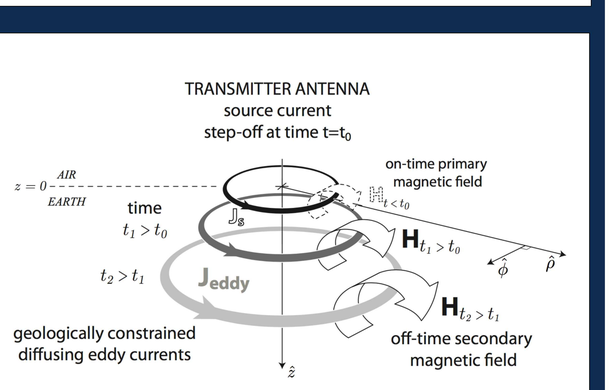
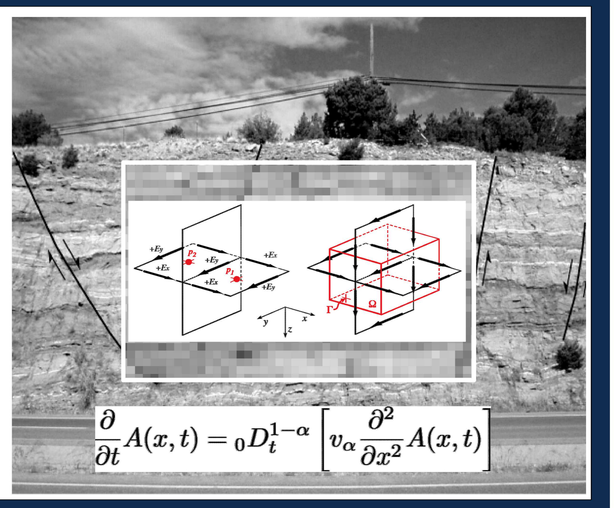
SAND2016-9605D

Prediction and Inference of Multi-scale Electrical Properties of Geomaterials

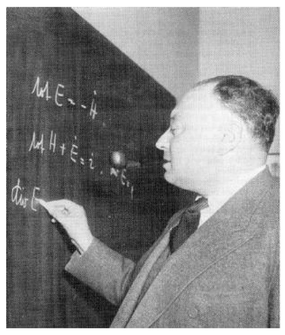
Chester J Weiss (Geophysics Dept 6911, SNL),
Bart van Bloemen Waanders (Optimization and UQ Dept 1441, SNL) and
Mark E Everett (Dept of Geology and Geophysics, Texas A&M Univ)





$$\frac{\partial}{\partial t}A(x,t) = {}_0D_t^{1-\alpha}\left[v_\alpha \frac{\partial^2}{\partial x^2}A(x,t)\right]$$

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



Diffusion on systems with embedded, multi-scale heterogeneity has been shown, in principle, to be described by novel class of partial differential equations – equations whose order of differentiation is non-integer.

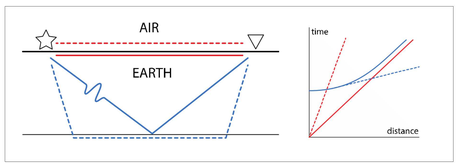
This realization is far reaching, with limits presently uncharted, but with applications to:

geoscience, economics, biophysics and signal analysis

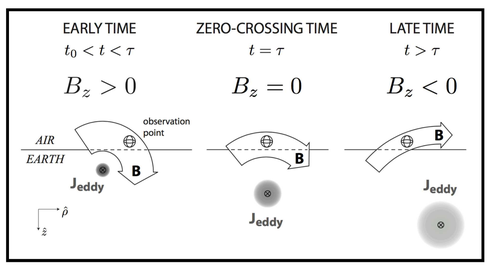
For problems in Earth science, the transition between classical and "anomalous" fractional electromagnetic field propagation is unknown. This research is novel and high-risk, which if successful, will enable a modeling capability unparalleled elsewhere in the world.

Observational Evidence for Anomalous Electromagnetic Diffusion

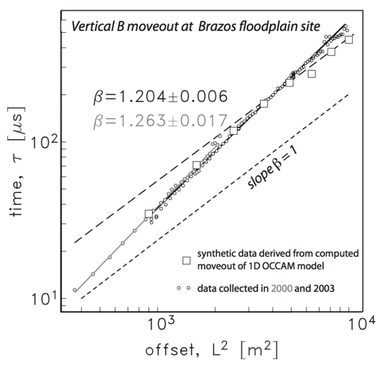
Arrival time analysis – analogous to seismic moveout



In low-frequency EM, we measure the diffusion rate of induced eddy currents.



Hallmark of anomalous diffusion is fractional order power law for EM pulse arrival time.



Weiss and Everett, JGR 2007

Spatial Statistics – non-Gaussian power law in the power spectral density of variability in electromagnetic response

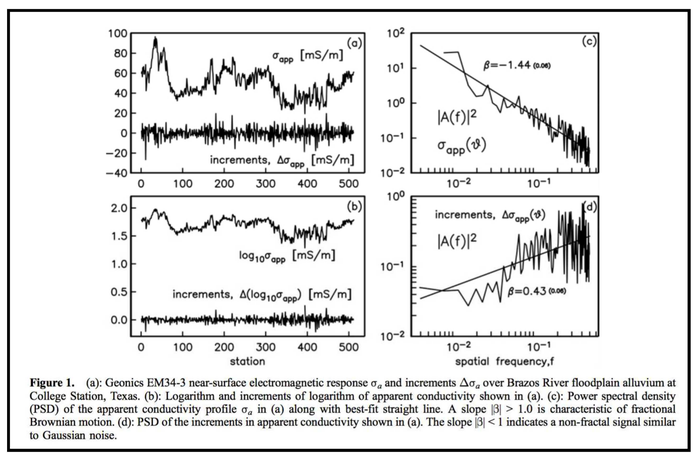


Figure 1. (a): Geonics EM34-3 near-surface electromagnetic response σ_a and increments $\Delta\sigma_a$ over Brazos River floodplain alluvium at College Station, Texas. (b): Logarithm and increments of logarithm of apparent conductivity shown in (a). (c): Power spectral density (PSD) of the apparent conductivity profile σ_a in (a) along with best-fit straight line. A slope $|\beta| > 1.0$ is characteristic of fractional Brownian motion. (d): PSD of the increments in apparent conductivity shown in (a). The slope $|\beta| < 1$ indicates a non-fractal signal similar to Gaussian noise.

Everett and Weiss, GRL 2002

Quantification Strategies for the Behavior of Multi-scale Systems

At the macro-scale, anomalous diffusion is characterized by heavy-tailed distributions that can be modeled by methods of fractional calculus.

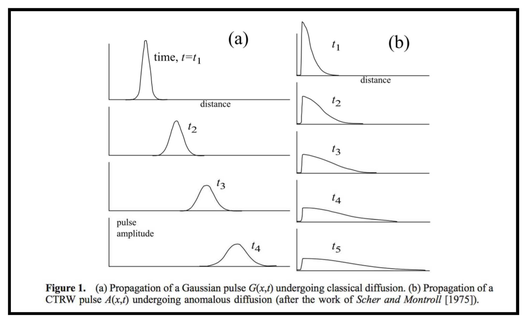
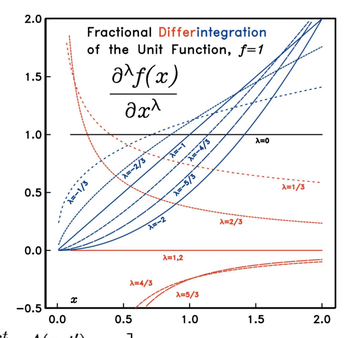


Figure 1. (a) Propagation of a Gaussian pulse $G(x,t)$ undergoing classical diffusion. (b) Propagation of a CTRW pulse $A(x,t)$ undergoing anomalous diffusion (after the work of *Scher and Montroll* [1975]).

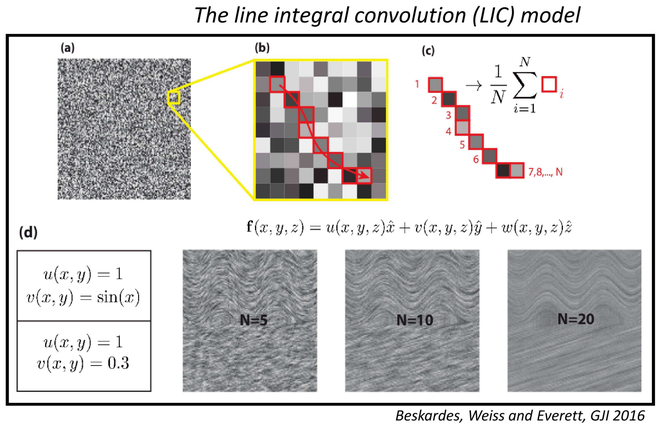


$$\frac{\partial}{\partial t}A(x,t) = {}_0D_t^{1-\alpha}\left[v_\alpha \frac{\partial^2}{\partial x^2}A(x,t)\right] \qquad {}_0D_t^{1-\alpha}A(x,t) = \frac{1}{\Gamma(\alpha)}\frac{\partial}{\partial t}\left[\int_0^t \frac{A(x,t')}{(t-t')^{1-\alpha}}\,\mathrm{d}t'\right]$$

Weiss and Everett, JGR 2007
Everett, GJI 2009

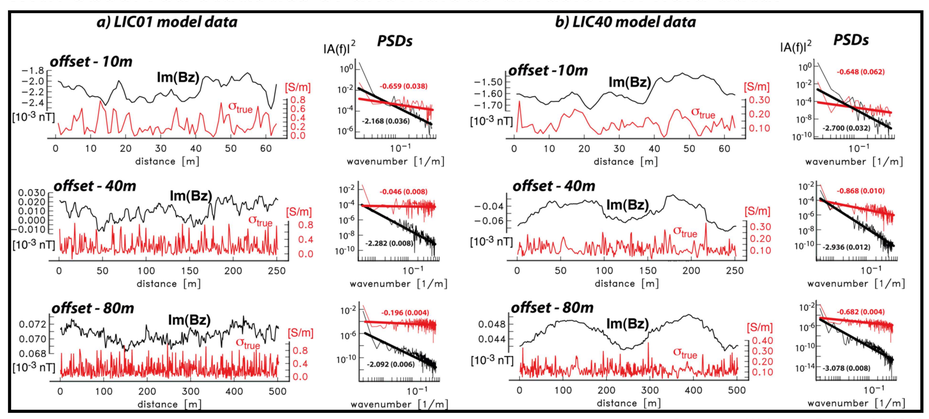
At the micro-scale, models are built with tunable correlation lengths and variability in the orientation of lithologic texture.

The line integral convolution (LIC) model



Beskardes, Weiss and Everett, GJI 2016

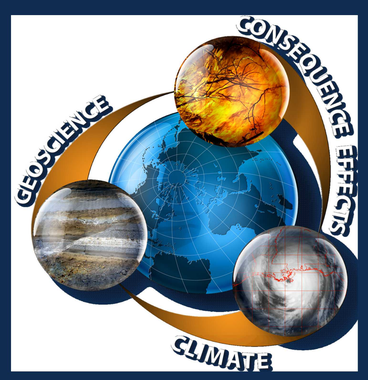
3D macro-scale simulations of correlated geologic texture are consistent with observed statistics of anomalous diffusion in field data.



Beskardes, Weiss and Everett, GJI 2016

Science questions and challenges to be addressed in this work

- At what length/frequency/time scales do the atomistic (brute force) and macroscopic (fractional diffusion) representations converge?
- How can diffusion character behavior at one length scale inform the prediction of behavior at another?
- Define and implement an algorithmic framework for estimation of petro-statistics from observational data.
- Apply the atomistic/macroscopic modeling framework to problems of national interest, such as assessment of energy resources, engineered fracture systems or anthropogenic targets.



Built on LDRD Laboratory Directed Research and Development

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND No xxxxxx

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration