Geophysical Monitoring of Geologic Sequestration

Investigator: Jerry M. Harris, Professor, Department of Geophysics

Sponsor: Global Climate and Energy Project

Objective: The objective of this project is to develop strategies for monitoring injected CO_2 in the subsurface. Geophysics offers a variety of methods that operate over a wide range of geological environments, scales, and reservoir depths. The focus of our approach is cost-effective time-lapse imaging that can provide quasi-continuous monitoring and adapt to changing reservoir conditions. An important principle to be followed is that the monitoring effort must decrease with time, barring a reservoir problem, and eventually stop when safe containment is no longer an issue.

Background: Subsurface monitoring will be required to provide: (1) early warning of reservoir leaks to address public safety issues; (2) images of the space-time distribution of injected CO_2 to aid optimization of the storage process; and (3) technical input to the safety case during the permit/licensing process. The imaging challenge is to follow the injection front (*i.e.*, to know where the CO_2 is going) while simultaneously monitoring the steadily growing reservoir volume for leaks. Though not yet specified, a thorough description and numerical simulation of subsurface flow and monitoring capability will be an important and most likely required part of the safety case when a site is presented for licensing. During the initial phase of the project, we developed first-order models that describe the changes in the bulk rock-fluid properties with injected CO_2. We then incorporated those models into a variety of geophysical monitoring methods, *e.g.*, seismic, electrical, magnetic, electromagnetic, gravity, and surface deformation [Wynn, D., 2003]. The major conclusion of this initial study was that seismic methods provide the most effective means, technically speaking, for subsurface monitoring for most geological storage scenarios. However, seismic imaging, as we do it for resource management, is too expensive for continuous or repeated long-term use.

Approach: Our monitoring strategy trades spatial resolution for temporal resolution. The conventional approach (Figure 1) is to produce a sequence of high-resolution snapshots, perhaps years apart as reservoir development progresses. Reservoir changes are detected by differencing the snapshots, but for many reasons the differences often have much lower resolution than the individual snapshots. Our new approach (also Figure 1) is designed for CO_2 waste monitoring, where high spatial resolution may not be as important. We produce a sequence of difference images $\triangle mi$, each taken perhaps months or even weeks apart. We record a sequence of time-lapse data sets, each with reduced spatial and temporal resolution and/or coverage. The data sequence is processed to explicitly include a time-varying reservoir model [Day-Lewis, 2003]. Moreover, we incorporate new survey geometries, acquisition schemes, and processing methods that together reduce costs and provide quasi-real-time monitoring capability. An example is the Stanford Cross Linear array (Figure 2) where sources and detectors are distributed along three linear arrays, two along the surface and one along the injection borehole. The 3-axis arrays provide reduced 3-D resolution, but at greatly reduced acquisition and processing costs relative to the usual 2-D surface array. Both sources and receivers are

Issued March 2004

permanently embedded to maximize survey repeatability and reduce deployment costs. Additional surface lines may be added or different sections of the Cross may be activated at different times to track the CO_2 front or to target specific reservoir zones or problems areas. Our new approach includes signal coding to permit the use of low-power sources for continuous operation; these attributes in particular enable quasi-real-time monitoring.

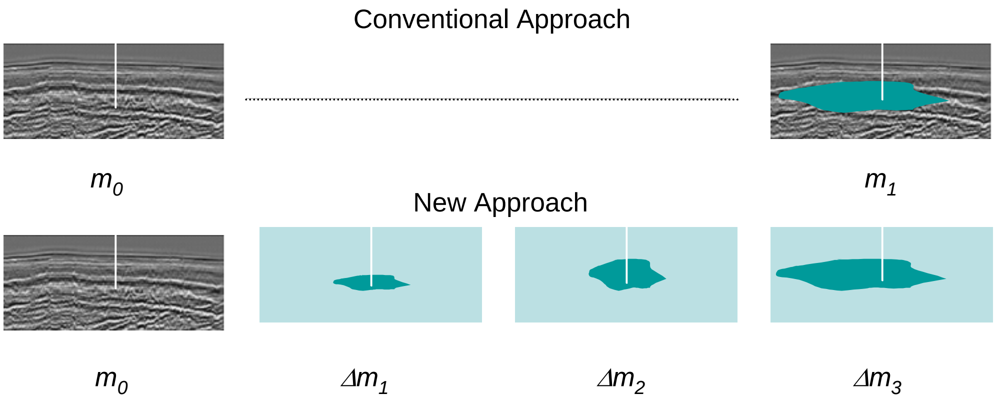

Figure 1. The conventional time-lapse imaging approach is to produce a sequence of snapshots, m_i, each taken perhaps years apart. Our new approach is to produce a sequence, albeit with lower resolution, of difference images, Δm_i, taken perhaps months or even weeks apart. The baseline image m_0 comes from the site selection and characterization study

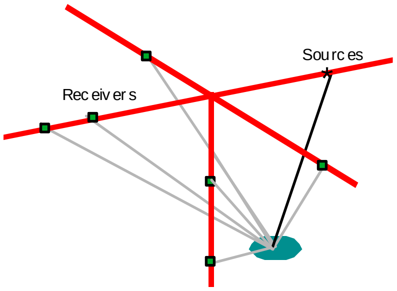

Figure 2. The Stanford Cross Linear array incorporates 3-axis source/detector linear arrays placed along the surface and embedded along the injection borehole.

Activities: The research is conveniently divided into three phases, each having several tasks:

1. Quantitative assessment of the geophysical options
    a. Rock properties study
    b. Sensitivity analysis
    c. Laboratory measurements, *e.g.*, coal
2. Numerical models to simulate selected monitoring strategies
    a. Multi-scale seismic modeling
    b. Space-time sampling criteria and tradeoffs
    c. Monitoring tests on synthetic datasets
3. Tests with field data
    a. In-house time-lapse datasets from petroleum reservoirs
    b. Available datasets from sequestration projects

Moreover, this monitoring project is leveraged by other research activities on CBM monitoring, multi-scale numerical simulation, and seismic attenuation.

References:

Wynn, D.,2003. Survey of geophysical monitoring methods for monitoring CO_2 sequestration in aquifers, M.S. Thesis, Department of Geophysics, Stanford University. [in edit/review for GCEP report].

Day-Lewis, F, J.M. Harris,and S. Gorelick, Time-lapse inversion of crosswell radar data, Geophysics, Vol. 67, no. 6, November-December; p. 1740-1752, 2003.

Contact: Jerry.Harris@stanford.edu