A 3D Time Domain CSEM Forward Modeling Code using custEM and FEniCS

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Introduction

TDcustEM is a new 3D time domain CSEM finite elements forward modeling software built upon the open-source frequency domain toolbox **custEM** [1] and the open-source finite-element library **FEniCS** [2]. The frequency domain results calculated by the custEM toolbox are transformed into the time domain by a **Fast Hankel Transform** (FHT) using 80 digital filters provided by Tilman Hanstein [3]. Nédélec finite elements are used for the tetrahedral meshes which are generated by TetGen. Grounded dipole and inductively coupled loop sources can be modeled using the total E-field approach. For more information, see [7], which also contains an application of the software to real field data.

The E-Field Equation

The quasi-static total E-field formulation in the frequency domain to be solved:

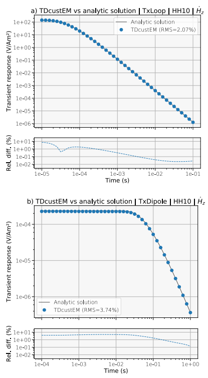
$$\nabla \times \mu^{-1} \nabla \times \mathbf{E} + i\omega\sigma\mathbf{E} = -i\omega\mathbf{j}_s. \quad (1)$$

The magnetic field is subsequently obtained by

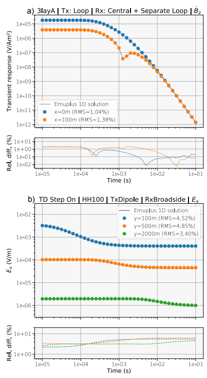
$$\mathbf{H} = -\frac{1}{i\omega\mu} \nabla \times \mathbf{E} \quad (2)$$

Cross-validation (Analytic and 1D)

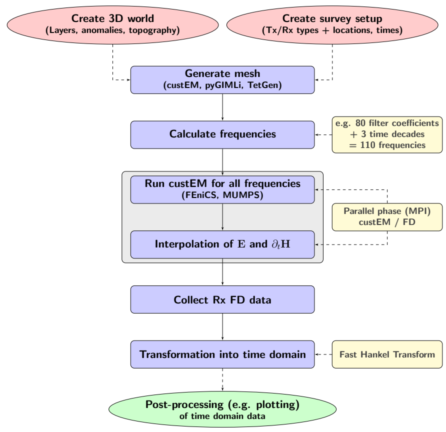
Cross-validation of synthetic loop and dipole source data against analytical solutions by Ward & Hohmann (1991) [4]. The model is a homogeneous half-space with 10 Ωm.



Cross-validation of synthetic data against the semi-analytic 1D algorithm *EMUPLUS*.
a) Loop source and 3-layer model (resistivities: 1, 10, 100 Ωm, thicknesses: 40 and 40 m)
b) dipole source and homogeneous half-space with 10 Ωm.

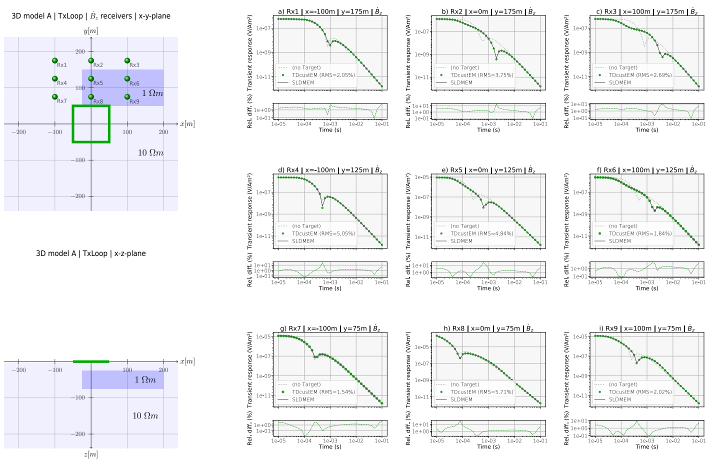


The TDcustEM Algorithm



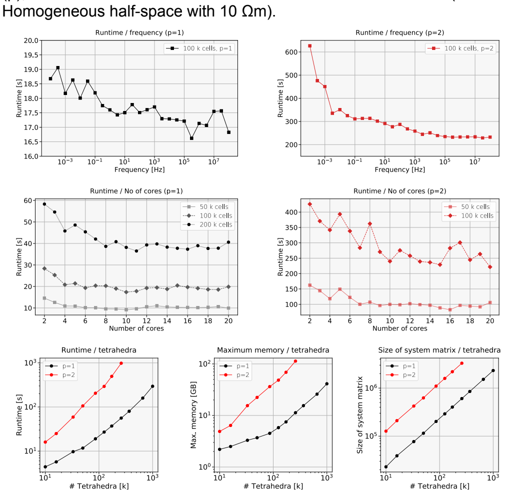
Cross-validation (3D)

Cross-validation against the finite-differences code SLDMEM [5] for a loop transmitter and nine receiver positions. The 3D model consists of a buried conductive cuboid (1 Ωm) inside a uniform half-space (10 Ωm). In [7], the same model is computed using a dipole source.



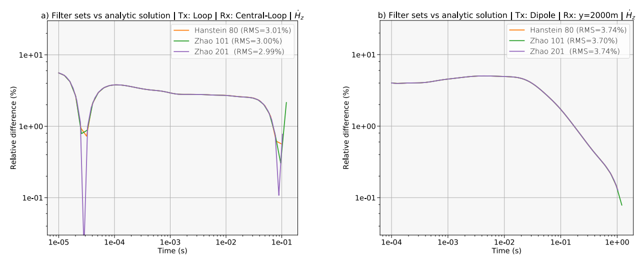
About runtimes

Algorithm runtimes depending on the input frequency, polynomial degree (p), number of cores and different mesh sizes / tetrahedra (Test model: Homogeneous half-space with 10 Ωm).



About Filter Sets

Comparing the performance of the implemented 80 FHT filter coefficients against a 101 and 201 filter coefficients set by Zhao et al (2018) [6] for a homogeneous half-space with 10 Ωm.



References

[1] Rochlitz, R., N. Skibbe and T. Günther (2019), custEM: Customizable finite-element simulation of complex controlled-source electromagnetic data, Geophysics, 84 (2), 1-17
[2] The FEniCS project (http://www.fenicsproject.org).
[3] Tilman Hanstein, KMS Technologies
[4] Ward, S. H. and G. W. Hohmann (1991), Time Domain Electromagnetic Prospecting Methods, in Electromagnetic Theory for Geophysical Exploration, vol. 1, M. N. Nabighian ed., chap. 4, pp. 131–311, Society of Exploration Geophysicists.
[5] Druskin, V. L. and L. A. Knizhnerman (1994), Spectral approach to solving threedimensional Maxwell's diffusion equations in the time and frequency domains, Radio Science, 29
[6] Zhao, Y., Z.-Q. Zhu, G.-Y. Lu and B. Han (2018), The optimal digital filters of sine and cosine transforms for geophysical transient electromagnetic method, Journal of Applied Geophysics, 150, 267-277
[7] Seidel, M. (2019), Dissertation, University of Cologne, Germany