Innovative tools for rapidly mapping / quantifying CO_2 leakage and determining its origin

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Abstract

Although deployment of onshore CO_2 storage will be crucial to reach the EU's ambitious goal of an 80% reduction in greenhouse gas emissions by 2050, some stakeholders are concerned about potential risks if CCS is situated on land near populated areas. The EU-funded, Horizon 2020 project ENOS (ENabling Onshore CO_2 Storage in Europe, grant agreement 653718) is addressing many of these concerns about onshore storage by demonstrating best practices through pilot-scale projects and field laboratories, integrating CO_2 storage in local economic activities, and creating a favourable environment through public engagement, knowledge sharing and capacity building/training.

As part of this work programme, ENOS is using sites where natural, geologically produced CO_2 is leaking to the surface, to test innovative monitoring tools and to better understand gas migration pathways and early warning signs that could be detected in the unexpected and unlikely event that CO_2 leakage were to occur. The advantages of such sites include: a wide range of leakage rates; different geological and surface settings (lithology, structure, topography, leakage style, vegetation, etc.); large-scale processes; and constant accessibility. At least four of these natural leakage sites in central Italy will be used, including the well-known Latera caldera (volcanics), San Vittorino valley (carbonate bedrock, sinkholes), Ailano (carbonate bedrock, very large leakage volumes, co-migration of CH4), and Fiumicino (Tiber river fluvial deposits). All sites exhibit the leakage of almost pure CO_2 along bedrock faults and through cover sediments prior to release to the atmosphere.

Results from recent ENOS field campaigns at these sites will be presented, focusing on data and interpretation related to i) large area, rapid leakage mapping and quantification tools; ii) innovative methods to determine the source of a CO_2 anomaly; and iii) studies of fault- and sediment-controlled leakage expression on surface. Additional funding for part of this work, from the Access to Research Infrastructures activity in the EU Horizon 2020 Programme (ECCSEL Grant Agreement 675206), is kindly acknowledged.

Although soil gas and flux measurements are the most accurate way to determine surface leakage, the fact that they require individual point measurements means that their mapping resolution is limited by the number of samples that can be measured in a given time for a given budget. Other methods have been developed to overcome these limitations, such as eddy covariance or remote sensing, however they too can be limited by, for example, insufficient sensitivity, potential for false positives, high data processing requirements, and high costs. To address this we have looked for a compromise between speed, resolution, and sensitivity by developing mobile tools that measure CO_2 concentrations at or near the ground surface. Field testing of this mobile platform was conducted at the Latera and Ailano sites, with the system consisting of two open path lasers (CO_2 and CH4) measuring at a height of about 20 cm, a low-cost GasPro Mapper unit measuring CO_2 at the soil-atmosphere boundary layer, and a sonic anemometer measuring wind properties. Work first involved detailed CO_2 flux surveys to define the actual leakage conditions followed by walking the mobile platform over leakage areas of different strengths, along profiles and grids, to assess instrument response time and sensitivity. The laser system was found to have a very rapid response time, little memory effect, and a stable background (making it highly sensitive), however it was more strongly influenced by wind conditions and the system is relatively expensive and bulky. The Mapper is much less costly and the measurement of gas directly within the boundary layer (which is not influenced by wind) means that measured anomalies (and sensitivities) are higher, however slower response times and memory effects causing tailing leave room for improvement. The results show how such mobile methods could accurately locate a leak (in the unlikely event this were to occur) in a fraction of the time that is usually required using normal point flux measurements, thus making CCS sites safer.

Anomalous CO_2 concentration or flux values in the near surface environment can potentially be caused by biological or chemical processes in the soil itself, by leakage of natural, deep-origin geogenic CO_2, or potentially by the leakage of anthropogenic CO_2 stored deep in the subsurface. Clearly it is critical that the true origin of an anomaly is defined, both for safety and carbon credit auditing purposes. In this regard CO_2 isotopologue analyses were conducted on leaking gas samples from Latera, San Vittorino and Ailano to see if this innovative method can be used to determine the depth of origin (i.e., source) of the gas. This is because the formation temperature of CO_2 determines the abundance of rare CO_2 isotopologues (abundance of ^{13}C and ^{18}O bonds in CO_2), with temperature being controlled by the local geothermal gradient. Preliminary results are promising, although the higher costs and longer analytical times means that this method would be used on a limited number of ambiguous anomalous samples.

The style of leakage on the ground surface will have great influence on both the potential for impact and risk, as well as the size and strength of a leakage target to be found with a given monitoring technology. This is because if leakage is more diffuse the target will be larger but the anomalous values (and impact) will be smaller, whereas the contrary would be true for more discrete spot leakage of the same total amount of gas, as flux rates and concentrations would be higher but the target much smaller. Work within ENOS at Latera and Ailano has used detailed soil gas and soil sampling, isotopic analyses, and shallow geophysics to infer processes controlling movement in the soil that controls the eventual footprint of leakage on the surface. Results highlight the complexity of CO_2 isotopes in the soil due to the combined effects of leakage, CO_2 production in the root zone, and diffusive fractionation. Whereas migration in the bedrock fault is primarily vertical along the structural discontinuity, the local topography, hydrogeology, and shallow stratigraphy of the sediments that bury a fault can potentially cause lateral movement away from the main leakage pathway.