Influence of steel infrastructure on transient electromagnetic fields

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1 Summary

Geophysical measurements for monitoring the processes of CO_2-sequestration or enhanced oil recovery usually take place on active or abandoned oil respectively gas fields. Considering the amount of steel infrastructure in the subsurface of these investigation sites it is crucial to take account of the effect of steel infrastructre on electromagnetic fields. Therefore we present three-dimensional finite element (FE) simulations of transient electromagnetic fields in the present of steel infrastructure. As a first approach we consider two common scenarios. The first scenario covers the case of surface transient electromagnetic measurements with a crossing pipeline beneath a receiver profile. The second scenario covers borehole transient electromagnetic measurements in a partially steel cased borehole. We demonstrate that steel infrastructure has a significant effect on the electromagnetic response.

2 Introduction

A large-scale borehole transient electromagnetic (TEM) field campaign is planned at a pilot CO_2-sequestration site in Alberta, Canada. The target area, however, contains an extensive steel infrastructure consisting of three oil pipelines (partially intersecting) as well as two full cased injection wells of 500 m (see Fig. 1 Injection well 1) and 300 m (see Fig. 1 Injection well 2) depth. Setting up a transmitter loop without having steel infrastructure beneath it, is almost impossible due to the limitations of the test site and the required survey layout. The test site has the dimension of 1000×1000 m^2. Therefore it is necessary to investigate the influence of various steel constructions (pipelines, steel casing) on TEM data. We present three-dimensional finite element (FE) simulations of transient electromagnetic fields for several receiver locations (M-4 to M4) considering steel infrastructure in the subsurface.

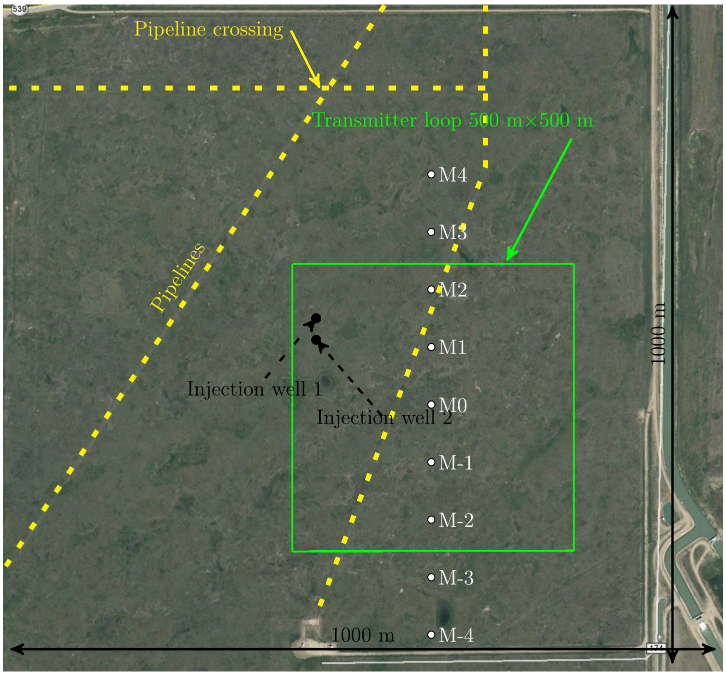

Figure 1: Plan view of the CO_2-sequestration site Brooks, Alberta(CA)

3 Model domain and parameters

The first model covers the case of a pipeline beneath the source crossing a receiver profil. As a first approximation the pipeline is a solid cylinder with a diameter of 2 m and an installation depth of 6 m. It strikes from south west to north east (Fig. 2). The model consists of a 5 km × 5 km × 2.5 km air halfspace and a 5 km×5 km×2.5 km subsurface. The transmitter is a square loop with a side length of 500 m centered at the point (0, 0, 0). The finite element grid employed for the numerical simulation consists of 2 306 479 tetrahedra (Fig. 3).

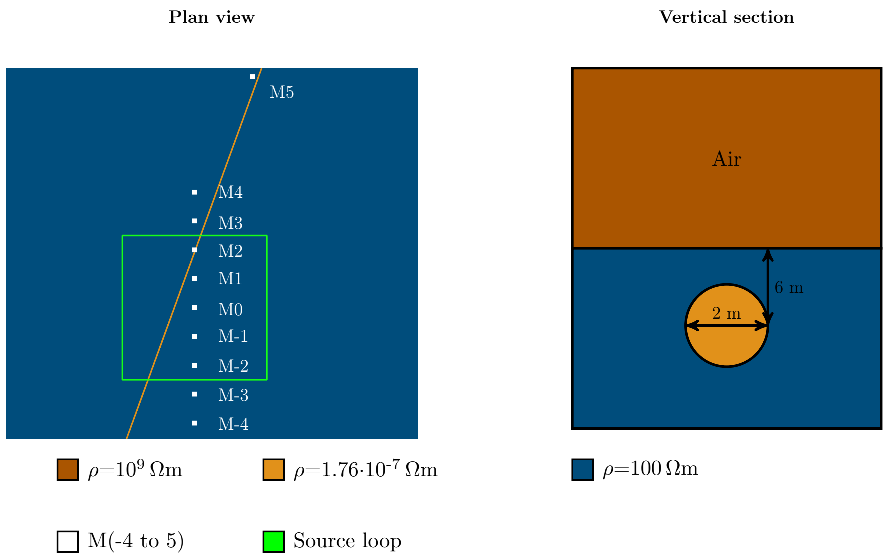

Figure 2: Parameter model of a pipeline crossing beneath the transmitter loop.

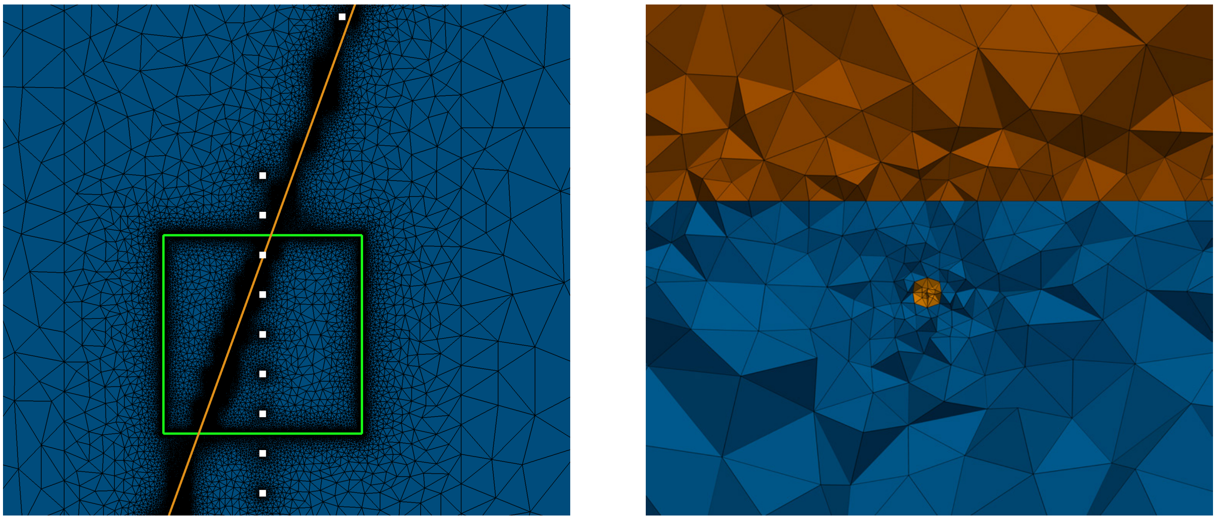

Figure 3: Pipeline model: Trace of the tetrahedral mesh at the plane z = 0 (left) and vertical section of the FE mesh along the plane x = 0.

The second model covers the case of a steel cased borehole. The model consists of a 2 km × 2 km ×1 km air halfspace and a 2 km × 2 km × 1 km subsurface in which a 200 m deep borehole with a diameter of 1 m is embedded. The casing of the borehole is 50 m long with a casing width of 10 cm (see Fig.4). The borehole is located at (x=200 m y=0 m z=0 m). The transmitter is a square loop with a side length of 100 m centered at the point (0, 0, 0). The finite element grid employed for the numerical simulation consists of 1 934 820 tetrahedra (Fig. 5).

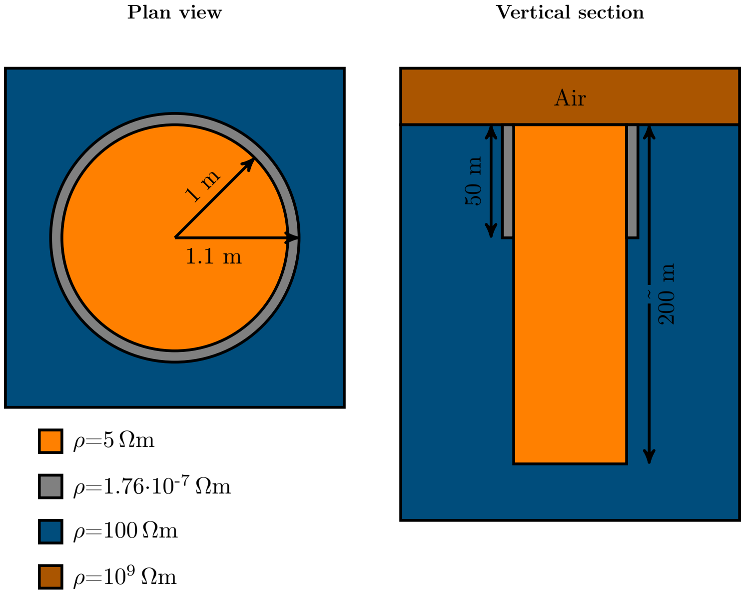

Figure 4: Model scheme and parameters for the cased borehole model

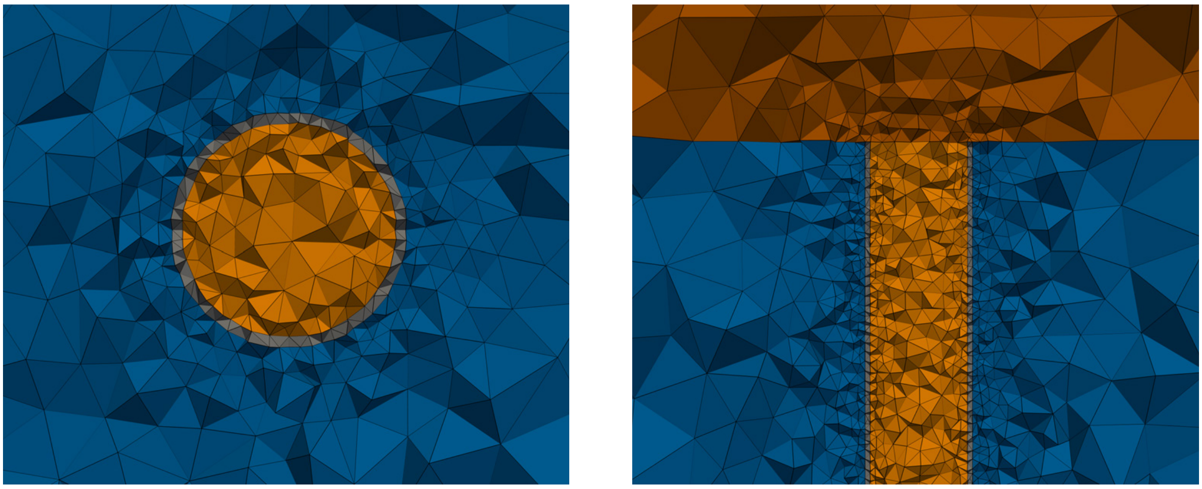

Figure 5: Cased borehole model: Trace of the tetrahedral mesh at the plane z = 0 (left) and vertical section of the FE mesh along the plane x = 0.

4 Simulation results

To solve the 3-D forward modelling problem we employ an approximation to the matrix exponential function using a Rational Arnoldi method (Börner, Ernst, and Güttel 2015). The mesh for scenario 1 consists of 2 306 479 tetrahedral elements which after discretizaton using linear Nedelec elements results in 2 696 577 degrees of freedom. Figure 6 shows the results of the simulation at the points M0, M-1, M1, M-3, M-4 (see Fig. 2). The black line denotes the analytical solution for a 100 Ωm homogeneous halfspace in the center of a circular loop with radius 282 m. The red line represents the numerical solution of the model with homogeneous conductivity distribution. The numerical solution of the actual conductivity model (Fig. 2) is represented by the blue line.

The mesh for scenario 2 consists of 1 934 820 tetrahedral elements which after discretizaton using linear Nedelec elements results in 2 271 984 degrees of freedom. Figure 7 shows the results of the simulation for different points inside the borehole (A - at surface, B - within, C - just below casing, D and E - far away). The black line denotes the analytical solution for a 100 Ωm homogeneous halfspace and a vertical magnetic dipole source. The red line represents the numerical solution of the model with homogeneous conductivity distribution. The numerical solution of the actual conductivity model (Fig. 4) is represented by the blue line.

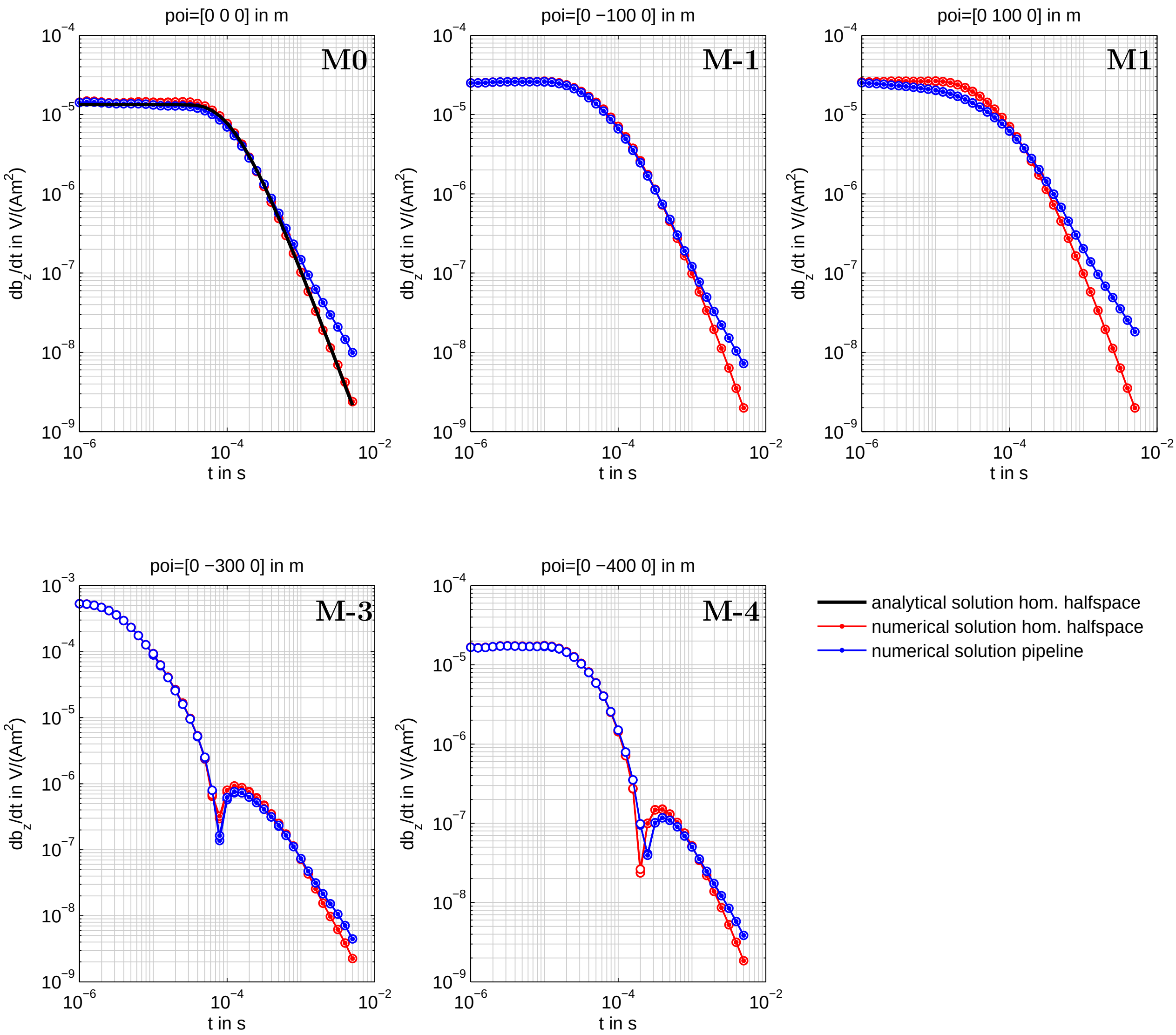

Figure 6: Simulation results for the pipeline model

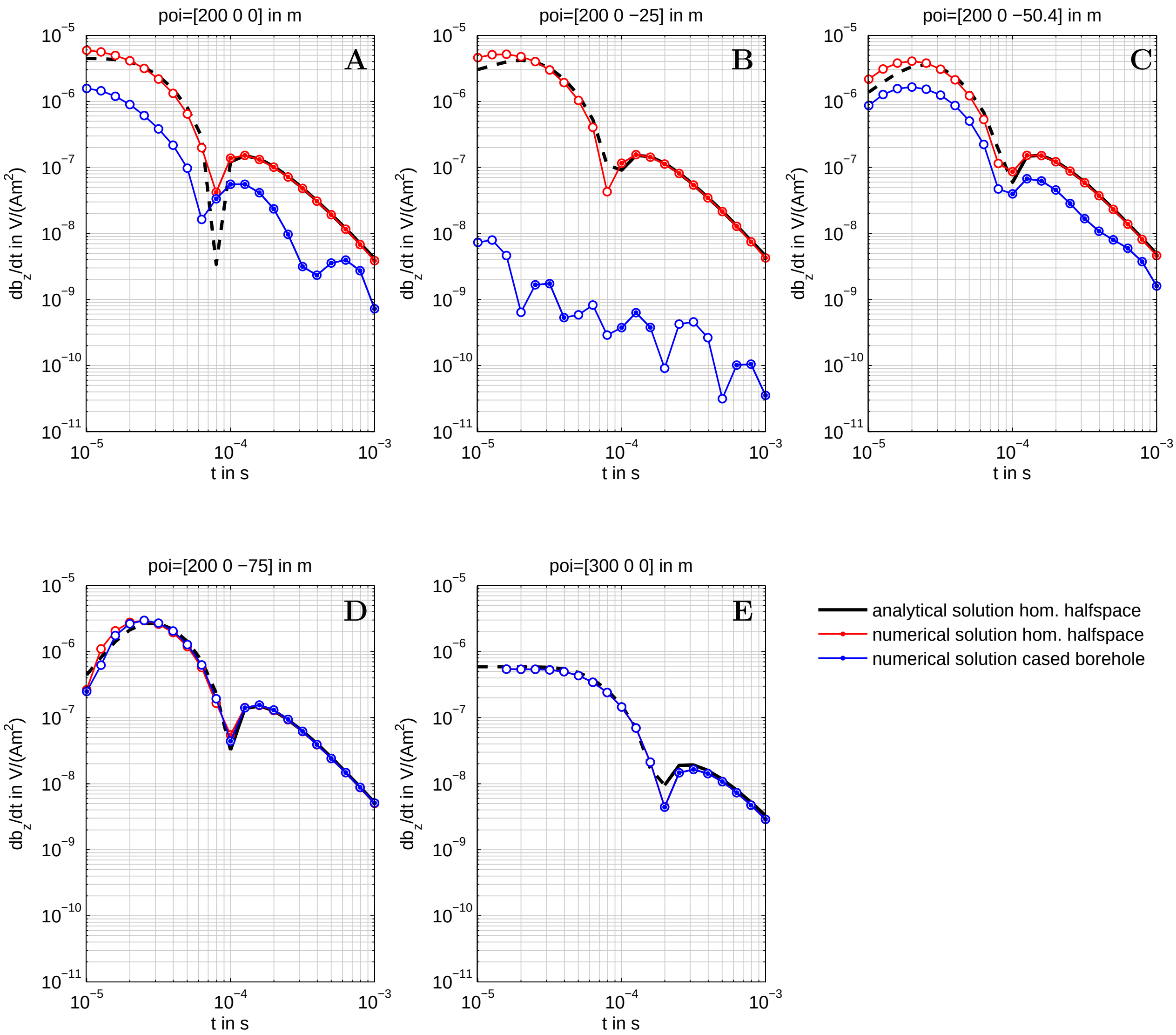

Figure 7: Simulation results for the cased borehole model

5 Conclusion

We have carried out three-dimensional transient electromagnetic finite element simulations for various steel constructions in the subsurface. Our computations demonstrate that steel infrastructure may shield, shift and/or distort the TEM response given the discretisation errors from the large conductivity contrasts are still moderate. However, a quantitative statement is not possible at this point. This is subject to intensive studies of the numerical error using e.g., a posteriori error estimators, appropiate boundary conditions for perfect conductors, and sequences of increasing conductivity contrasts. Mesh refinement close to large conductivity contrasts is crucial. The mismatch between the numerical solution for the homogeneous halfspace (red line) and the analytical solution for the homogeneous halfspace (black line) in the early times for scenario 2 (Fig. 7) indicates that further efforts have to be made with respect to the mesh size and quality.

References

Börner, Ralph-Uwe, Oliver G Ernst, and Stefan Güttel (2015). "Three-dimensional transient electromagnetic modelling using Rational Krylov methods". In: *Geophysical Journal International* 202.3, pp. 2025–2043.