Evaluation of surface movement observability and optimization of the monitoring plan through conceptual and coupled flow-geomechanics models

Examples of carbonate and sandstone reservoirs in CCS context

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Abstract

Developing techniques of geological CO\textsubscript{2} storage sites monitoring is crucial for both, the long-term safety of the sites themselves and the widespread deployment of CO\textsubscript{2} sequestration to be accepted as a reliable method of reducing CO\textsubscript{2} emissions worldwide. The SENSE project aims to develop reliable, continuous and cost-effective monitoring based on ground motion detection combined with modelling and geomechanical inversion, using new technological developments, data processing optimization and interpretation algorithms. It is funded through the ACT program (Accelerating CCS Technologies, Horizon2020 Project No 294766). As partner of this project, we present a methodology based on coupled flow-geomechanical simulations which, from the uncertainties on the subsurface properties and on the measurements, can reproduce measurements from different surface monitoring tools. By carrying out an uncertainty study on simulations results and taking into account the advantages and disadvantages of each of these tools, a monitoring strategy can be designed such that the tools will record potential displacements at the most sensitive periods and locations, taking into account their respective accuracies. Based on this methodology, a workflow is developed and applied in this work to several conceptual models in order to identify which conditions induce different surface displacements and thus may require specific surface monitoring strategy. These conceptual models are built using several structural models and considering different sedimentary deposits contexts to cover different aspects of surface displacements that can be encountered at storage sites. A 10-years CO\textsubscript{2} injection (at a maximum 1 Mt/year constrained by a maximum overpressure of 50 bar) is defined for three on-shore scenarios considering or not faults and heterogeneities: “Carbonate” case, inspired from Brindisi and Michigan Basin storage sites, “Sandstone I” case, inspired from In Salah and Gorgon projects and “Sandstone II” case, inspired from Snøhvit, Decatur and Otway storage sites. For each of them, 115 coupled hydro-mechanical simulations are launched with a one-way coupling scheme. Simulated surface displacement results are significantly different between scenarios with an expected uplift which can reach the centimeter-scale for Sandstone I, while for Sandstone II most of the expected uplifts would be far below the centimeter at the end of injection. For studied faulted synthetic cases, only a variation of the area of a maximum surface displacement (not center on the well) seems to be observable considering sealing faults while matrix heterogeneities and the open faults have not a strong impact on the displacements. From a surface monitoring point of view, these results also show the importance to study the near well surface displacements first. Indeed, a shift between the location of the center of the maximal surface displacement area and the top of the well might indicate the presence of a strong heterogeneity. Similarly, an evolution of

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this shift would indicate an evolution of the heterogeneity properties (typically a fault aperture increase) and a possible CO\textsubscript{2} migration through it. All these simulations are also analyzed considering both INSAR technology and tiltmeters to study their usefulness by estimating both the area and time period of validity for the three scenarios. Thus, we conclude that a monitoring area of 3 km radius from the well would be adapted for the Carbonate and Sandstone I scenarios at the early stage of the injection based on a detection limit of 1 mm/year for INSAR measurements while for Sandstone II the monitoring area radius could reach 4.5 km during all the injection period. Then, a methodology based on statistical analysis is applied for estimating the most sensitive locations for tiltmeters that allow to better constraint the \textit{a posteriori} distribution of uncertain subsurface properties close to the real ones. The comparison results show it is most effective than using random locations. Finally, we propose to analyse a storage integrity with failure criteria to define the locations where a risk of damage is identified. In this stage, four different initial stress regimes are assumed: extensive regime, two strike slip regimes and a compressive regime. In addition to the estimation of the risky locations, we conclude that the initial stress regime stays a critical input to study the reservoir integrity while the hydraulic behavior of faults has an impact on induced stress variation magnitude.

\textit{Keywords:} Surface displacement ; Coupled flow-geomechanical simulation ; CO\textsubscript{2} storage integrity ; monitoring design ; conceptual models ; subsurface uncertainties