Introduction

During the last years, controlled-source electromagnetic method (CSEM) abandoned its academic condition to become a promising tool for characterization and monitoring of hydrocarbon reservoirs. Despite of its initial developing in marine studies, the implementation of the method in onshore problems, particularly in CO2 storage sites monitoring, has started and the first results obtained are promising. Nevertheless, several features of land CSEM, such as optimal frequencies or appropriate source-receivers configuration, are insufficiently studied and probably depend on the particular properties of every storage site.

Models have been tested to verify the feasibility of CSEM method for monitoring the CO2 injection in the Hontomín storage site (Burgos, Spain). A simple but realistic stratified resistivity model has been used during the modelling. Results show that the CO2 response can be clearly detected by measuring the electric field at the surface if an electromagnetic source located at the reservoir depth is used.

Methodology

Different scenarios have been considered in order to maximize the CO2 response and obtain the optimal frequency range of emission of the source and the most sensitive source-receivers configuration. Stratified models with an x- and y-directed infinite plume layer provided an initial idea of the relevant values of the frequencies and permitted removing some of the configurations first considered. 1D simulations have been performed using the Occam1DCSEM code (Key, 2009), which obtains the magnetic vector potential computing the transform kernel from the Bessel’s functions.

Dimension-finite plumes have been simulated to obtain definitive conclusions about the requirements of the monitoring logistics. For that purpose, a 3D frequency-domain code based on a volume integral equation has been used (Avdeev et al., 2002). Plumes of realistic size and resistivity values have been taken in account over the layered resistivity model of reference, accordingly to the CO2 amount expected to be injected. With the goal to evaluate two possible designs, migration of the CO2 plume has been considered in two different directions: eastward and north-eastward.

Results

The critic and qualitative interpretation of the CO2 responses obtained with the simulations has enabled to verify that the resistivity change associated to the presence of carbon dioxide can be measured using the CSEM method. 1D modelling pointed that the optimal source-receiver configuration is downhole-to-surface, in front of surface-to-surface. Electromagnetic reciprocity principle suggests that we would obtain equivalent results considering surface-located sources and receivers buried at the reservoir depth. Taking into account the technological limitations associated at the well design (limited moment of the source) and the worse signal-to-noise ratio probably measured at shallow depths, this second configuration is probably more effective in a real case.

Stratified and three-dimensional models suggest that the proper frequency range to be emitted by the source is 0.01-5Hz. Vertical transmitters located beneath the CO2 plume and into it generate the largest responses, in spite of inline transmitters at the same depth give comparable results. 3D simulations allowed a plume migration synthetic experiment. Two possible receiver configurations were compared for a downhole-to-surface situation (figure 1): cross-shaped and circle-shaped of 1 and 4 km radius. Both of them are capable to detect the presence of CO2 in the reservoir, but their responses (figure 2) in a forward modelling migration scenario are strongly influenced by the direction of the movement: if the migration coincides with one of the cross arms, the cross-shaped configuration detects it better, but if it doesn’t, probably the circle-shaped design is more advisable.
In order to compare the electric field amplitudes to be measured with the electromagnetic noise in the area, magnetotelluric field data have been measured. A preliminary comparison reveals large enough signal-to-noise ratios.

Figure 1: Scheme of the two receiver configurations considered. Red symbols correspond to the cross-shaped design and green symbols, to the circle-shaped one.

Figure 2: Comparison of the electric field amplitude (relative to the response without CO2) for an x-directed source of one unit-moment for a cross-shaped (a) and circle-shaped (b) receivers configuration. a) Relative electric field amplitude versus source-receiver offset. b) Relative electric field amplitude in each receiver (red at: 1 km, blue at: 4 km).

Conclusions

Synthetic CO2 responses evaluated enable considering CSEM as an appropriate method for CO2 monitoring at Hontomín site. A vertical downhole-to-surface configuration seems to maximize the response. Cross- and circle-shaped receiver configurations detect this effect.
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References
