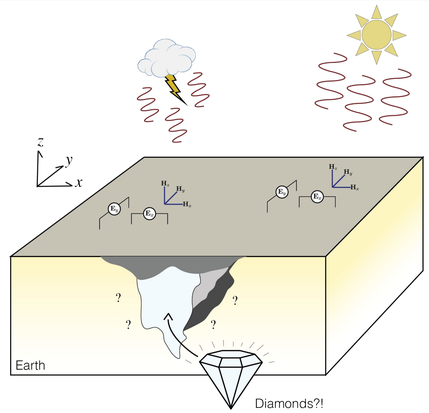
Where are the diamonds? - *using the northern lights*

Thibaut Astic, Guðni Karl Rosenkjær and the SimPEG Team

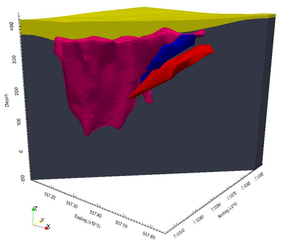
Magnetotellurics

- **Why?** Electrical properties of rocks can be diagnostic for finding diamond-bearing kimberlites
- **How?** Solar wind and lightning generate Natural Source (NS) EM waves that excite currents in the subsurface
- **Response.** EM response depends on the electrical properties of the geologic units, we measure electric and magnetic fields at the earth's surface
- **Goal.** Use MT data to characterize the kimberlite and find some diamonds

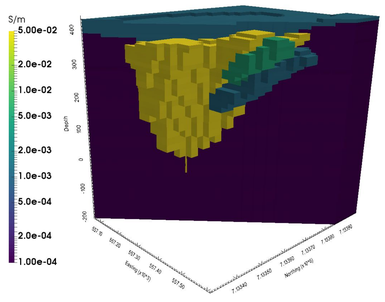


Model

- Diagnostic physical properties in MT
  - Electrical conductivity: ease with which current passes through geologic materials
- Simulation Mesh: Tensor
  - Core cell size: 25m x 25m x 10m
  - 10^5 cells



	Conductivity	Value (S/m)
Host	V. Low	1e-4
Till	Mod	1e-3
PK	High	5e-2
HK	Mod	1e-3
VK	Mod	5e-3



Physics

- Frequency Domain Maxwell's Equations (Quasi-static)

$$\nabla \times \mathbf{E} + i\omega\mathbf{B} = 0$$
$$\nabla \times \frac{1}{\mu}\mathbf{B} - \sigma\mathbf{E} = \mathbf{s}_E$$

- Skin depth (in m)

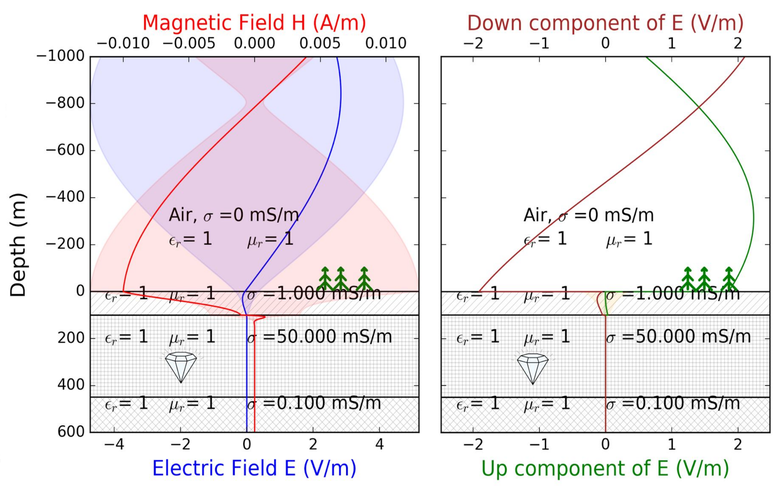
$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \simeq \frac{500}{\sqrt{\sigma f}}$$

- Solve using Primary-Secondary formulation

$$[\nabla \times \frac{1}{\mu}\nabla \times + i\omega\sigma]\mathbf{E}_s = -i\omega\sigma_s\mathbf{E}_p$$

$\mathbf{E_p}, \mathbf{E_s}$: primary and secondary fields
σ_s: secondary conductivity (S/m)

Plane waves propagate through the earth and are damped as they travel through conductive layers.



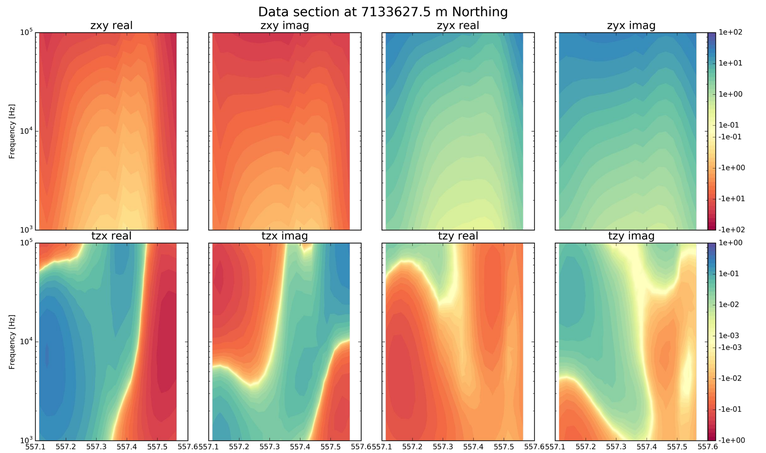
Survey & Data

- Evaluate data on 25x25m grid
  - Total of 475 locations, 16 frequencies, 10^5 to 10^3 Hz
- Data are ratios of the fields:
  - Impedance

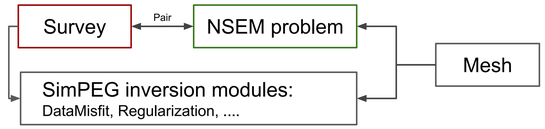
$$\mathbf{Z}(\omega) = \begin{bmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{bmatrix} = \begin{bmatrix} \frac{E_x(\omega)}{H_x(\omega)} & \frac{E_x(\omega)}{H_y(\omega)} \\ \frac{E_y(\omega)}{H_x(\omega)} & \frac{E_y(\omega)}{H_y(\omega)} \end{bmatrix}$$

  - Tipper

$$\mathbf{T}(\omega) = \begin{bmatrix} T_{zx}(\omega) \\ T_{zy}(\omega) \end{bmatrix} = \begin{bmatrix} \frac{H_z(\omega)}{H_x(\omega)} \\ \frac{H_z(\omega)}{H_y(\omega)} \end{bmatrix}$$



Inversion Implementation



Use SimPEG inversion framework

- For the NSEM problem need to implement
  - Sources, Receivers and Data (Survey)
  - Numerical systems and derivatives (Problem)

Run inversions for

- Off-diagonal components: Z_{xy}, Z_{yx}
- Tipper components: T_{zx}, T_{zy}

Both with

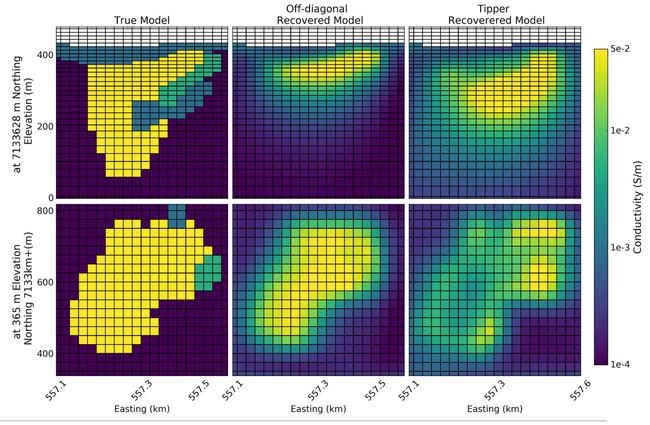
- 5% uncertainties plus a noise floor
- Tikhonov regularization

Goal: Recover conductivity models that fit the data to the level of uncertainty.

Results

Recovered 3D conductivity models from:

- **Impedance**
  - Top and sides of the diamond bearing PK unit are outlined well
  - Below the conductor, model is poorly resolved
    - Signals decays through conductor
- **Tipper**
  - Sides of the PK unit less well resolved
  - Recovered conductive body extends deeper



Summary

Off-diagonal and tipper data are inverted using **`SimPEG.NSEM`**. Both recovered conductivity models image the targeted conductive pipe at depth with different resolutions, giving us a trajectory for our diamond-hunt and an opportunity for exploring joint or cooperative inversion of both data sets.

simpeg.xyz github.com/simpeg @simpegpy gif.eos.ubc.ca