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Sandia National Laboratories

Prediction and Inference of Multi-scale Electrical Properties of Geomaterials

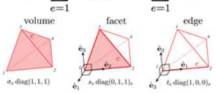
Chester J Weiss and G Didem Beskardes (Geophysics Dept 8861, SNL),
Bart van Bloemen Waanders (Optimization and UQ Dept 1441, SNL)

Project Objective: To integrate the latest discoveries in understanding material complexity into the laboratory's evolving needs for subsurface imaging and characterization.

1st KEY BREAKTHROUGH: HIERARCHICAL MATERIAL PROPERTIES FOR FE ANALYIS

Associate material properties with volumes, facets and edges of a numerical discretization to represent thin, strong targets of geophysical interest.

$$\boldsymbol{\sigma}(\boldsymbol{x}) = \sum_{e=1}^{N_V} \sigma_e \boldsymbol{\psi}_e^V(\boldsymbol{x}) + \sum_{e=1}^{N_F} s_e \boldsymbol{\psi}_e^F(\boldsymbol{x}) + \sum_{e=1}^{N_E} t_e \boldsymbol{\psi}_e^E(\boldsymbol{x})$$



Reduces compute time from months to hours for complex problems.

Variational formulation for Poisson Eq:

$$\int_\Omega \nabla v \cdot (\boldsymbol{\sigma} \cdot \nabla u)\ dx^3 = \int_\Omega v f\ dx^3$$

Weiss, Geophysics, 2017
USPTO Application 15/871,282

2nd KEY BREAKTHROUGH: NON-LOCAL EFFECTS FROM SUB-GRID DETAILS

Replace the exquisite discretization of infinitely complex, multi-scale materials with an economy of model parameters using the architecture of *fractional calculus*.

Application to Maxwell's Equations.

$\nabla \times \mathbf{E} = -\mathrm{i}\omega\mu_0\mathbf{H}.$ Faraday's Induction Law

$\nabla \times \nabla \times \mathbf{E} = -\mathrm{i}\omega\mu_0\mathcal{D}_z^\alpha\left[\sigma_{\alpha,z}\mathbf{E}\right]$ Ampere's Current Law with fractional Derivatives to describe complexity of material property σ.

In simple, 1D media…

$$-\frac{\mathrm{d}^2 u}{\mathrm{d}\zeta^2}\left(\frac{1}{z^*}\right)^2 + \mathrm{i}\omega\mu_0\mathcal{D}_\zeta^\alpha\left[\sigma_{\alpha,\zeta}\,u(\zeta)\right] = 0$$

… a fractional Helmholtz equation emerges.

$$(-\Delta_\zeta)^s\,u + \mathrm{i}\kappa^2\,u(\zeta) = 0$$

Weiss et al., AGU, 2018
Weiss, et al., SISC, 2019
Collaboration with H Antil, George Mason Univ.

RESOLVE THE INTERFACE BETWEEN MACRO- AND MICRO- WORLDVIEWS

Hierarchical FE simulations provided first-ever look at electrical response of large, arbitrary fracture systems.

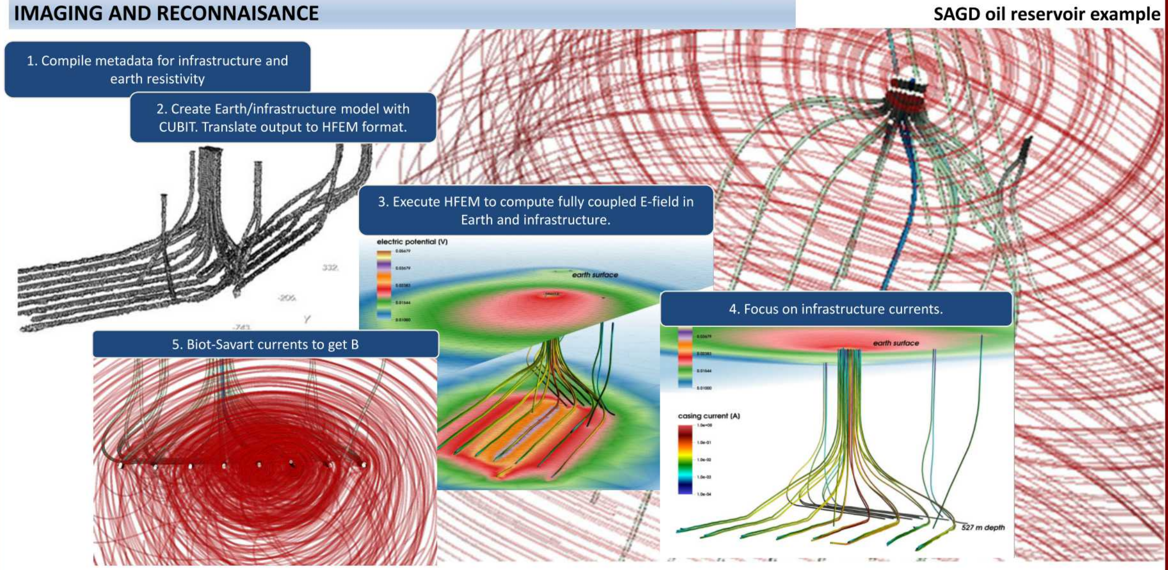
Outstanding research questions.
How to interpret fractional calculus parameters in term of tangible quantities, like texture or orientation? Space-time non-locality?

Beskardes et al., GJI, 2017; 2018

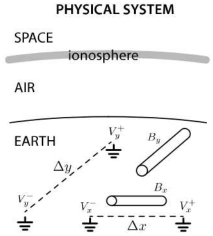
Exceptional service in the national interest

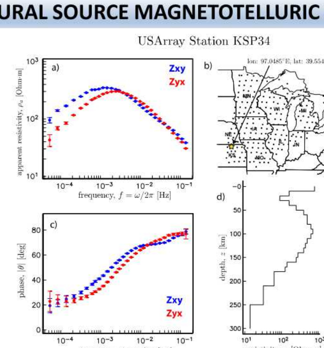
EXPLOITATION OF INFRASTRUCTURE FOR THROUGH-THE-EARTH TELEMETRY, IMAGING AND RECONNAISANCE

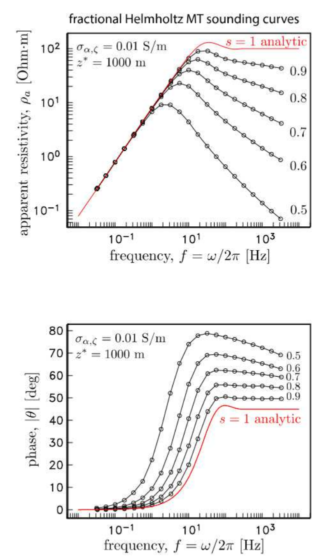
SAGD oil reservoir example



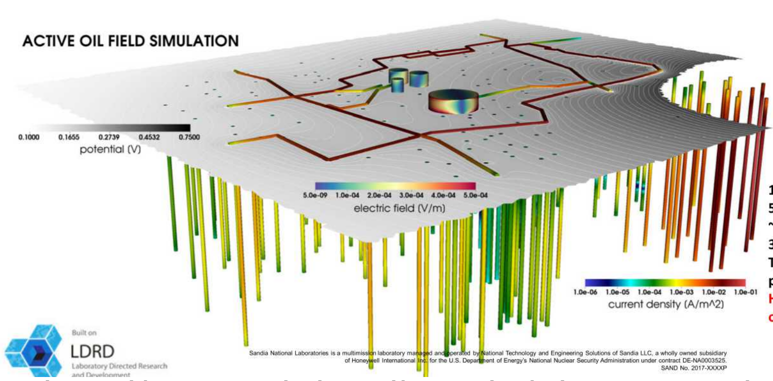
CAPTURING NON-LOCAL EFFECTS IN NATURAL SOURCE MAGNETOTELLURIC DATA







SITUATION AWARENESS IN URBAN/INDUSTRIALIZED SETTINGS



122 cased wells, 300 m deep
5 km surface pipes
~35 km pipeline/casing modeled at 10 m grid spacing: 3500 elements
Traditional FEM requires ~7e6 elements per km of pipeline/casing.
HFEM decreases computational burden by ~4 orders of magnitude in this example (10 min vs 2 mo, est.)

Built on LDRD Laboratory Directed Research and Development

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