An Integrated Model for Basin-Scale and Plume-Scale Processes Related to Full-Scale Employment of CO$_2$ Storage:
The Illinois Basin as an Example*

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Abstract

If employed at the scale necessary to help mitigate climate change, geologic carbon sequestration (GCS) needs to be conducted at multiple storage sites in large sedimentary basins. Such full-scale deployment of CO$_2$ storage will cause basin-scale fluid pressurization and migration of native brines, which may affect valuable groundwater resources overlying the deep sequestration reservoirs. Assessment of GCS-induced flow and transport processes at the basin scale, with possible interference between individual storage sites, will thus become important, in addition to the transport processes of stored, contained, and potentially leaking CO$_2$ at the plume scale. In this abstract, we describe development of an integrated high-performance model of basin- and plume-scale transport processes and its application to a hypothetical GCS scenario with CO$_2$ injection and storage in the extensive Mt. Simon formation in the Illinois Basin (Figure 1). A three-dimensional unstructured mesh was generated with grid resolution adequate for detailed modeling of multiscale transport processes. Local mesh refinement was achieved around 20 hypothetical injection sites, approximately 30-km spaced in the center of the basin. A total annual CO$_2$ injection rate of 100 million metric tonnes (corresponding to one-third current stationary emissions in the region) over 50 years was employed.

Illustrative model results showing the characteristics of individual CO$_2$ plumes after 50 years of continuous injection are presented in Figure 2. The maximum size of CO$_2$ plumes, on the order of 6 to 8 km, is much smaller than the lateral separation of about 30 km between different injection sites, suggesting that merging of plumes would only occur after very long times, if at all. The close-up view in the vertical cross section highlights the variability of CO$_2$ saturation and how it relates to the internal layering and permeability differences within the Mount Simon. In addition to the local heterogeneity structure, the shape of CO$_2$ plumes is affected by the thickness of the Mount

Simon and the slope of the structural surfaces, while pressure interference from neighboring injection sites has evidently little effect on plume shape.

Unlike the limited-extent CO_2 plumes, the pressure propagation induced by injection and storage travels fast and far. Figure 3 shows the simulated pressure buildup (in bar) at the top of the Mount Simon at 10, 50 (end of injection period), 100, and 200 years after start of injection. After 10 years, a continuous region with pressure increases of 10 bar or more has evolved in the core injection area, indicating strong pressure interference between different storage sites. After 50 years of injection, the pressure buildup in the core injection area has increased to between 20 and 30 bar, with peak values near 40 bar observed near the injection centers. While this is a considerable pressurization over a large region, it does not constitute an immediate concern with respect to geomechanical damage and caprock integrity, as the pressure increase is less than the regulated maximum value. With respect to the far-field impact of CO_2 injection and storage, small pressure changes can be observed as much as 150 to 200 km beyond the core injection area, reaching the boundaries of the basin. While this pressure buildup is not likely to directly impact the freshwater resources within the Mount Simon (located much farther north outside of the model domain), the potential hydrologic impact on overlying groundwater regimes in northern Illinois requires additional evaluation.

The far-field pressure buildup predicted for this selected sequestration scenario has clear implications regarding (1) regulation of CO_2 storage projects and (2) revision of current storage capacity estimates. It is obvious that (1) the area that needs to be characterized in a permitting process may comprise a very large region within the basin if reservoir pressurization is considered, and (2) permits cannot be granted on a single-site basis alone because the near- and far-field hydrologic response are affected by interference between individual sites. Our results also support recent studies in that environmental concerns related to near-field and far-field pressure buildup may be a limiting factor on CO_2 storage capacity. In other words, estimates of storage capacity, if solely based on the effective pore volume available for safe trapping of CO_2, may have to be revised based on assessments of pressure perturbations and their potential impact on caprock integrity and groundwater resources, respectively.
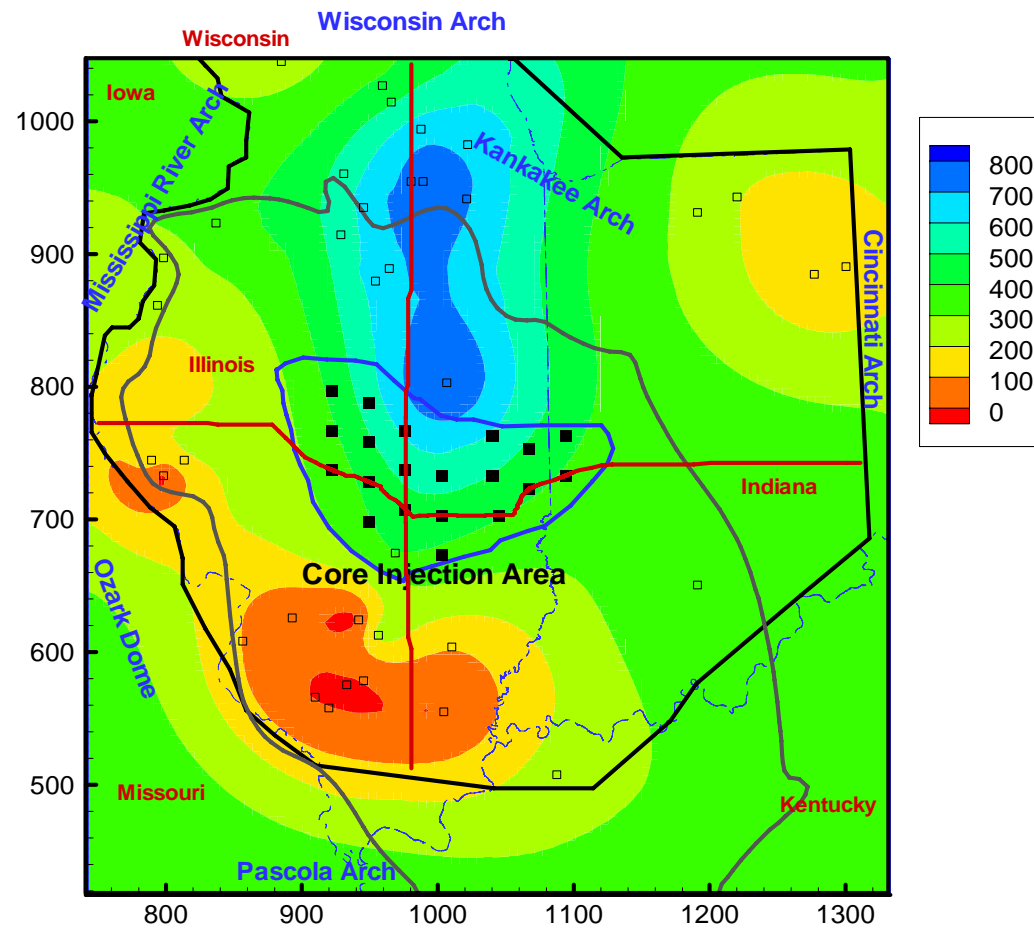
Figure 1. Illinois Basin model domain (black line) and thickness of the Mount Simon (contours given in m). Also shown are the core-injection area (blue line) and 20 hypothetical injection sites (solid square). Illinois easting and northing coordinates given in km.
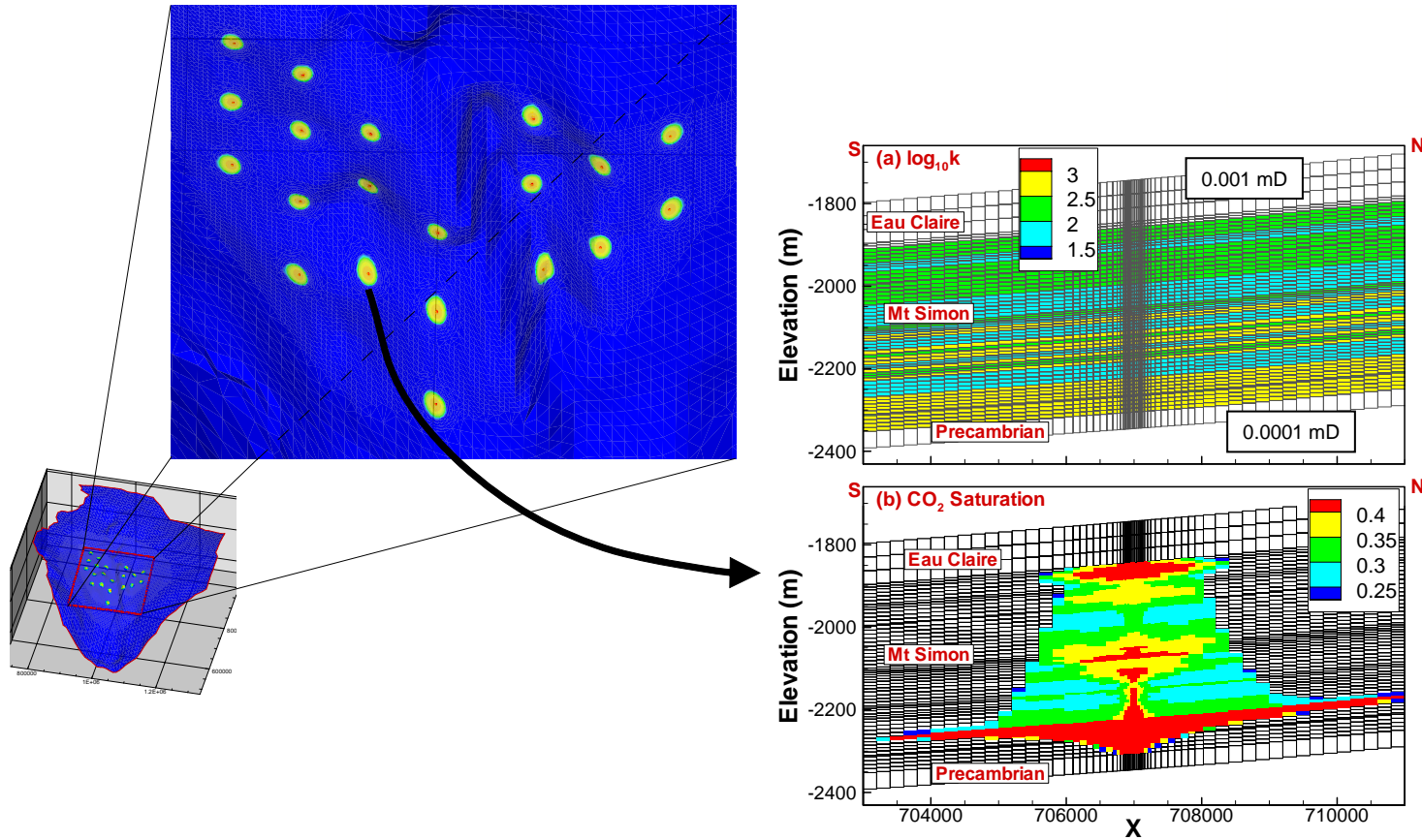
Figure 2.   Graph on left shows contours of CO_2 saturation at 50 years of injection. Graphs on right show (a) vertical permeability field (in millidarcy), and (b) CO_2 saturation in a south-north cross section for a selected injection site.
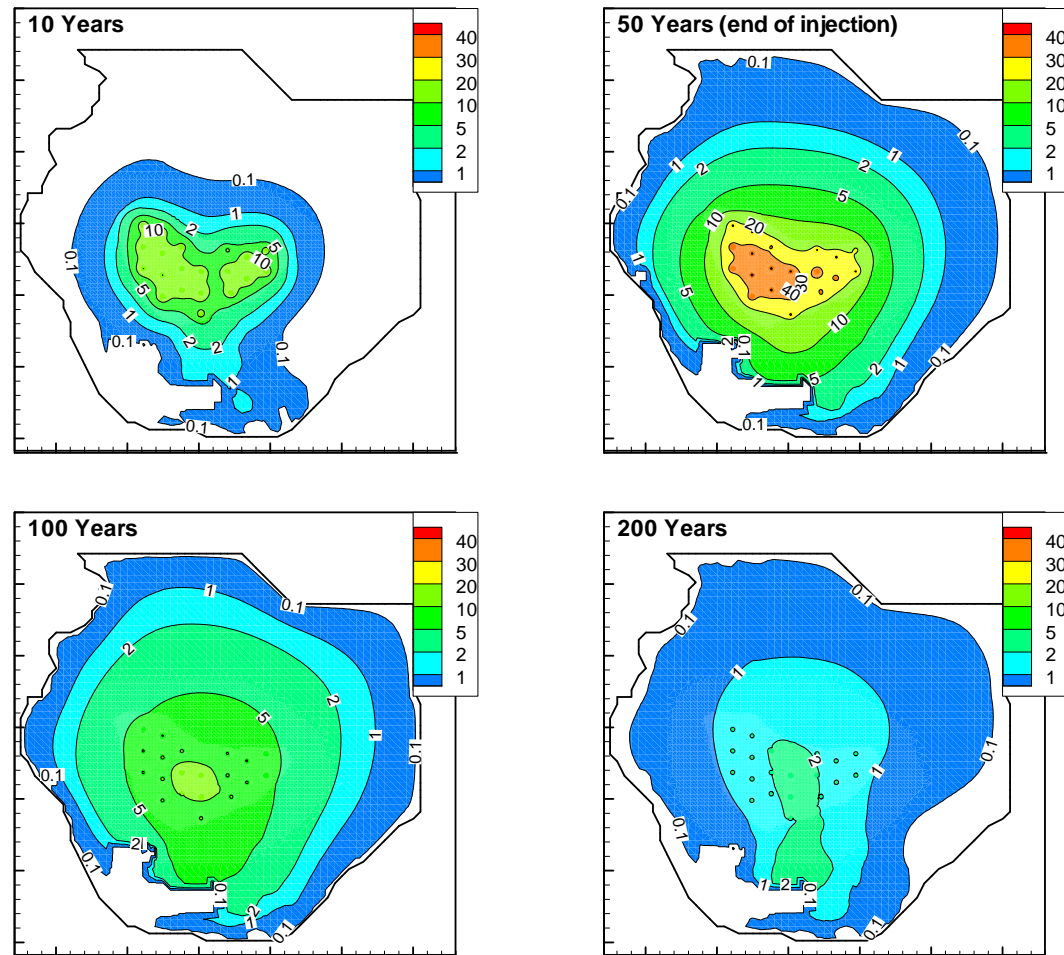
Figure 3.   Contours of pressure increase (in bars) at the top of the Mount Simon Sandstone at 10 and 50 years during the injection period, and 100 and 200 years during the post-injection period. Pressure buildup below 0.1 bar is not colored.