Reconciling Surface Measurements with Ionospheric Measurements

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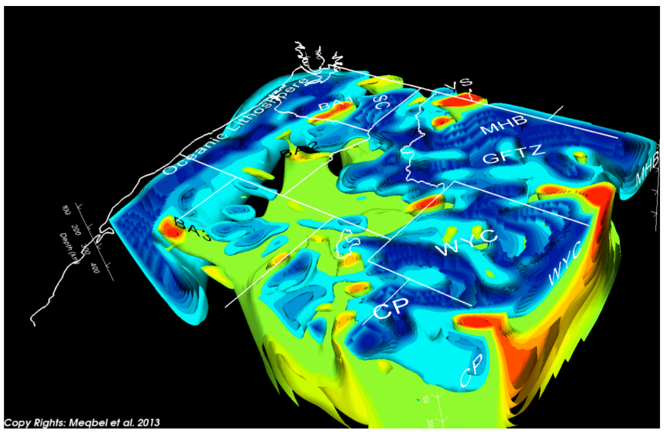
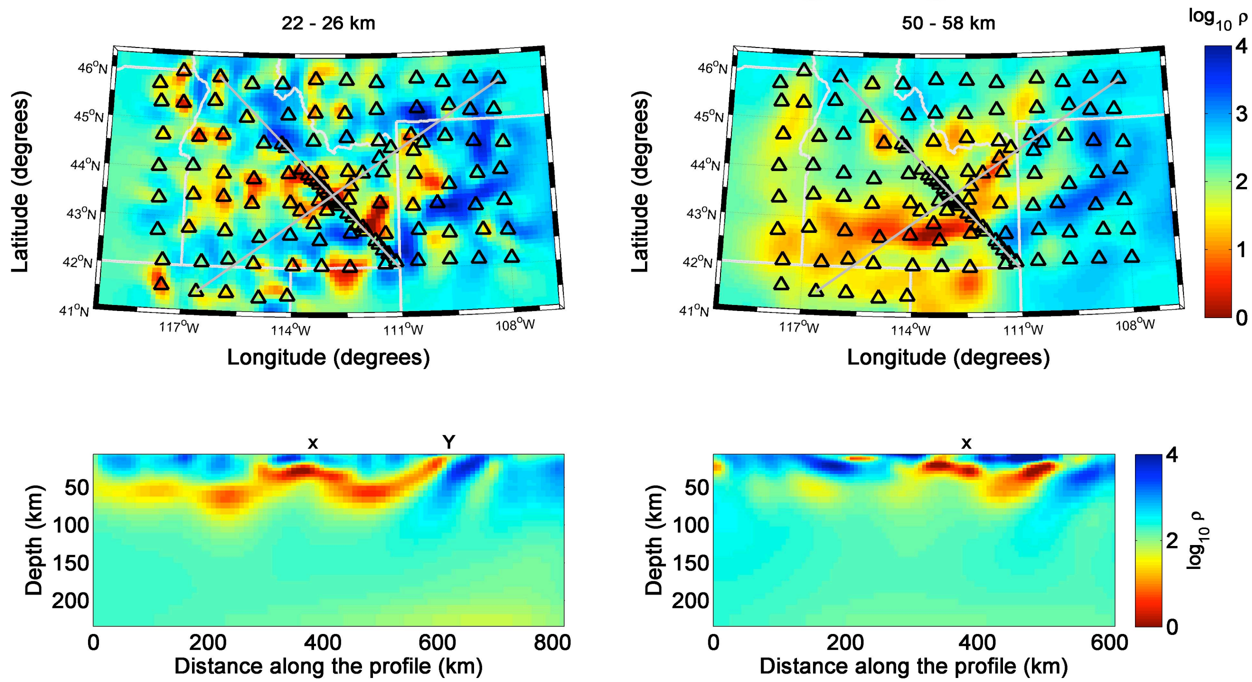
The Problem

* Ground based magnetometers respond to currents in the ionosphere, but also to currents underground.
* Underground currents are induced by ionospheric time-variation within a complex, 3D conductivity structure.
* There is a whole community of Earth scientists who use surface magnetic- and also surface electric-field measurements to image the underground conductivity in 3D.
* We have a project to combine methods and parse out the effects….

3D Conductivity from Magnetotelluric Imaging



(Meqbel et la., 2013)



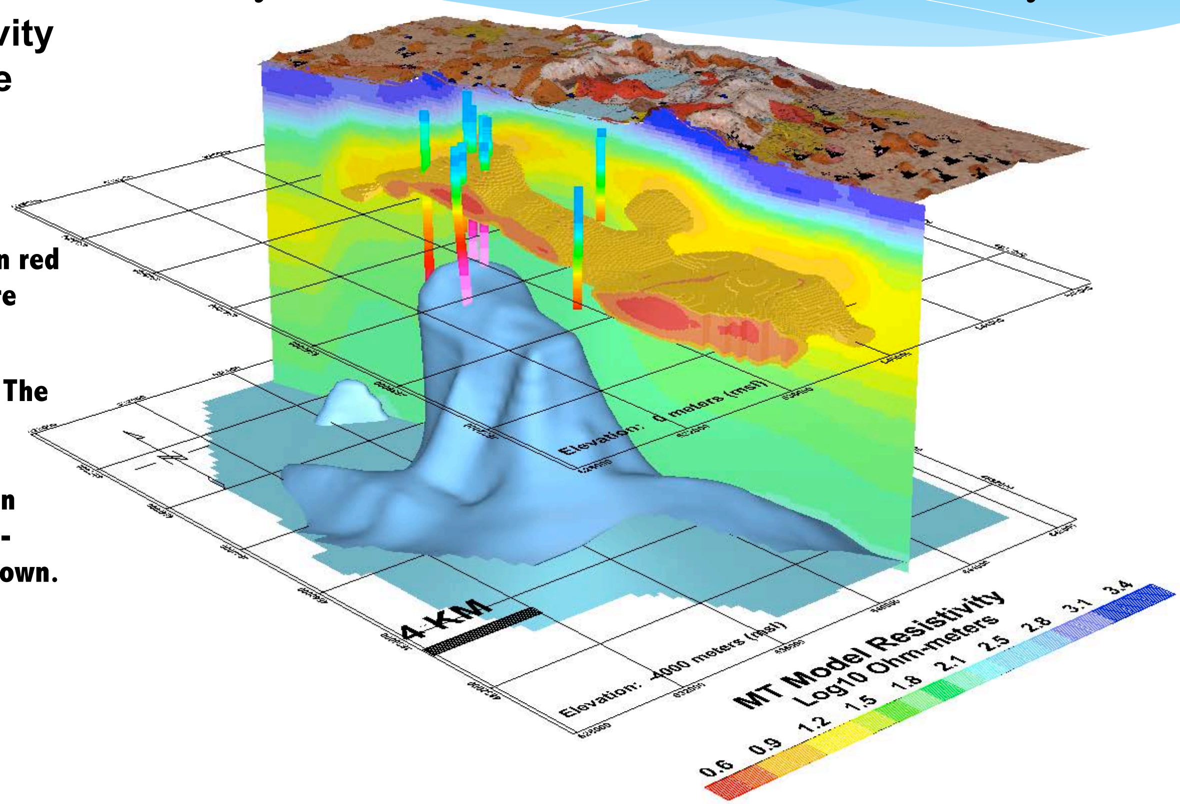
(From keynote talk, 2011 EarthScope National Meeting, Anna Kelbert, Gary Egbert, Catherine deGroot-Hedlin)

Newberry Volcano Enhanced Geothermal System
4D Imaging of Fluid Migration by combined MT/CSAMT, Gravity, Interferometric Radar, Microseismicity

Fine-scale studies reveal several orders of magnitude lateral variations in conductivity in the upper several km of the Earth's crust.

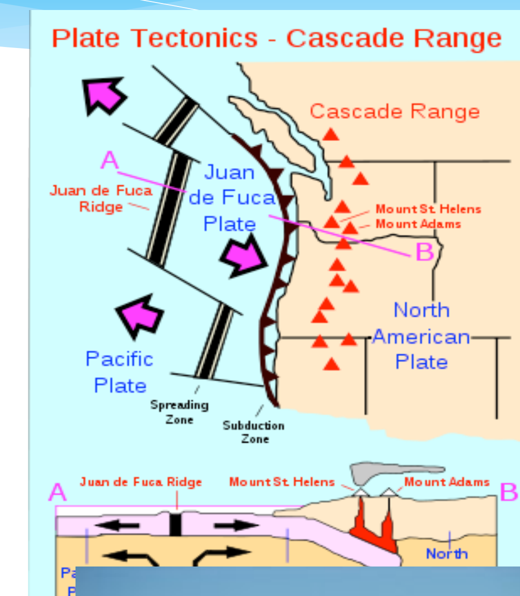
(right) 3D resistivity volume centered on Paulina Lake, Newberry Caldera. Regions in red are highly conductive, and those in blue are highly resistive.

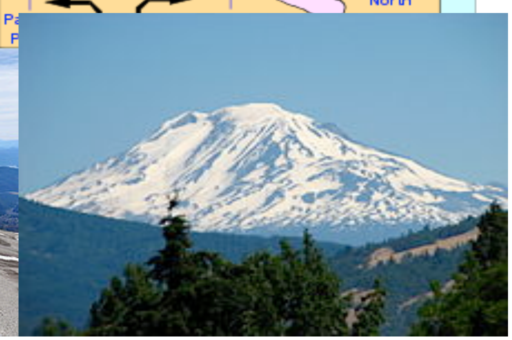
A 100 ohm-m isosurface is also indicated. The grid marked "Elevation: 0 meters (msl)" corresponds to the top of the stimzone. Existing wells are shown including injection well NWG 55-29, which is the directionally-drilled well path furthest west of those shown.



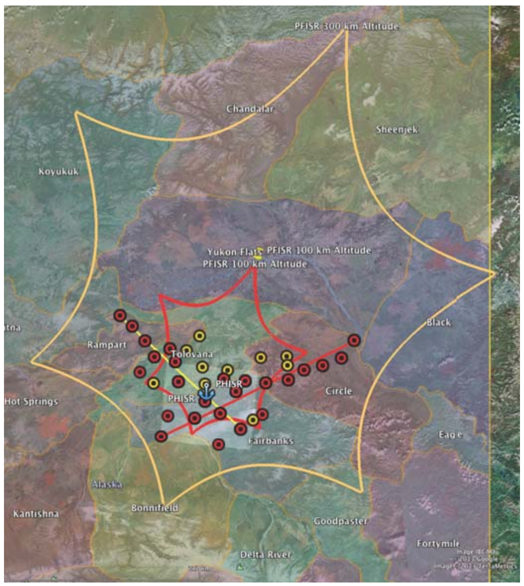
Figures shown with the agreement of Zonge International, Inc and Davenport Newberry Holdings LLC

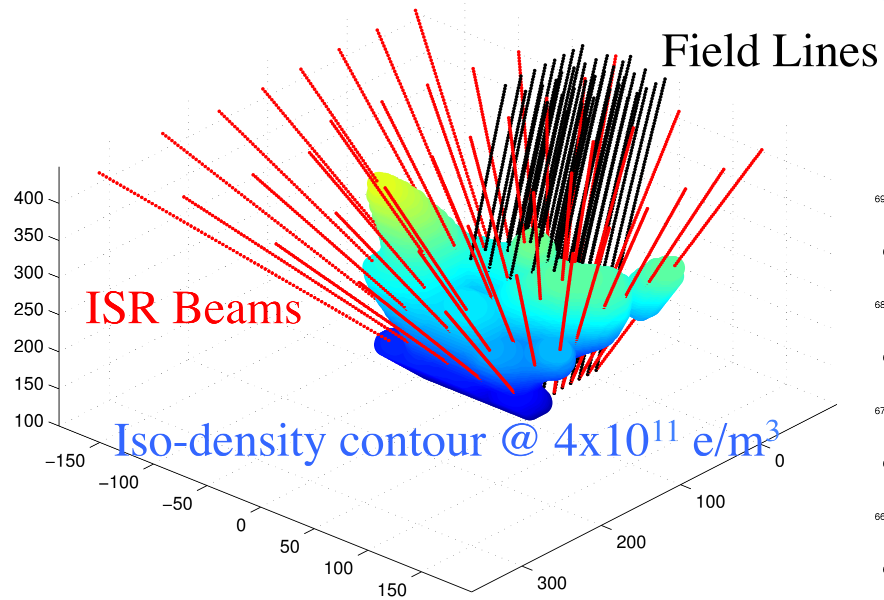
MT FlexArray studies to observe fluids rising up from the subducting Juan de Fuca Plate, and to detect the magma feeding Mt St Helens, Mt Adams and Mt Rainier volcanoes in S WA State

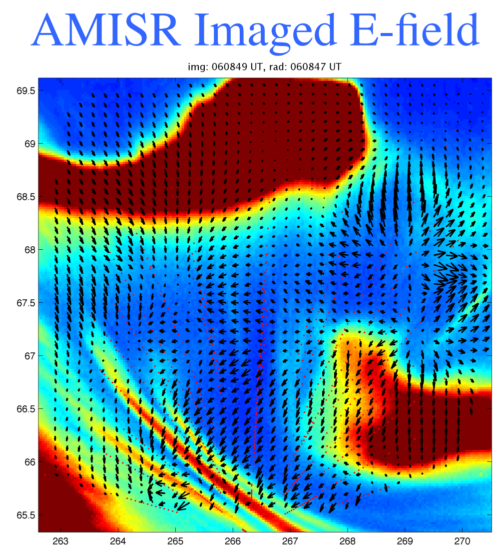




Poker Flat Experiment: Combined AMISR and MT Sensor Array

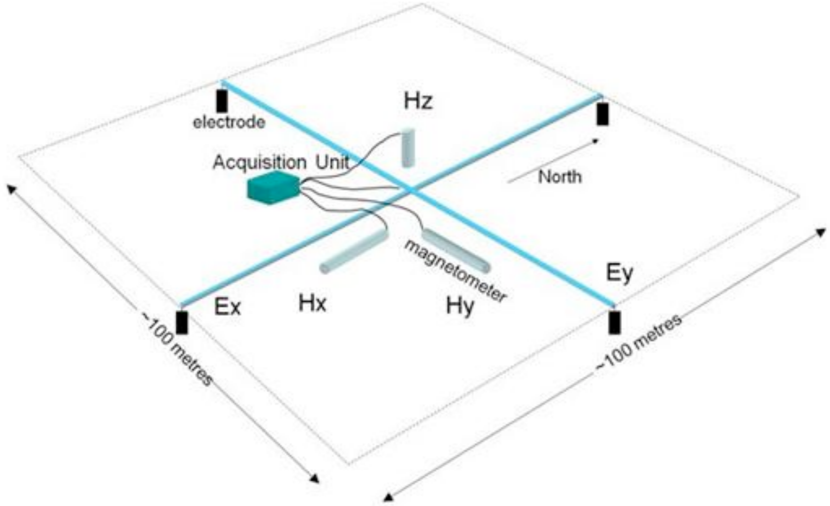


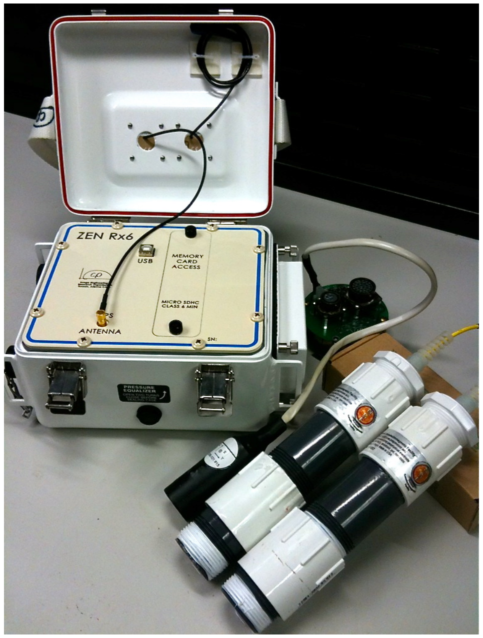




EarthScope MT Array

By measuring the electric and magnetic fields at the Earth's surface due to induced electric currents in the subsurface, we determine the electrical resistivity structure of the **<u>mid-crust</u>** through the **<u>upper mantle</u>**



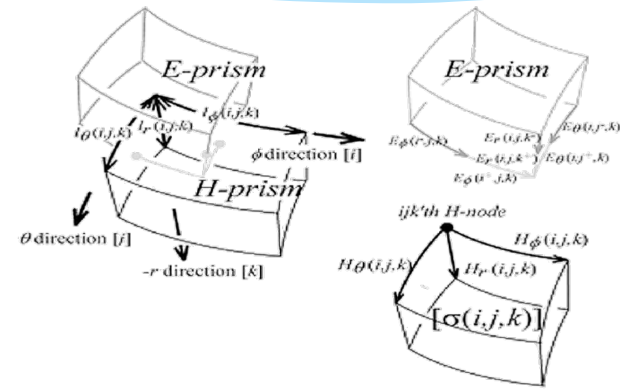


OSU's 3D Spherical/Cartesian Staggered Grid Finite Difference Forward/Inverse Solver

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yz} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix} + \mathbf{U}$$

$$H_z = \begin{bmatrix} T_{x,z} \\ T_{y,z} \end{bmatrix} \begin{bmatrix} H_x & H_y \end{bmatrix} + \mathbf{U}$$

Inputs are measured impedance and transfer functions



Solves integral form of Maxwell's eqns.

$$\oint \mathrm{H} \times dl = \iint J \times dS$$

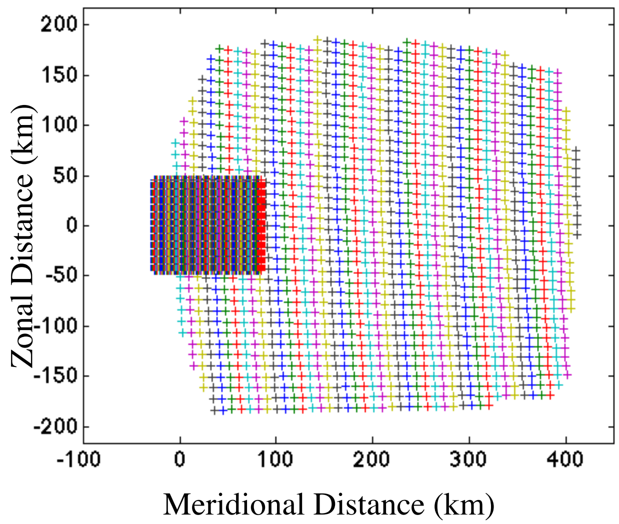
$$\oint E \times dl = -\iint i\omega\mu_0 \mathrm{H} \times dS$$

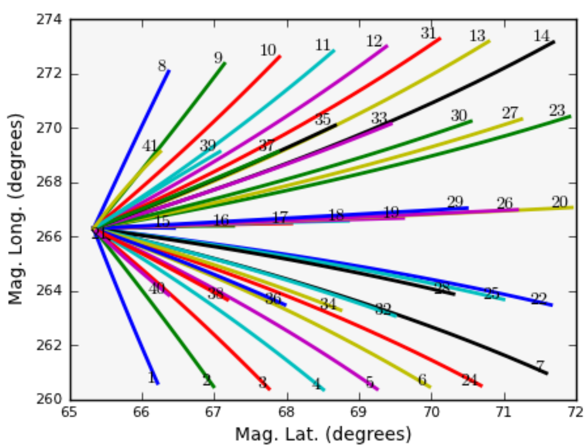
$$J = \sigma E$$

Domain enclosed between core-mantle boundary and upper atmosphere

The large, sparse complex symmetric system of 2nd-order finite difference equations is solved for H or E using biconjugate gradient method (BICSTAB) (Toh, Schultz & Uyeshima, 2002). We also use cartesian grids for regional and local scale MT and electric and magnetic field induction modeling

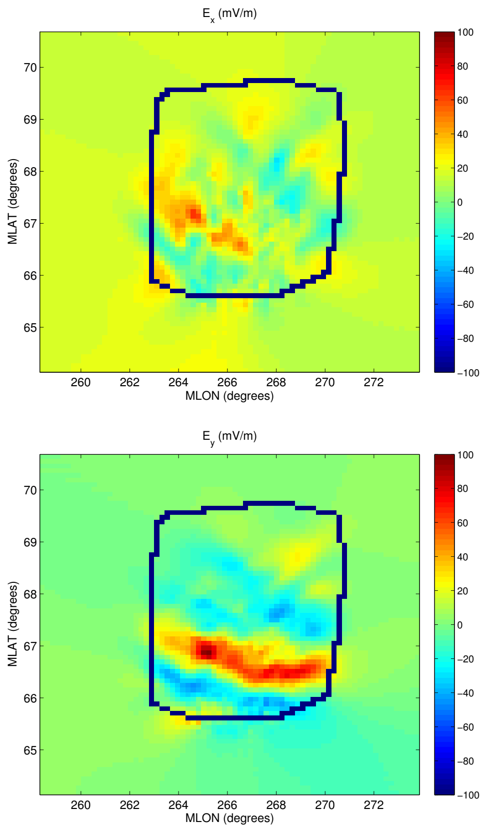
AMISR Imaging Techniques





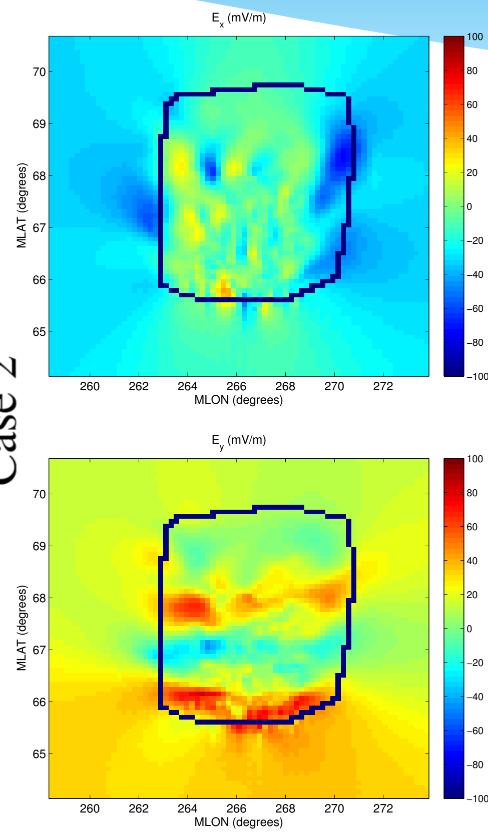
- Define electric field at every point on large grid. Integrated conductivity at every point on small grid.
- The electric field is the unique one that minimizes a chosen function S(E), subject to the constraints that the line of sight velocities are reproduced to within an allowed measurement error, and E is curl free.
- The function S(E) is a measure of curvature and flatness, with parameters that allow balancing the two.
- Within the masked region (shown) curvature is emphasized. Outside, flatness is emphasized, to affect a gradual approach to an unspecified constant boundary.
- This general problem is solved via a Lagrangian, and passing to the dual problem, which is standard optimization theory.

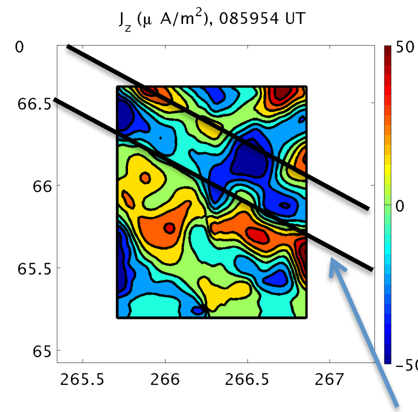
AMISR Imaging Results



Case 1

Case 2





Field aligned current

Upward FAC in arc, downward to south of arc; divergence of E and gradient of conductance both contributing

Reconciliation and Application

- With the underground conductivity distribution known, we should be able to predict the surface measurements from PFISR (with SuperDARN for the background, ASI to help with conductivity, and FPI for winds). Will it work, and if not, what are the implications?
- What is the importance of the local structure?
- What is the influence of the 3D conductivity distribution, and of non-ionospheric currents?
- Is the surface electric field useful for imaging the ionosphere?