What have we learned about CO_2 leakage from field injection tests?

Jennifer J Roberts[1], Linda Stalker[2]

[1] University of Strathclyde (Glasgow, Scotland)

[2]National Geosequestration Laboratory (Perth, Australia)

Abstract

Over the past decade, a number of field scale experiments have been conducted around the world to address many of the uncertainties regarding CO_2 leakage. In these experiments, free phase or dissolved CO_2 is injected and released into the shallow subsurface to artificially simulate a CO_2 leak into the near surface environment. The experiments differ in regard to the geological and surface environments and experimental set-up - including the injection and monitoring strategy. Though the specific aims vary between sites, their broad aims classify into the following categories:

1. To investigate ecosystem responses to the injected CO_2
2. To establish the fluxes, transformations and fate of CO_2 as it migrates from the injection point
3. To investigate geochemical interactions between CO_2 and groundwater
4. To test and calibrate models
5. To test a broad or specific suite of monitoring techniques.

We have collated a global dataset of CO_2 release experiments to establish:
(a) Similarities and differences between the experiments (such as the environment, subsurface conditions, injection strategy and whether gaseous or dissolved CO_2 were injected and in what quantities).
(b) Harmonized CO_2 injection and surface release rates at these experiments, and how these rates compare to potential leak rates from commercial CO_2 stores (see Roberts and Stalker (2016) submitted abstract).
(c) What has been learnt, cumulatively, about the following issues:

1. *The fate of the injected CO_2*, and how well this can be determined with current techniques.
2. *The rates of CO_2 flux to surface* ($gCO_2\ m^2\ s^{-1}$), how much of the injected CO_2 is released to land or seabed surface, and current ability to estimate these parameters. How long does it take for injected CO_2 to reach surface? How does the rate evolve or vary over time? Are these dependent on injection strategy, or environmental parameters?
3. *The surface characteristics of CO_2 leakage*. Are the surface leaks displaced from the CO_2 injection point? Is CO_2 released at the land surface or seabed patchy or uniform? How do characteristics differ according to the experimental environment (e.g. water table depth)? How do characteristics vary through time - are patches static or mobile? How do they respond to weather/climate variation? How do these observations compare to natural analogues for CO_2 leakage.

4. *CO_2 spread in the subsurface*. How does subsurface CO_2 spread compare with surface CO_2 release? Is CO_2 usually detected in the subsurface before the surface? Are CO_2 concentrations in the subsurface patchy or uniform, and how do they evolve with time? How do characteristics differ according to the experimental environment?
5. *Use of chemical tracers.* Which sites have used chemical tracers and for what purpose? What information was provided and what practical issues were encountered?
6. *Recovery time for CO_2 and its impacts*. How long does it take to return to baseline conditions? Are recovery times different for soil flux, soil gas, water, and ecosystem responses?
7. *Experimental design.* What worked well and what hasn't worked so well? What can we learn for future experiments?

(d) Remaining knowledge gaps that future experiments should seek to address.

Since we were interested in experiments releasing CO_2 into the near-surface, we only considered experiments injecting CO_2 at depths shallower than 25 m depth. Our detailed dataset includes 14 different field experiment locations around the world (we refer to each by their project acronym or their location). These are shown in Figure 1.

As can be seen in Figure 1, the majority (12) of these experiments are located in Europe (ASGARD, CO2-Vadose/Demo, CO2Field Lab, QICS, PISCO2, Grimsrud Farm, Vrogum, CIPRES, SIMEx, Brandenburg), with the remaining four located in the USA (ZERT and Brackenridge), Australia (Ginninderra) and South America (Ressacada Farm). At the majority of these sites, gaseous CO_2 was injected rather than dissolved CO_2. Importantly, of all these field experiments to date, there has been only one subseabed release (QICS). At a number of these CO_2 release facilities, several release experiments have been performed, often with different injection strategies. Injection rates range from 2.7 to 1,500 kg(CO_2)/day, the period of injection ranged from a couple of hours to 99 days, and a steady injection rate is favoured by most experiments though four injected CO_2 at incrementally increasing rates and three injected CO_2 at variable rates (though in some cases this was unintended).

Nine of the CO_2 release facilities intended that the injected CO_2 be released to surface. Only one experiment, CO_2-Vadose project, did not achieving this goal, and the experiment has since been successfully redesigned as the CO_2-Demo project. In all the cases where CO_2 was intended to be released to surface, it was rapidly detected; often within 24 hours of injection. The surface leakage typically expressed as (several) patches of 2.5 – 5.5 m radius. These patches are often static once leakage has become established, though soil saturation (related to rainfall) has been observed to affect the location and width of these patches. The extent of subsurface CO_2 is often observed to be much greater than the area of surface degassing, and subsurface gas concentrations are heterogeneous, influenced by subsurface permeability and structure. Although gas flux surveys were conducted at these sites, quantifying the proportion of injected CO_2 that leaked to surface has proven challenging. Six sites estimated total CO_2 leakage to surface, often by integrating surface flux measurements and modeling, and these estimates range from 5% (reported to be a likely underestimate), to 82%.

This is a small insight into the wealth of information these field experiments have generated to date, and the value in bringing together the approaches, observations, and challenges in this dataset, in terms of lessons learned, remaining challenges knowledge gaps, and also the design of future experiments.
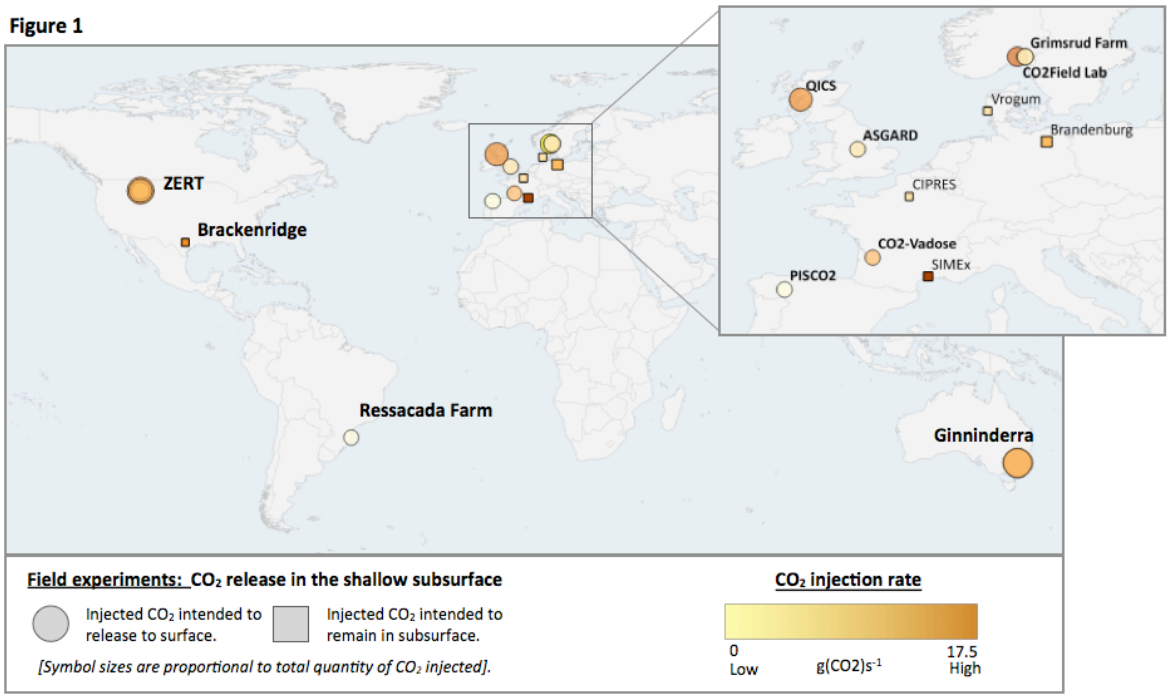
Figure 1: Map of CO_2 release experiments around the world. Symbols are coloured according to the CO_2 injection rates at the site, and sized proportional to the total amount of CO_2 injected.