Open-Source Landscape for Three-Dimensional Controlled-Source Electromagnetic Modeling

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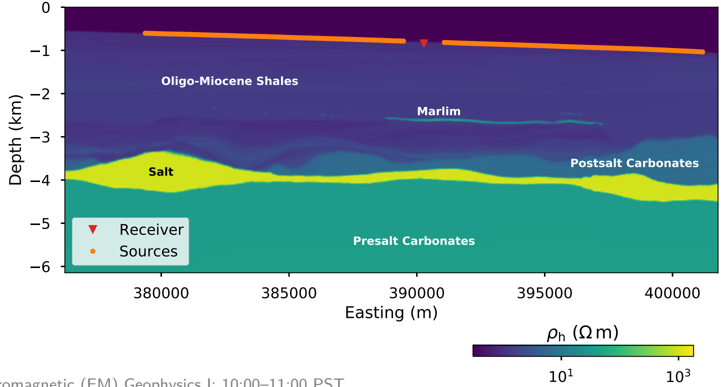


14th December 2020

Paper Number GP005-06; *Session* Frontiers in Electromagnetic (EM) Geophysics I; 10:00–11:00 PST

AGU FALL MEETING

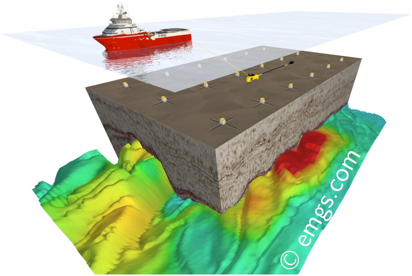
Validation of large-scale 3D CSEM modelling using the open-source codes `custEM`, `emg3d`, `PETGEM`, and `SimPEG`

empymod.github.io

petgem.bsc.es

simpeg.xyz

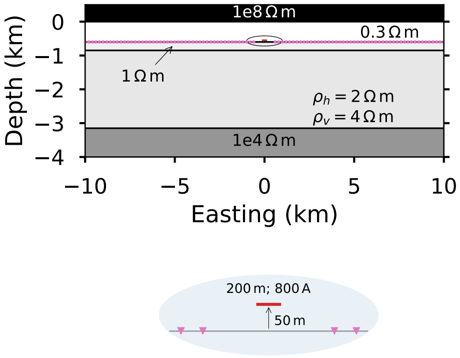
custem.rtfd.io

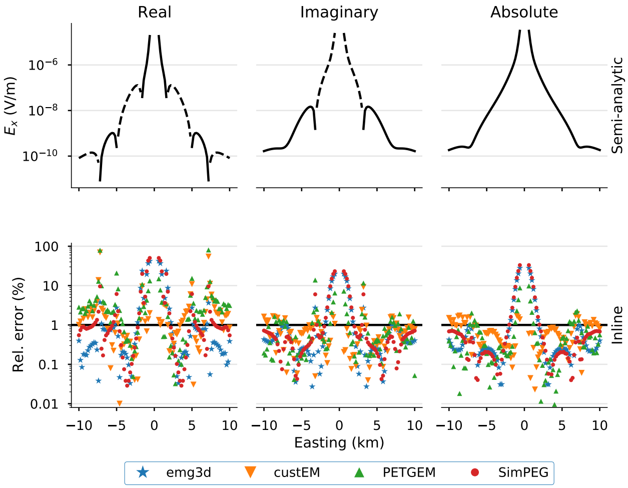


Werthmüller, Rochlitz, Castillo-Reyes, and Heagy, 2020, submitted to GJI; arXiv: 2010.12926

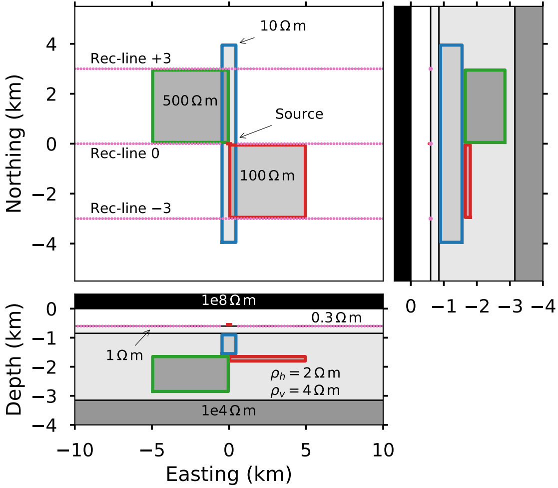
Numerical Results

Verification for layered model using semi-analytical solutions shows a relative amplitude error in the order of 1 % or less





Adding three resistive blocks to the layered model requires the normalised difference instead of the relative error



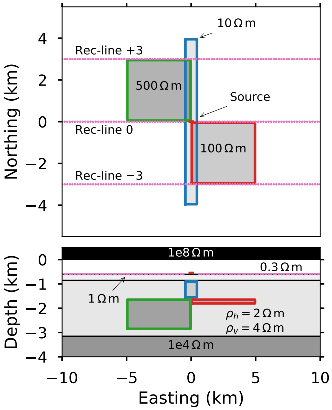
Normalised Root-Mean Square Difference (NRMSD) in percent:

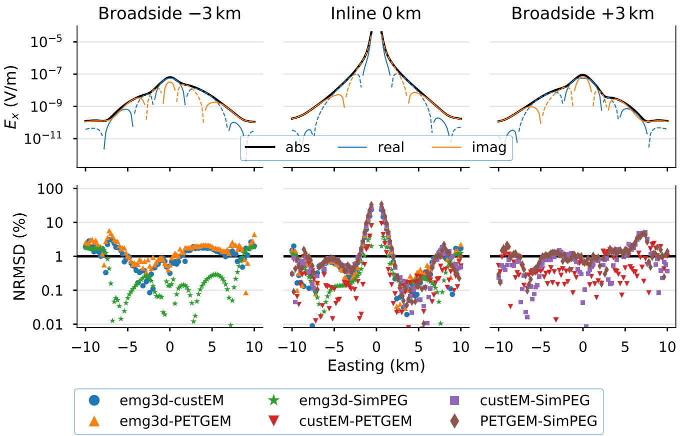
$$200\,\frac{|R_1 - R_2|}{|R_1| + |R_2|}$$

After *Dublin Test Model 1*,

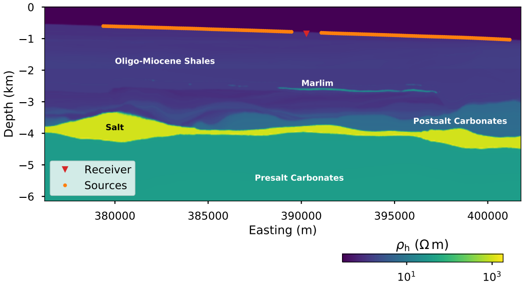
Miensopust et al., 2013, GJI

Validation between the codes shows a normalised difference of 1–2 % or less



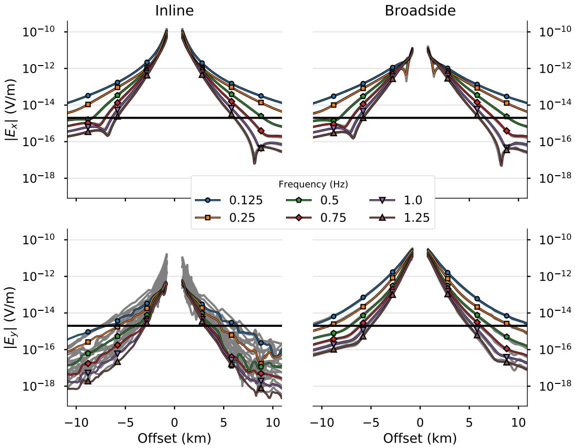


Marlim R3D model: Responses at receiver locations look visually the same for all relevant responses

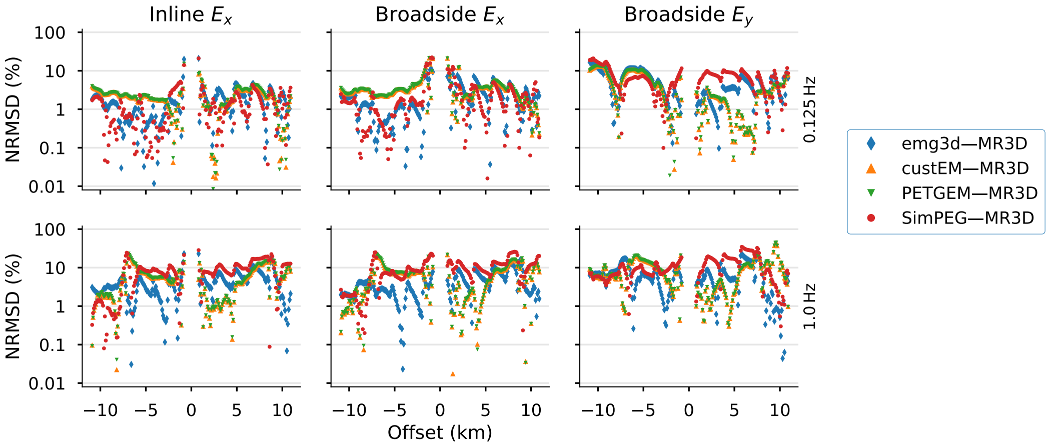


Marlim R3D:

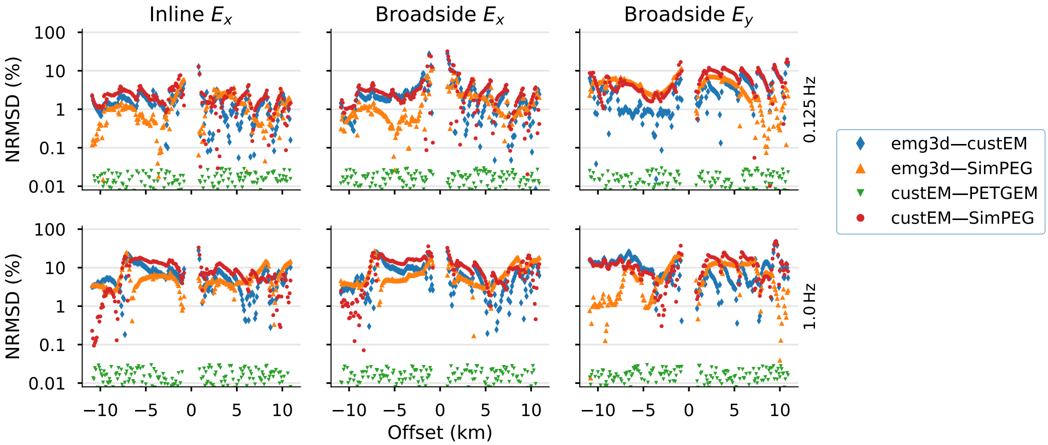
Correa and Menezes, 2019, Geophysics



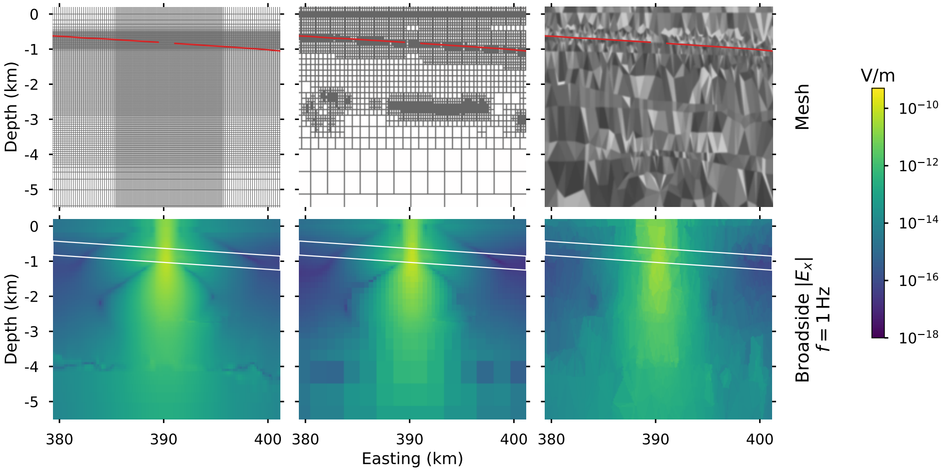
Normalised difference to published data is mostly below 10 % and very different from code to code



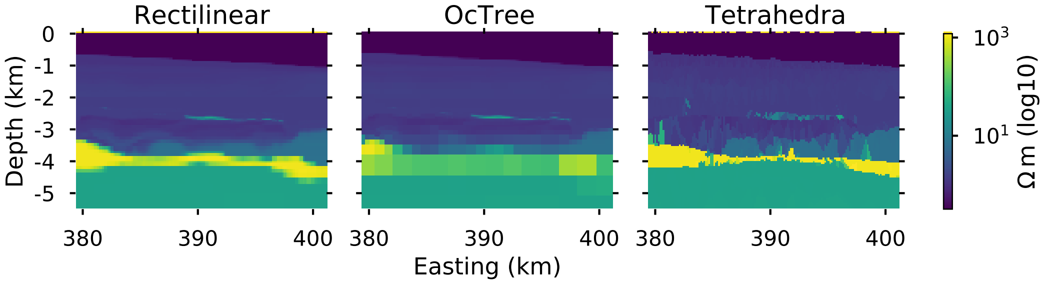
Normalised difference between our codes is very similar and mostly below 10 %



Very insightful is to look at the entire meshes and their different behaviours



A look at the models in different mesh yields interesting insights with regards to recoverability in inversions



Code	#Procs	CPU (s)	RAM (GiB)	#dof
custEM	64	872	230.1	1 918 106
emg3d	1	1254	0.6	5 998 992
PETGEM	96	524	175.4	1 918 106
SimPEG	4	422	12.8	720 146

Conclusions and Outlook

References

A more extensive reference list can be found in:

Werthmüller, D., R. Rochlitz, O. Castillo-Reyes, and L. Heagy, 2020, **Open-source landscape for 3D CSEM modelling**, submitted to Geophysical Journal International, arXiv: 2010.12926.

Modelling codes: `custEM`, `emg3d`, `PETGEM`, `SimPEG`, and `empymod`:

Castillo-Reyes et al., 2018, **PETGEM: A parallel code for 3D CSEM forward modeling using edge finite elements**, Computers & Geosciences, 119, 126–136, doi: 10.1016/j.cageo.2018.07.005.

Cockett et al., 2015, **SimPEG: An open source framework for simulation and gradient based parameter estimation in geophysical applications**, Computers & Geosciences, 85, 142–154, doi: 10.1016/j.cageo.2015.09.015.

Rochlitz et al., 2019, **custEM: customizable finite element simulation of complex controlled-source electromagnetic data**, Geophysics, 84, F17–F33, doi: 10.1190/geo2018-0208.1.

Werthmüller, 2017, **An open-source full 3D electromagnetic modeler for 1D VTI media in Python: empymod**, Geophysics, 82(6), WB9–WB19; doi: 10.1190/geo2016-0626.1.

Werthmüller et al., 2019, **emg3d: A multigrid solver for 3D electromagnetic diffusion**, Journal of Open Source Software, 4(39), 1463; doi: 10.21105/joss.01463.

Solvers `PETSc`, `MUPMS`, `FEniCS`, and `PARDISO`:

Abhyankar et al., 2018, **PETSc/TS: A modern scalable ODE/DAE solver library**, arXiv: 1806.01437.

Amestoy et al., 2001, **A fully asynchronous multifrontal solver using distributed dynamic scheduling:** SIAM Journal on Matrix Analysis and Applications, 23, 15–41, doi: 10.1137/S0895479899358194.

Langtangen et al., 2016, **Solving PDEs in Python: The FEniCS Tutorial I**, vol. 3 of Simula SpringerBriefs on Computing, Springer International Publishing, doi: 10.1007/978-3-319-52462-7.

Schenk and Gärtner, 2004, **Solving unsymmetric sparse systems of linear equations with PARDISO**, Future Generation Computer Systems, 20, 475–487, doi: 10.1016/j.future.2003.07.011.

Marlim R3D model:

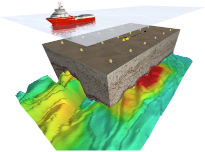
Correa and Menezes, 2019, **Marlim R3D: A realistic model for controlled-source electromagnetic simulations–Phase 2: The controlled-source electromagnetic data set**, Geophysics, 84, E293–E299, doi: 10.1190/geo2018-0452.1.

MT comparison study:

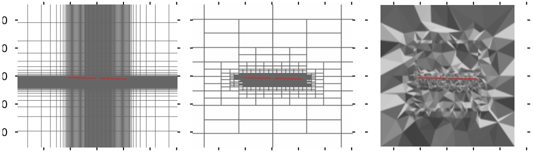
Miensopust et al., 2013, **Magnetotelluric 3-D inversion–a review of two successful workshops on forward and inversion code testing and comparison**, Geophysical Journal International, 193, 1216–1238, doi: 10.1093/gji/ggt066.

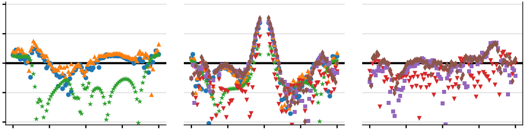
More Comparisons & Benchmarks
Other Scenarios, other programming languages

emg3d

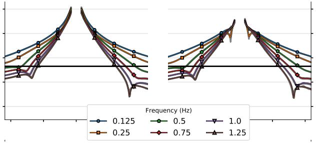


custEM





simpeg



petgem