Summary and the Future

Roadblocks

In general, geoscientists…

- Don't realize that EM can play a role in solving the problem
- Don't understand the technique
  - Confusing terminology
  - Seems complicated and unintuitive

What is the connection between my problem and the physical properties?

So many types of surveys, how to choose?

- DC, frequency, time?
- Surveys in air on ground, downhole?
- What to expect for resolution?

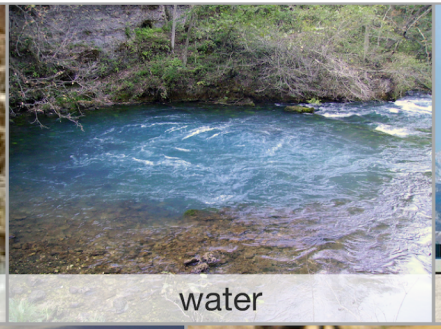
Are there situations, similar to mine, in which EM has been applied?

Many applications

Electromagnetics can be used for …


minerals


contaminants


water


geothermal

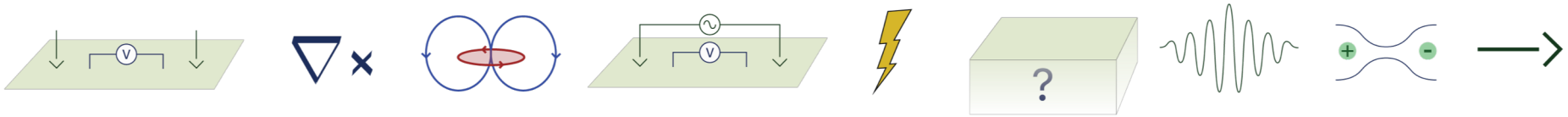

geotechnical


slope stability


hydrocarbons


unexploded ordnance

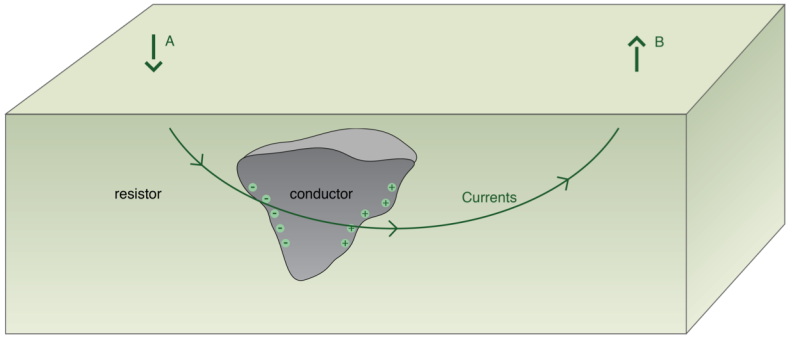
Summary



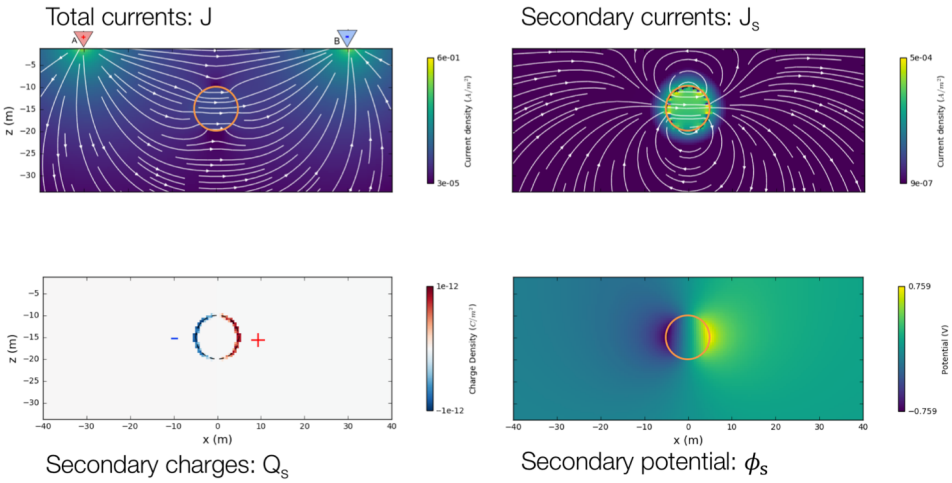
DC Resistivity | EM Fundamentals | Inductive Sources | Grounded Sources | Natural Sources | Inverse Theory | GPR | Induced Polarization | The Future

DC Resistivity

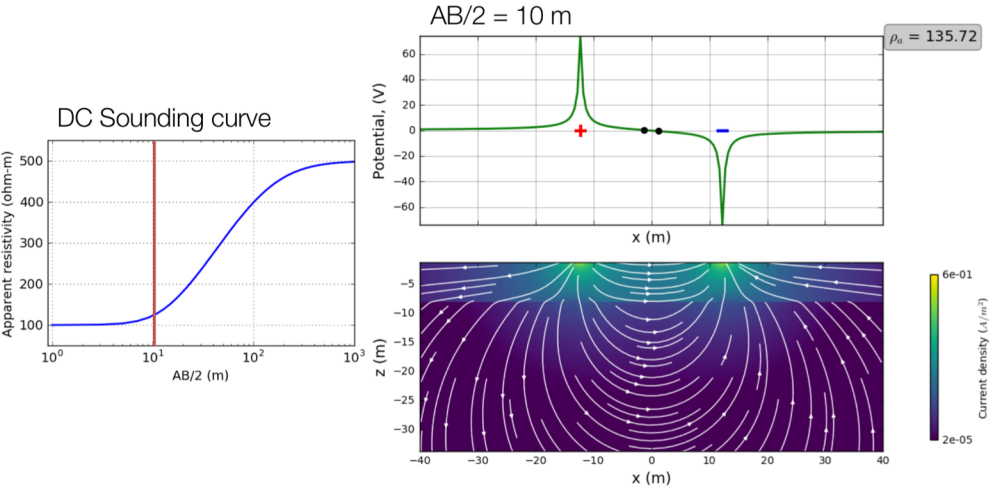
Basic experiment



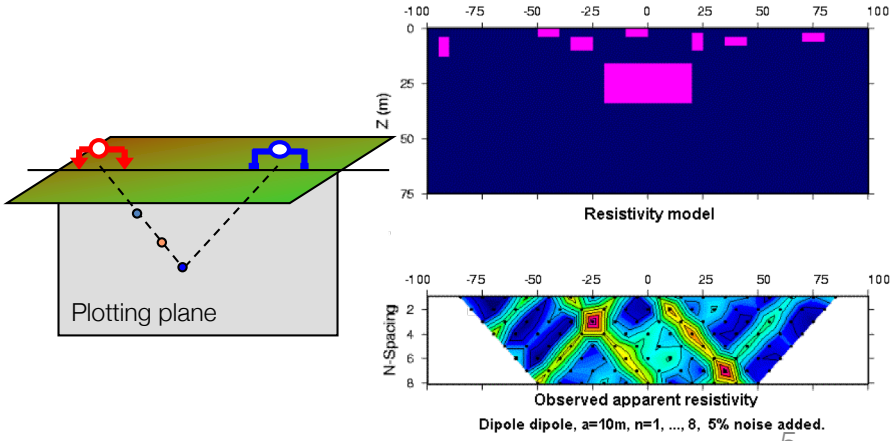
Currents, charges and potentials



Soundings and arrays

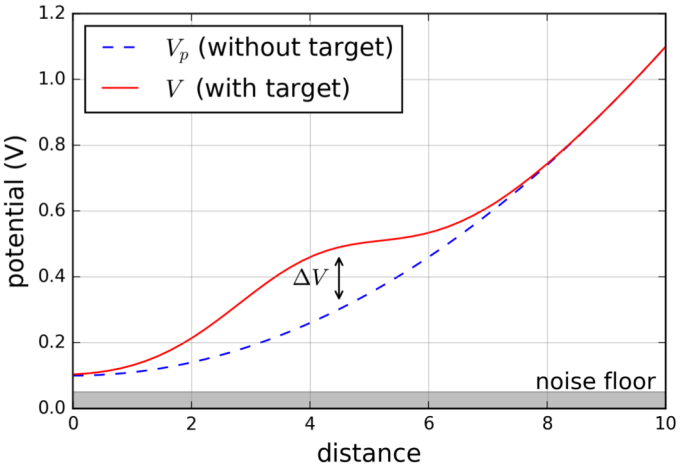


Pseudosections

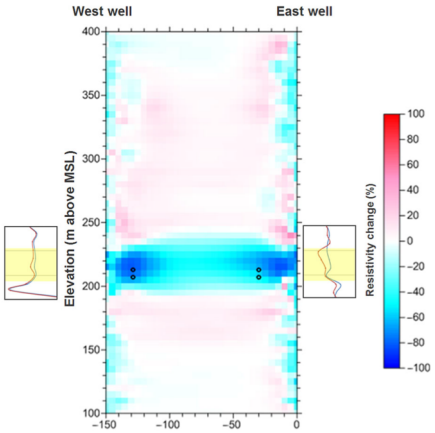


DC Resistivity

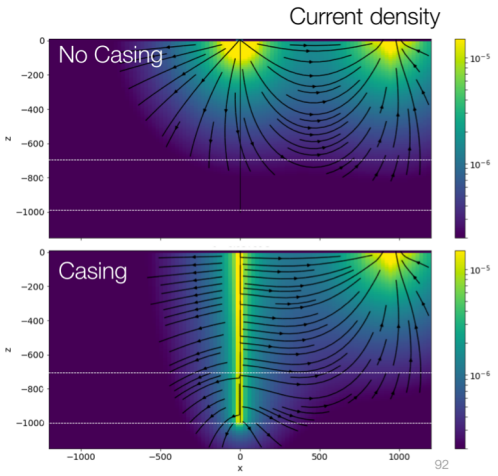
Survey design and sensitivity



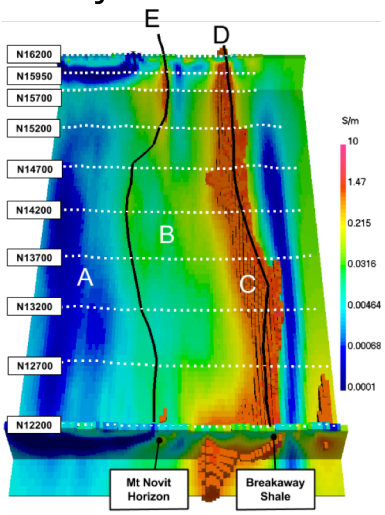
Case History: Reservoir Monitoring



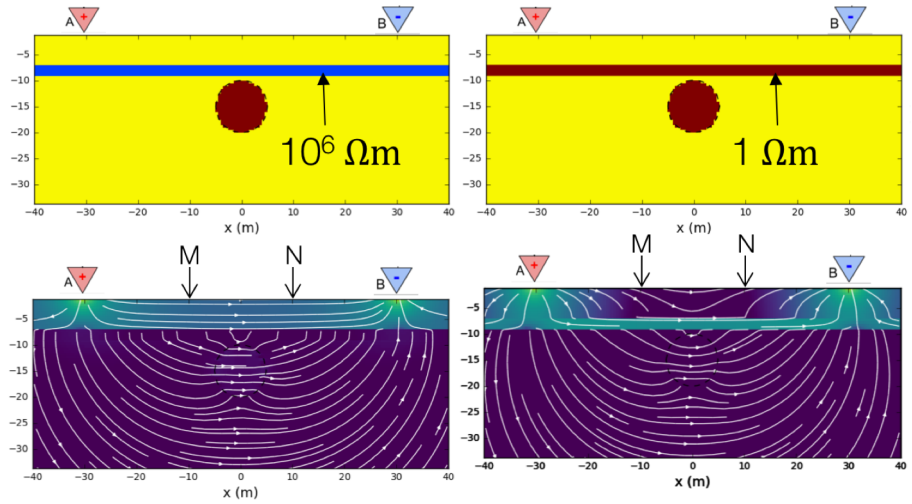
DC with steel cased wells



Case History: Mt. Isa

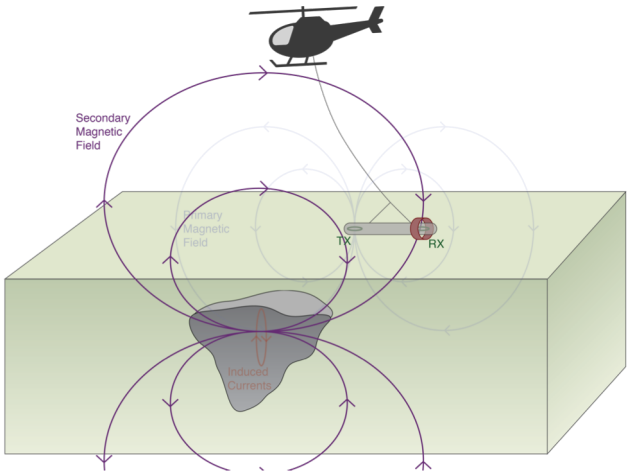


Shielding

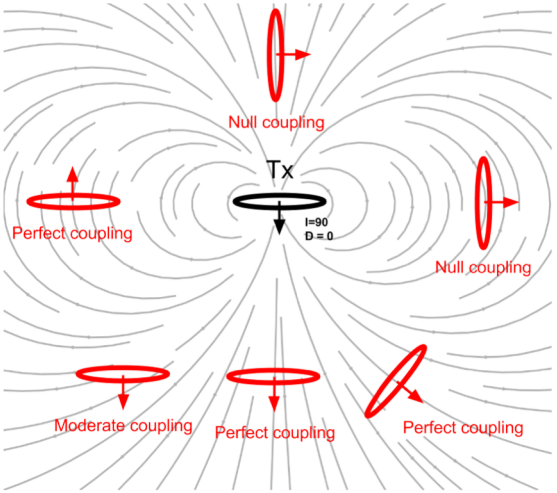


EM Fundamentals

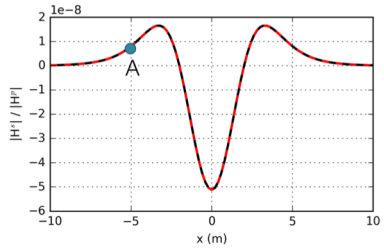
Basic experiment

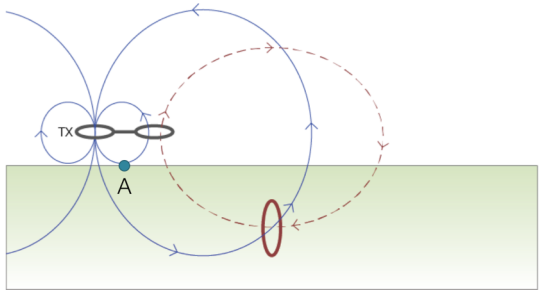


Coupling

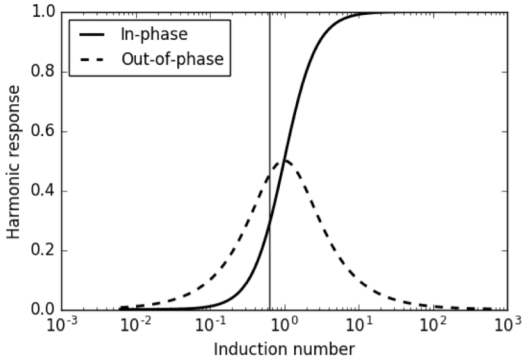


3 loop model

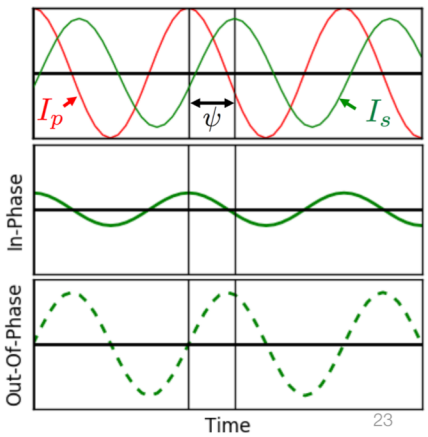




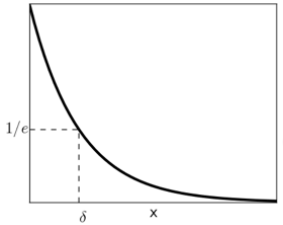
Response function



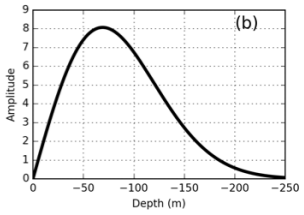
$$\alpha = \frac{\omega L}{R}$$



Skin depth and diffusion distance



$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = 503\sqrt{\frac{1}{\sigma f}}$$

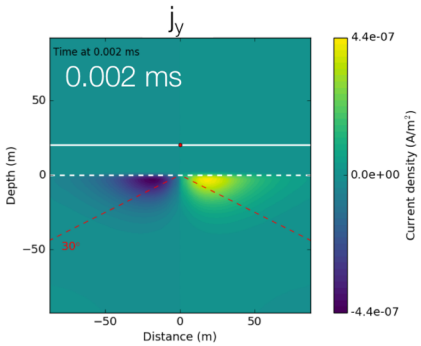


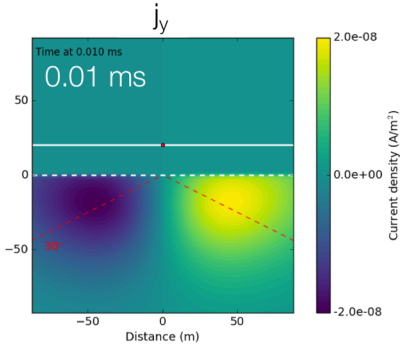
$$d = \sqrt{\frac{2t}{\mu\sigma}}$$

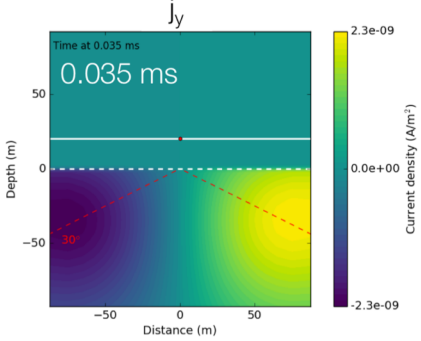
$$\approx 1260\sqrt{\frac{t}{\sigma}}$$

EM Fundamentals

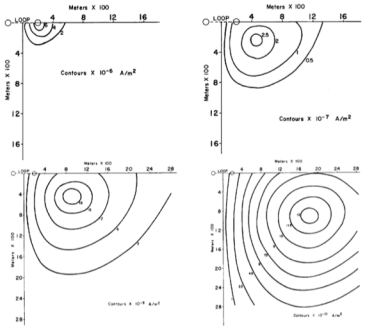
Dipole sources



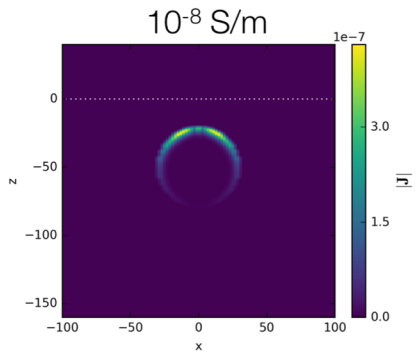


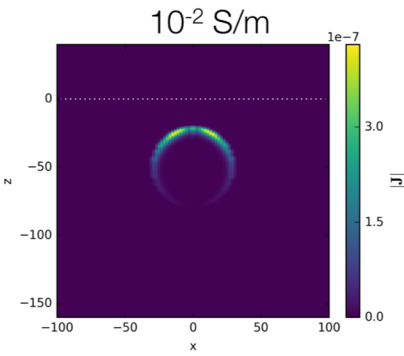


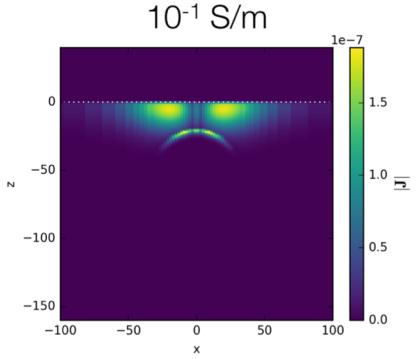
Nabighian (1979)

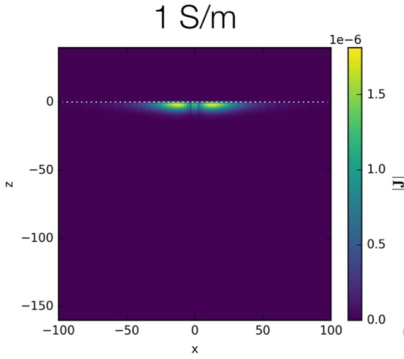


Background conductivity



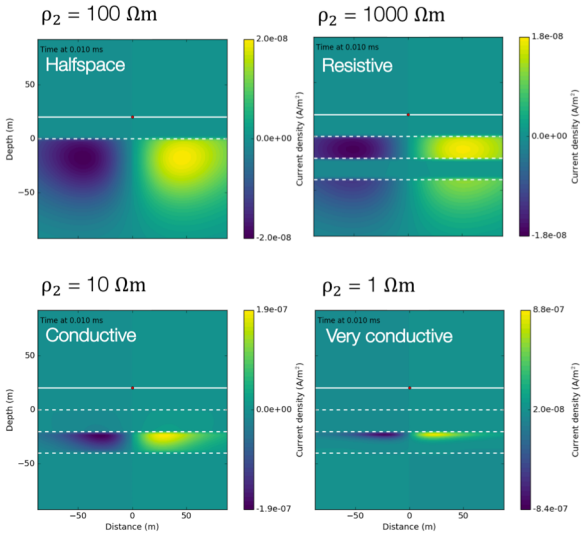




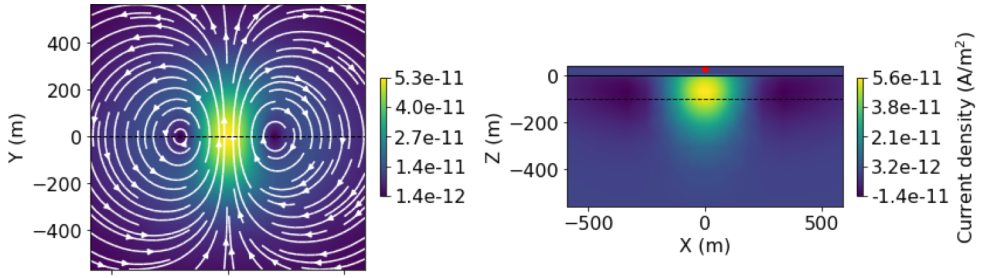


Inductive Sources

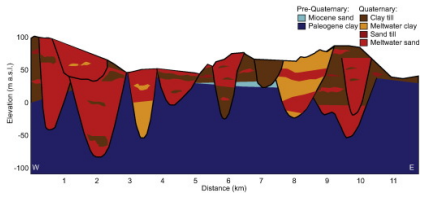
VMD over a layered earth



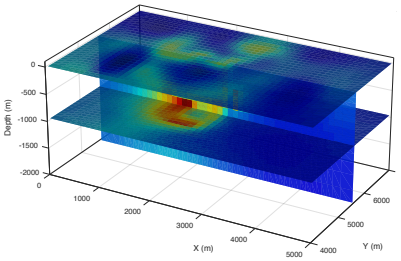
Horizontal magnetic dipole



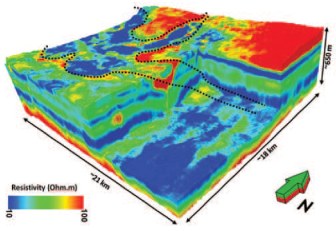
Kasted



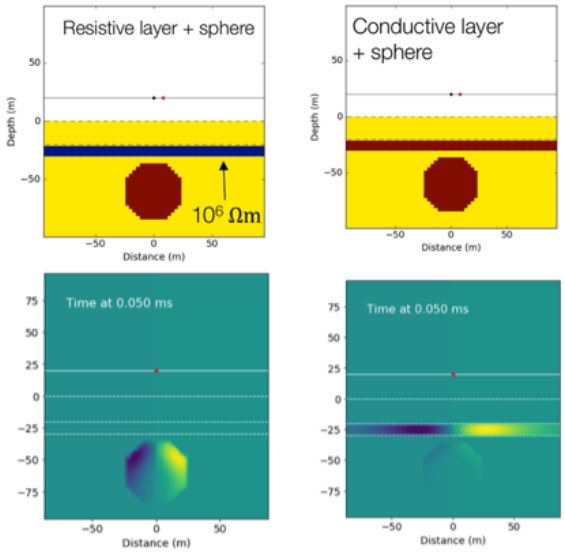
Lalore



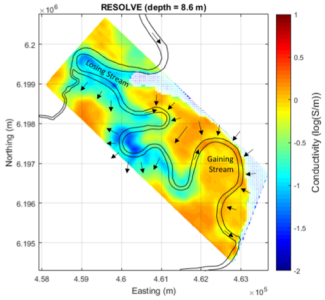
Wadi Sahba



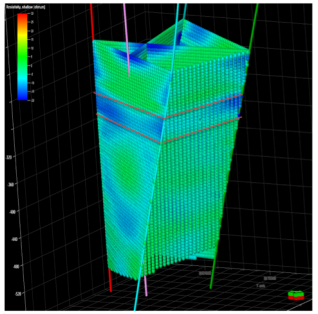
Shielding



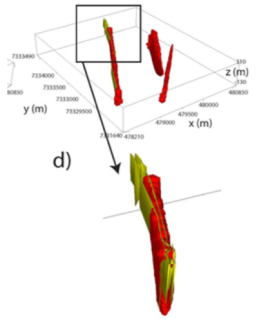
Bookpurnong



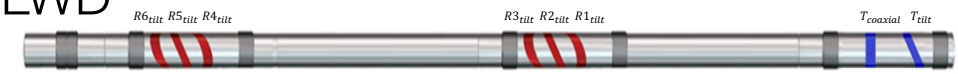
Dom João



Westplains

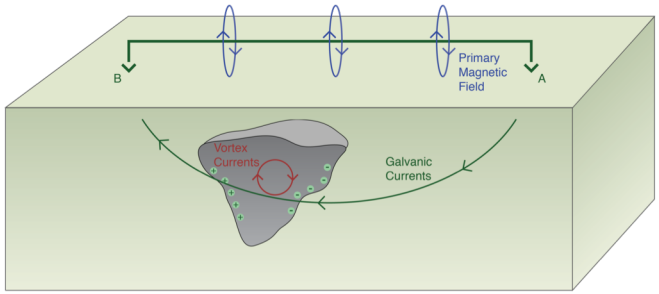


LWD

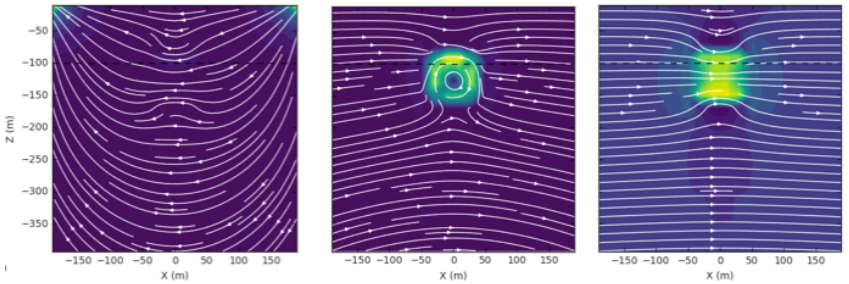


Grounded Sources

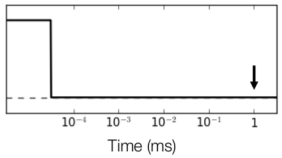
Basic Experiment



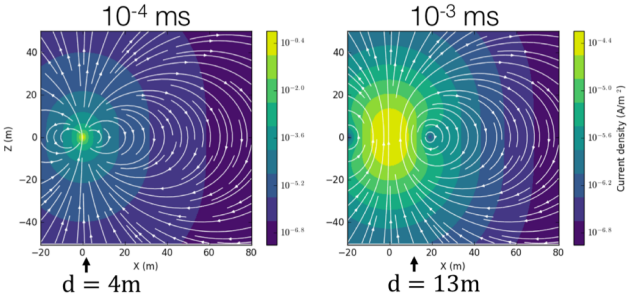
Grounded sources with a target



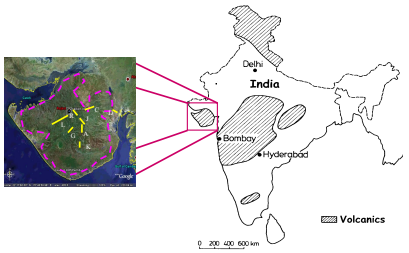
Electric dipole in a wholespace



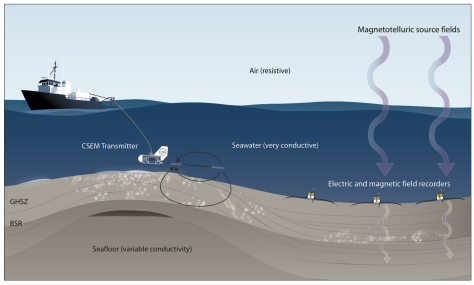
Diffusion distance $d = \sqrt{\frac{2t}{\mu\sigma}}$



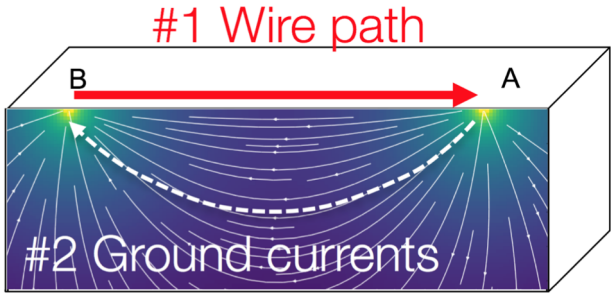
Deccan Traps



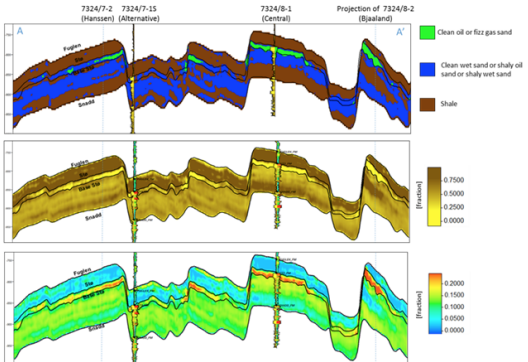
Marine CSEM



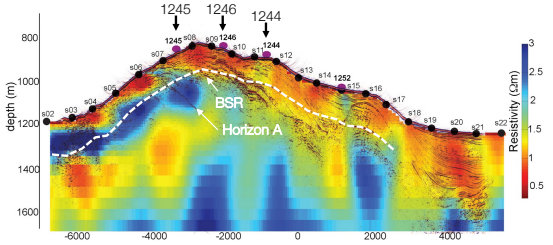
Currents in a TDEM experiment



Barents Sea

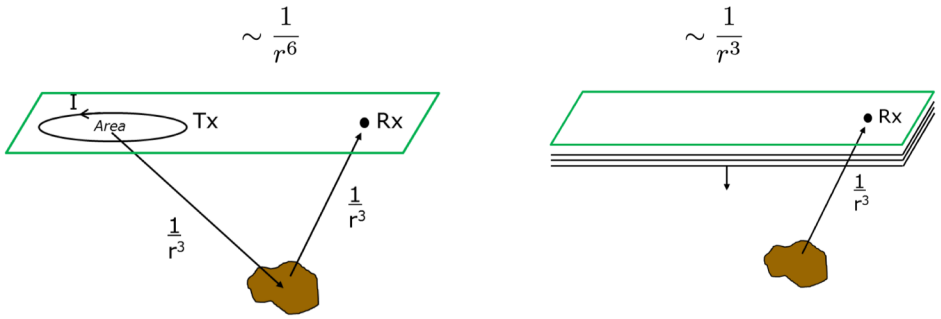


Hydrate Ridge

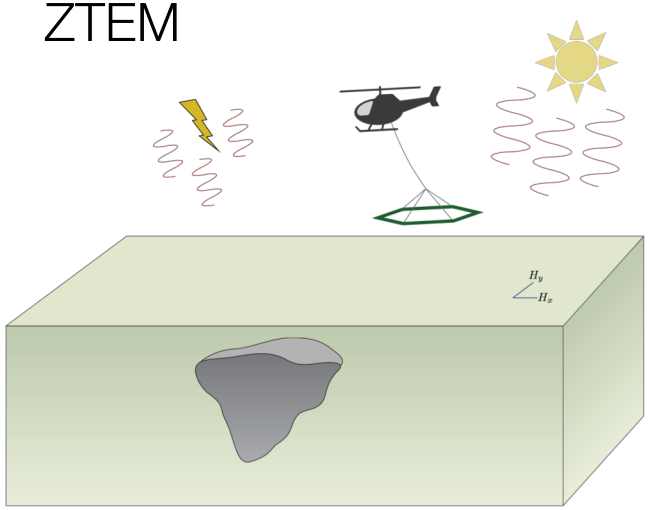


Natural Sources

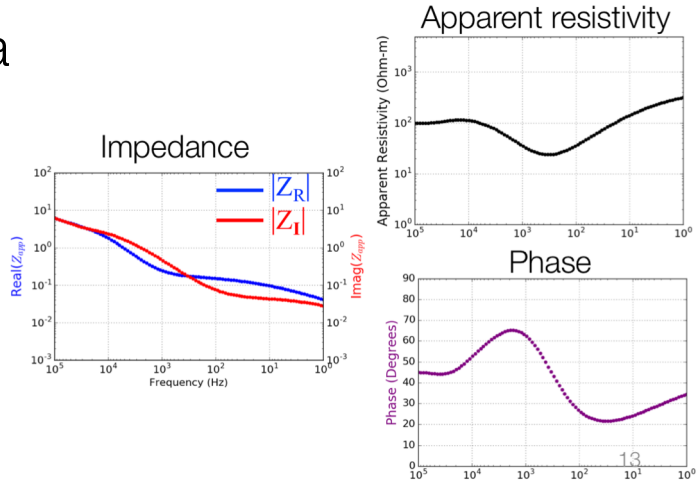
Seeing deeper



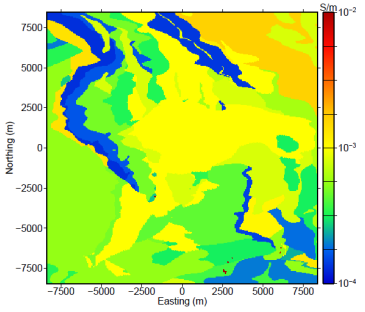
ZTEM



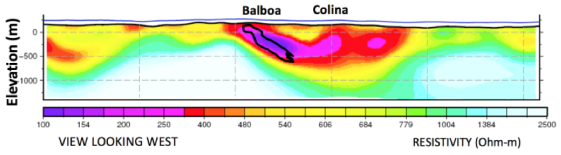
Data



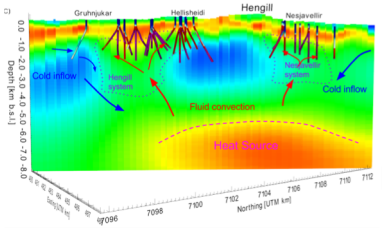
Noranda



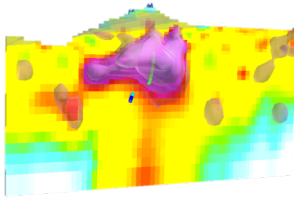
Balboa



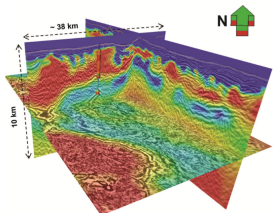
Hengil



Santa Cecilia

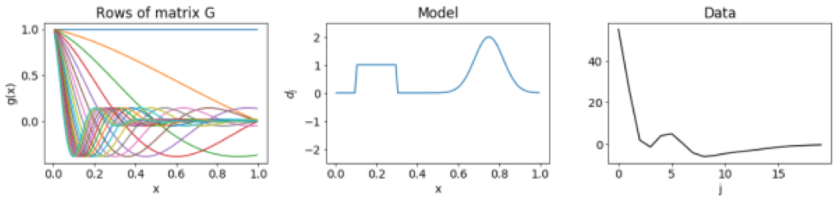


Red Sea

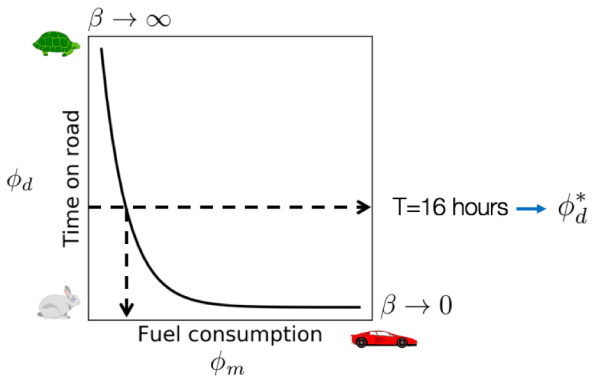


Inverse Theory

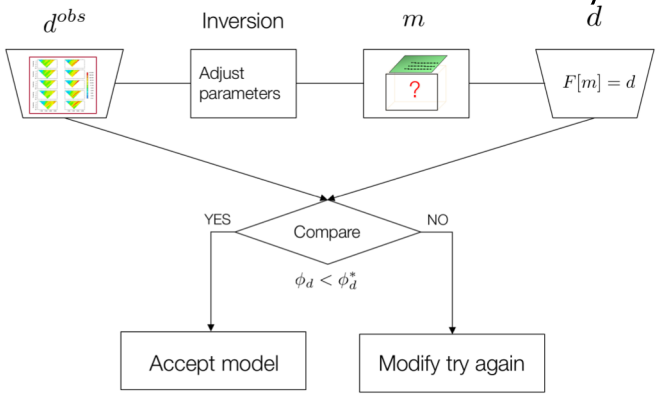
Linear problem



Tikhonov curve

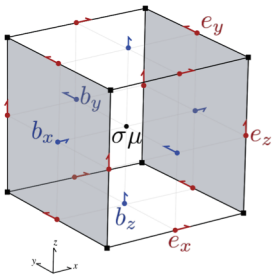


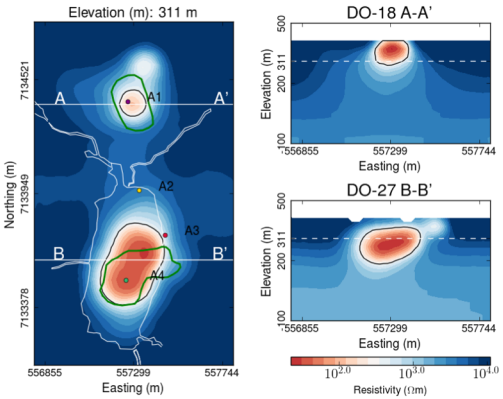
Inversion with misfit only



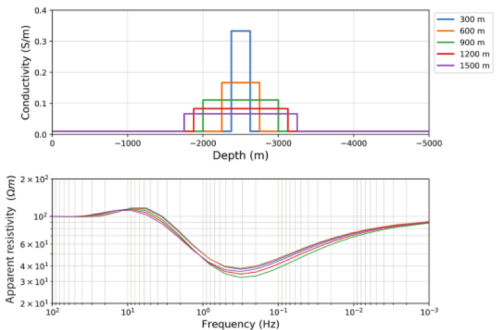
$$\phi_d = \sum_{j=1}^{N} \left(\frac{d_j - d_j^{obs}}{\epsilon_j} \right)^2$$

Modelling Maxwell's equations & Non linear inversions

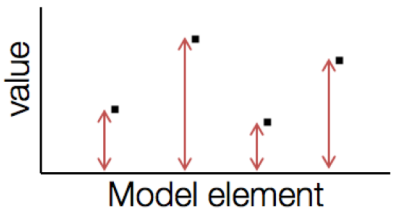




Non-uniqueness

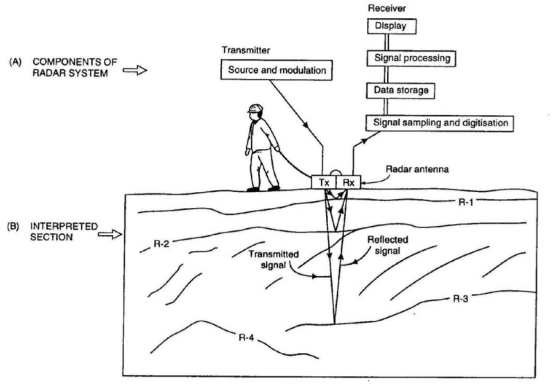


Model norms

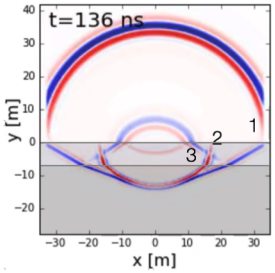


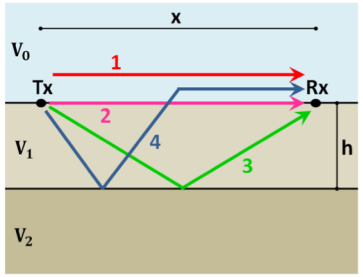
Ground Penetrating Radar

Basic Experiment

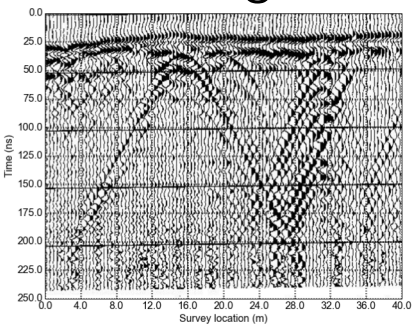


Waves and Rays

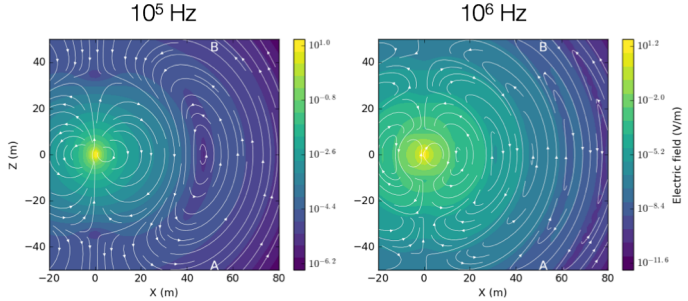




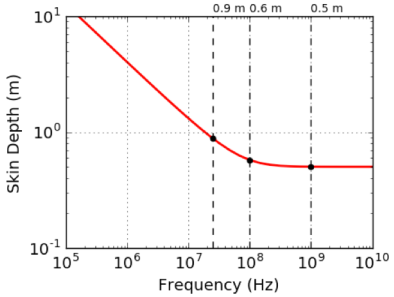
Radargrams



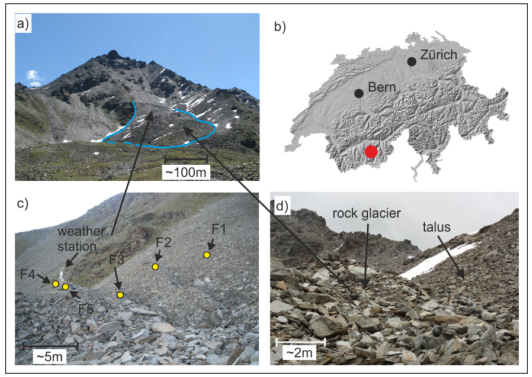
Electric dipole in a wholespace



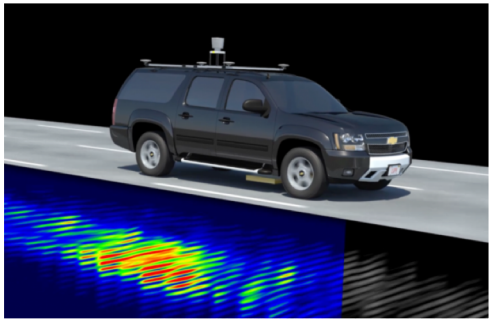
Attenuation



Rock Glaciers

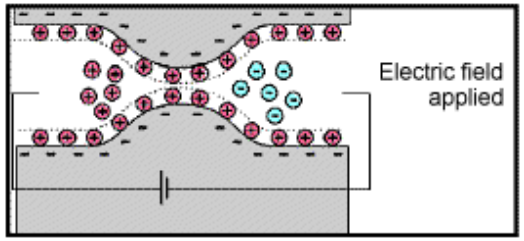


Driverless Cars

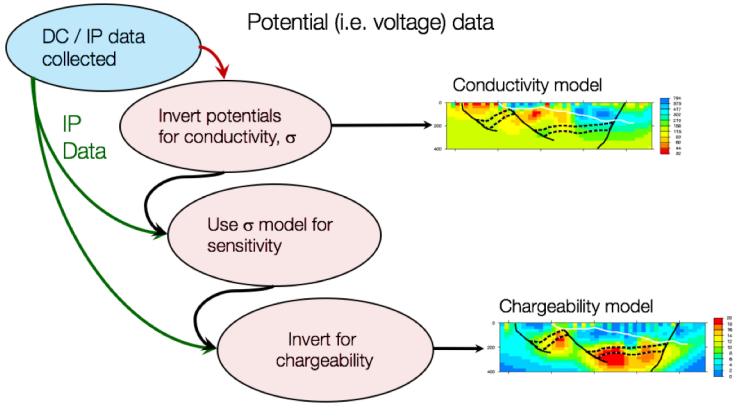


Induced Polarization

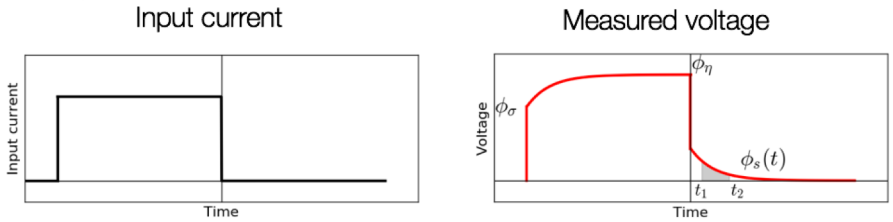
Conceptual model



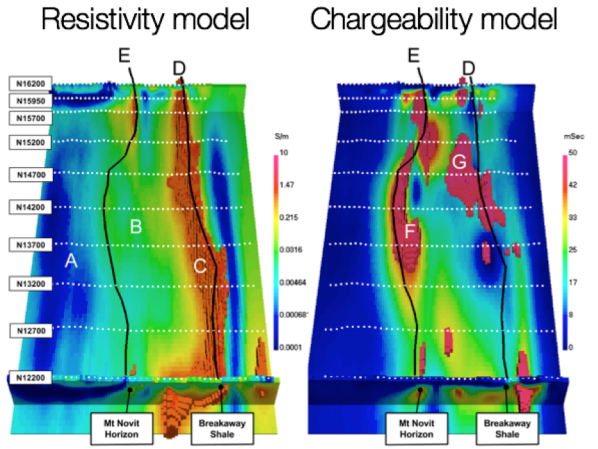
IP inversion



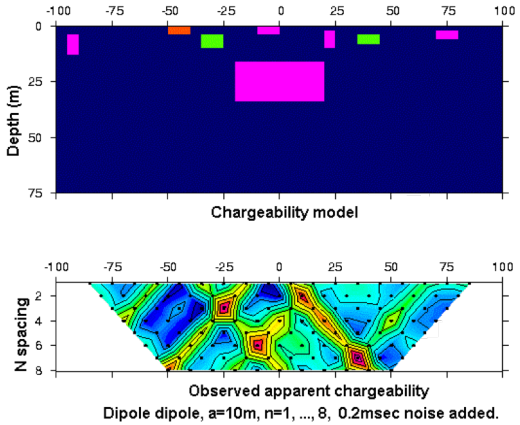
IP data



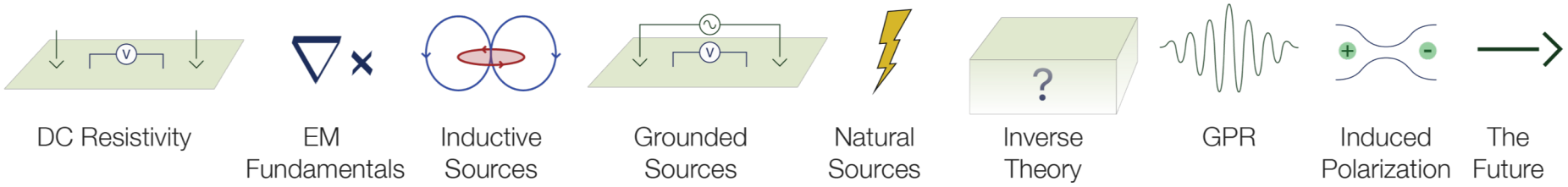
Mt Isa



Pseudosections



Summary


V
?
V
DC Resistivity
EM Fundamentals
Inductive Sources
Grounded Sources
Natural Sources
Inverse Theory
GPR
Induced Polarization
The Future

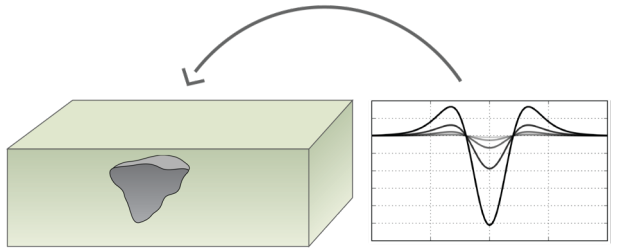
What does the future hold?

What does the future hold?

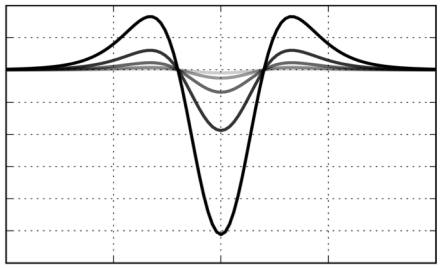
What does the future hold?

Problems

Inversion capabilities



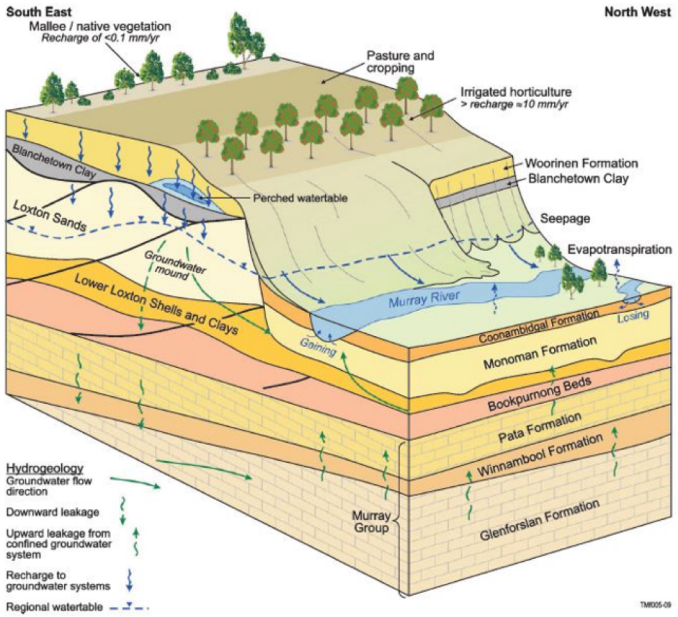
High quality data



Web tools to communicate

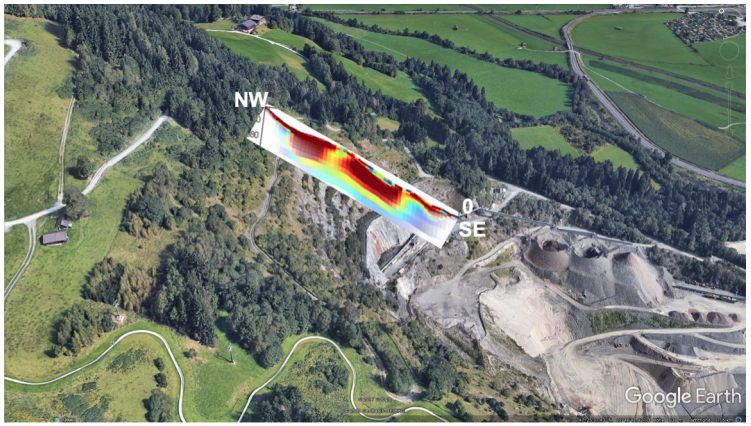
The Future: Monitoring

- Dam integrity
- Slope stability
- Aquifers
- Coal seam gas
- Enhanced oil recovery



Mt. Polly tailings dam collapse

Water infiltration and slope stability

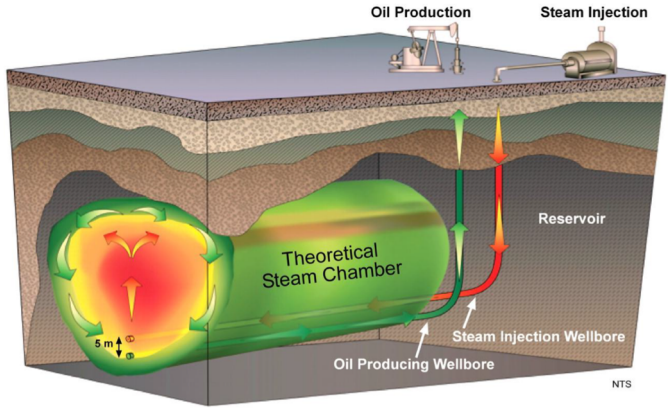


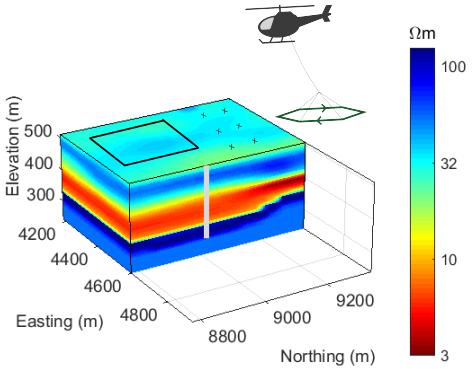
Florian Bleibinhaus

Monitoring: Choosing the appropriate survey

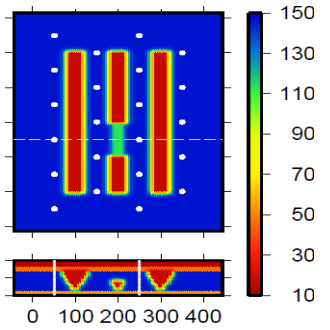
Different EM surveys needed to answer different questions

SAGD (Injection and monitoring steam flooding)

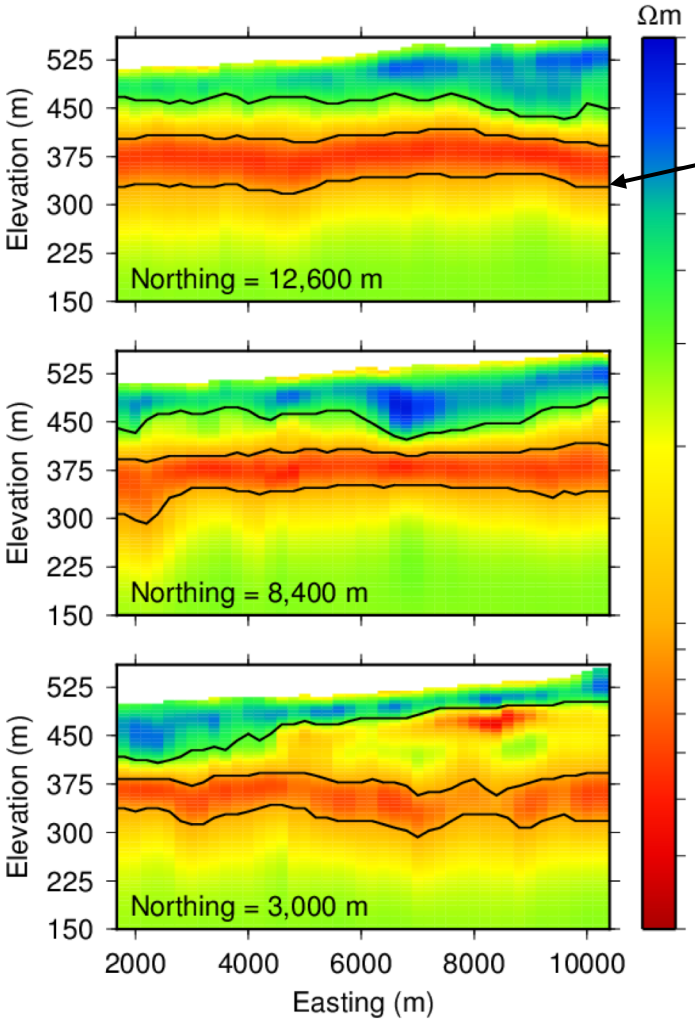




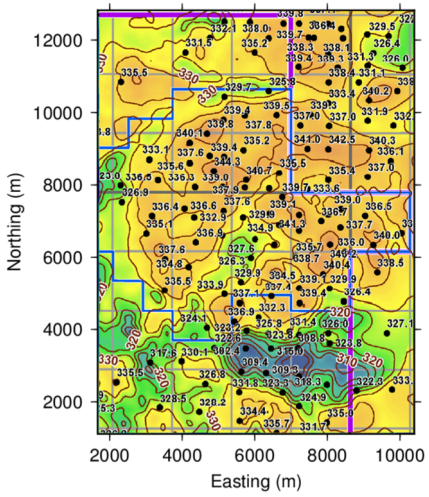
- Stage 1: Airborne reconnaissance survey
- Stage 2: Surface and borehole for pre-injection
- Stage 3: Monitoring array



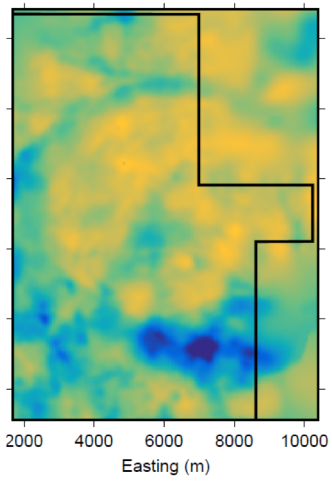
Large scale reconnaissance (SAGD)



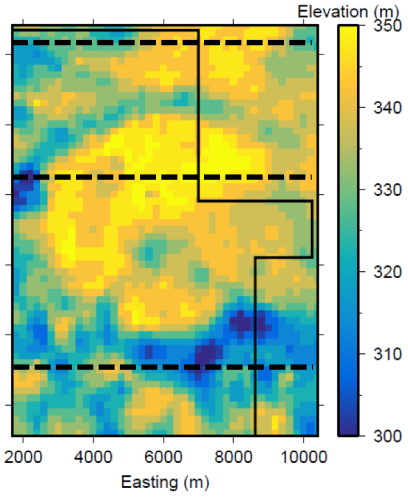
Boreholes



Boreholes (interpolated)

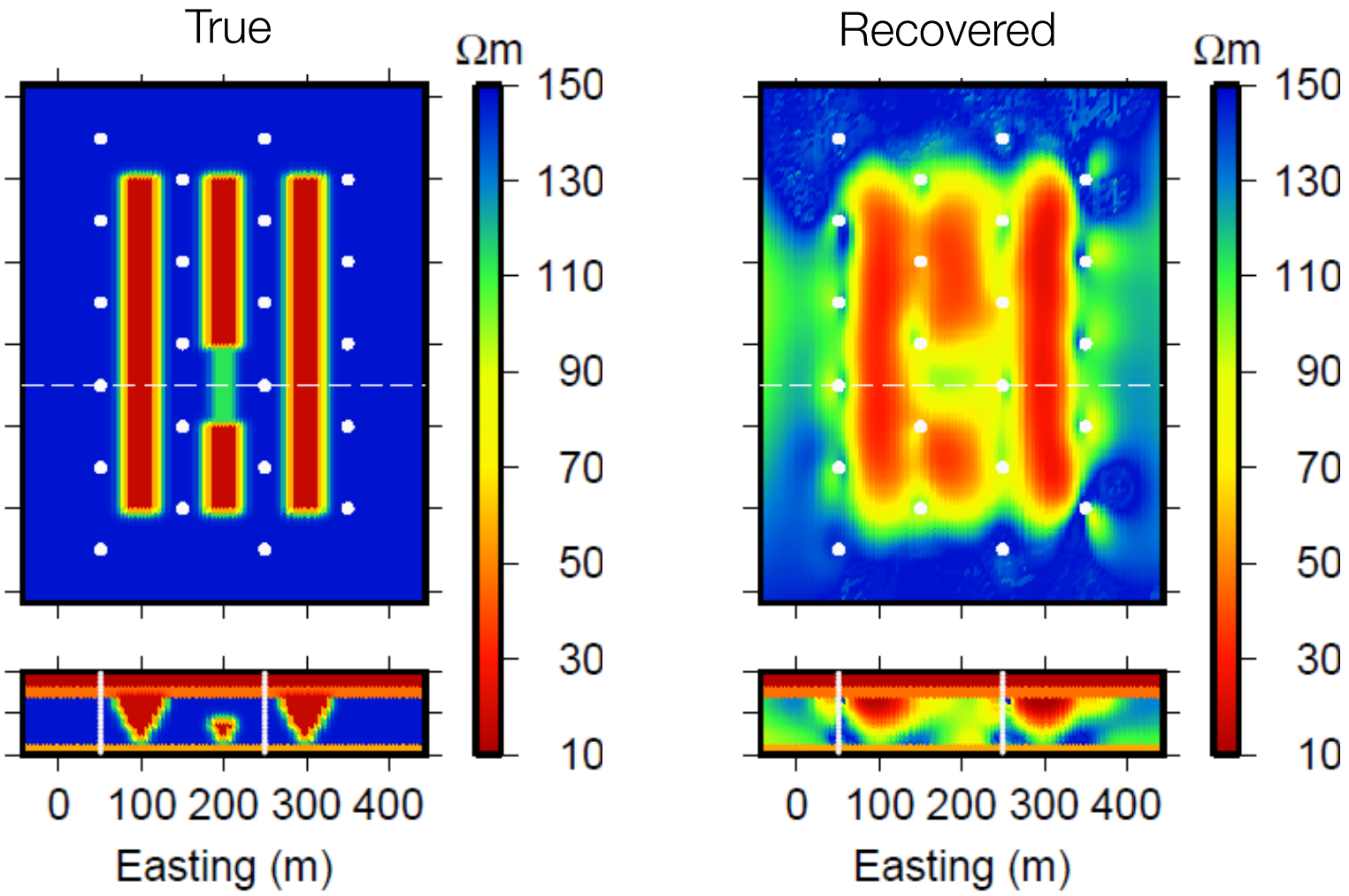


Airborne EM



Multi-stage EM for monitoring

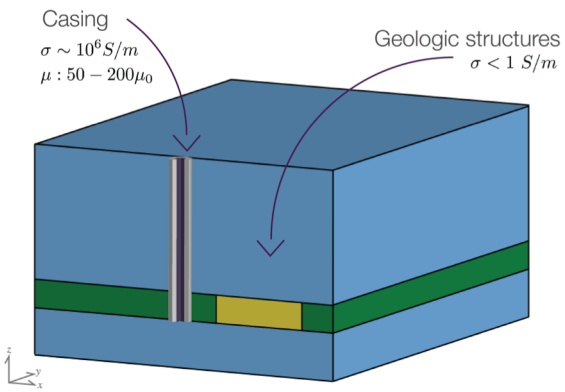
Post-injection: surface sources, borehole receivers



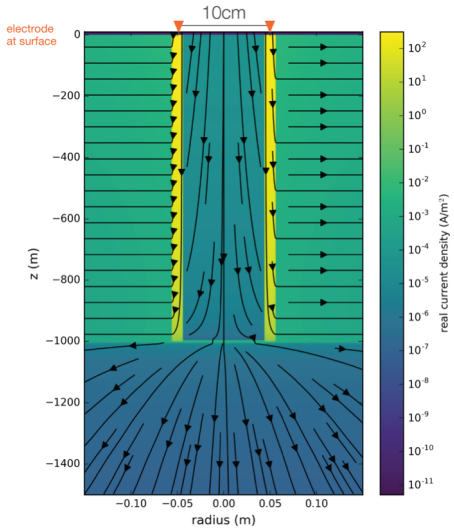
The Future: Large Contrasts

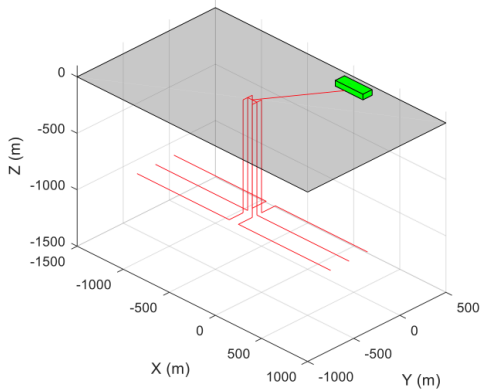
- Conductivity contrasts
- Permeability contrasts
- eg. Steel Casing
  - Mechanism for getting current to depth
  - Challenges:
    - Scales
    - Physical properties

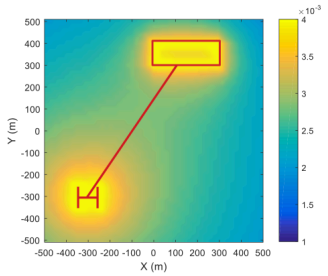
eg. Sudbury basin

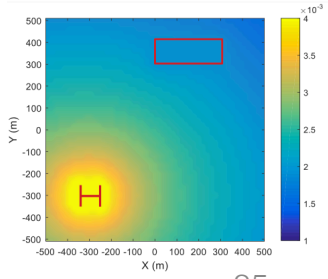


Corrosion



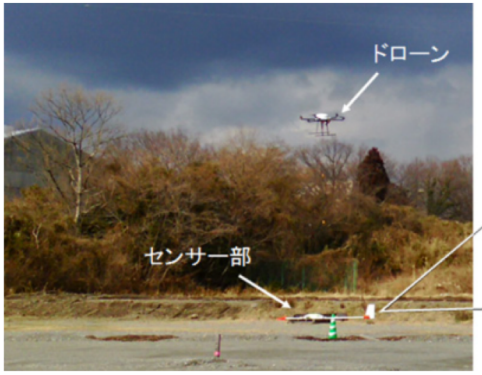


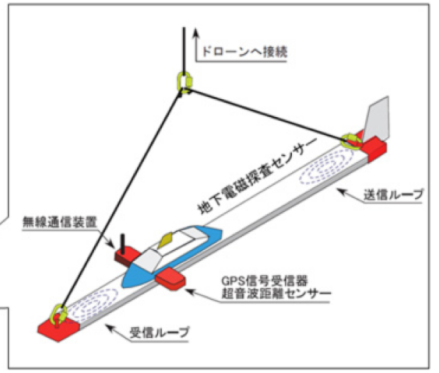


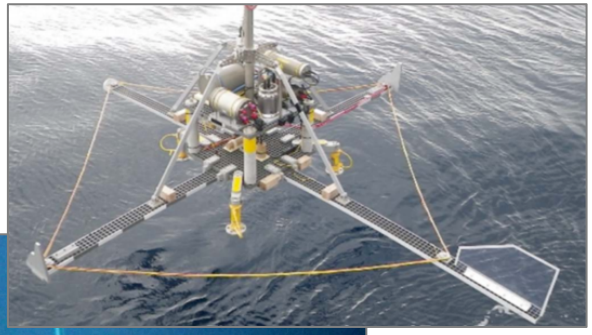


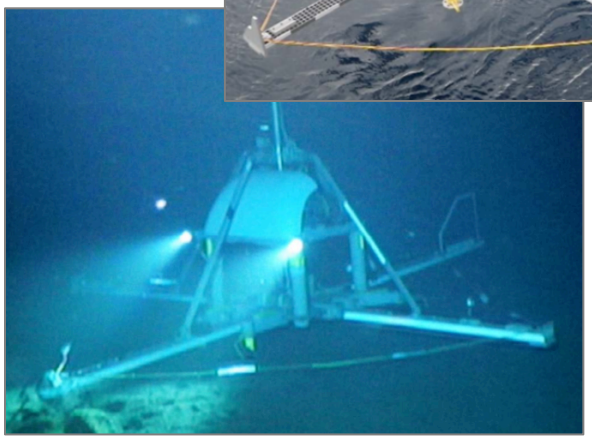
The Future: High Quality Data

- Improved instrumentation
  - Lower noise
  - More power
  - Better control on transmitters and receivers
    - Current waveform
    - Filtering parameters
    - Position and orientation
    - Higher sampling rates
    - …
- Data collection
  - Drones
  - AUVs
  - ROVs
- Mathematical modelling requires that we know all the details.



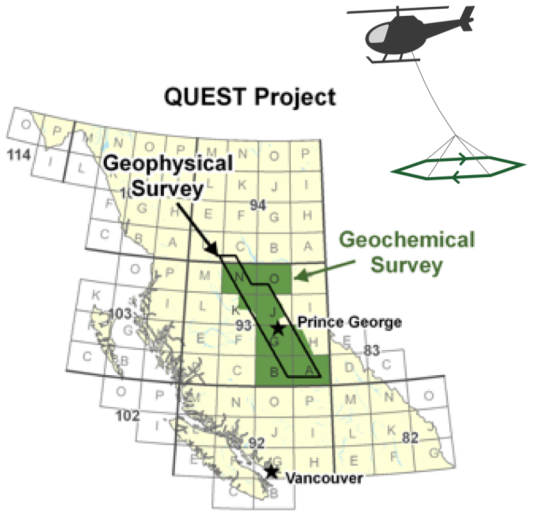


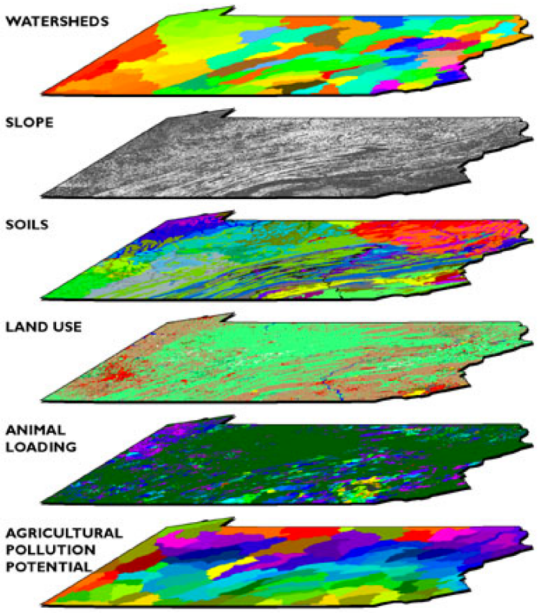




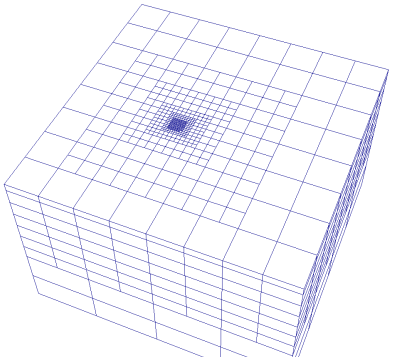
The Future: Lots of Data

- Big data
  - Multicomponent receivers
  - Many transmitters, receivers
  - High sampling rates
  - Large areas
- Multiple types of data
  - geophysical surveys
  - Physical properties
  - Geochemistry
  - Geology
  - …
- Machine learning

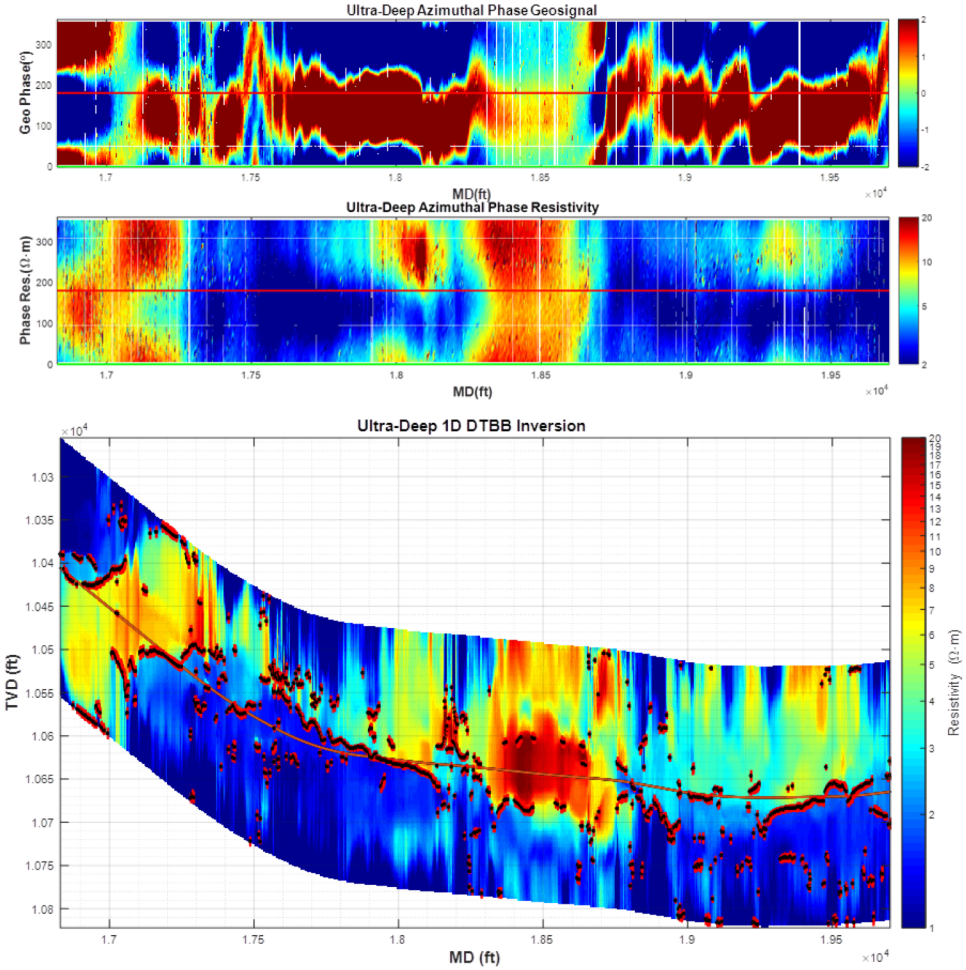




Real-time 3D inversions



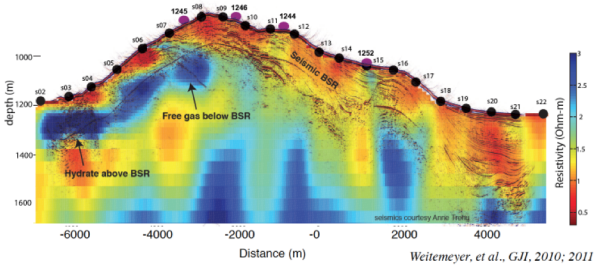
Logging while drilling



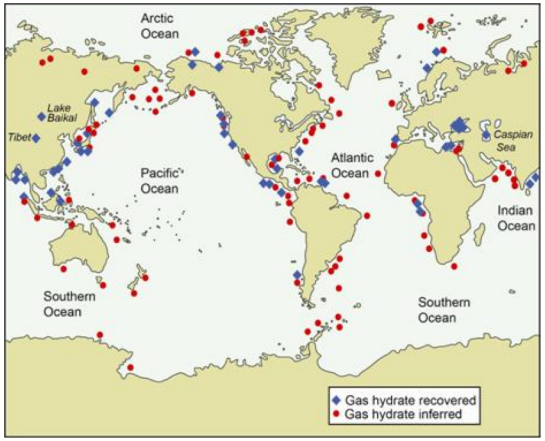
Tunnel boring machines

The Future: Marine EM

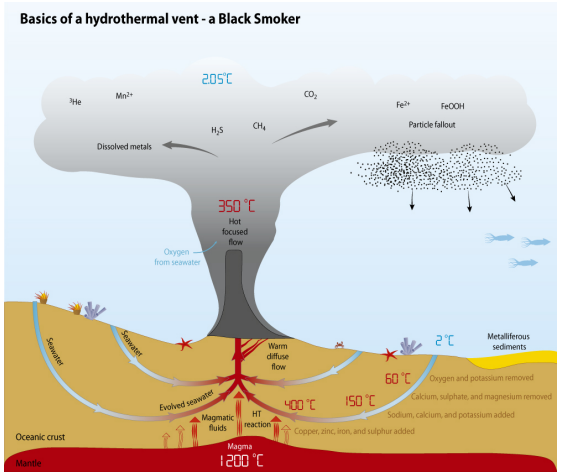
Gas hydrates

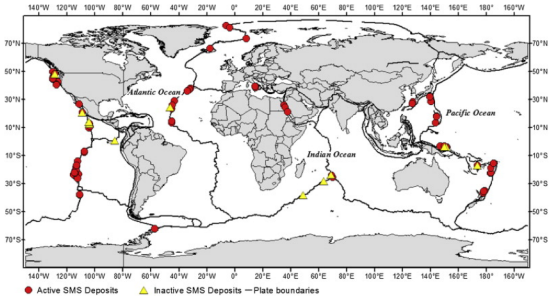


Weitemeyer, et al., GJI, 2010; 2011

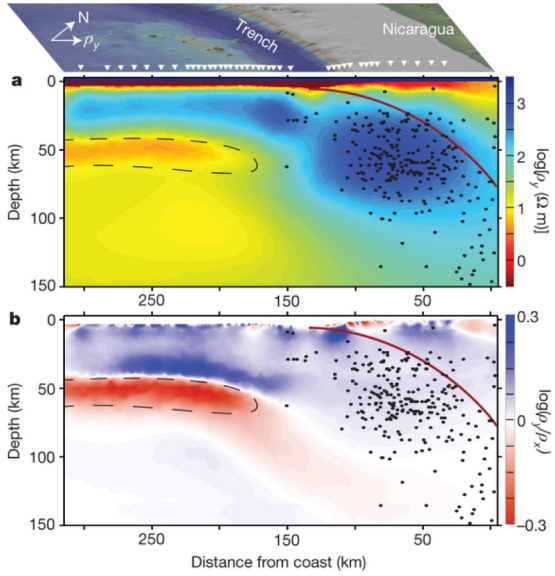


Seafloor massive sulfides





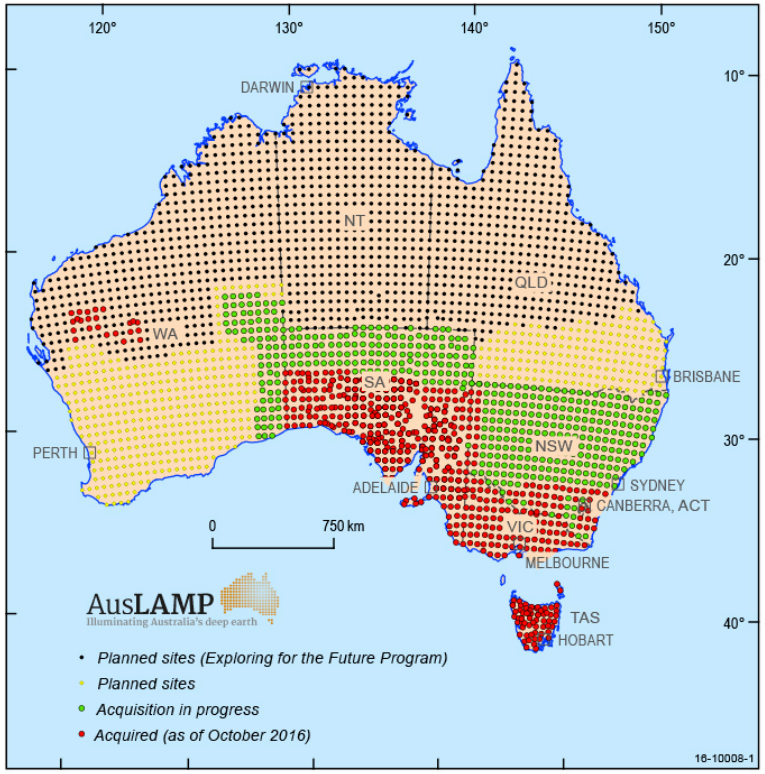
Tectonic studies, natural hazards



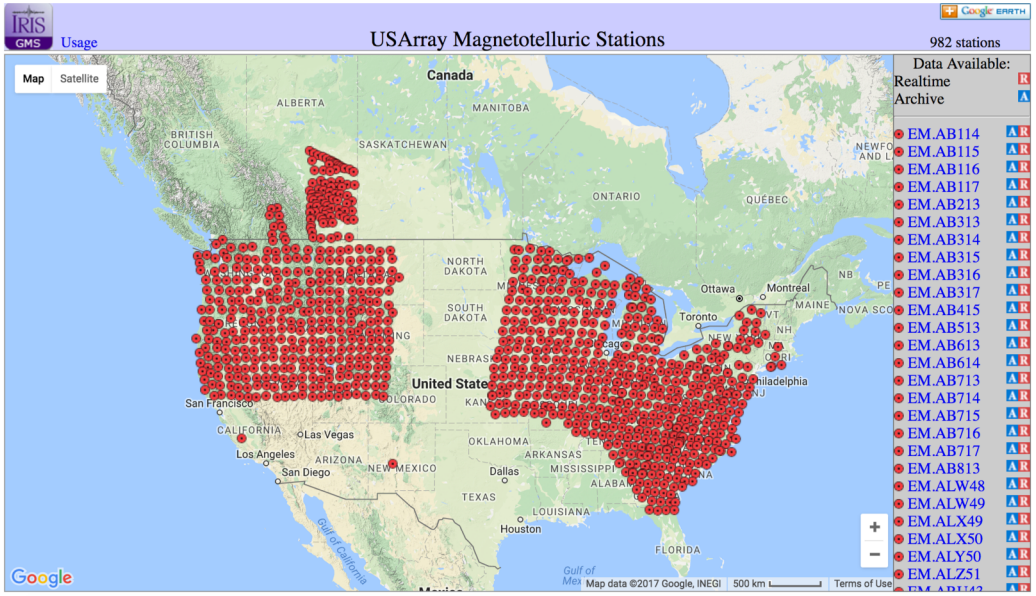
Naif et al., 2013

The Future: Large Scale EM

AusLamp

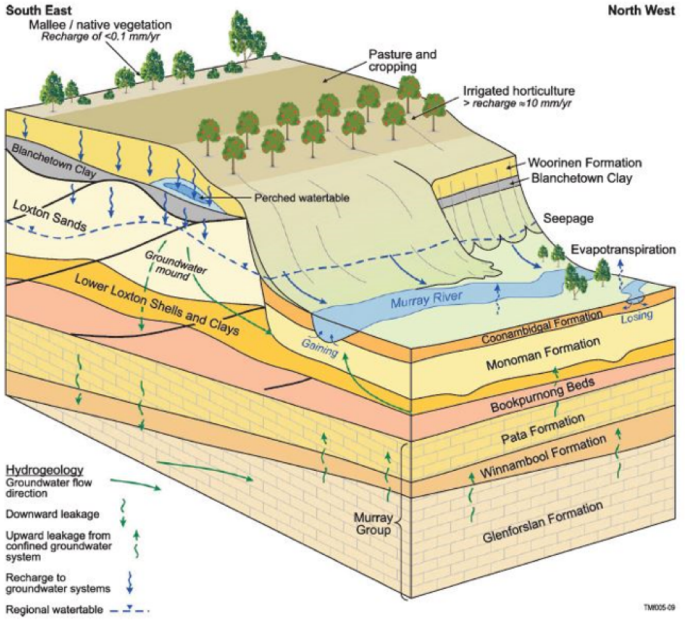


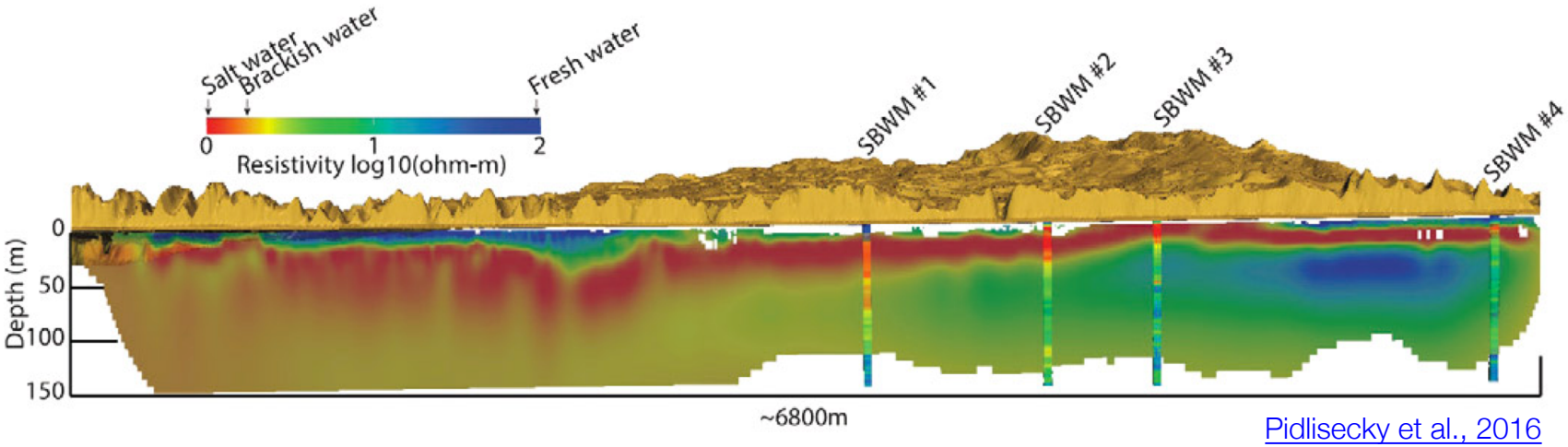
Earth scope



The Future: Water

- Finding and delineating water
- Aquifer monitoring and management
- Salt water intrusions
- Pollutants



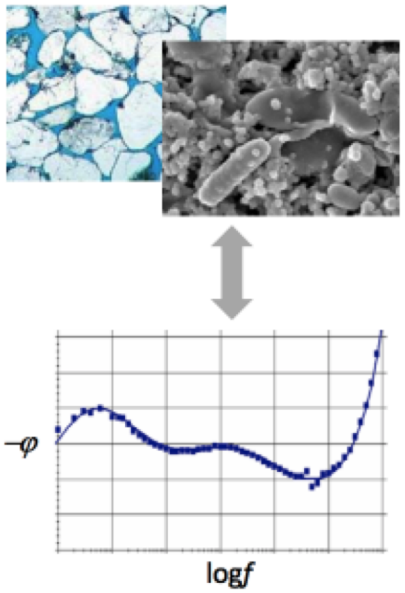


Pidlisecky et al., 2016

The Future: Physical Properties

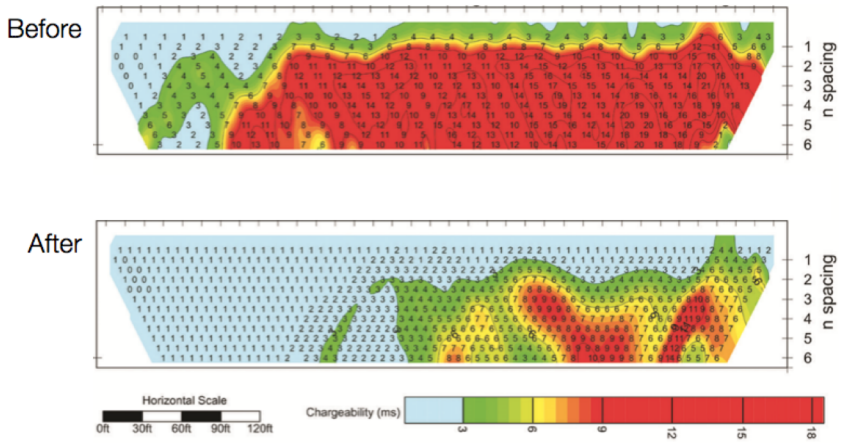
Dispersive Conductivity (IP)

- Ice / water, permafrost
- Organic materials
- Bioremediation
- Hydraulic permeability
- Characterizing materials based on spectral IP response



Dispersive Magnetic Permeability (Viscous Remanent Magnetization)

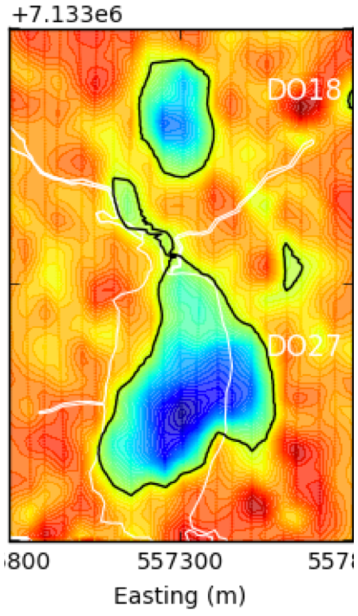
- Soils
- Bioremediation (?)



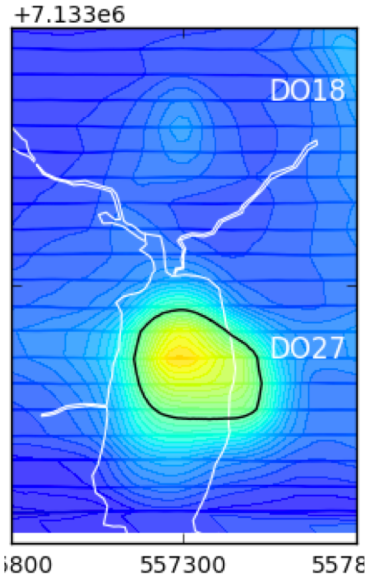
Numerical Modelling

The Future: Data Integration & Multi-physics

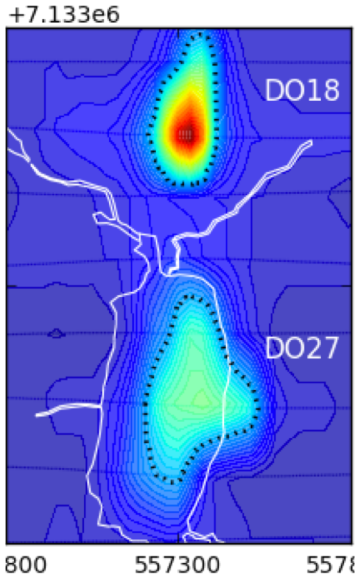
Gravity



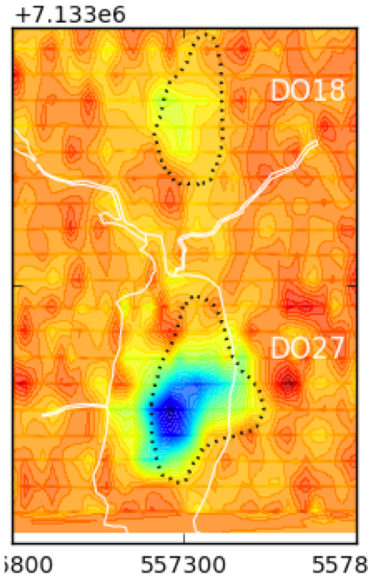
Magnetics



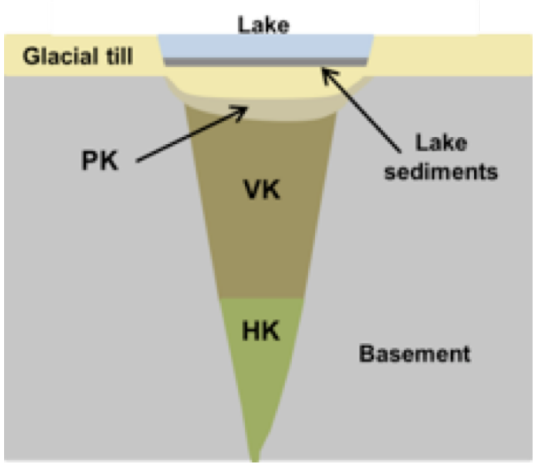
DIGHEM



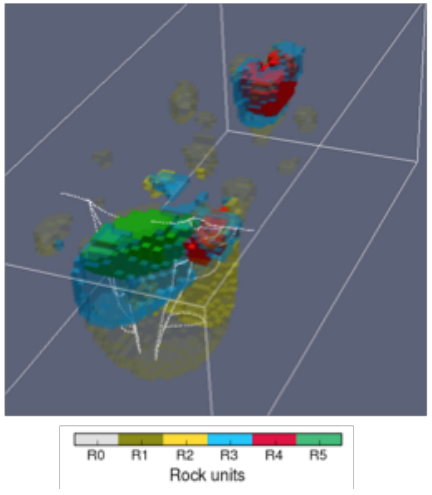
VTEM



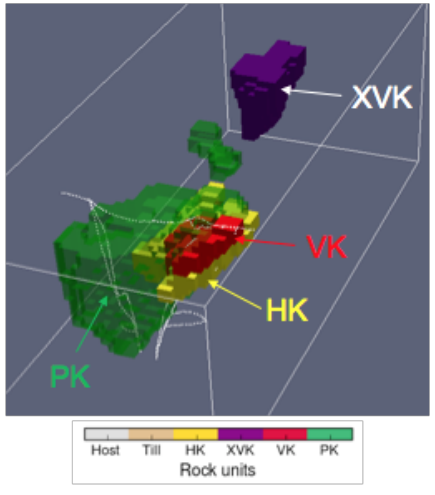
Kimberlite Model



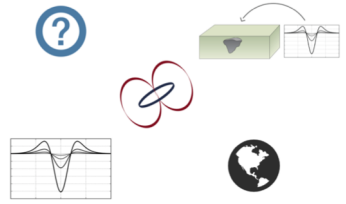
Rock Model from Geophysics



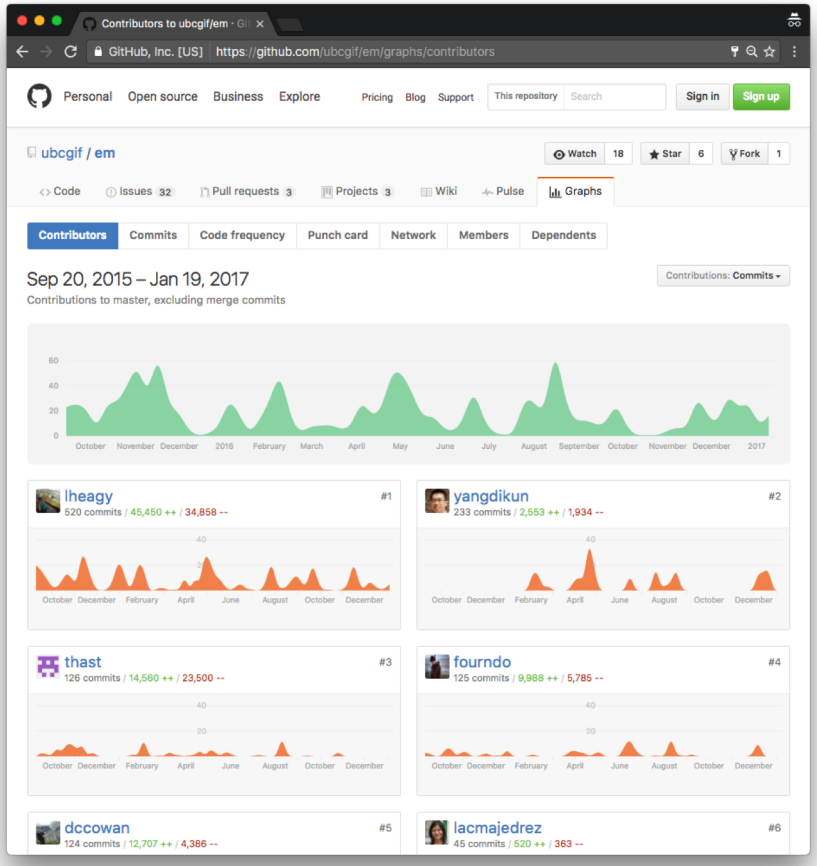
Rock Model from Drilling



The Future: Modelling and Inversion



- HPC, Cloud computing
- Collaborative development
- Open source



simpeg

Simulation and Parameter Estimation in Geophysics

http://simpeg.xyz

pyGIMLi

Geophysical Inversion & Modelling Library

Github
versioning, collaborating

Travis CI
testing, deploy

Jupyter
interactive computing

Creative Commons
licensing, reuse

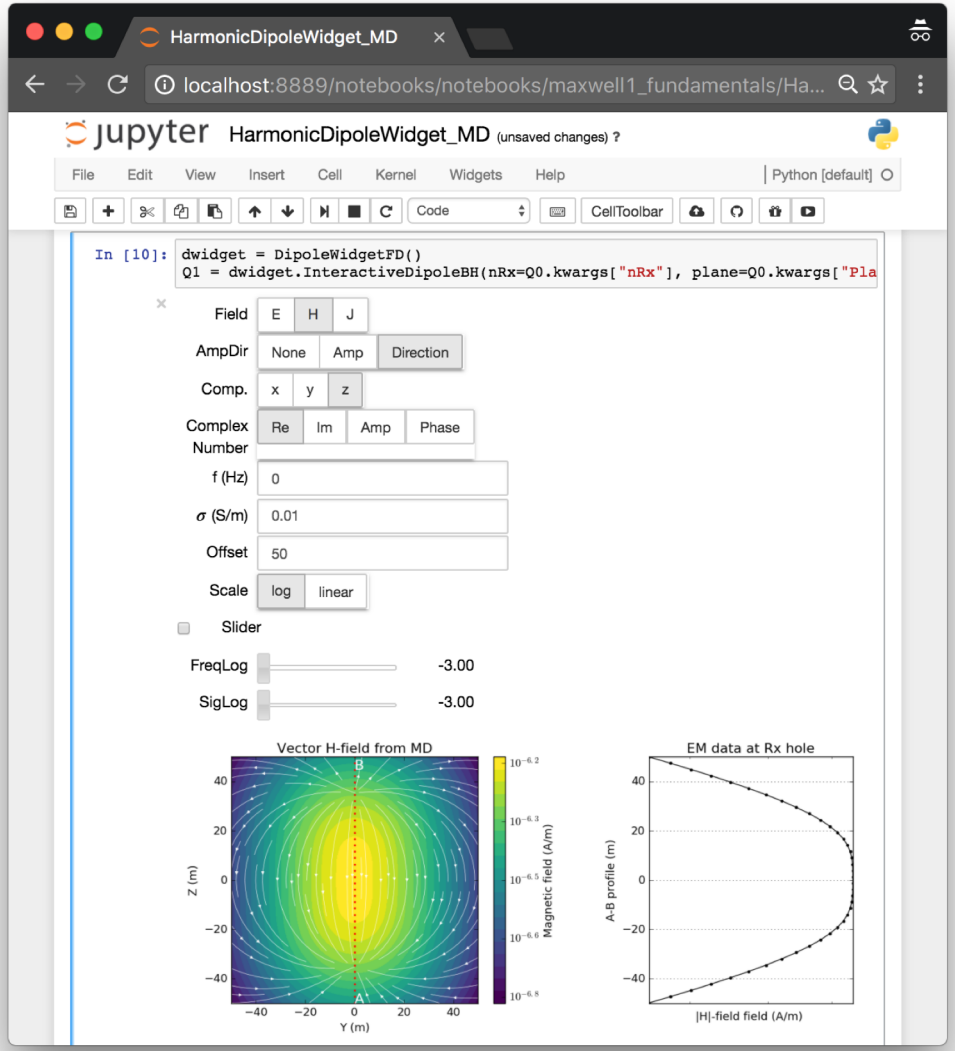
Python
computation

The Future: Modelling and Inversion

- Interactive computing
- Visualization

$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

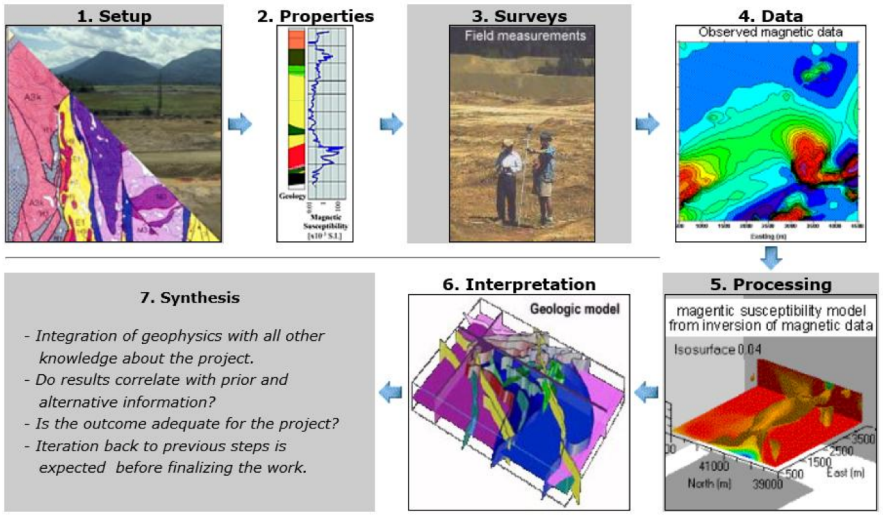
$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$

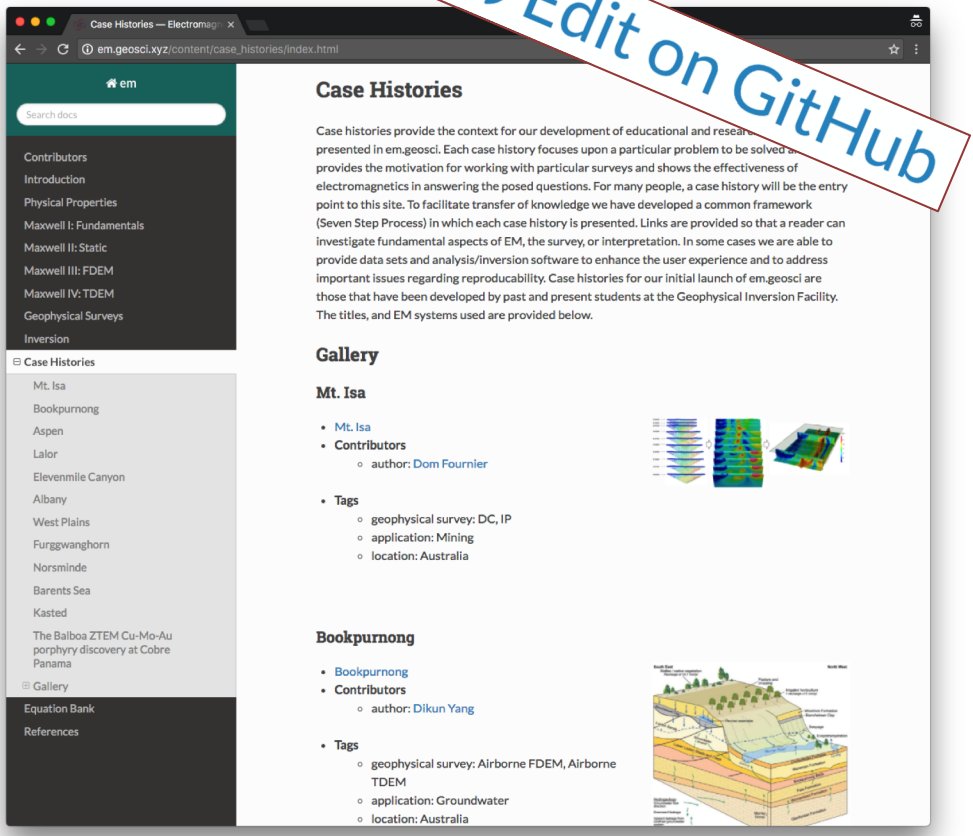


simpeg

http://em.geosci.xyz/apps.html

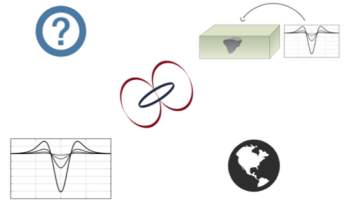
The Future: Collaboration





http://slack.geosci.xyz

Goals for the Course



- Inspire
  - See the variety of potential applications
  - Illustrate effectiveness using case histories
- Build a foundation
  - Basic principles of EM
  - Exploration and visualization with interactive apps
  - Open source resource: http://em.geosci.xyz
- Set realistic expectations
- Promote development of an EM community
  - Open source software
  - Capturing case histories world-wide

Resources

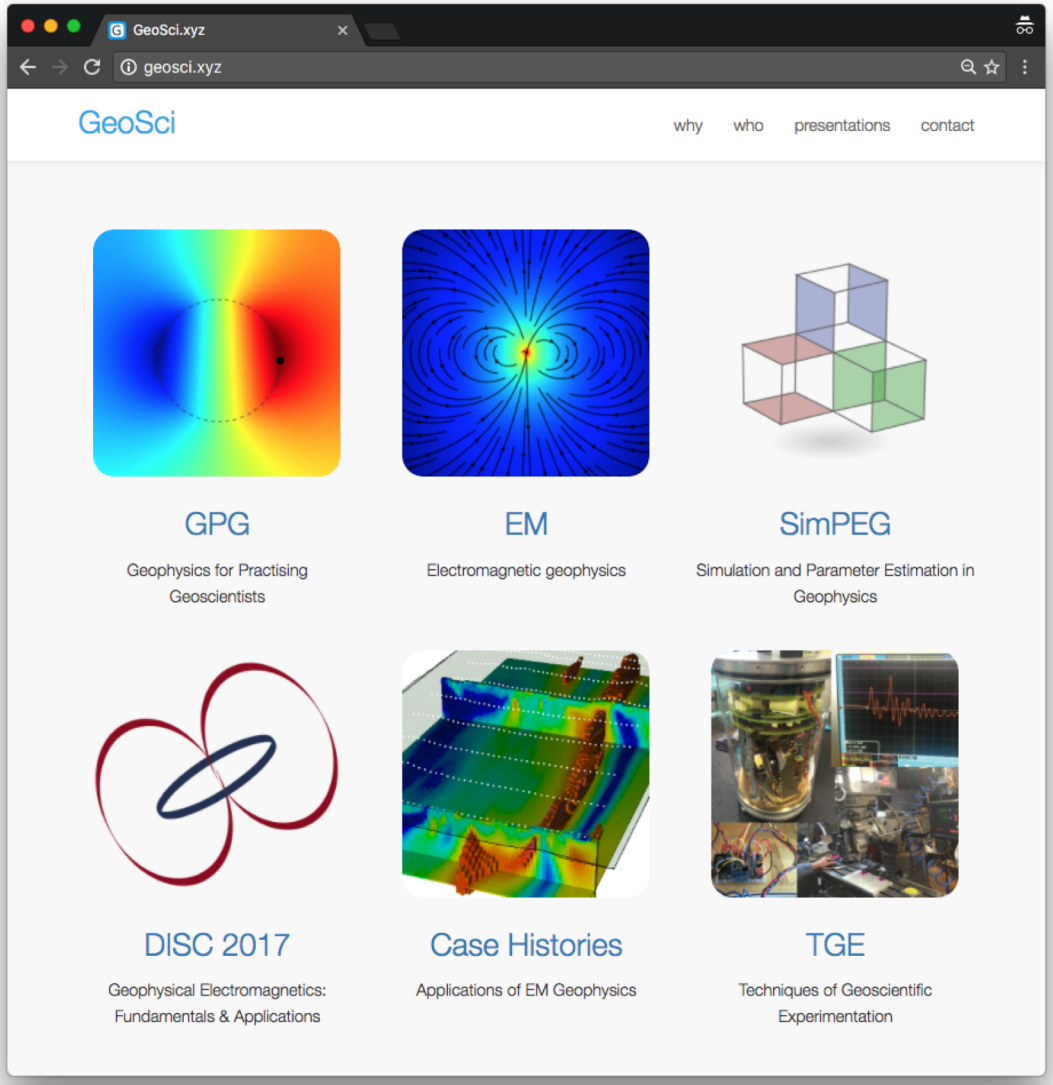
- GeoSci

  http://geosci.xyz

  - Web-textbooks
  - Software
  - Apps

- Apps:

  http://em.geosci.xyz/apps.html



GeoSci Team


doug


lindsey


seogi

UBC GIF Team


Thibaut


Patrick


Rowan

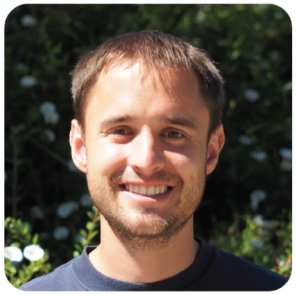

Devin


Kris


Sarah


Dom


Mike


Mike


Gudni


Dikun

Thank You!

http://geosci.xyz