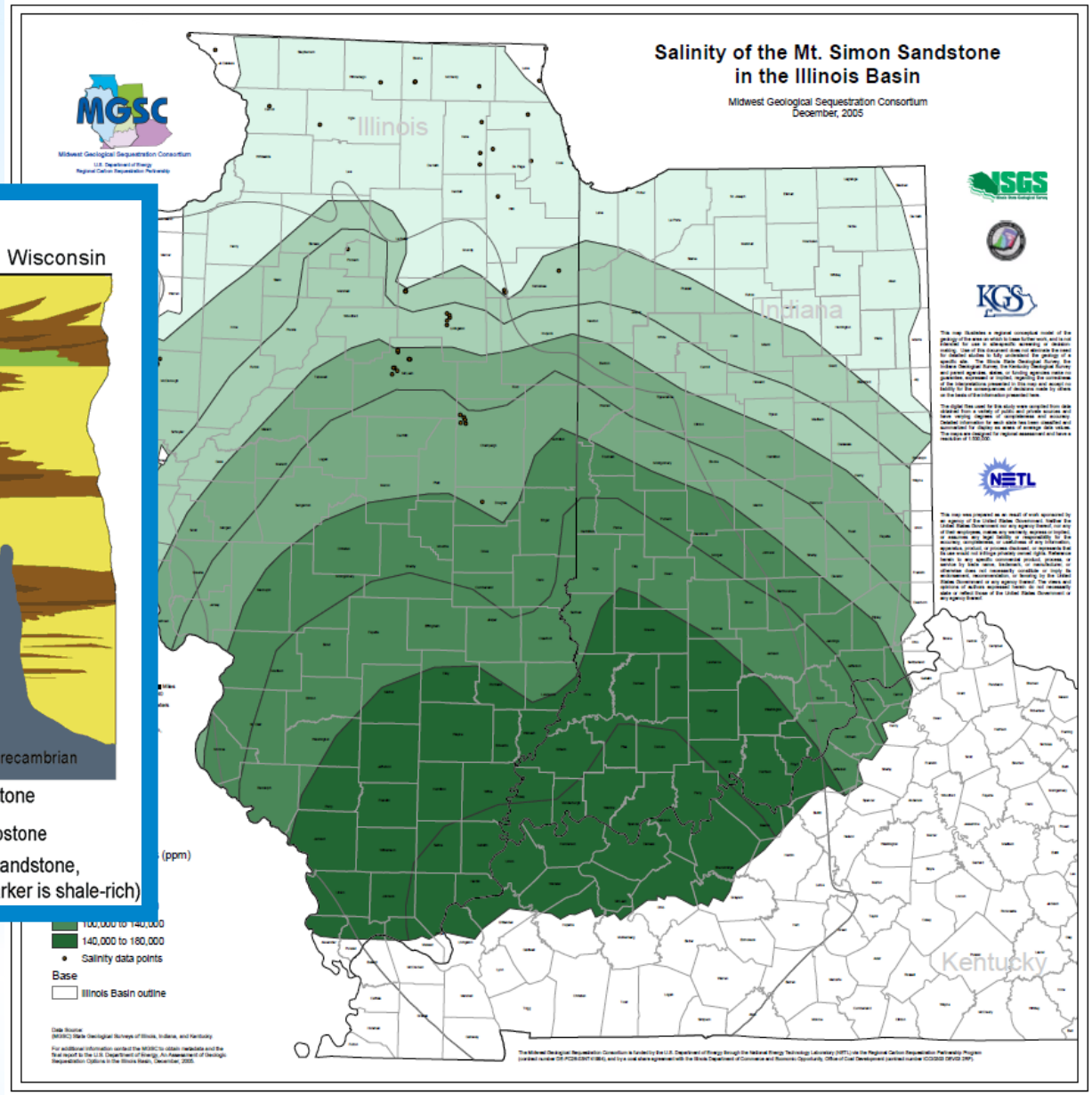
- Less than 20,000
- 20,000 to 60,000
- 60,000 to 100,000
- 100,000 to 140,000
- 140,000 to 180,000
- Salinity data points



Background/ Geology

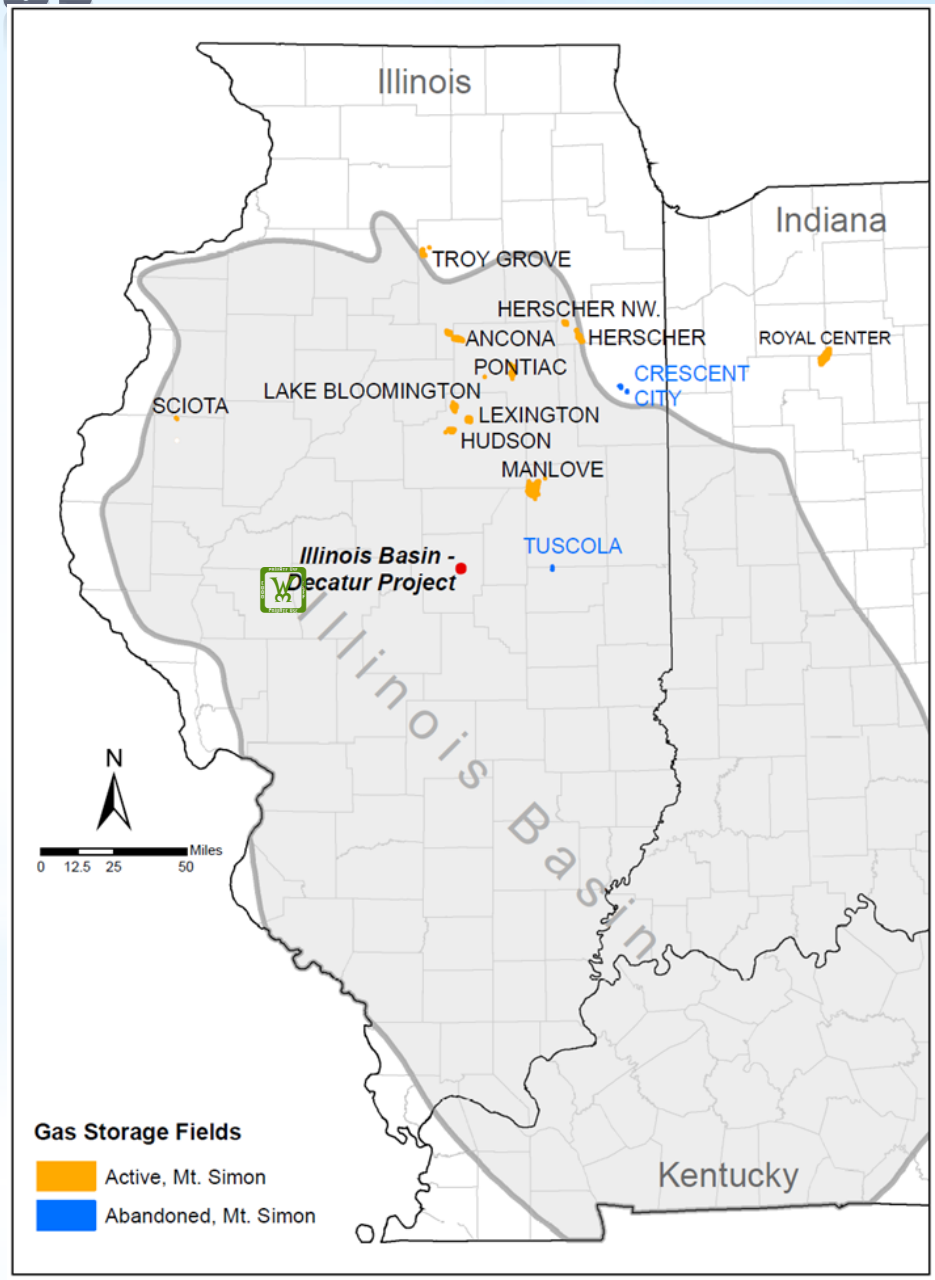
- TDS of Mt. Simon brine





Background/ Geology

- Natural gas storage facilities
- FutureGen 2.0 in Morgan County (green hexagon)



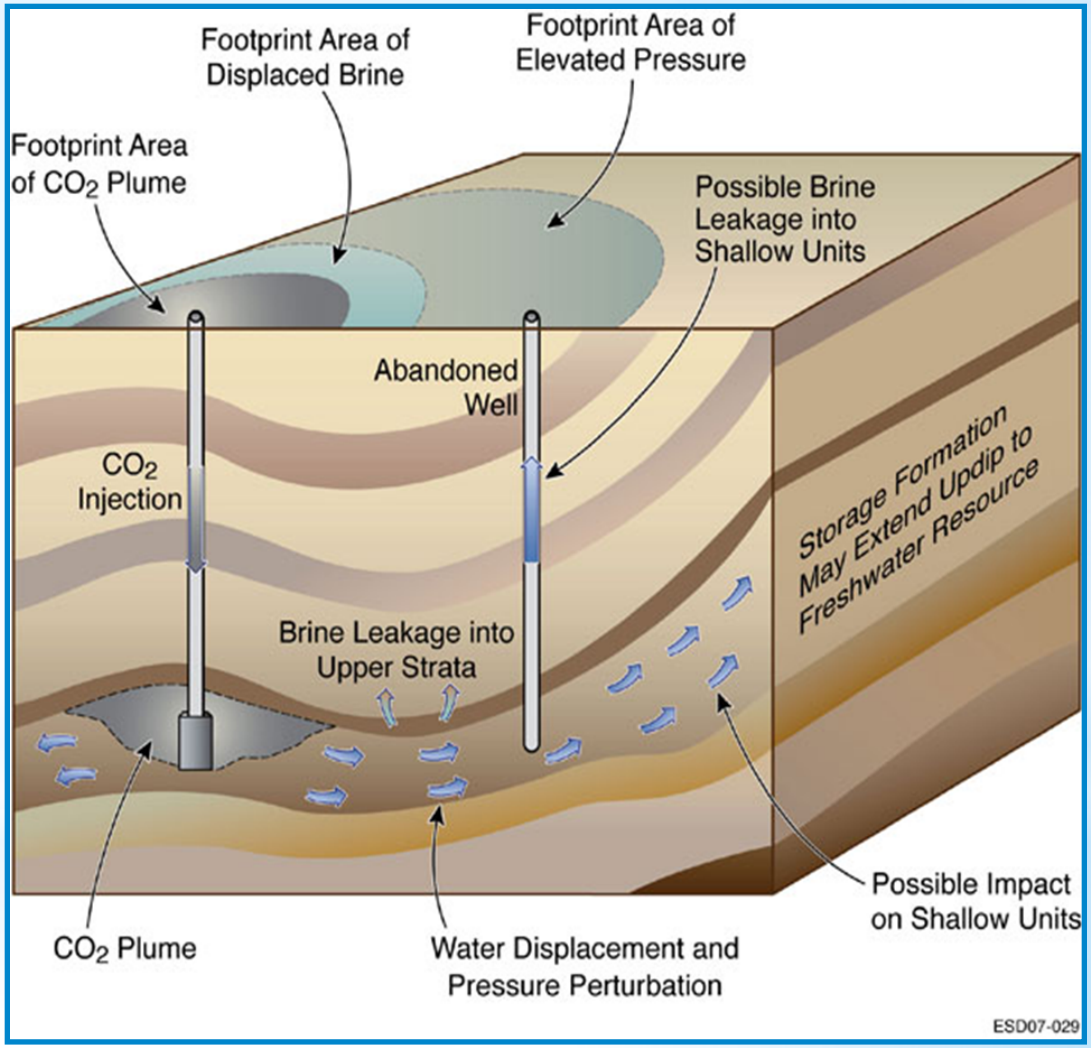
Background/ CCS#1

- Injection well completed 5/4/09
- TD= 7,230 ft, into Precambrian rock
- >1,500 ft of Mt. Simon sandstone
  - 600 ft has porosity >10%, some >25%
  - Sidewall cores shows k > 500 md
- 500 ft of Eau Claire (cap rock)

Background/ Sequestration Effects

Possible concerns

- CO_2 leakage
- Brine displacement



Source: Birkholzer et al. (2009) IJGGC, 3, 181-194

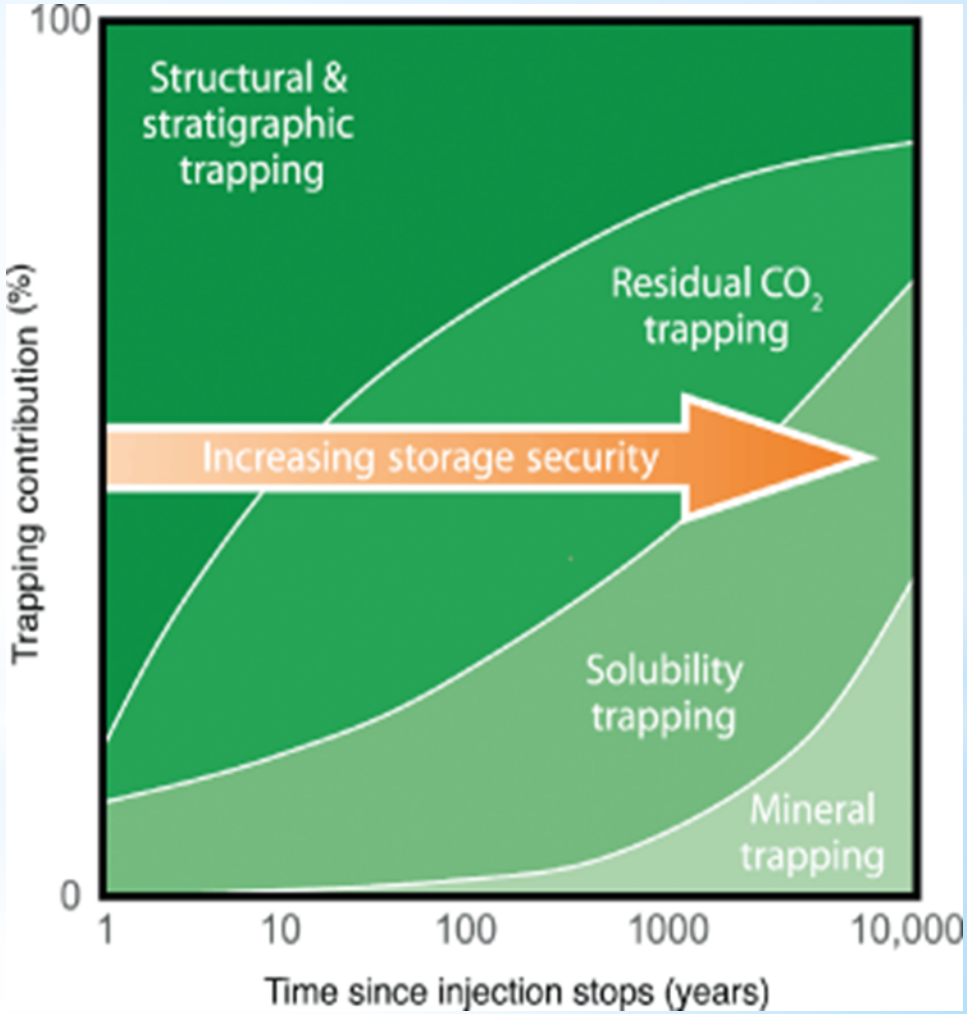
Modeling Approach

- Introduction
  - If CO_2 is sequestered on a commercial scale in the Mt. Simon *in the future*, what will happen to the native groundwater?
  - Will the CO_2 be stored permanently?
  - Will GCS affect the integrity of the injection zone or caprock?
  - Will other Mt. Simon users/stakeholders be affected?
- Purpose
  - Develop modeling tools & expertise to answer these questions for the Mt. Simon Sandstone
  - Evaluate on a basin-scale
  - Develop a series of solutions, not a single solution

Modeling Approach

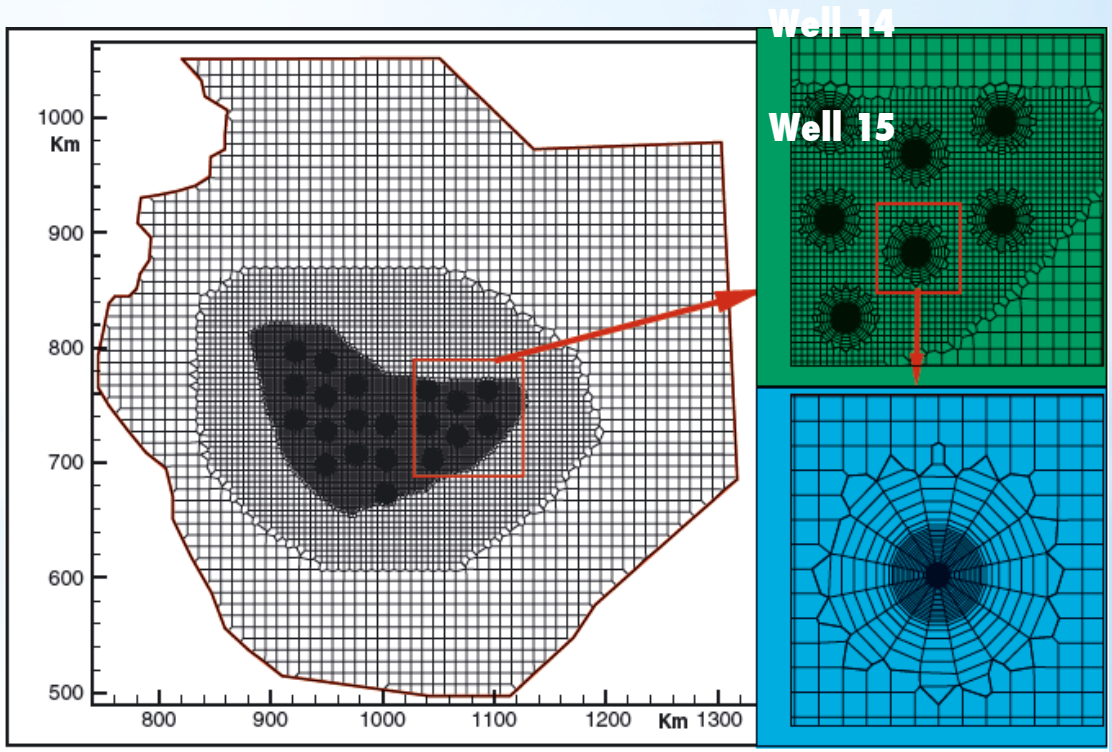
- GCS trapping mechanisms
  - Structural or stratigraphic trapping
  - Residual saturation trapping
  - Solubility trapping
  - *Mineral trapping (not modeled)*
- Using TOUGH2-MP (LBL code)

Source: IPCC (2005)



Modeling Approach

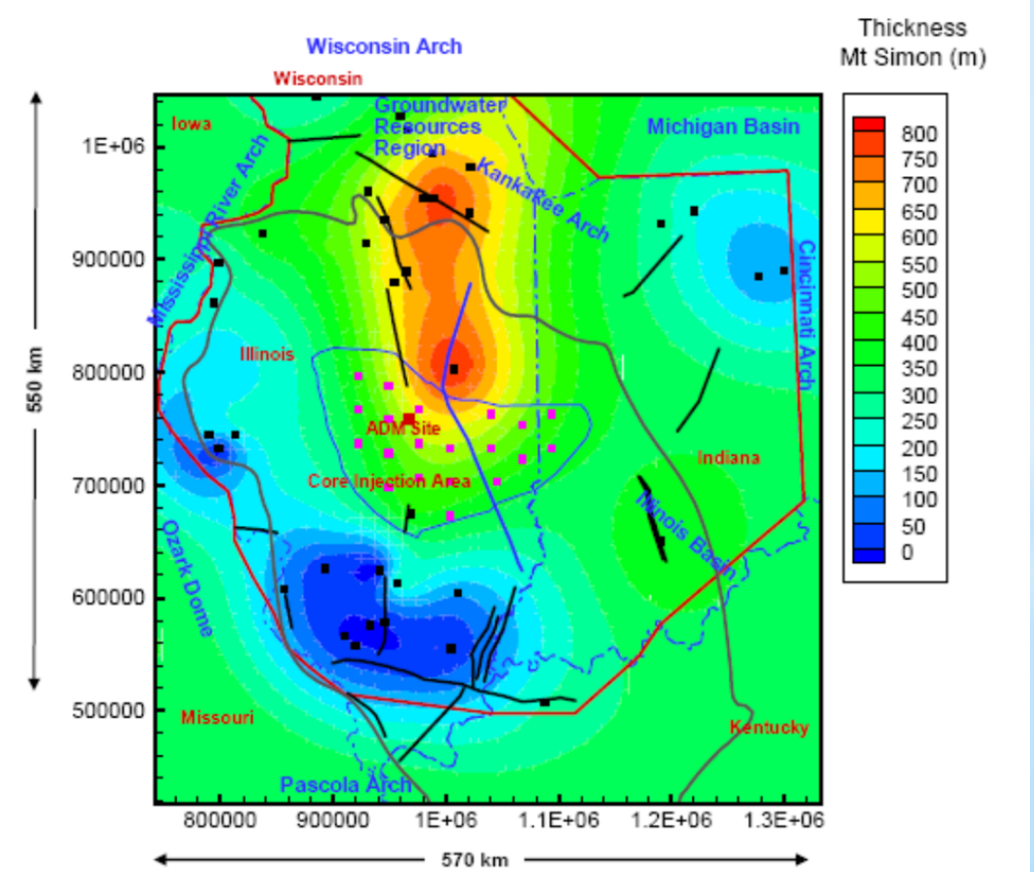
- Using TOUGH2-MP (LBL code)
- Large model with 20 injection wells
  - >1.2 million elements, which vary in size
  - Mt. Simon has 4 to 24 vertical layers
  - Eau Claire has 3 layers
  - Precambrian has 1 layer
- Boundary Conditions
  - Fixed pressure- sides & top
  - No flow on bottom



Modeling Approach

- Predict *future*, commercial scale GCS
  - 50 or 100 million tonnes/yr [annual emissions= 291 million tons]
  - Model 50 years of injection and 150+ years post-injection
  - Injection occurs at base of Mt. Simon

- Map features
  - Mt. Simon thickness (m)
  - 20 GCS wells
  - Model boundary (red line)
  - Geologic structures
  - IL, IN & KY

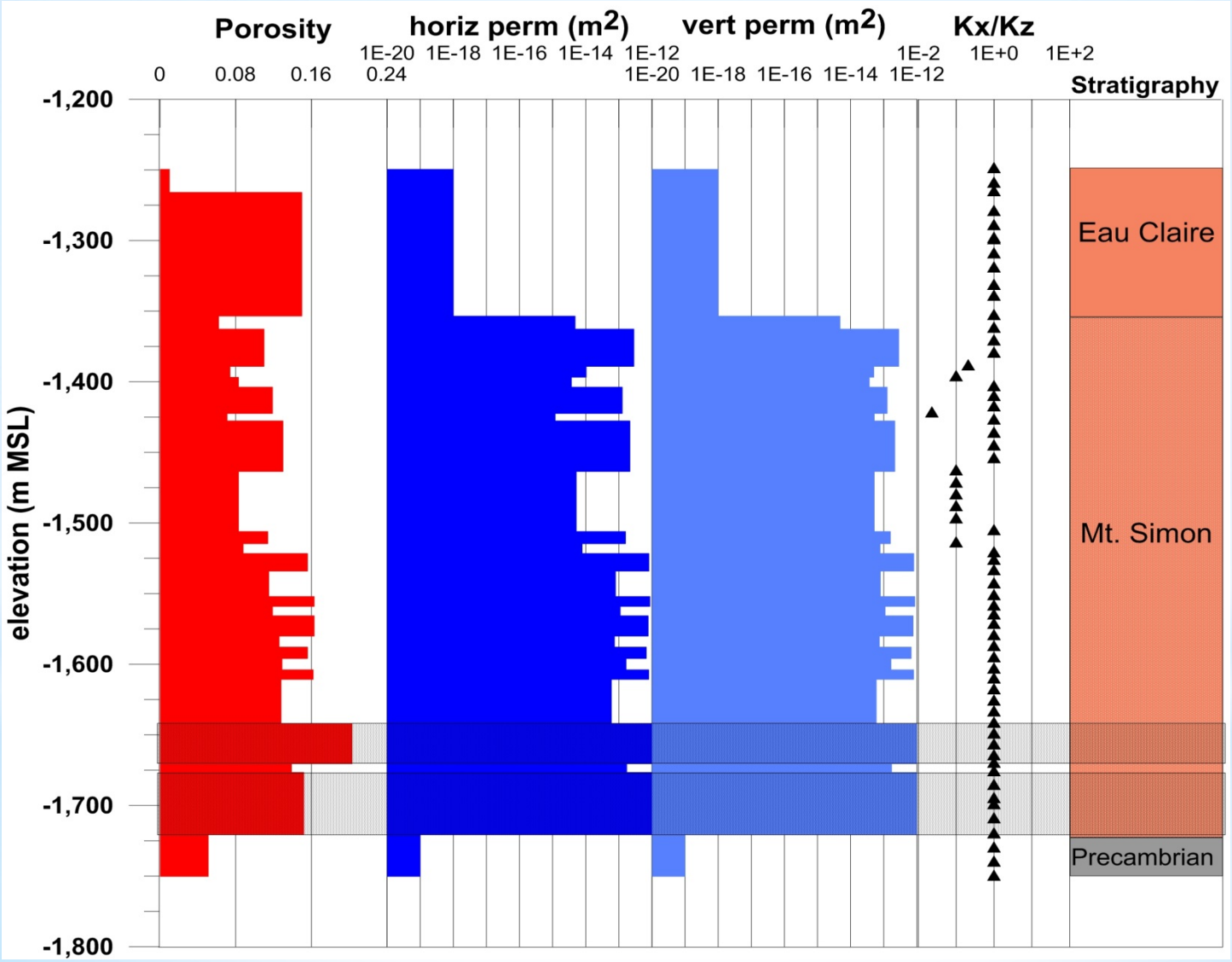


Numerical Modeling Approach

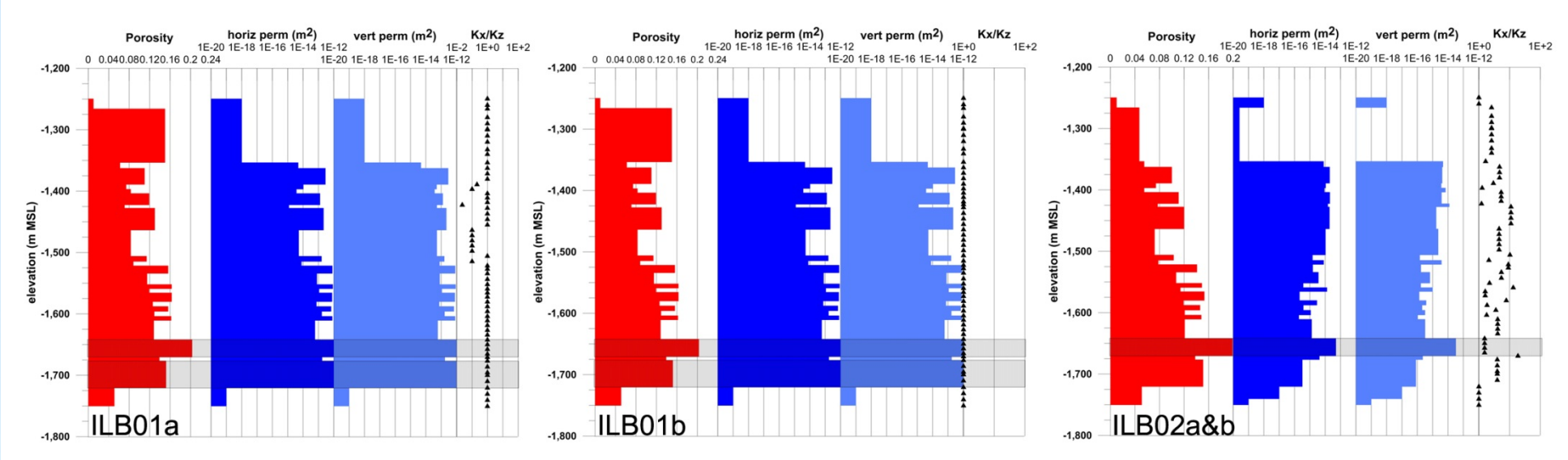
Scenario Descriptions	
ILB01a	Baseline scenario (no IBDP well data) 2 injection zones with $K_{injection\ zones}$ = $1x10^{-12}$ m^2 or 1,000 mD Inject 100 million tons per year (20 wells, 5 million tons/well) Results in Zhou et al. (2010)
ILB01b	Reduced Kv for 9 layers in Mt. Simon, now Kv = Kh Inject 100 million tons per year (20 wells, 5 million tons/well)
ILB02a	Revised K & porosity based on IBDP static & borehole data 1 injection zone (upper zone retained) $K_{injection\ zones}$ = $5x10^{-14}$ m^2 or 50 mD Inject 50 million tons per year (20 wells, 2.5 million tons/well)
ILB02b	Revise distant elements using available data & professional judgment Used T & S data from ISWS bedrock aquifer model (Meyer et al. 2009)
ILB03a *Future work*	Revised K & porosity based on IBDP dynamic data

Zhou, Q.L., J.T. Birkholzer, E. Mehnert, Y.F. Lin and K. Zhang, 2010. Modeling Basin- and Plume-Scale Processes of CO_2 Storage for Full-Scale Deployment. ***Ground Water*** **48**(4): 494-514.

Modeling Approach/ Input data for ILB01a

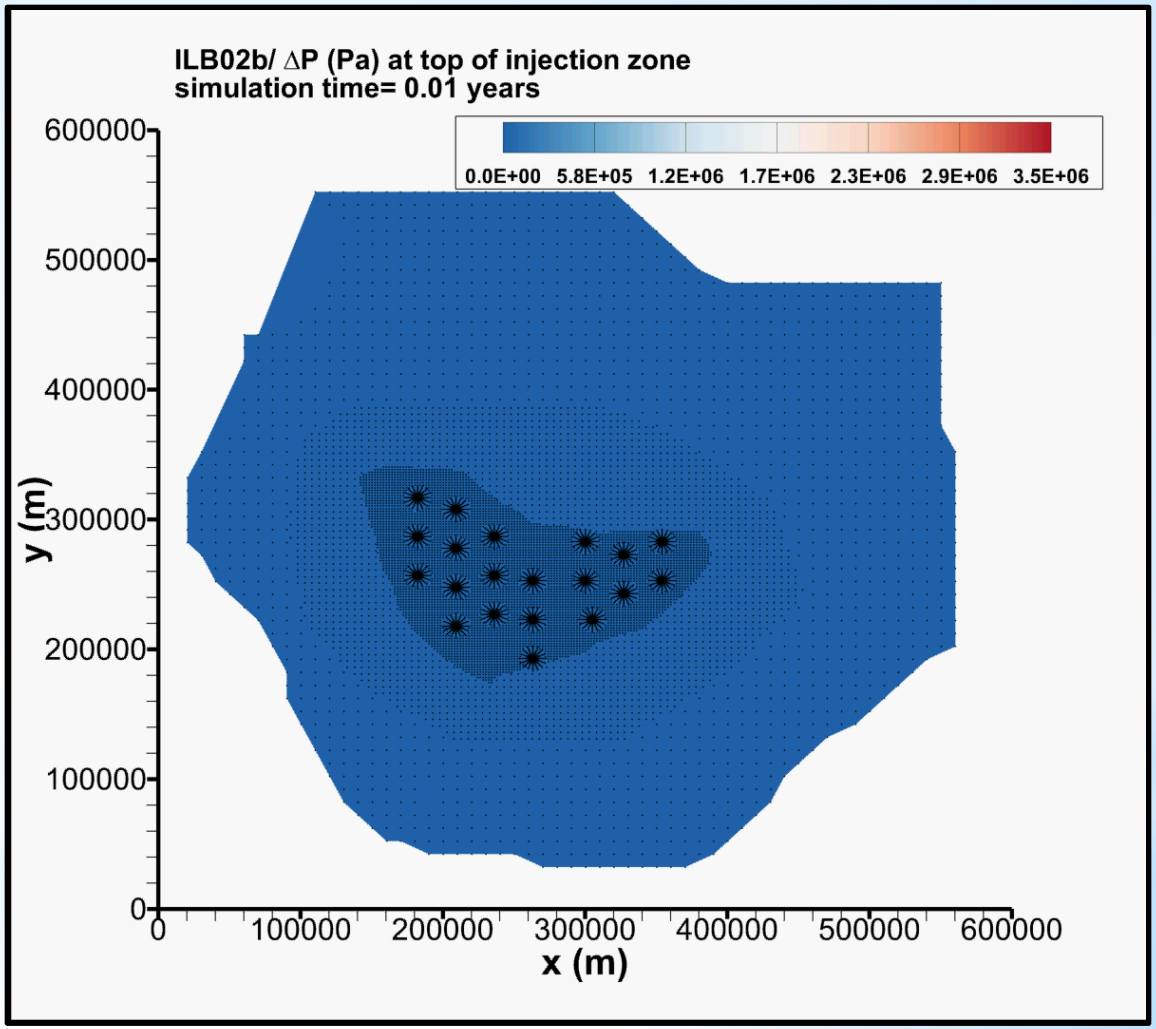


Modeling Approach/ Input data



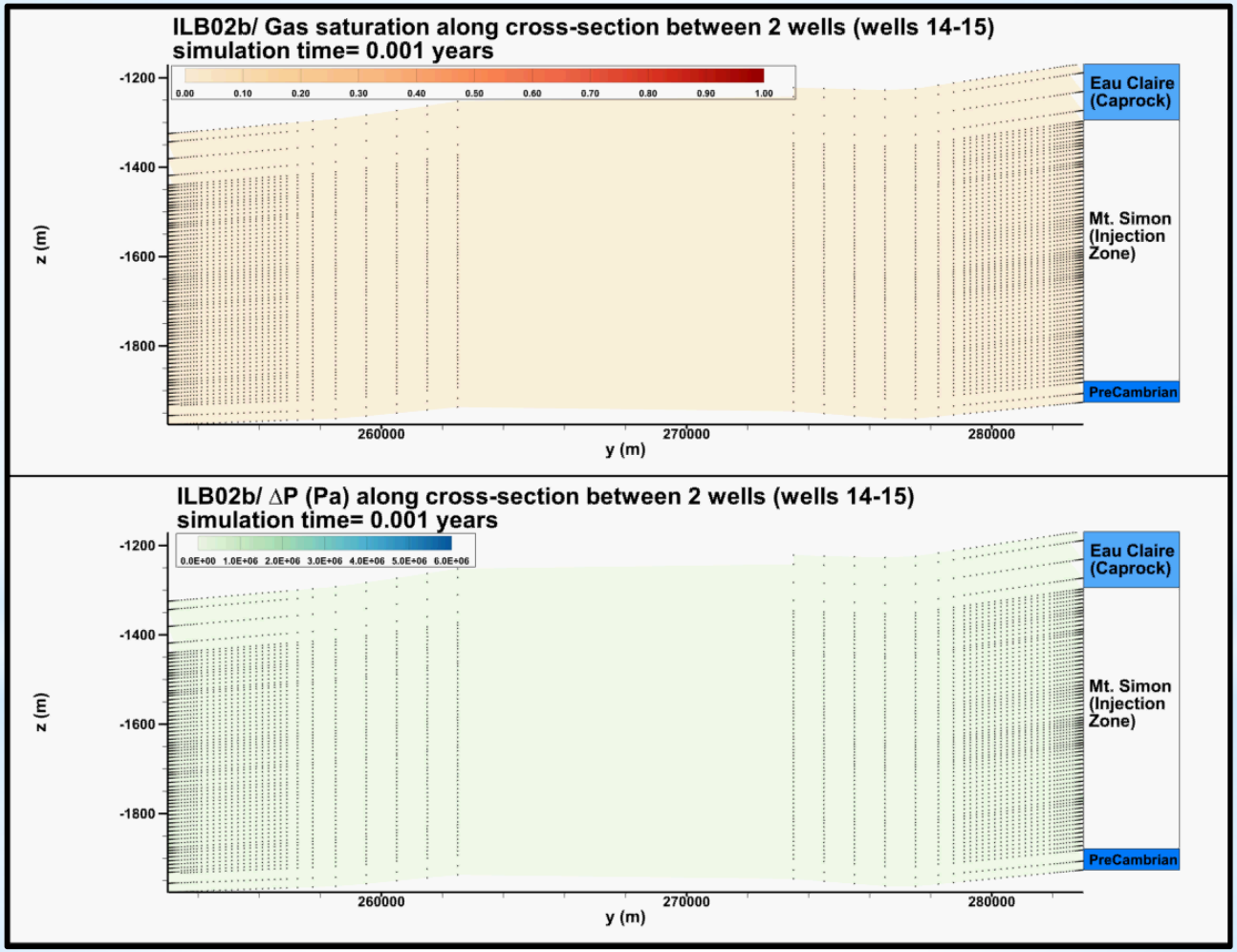
Modeling results– ILB02b

- Predicted pressure change (Pa) at the top of the injection zone (Mt. Simon)
  - Max change= 5.6 MPa (808 psi) at T= 50 years
- No free-phase CO_2 at top of injection zone



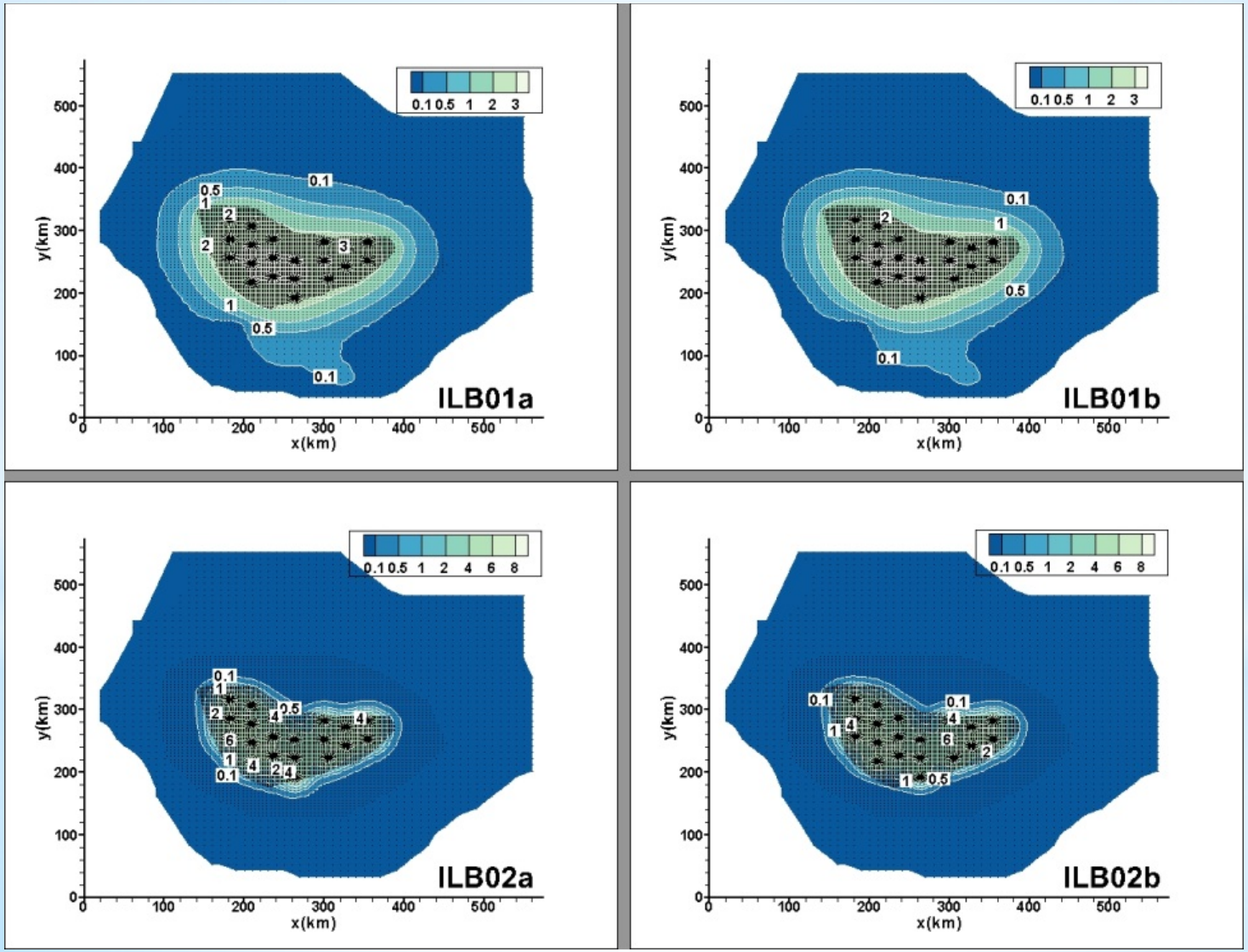
Modeling results– ILB02b

- Predicted gas saturation (top) and pressure change (bottom) between 2 wells.
- Cross-section between wells 14 & 15: caprock, injection zone (Mt. Simon) and Precambrian
- Max change= 13.3 MPa (1,929 psi) at T= 50 yrs (1 MPa= 145 psi)



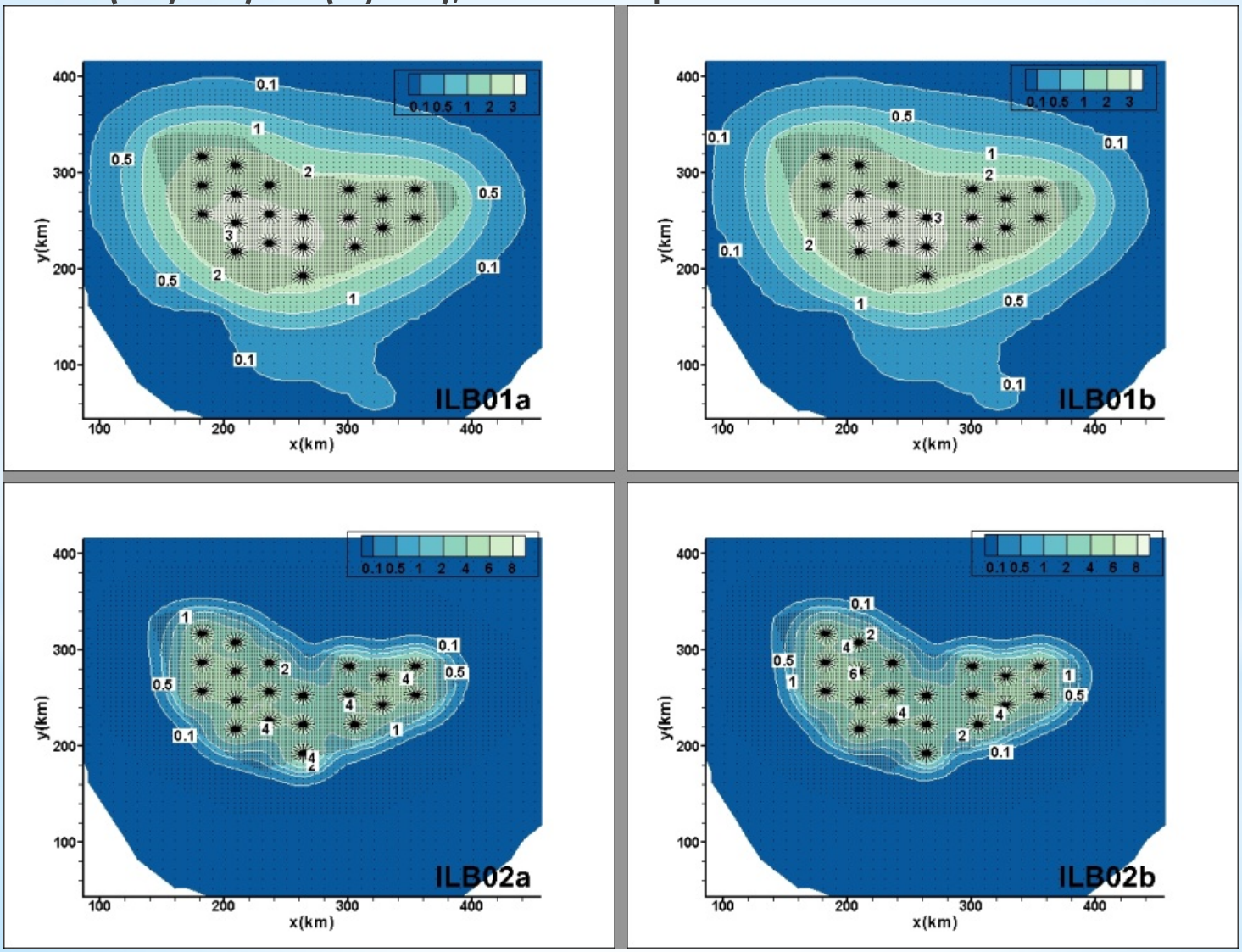
Modeling Results/ 4 Scenarios

- ΔP after 50 yrs & for top of the Mt. Simon (injection zone)
- ΔP= P (50 years) – P (0 years), 1 MPa= 145 psi



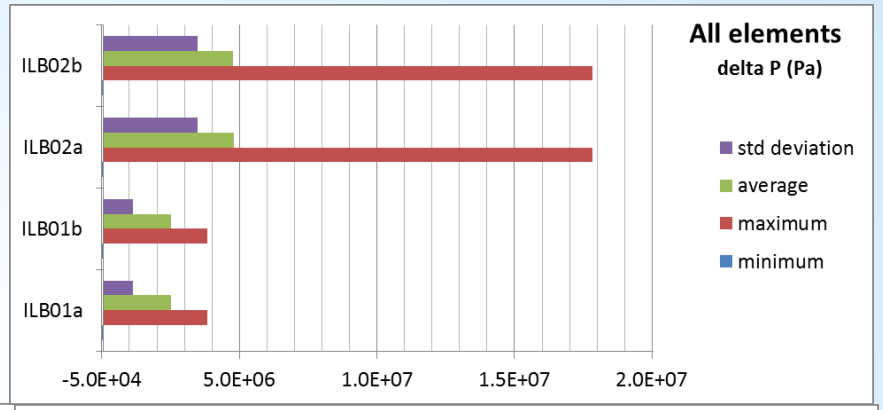
Modeling Results/ 4 Scenarios (zoomed)

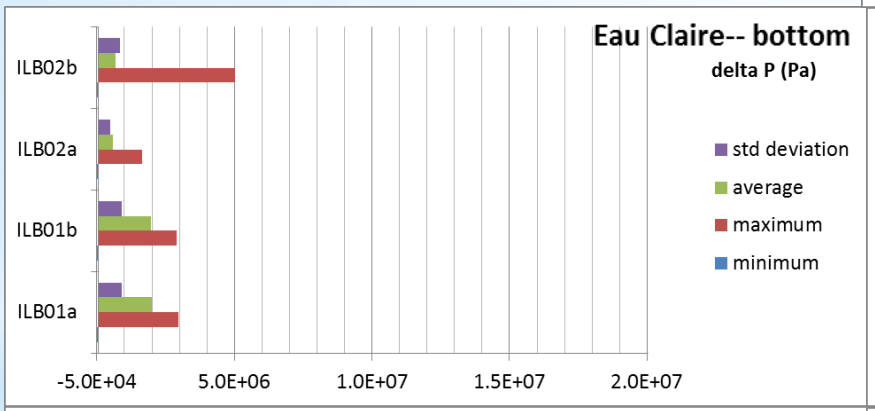
- ΔP after 50 yrs & for top of the Mt. Simon (injection zone)
- ΔP= P (50 years) – P (0 years), 1 MPa= 145 psi

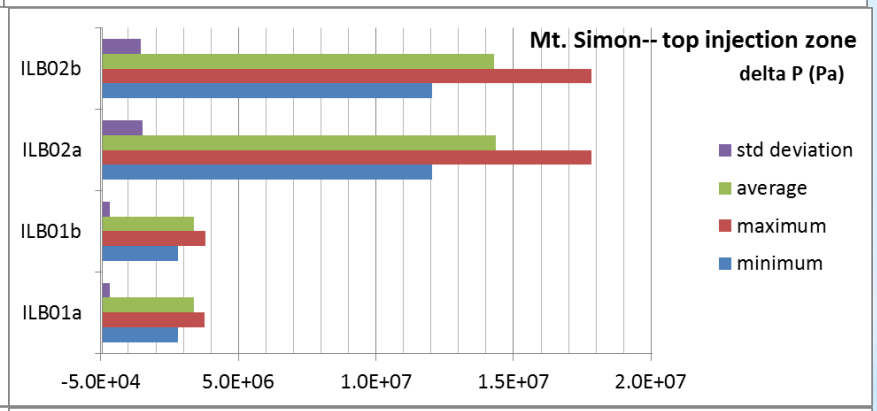


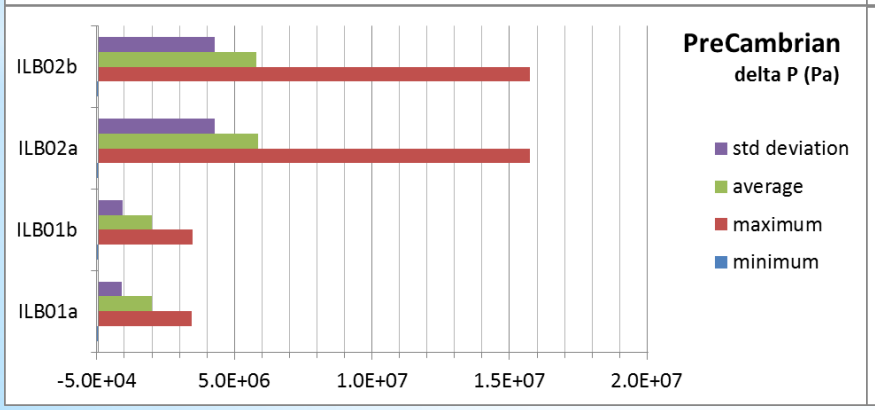
Modeling Results/ 4 scenarios

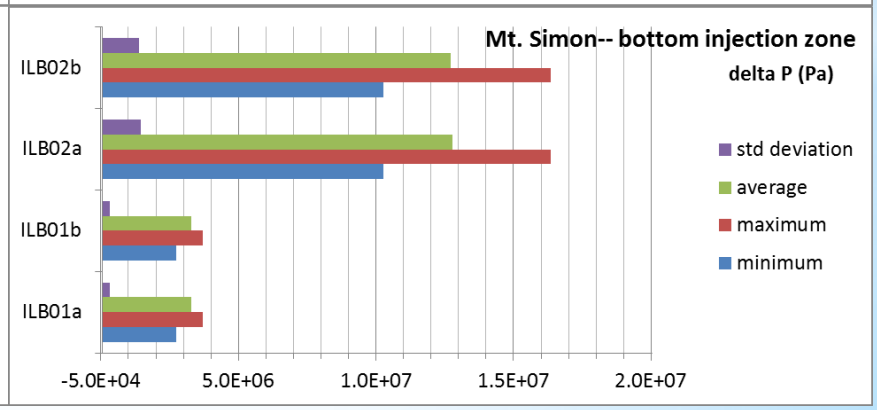
- ΔP (Pa) at different locations
  - Minimum, maximum, average & std deviation



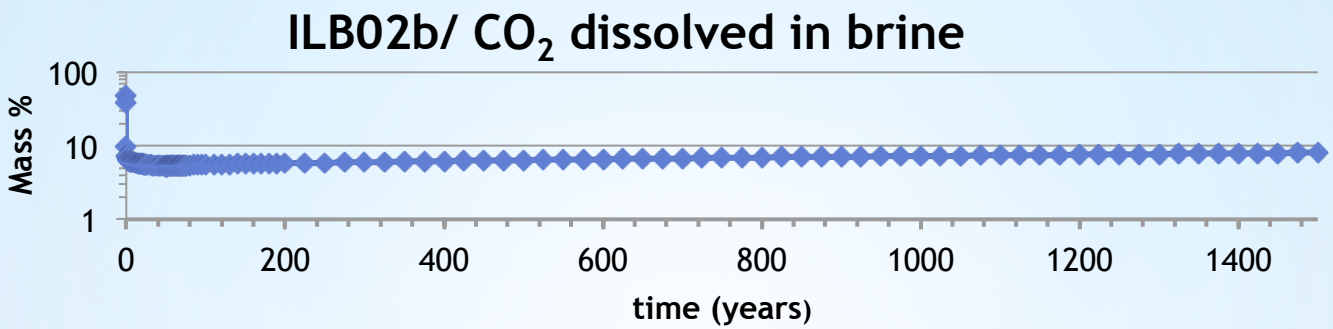








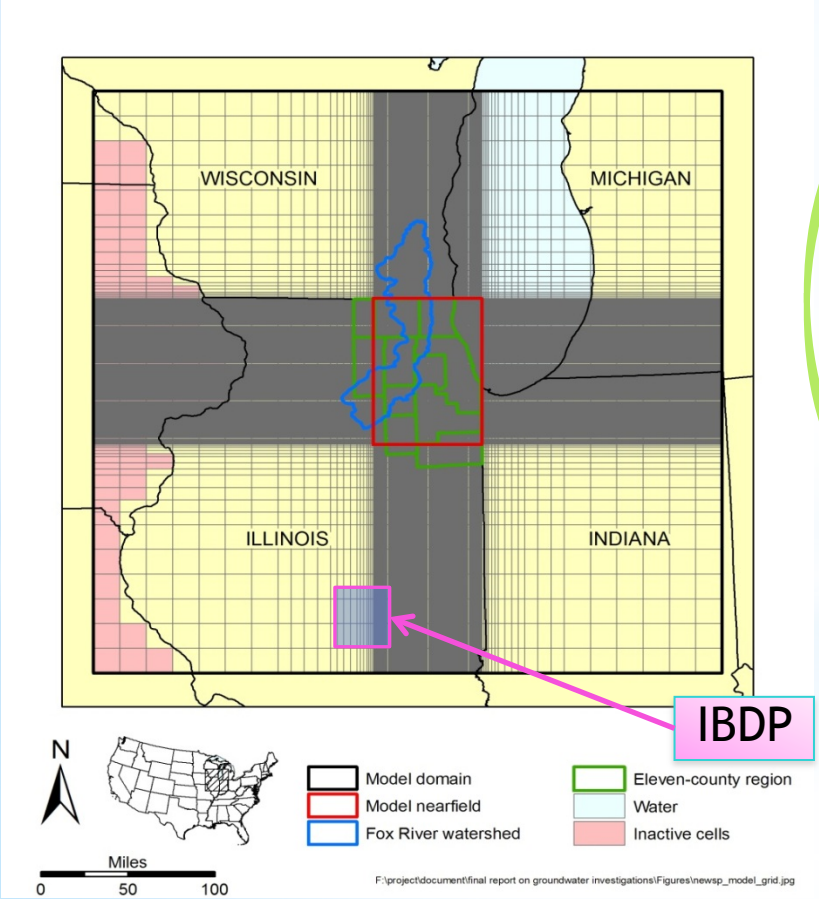
Modeling Results/ Mass balance



Scenario	% of CO_2 mass, dissolved in brine	
	Early time	End of simulation
ILB01a	5.8	10.0
ILB01b	5.7	6.8
ILB02a	7.4	5.8
ILB02b	7.2	8.1

Modeling …

- Improve link between ISWS Bedrock Aquifer model & ISGS GCS basin-scale model



TOUGH2-MP

1. Pressure (Head)
2. Temperature
3. Gas Density
4. Liquid Density

1. Head (Pressure)
2. Saline Concentration
3. Brine Density

SEAWAT (MODFLOW+MT3DMS)

Conclusions

- Modeling results show–
  - Significant effect that porosity and permeability can have on injection rate and resulting pressures.
  - Well interference for the pressure front
  - Limited transport of CO_2 from injection wells (radially & vertically)
- Will continue modeling effort
  - New data from IBDP CO_2 injection well
  - Far-field data available from natural gas storage companies and FutureGen 2.0
  - Evaluate pressure change wrt fracture gradient
  - Working to improve link between GCS and groundwater flow models