Ranking importance of uncertainties for the assessment of residual and dissolution trapping of CO_2 on a large-scale storage site

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The behaviour of the injected CO_2 on the long term is of primary importance and numerous authors have pointed out the essential role of trapping mechanisms in the evolution of the storage. In terms of safety and more specifically of CO_2 containment, two of the greatest issues concerns the location of the plume – in comparison with the potential leakage pathways – and the quantity of mobile CO_2 in case of unwanted upward migration. The migration of the injected plume has therefore been the subject of numerous studies. All these studies highlight the site- and condition-specificity of the evolution of the trapped plume fraction. Particularly, the structural characteristics of the geological formations, the initial hydrogeological conditions and absolute flow properties of the reservoir, as well as the multiphase flow parameters (relative permeability and capillary pressure) relatively to the CO_2/brine system have been shown to influence the pressure evolution and the behaviour of the mobile gaseous plume after the injection.

Knowledge of these parameters is often limited especially in the early stages of a storage project (before or in the first years of injection); the assessment of the fate of the injected CO_2 is therefore associated to several sources of uncertainties. The improvement of the knowledge on a specific site, before and during the life-time of the storage operations is essential as it may allow a decrease of the uncertainty on the outputs. However, additional data acquisition is likely to be expensive and time consuming, and the parameters to be characterized might be numerous. Thus, under time and budget constraints, ranking the parameters to be estimated according to their impact for the long term assessment of the CO_2 fate seems necessary. Such an importance ranking (aka sensitivity analysis) has been advocated by regulators in the European directive on CO_2 storage for instance.

However, performing such a sensitivity analysis might be challenging in the context of CO_2 storage. First, assumptions in the modelling procedure can be strong, because data can be scarce and might not be well-defined on a specific site. This is particularly the case for multiphase flow parameters (relative permeability and capillary pressure including hysteresis effects) curves specific to the CO_2/brine system and to the storage conditions; most of the time they do not benefit from previous studies of the site, even in sedimentary basin that are historically well-characterized with regards to intrinsic hydraulic properties. Secondly, a robust sensitivity analysis requires a large amount of simulations, which might not be feasible when using computationally intensive simulations of the CO_2 fate on long term at reservoir-scale. Meta-modelling techniques (aka response surface or reduced order models) can be developed to circumvent such a difficulty.

In this work, we propose an approach to assess the importance ranking of uncertainty sources, with regards to the long term fate of the mobile CO_2 on a specific case, considering notably solution and residual trapping. We consider the case of a large-scale storage site in the Paris basin (France) at the post-screening stage, which is characterized by a relatively high but typical level of uncertainty.

In a first step, the data at disposal have been collected and the outcome variables of interest according to our problem selected (in our case, the dissolved CO_2, the residual CO_2, and the distance of the mobile plume from the injection point over time). A 3D dynamic model has been developed from a geological model of the targeted formation.

In a second step, choices in terms of input parameters and associated uncertainty representation have been made. In total, we investigate the sensitivity to seven different input parameters: porosity, permeability, permeability anisotropy, regional hydraulic gradient, relative permeability, capillary pressure and mesh size. According to the different levels of knowledge, the uncertainty on the input parameters have been represented either by a continuous probability distribution (when enough information is available) or by a set of possible scenarios (when little information is available), i.e. by a categorical variables taking on discrete values, each of them assigned to a different scenario.

Considering each of the variables of interest, the approach for importance ranking is divided into two steps: 1. qualitative analysis: some reference simulations are precisely studied in the purpose of producing tornado diagrams for a better understanding of input parameters variations qualitative effects; 2. Quantitative analysis: a robust global variance-based sensitivity analysis VBSA relying on the Sobol' indices is chosen and performed. Yet, the implementation of VBSA in our case is hindered by two major limitations. First, VBSA is computationally intensive and requires a large number of model runs, of the order of 10,000, which is impractical using a large-scale flow model with CPU time typically reaching a few hours. The second problem is related to the nature of the model input parameter: several of them are represented by a set of possible scenarios to which a discrete categorical indicator is assigned. To circumvent both limitations, VBSA is combined with ACOSSO-like meta-modelling technique, which can jointly account for continuous variables and categorical variables.

This strategy is applied by using 300 large-scale complex dynamic 3D model runs. This procedure gives the temporal evolution of the sensitivity indices assigned to each input parameter considering each variable of interest. Interestingly, porosity, relative permeability and capillary pressure have the main influence but with different magnitude over time and depending on the variable of interest.

In summary, the approach, generic and applicable to different uncertain contexts, allows to answer two main issues: 1) the identification of the inputs parameter ranges or scenarios that contribute to a higher safety or contrarily to unwanted situations; 2) the identification of the main sources of variability as well as the parameters with negligible influence and therefore the prioritization of the effort to be made to improve the predictability of the numerical simulations.