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CSEM Monitoring of a CO2 Reservoir Imaged by MT

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SUMMARY

During the last years, different studies based on numerical simulations have shown the potential of CSEM for CO2 monitoring. In this study, we carried out a set of simulations for CSEM monitoring of CO2 realistic deep saline reservoir in a 3D dome anticline structure. We perform numerical simulations in different scenarios (emission frequencies and surface-to-borehole configurations) in order to investigate the effect on the resolution when the simulations are done considering a baseline geoelectric model resulting from the inversion of MT synthetic data.

Introduction

During the last years, different studies based on numerical simulations (e.g. Streich et al. 2011, Wirianto et al. 2011) have shown the potential of CSEM for monitoring a CO_2 plume. Case studies were reported by Girard et al. (2011) and Bergman et al. (2012) in Ketzin (Germany) and Vilamajo et al. (2013) in Hontomín (Spain).

In this study, we carried out simulations of a monitoring exercise in a CO2 deep saline reservoir using CSEM. We consider a series of synthetic scenarios by varying certain parameters such as frequencies and surface-to-borehole configurations, the goal of which is investigating their effect on the MT inversion resolution.

Design of the model

We define a simple but representative 3D model that describes a dome anticline structure. The dome folds a 100 m thick layer that constitutes a deep saline aquifer with a resistivity of 10 Ω·m. The overburden seal layers, as well as the subreservoir units, have relatively high resistivity (400 Ω·m < ρ < 1000 Ω·m) and the basement is resistive (3000 Ω·m starting from ~3km). An accurate characterization of the described geoelectrical structure can be obtained with a 3D MT survey.

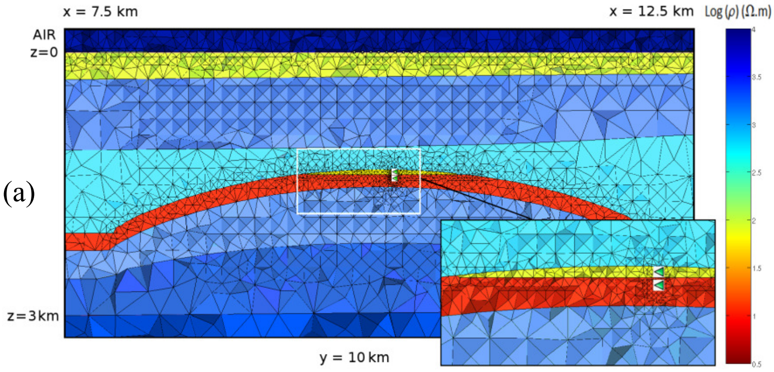
The supercritical CO_2 plume considered is trapped at the top of the anticline at a depth of 1500 m. Its maximum extension is 1 x 1 km wide and 80 m deep, representing an industrial-scale storage of CO_2 (3 Mton). According to Archie's law and assuming the presence of only two fluid phases within the post-injection reservoir formation (water and CO_2) and that the carbon dioxide will not modify the rock porosity, the pre-injection and post-injection resistivity, ρ_0 and ρ of the bulk rock follow the relationship: $\rho = \rho_0 \left(1 - S_{CO_2}\right)^{-2}$ where S_{CO2} is the CO_2 saturation and a value 2 for the saturation exponent has been assumed. We use a ρ_0 value of 10 Ω·m and ρ of 60 Ω·m, that corresponds to a homogeneous saturation of approximately S_{CO2} = 60%.

Simulations for CSEM synthetic models are performed using the finite-element code by Puzyrev et al. (2013). The use of completely unstructured tetrahedral meshes allows us to simulate complicated 3D reservoirs more accurately and with modest computational cost. This is a significant improvement compared to generally considered simple 3D reservoirs (discs or rectangular boxes) in stratified media.

The dimensions of the simulated models are 20 x 20 x 4 km and the number of mesh elements range between 1.5 and 2 millions. Fig. 1a shows an X-Z slice of the model with the mesh that has refinements near the source, the plume and the receivers. A grid of 41 x 41 receivers is located at the surface on an area of 10 x 10 km with 250 m spacing.

Example

We present here one of the results from CSEM simulations using the synthetic model previous to use the inverted MT model. The electric and magnetic field are calculated in a grid of receivers at the surface in a central area of the model. Fig. 1b presents the time-lapse measurements of the CO_2 plume illuminated with a source located below it. The source is modelled as a horizontal (x-direction) point dipole and emission frequency is 1 Hz. The electric field is computed considering only horizontal components, while for the magnetic field we considered all three components. For both magnetic and electric fields the ratios are larger than 1 for all offset distances, but the patterns are different. For the horizontal electric field the maximum is slightly larger and it is not centered above the plume location, as in the case of the magnetic field.



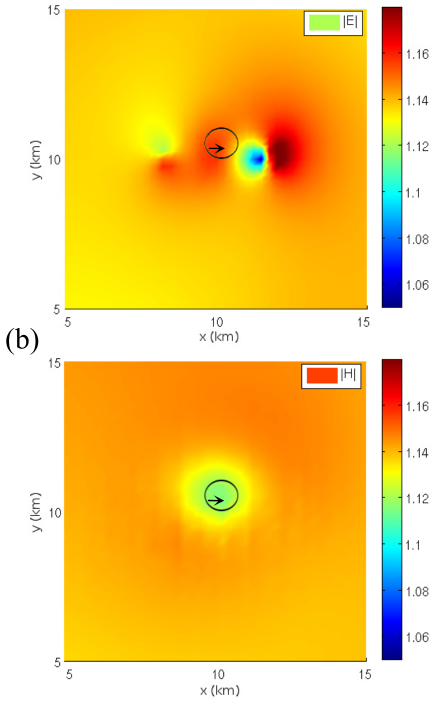


__Figure 1__ (a) X-Z slice of the central part of the 3D resistivity model with the mesh used. The zoom shows a detail of the plume (yellow) in the saline aquifer reservoir (red) indicating (green triangles) two positions of a HED (inside and below the plume); (b) X-Y slice of horizontal electric and total magnetic field ratios of post- and pre-injection. The frequency is 1 Hz; the source (arrow) is located below the plume (black contour).

Conclusions

We have presented modelling results for a realistic 3D dome obtained with a finite-element code using unstructured tetrahedral meshes. The subsurface structure is imaged by the MT method and includes a deep saline reservoir available for CO_2 storage. The changes in resistivity of the reservoir due to replacing saline water with CO_2 injected are well imaged by the change in electric and magnetic fields at the surface when the plume is illuminated by a deep source although the particular values and patterns of the fields' ratios depend on the type of source (orientation, emission frequency and relative position to the plume) and offset distance.

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