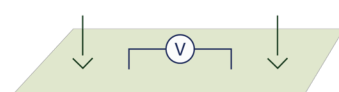
DC Resistivity

GeoSci.xyz



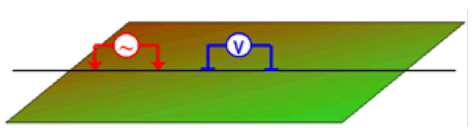
DC Resistivity Survey

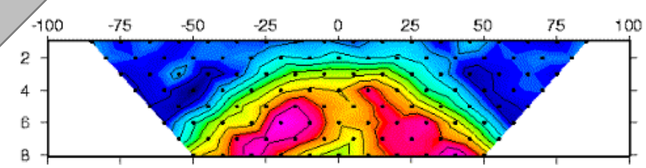
Source

Input energy

measure

Data





ρ

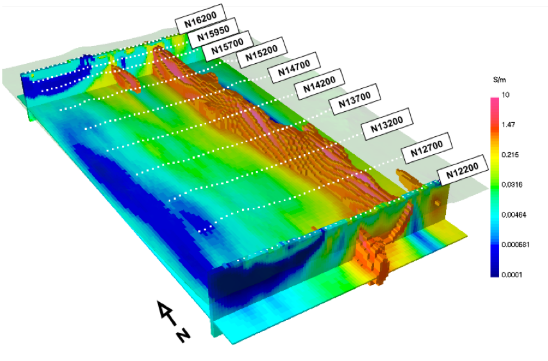
$$\rho = 1/\sigma$$

ρ : resistivity

σ : electrical conductivity

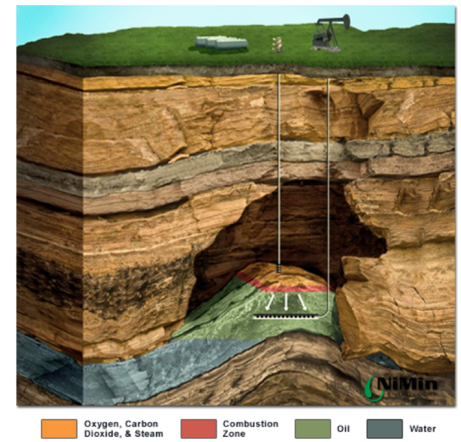
Motivation

Minerals

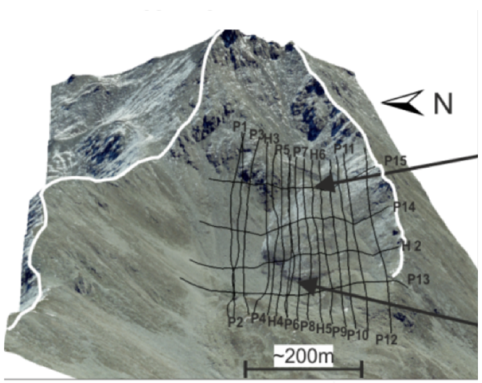


Water inflow in mine

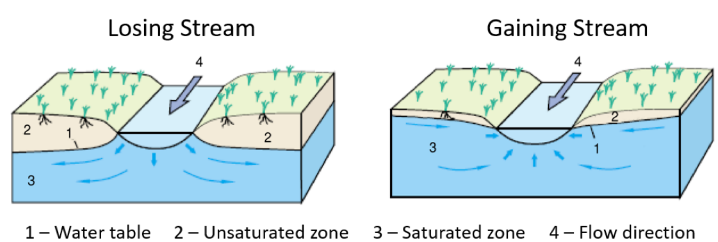
Oil and Gas



Geotechnical

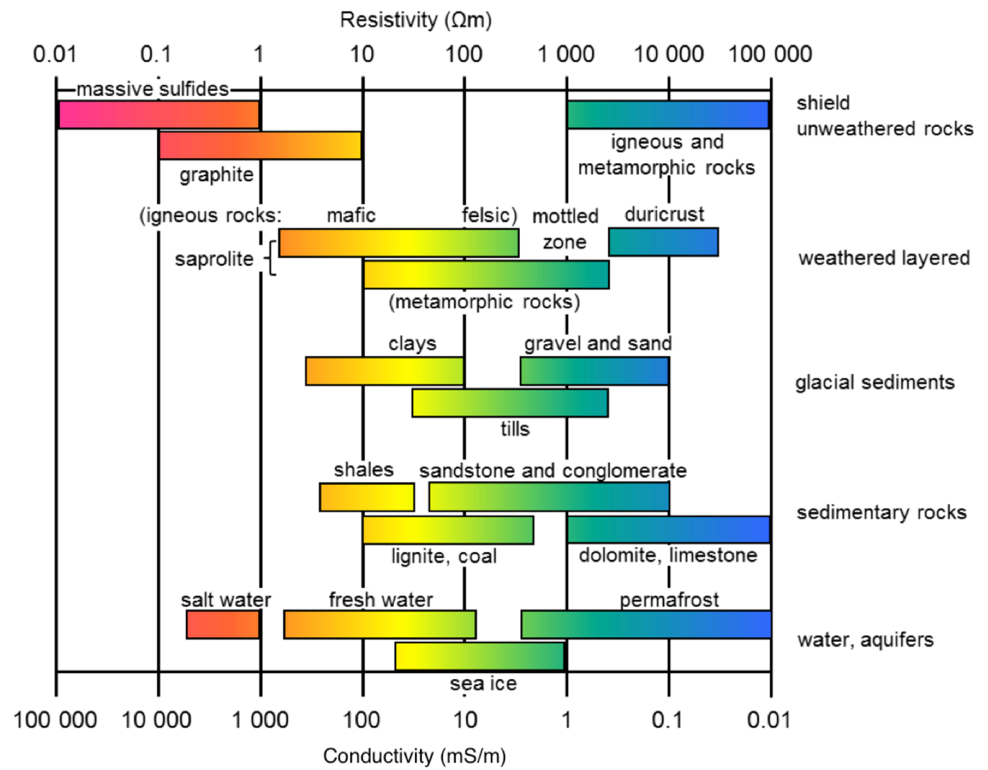


Groundwater



Electrical conductivity

- DC resistivity is sensitive to:
  - σ: Conductivity [S/m]
  - ρ: Resistivity [Ωm]
  - $\sigma = 1/\rho$
- Varies over many orders of magnitude
- Depends on many factors:
  - Rock type
  - Porosity
  - Connectivity of pores
  - Nature of the fluid
  - Metallic content of the solid matrix



Outline

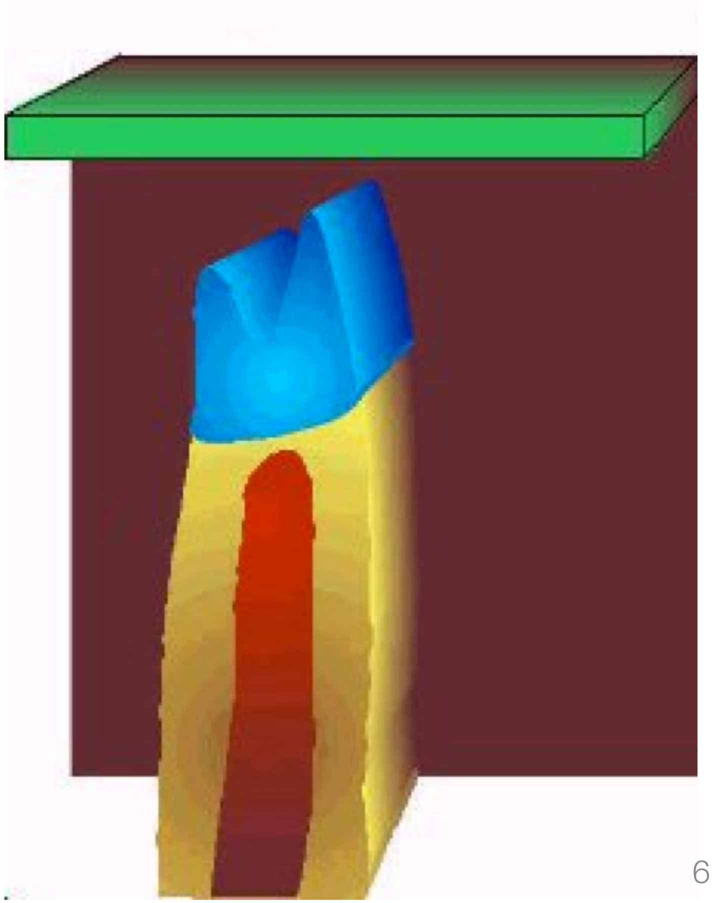
- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- Case History – Mt Isa
- Case History – Reservoir monitoring for oil sands
- Steel casing + DC
- Working with the apps
- Effects of background resistivity

Basic Experiment

- Target:
  - Ore body. Mineralized regions less resistive than host

Elura Orebody Electrical resistivities

Rock Type	*Ohm-m*
Overburden	12
Host rocks	200
Gossan	420
Mineralization (pyritic)	0.6
Mineralization (pyrrhotite)	0.6



Basic Experiment

- **Target:**
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- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes

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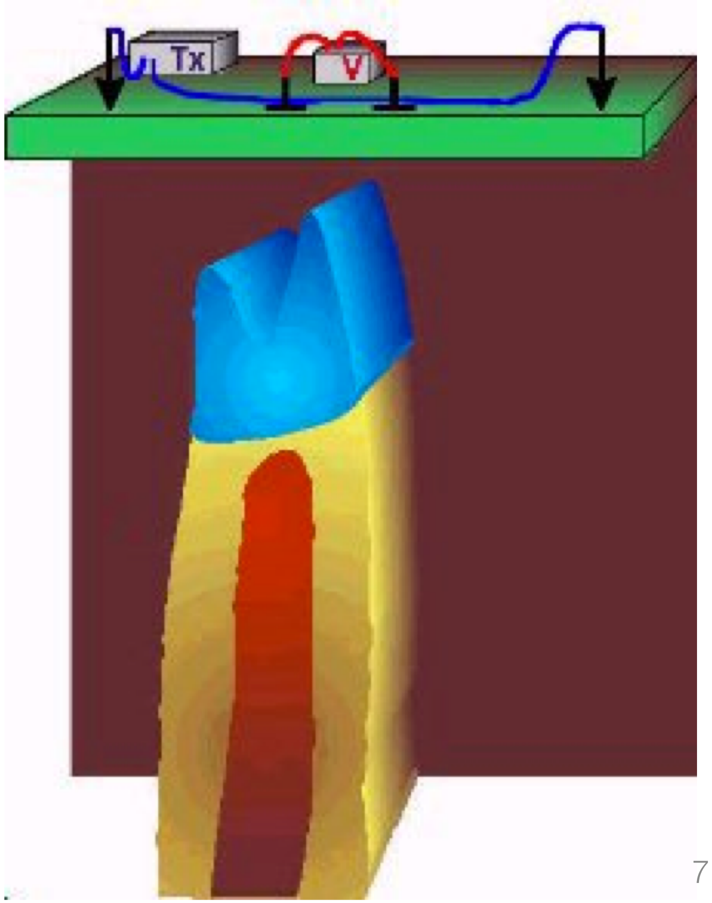

Basic Experiment

- **Target:**
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  - Tx: Current electrodes
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- **Currents:**
  - Preferentially flow through conductors

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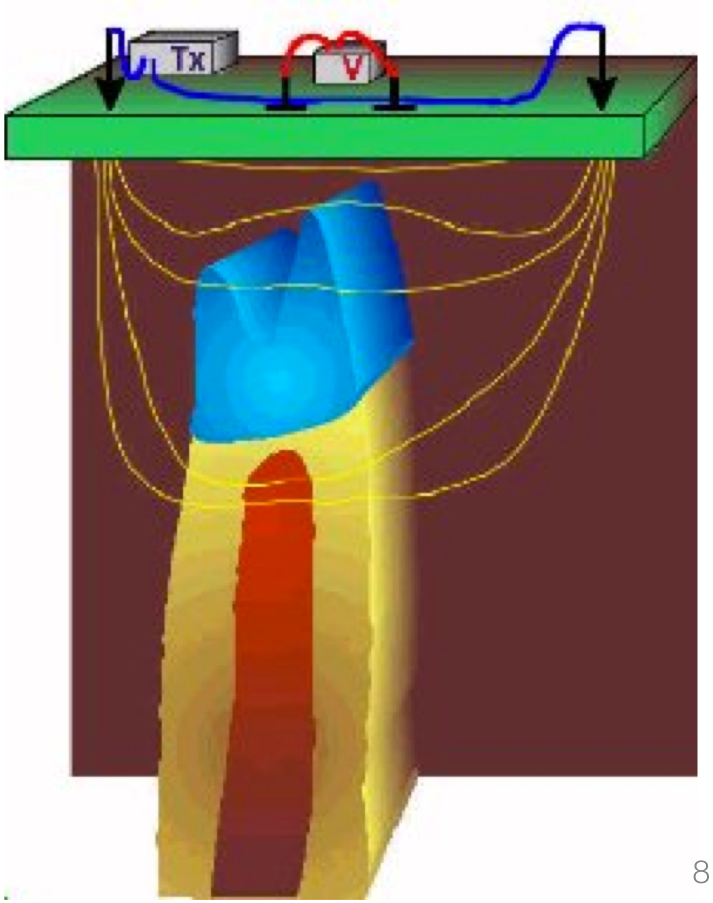

Basic Experiment

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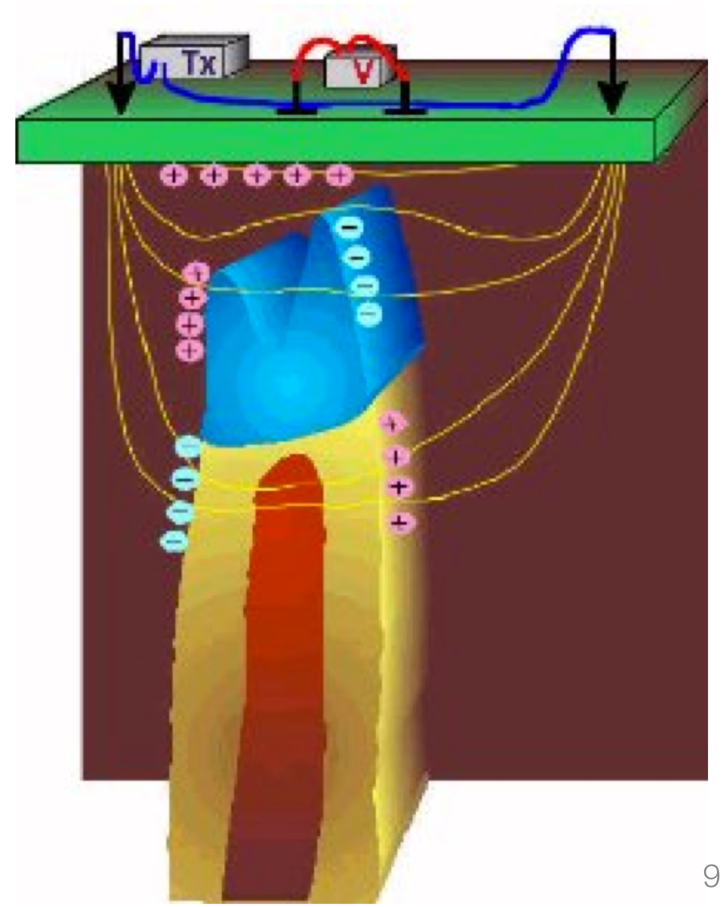
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces



Basic Experiment

- **Target:**
  - Ore body. Mineralized regions less resistive than host
- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces
- **Potentials:**
  - Associated with the charges are measured at the surface

Elura Orebody Electrical resistivities

Rock Type	*Ohm-m*
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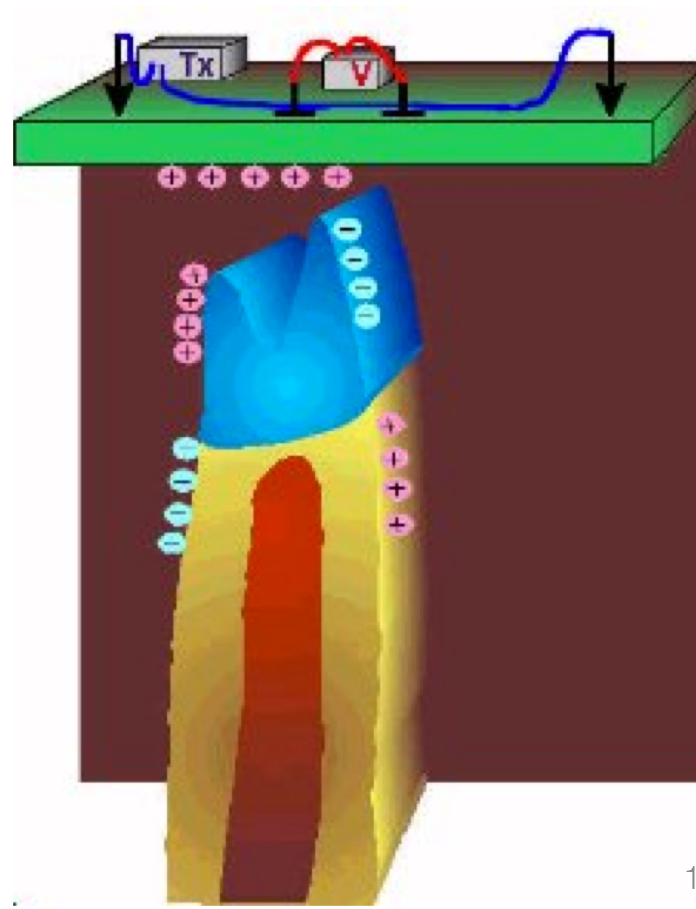


How do we obtain resistivity?

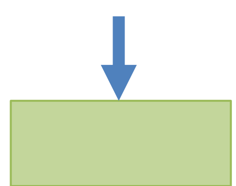
Steady State Maxwell equations

	Full	Steady State
Faraday	$\nabla \times \vec{e} = -\frac{\partial \vec{b}}{\partial t}$	$\nabla \times \vec{e} = 0$ $\quad \vec{e} = -\nabla V$
Ampere	$\nabla \times \vec{h} = \vec{j} + \frac{\partial \vec{d}}{\partial t} + \vec{j}_s$	$\nabla \cdot \vec{j} = -\nabla \cdot \vec{j}_s$
Ohm's Law	$\vec{j} = \sigma \vec{e}$	

Put it together

$$\nabla \cdot \sigma \nabla V = I\delta(r)$$

Potential in a homogeneous halfspace

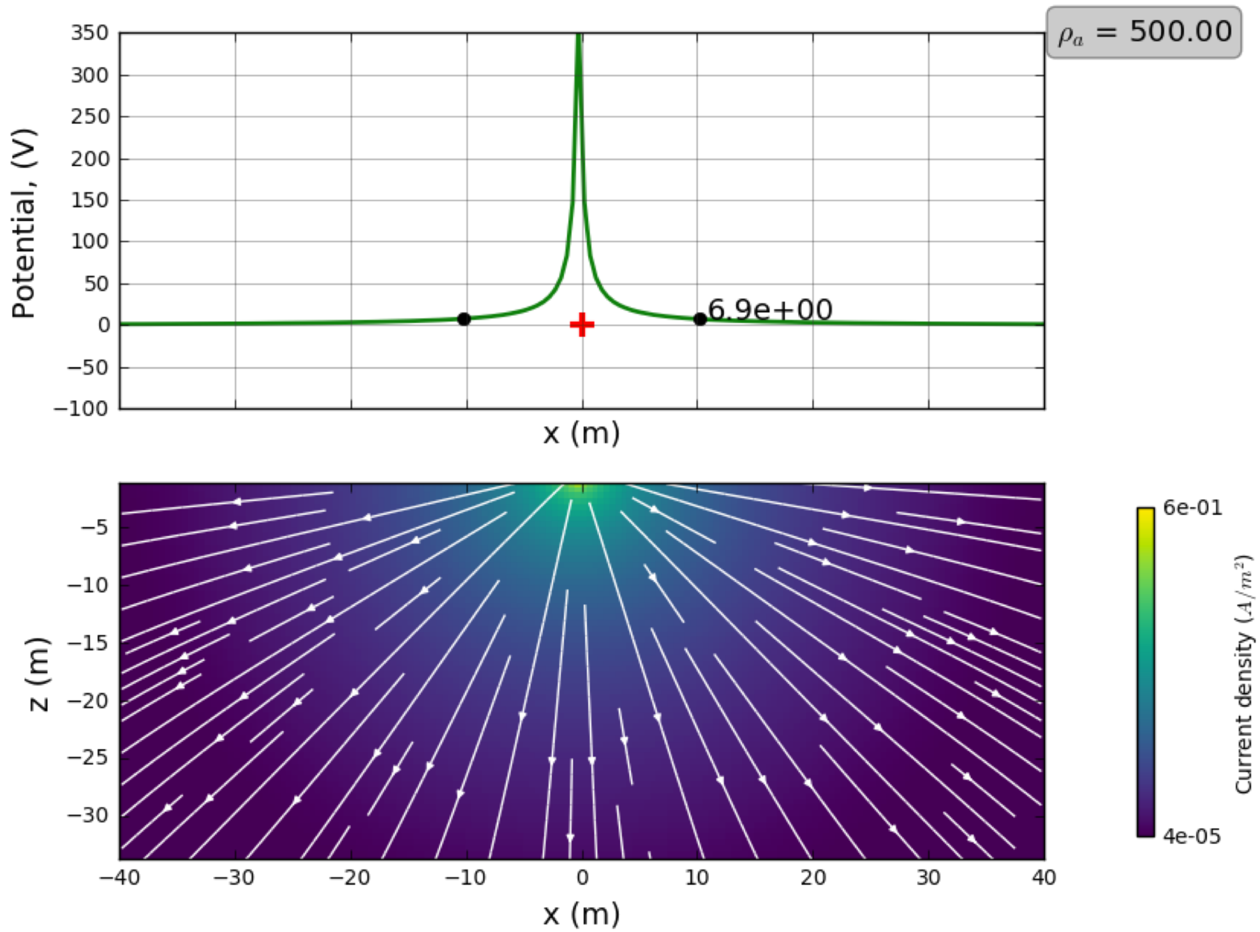


$$V = \frac{I}{2\pi\sigma}\frac{1}{r} \qquad V = \frac{\rho I}{2\pi r}$$

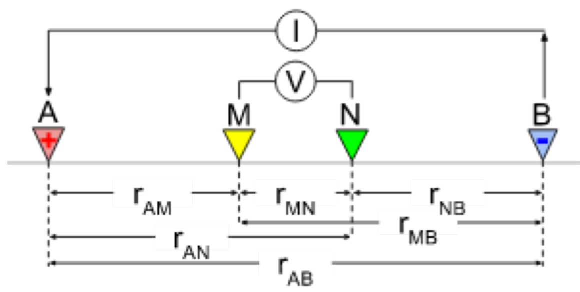
Currents and potentials: halfspace

$$V = \frac{\rho I}{2\pi r}$$

$$\rho = \frac{2\pi r V}{I}$$



Currents and potentials: 4-electrode array

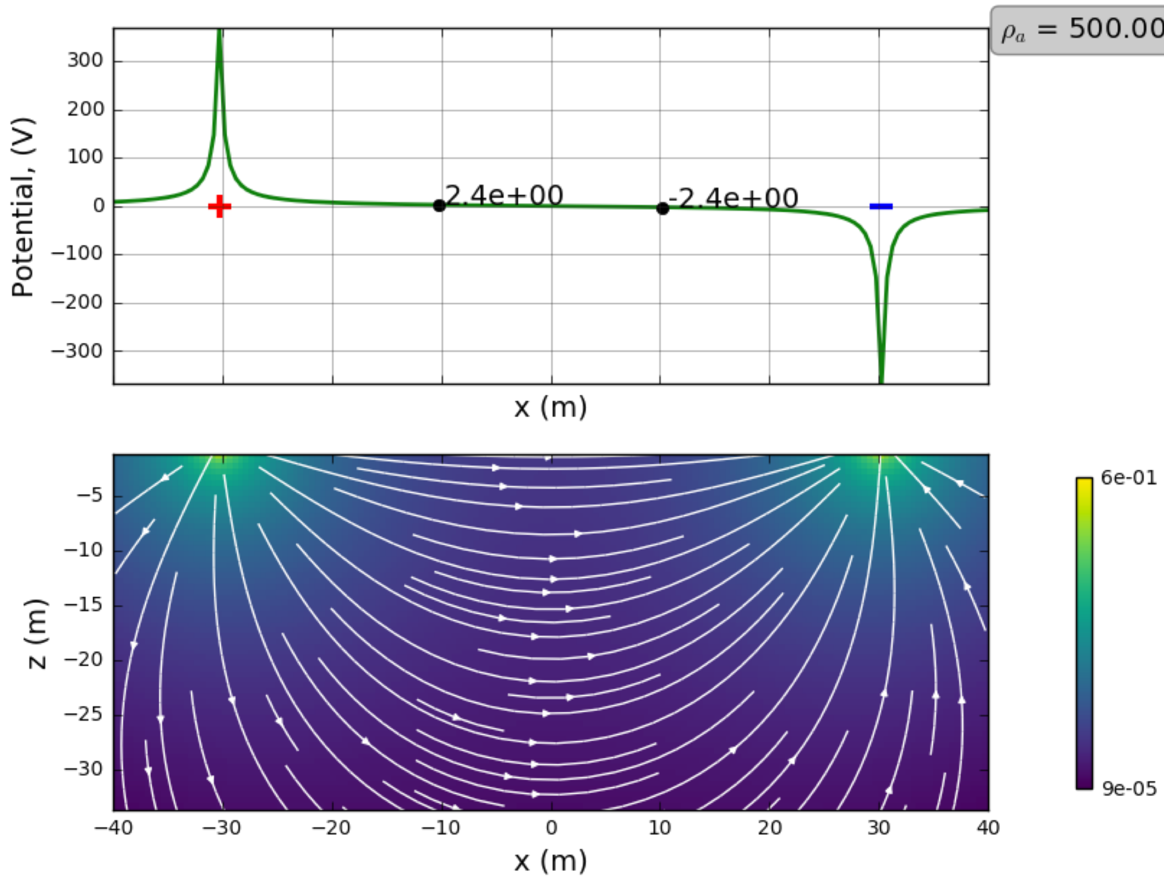


$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

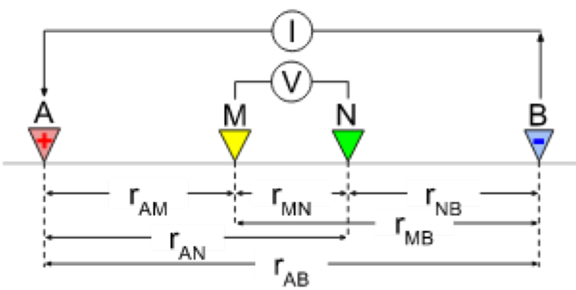
Resistivity

$$\rho = \frac{\Delta V_{MN}}{IG}$$

Halfspace (500 Ωm)



Currents and Apparent Resistivity

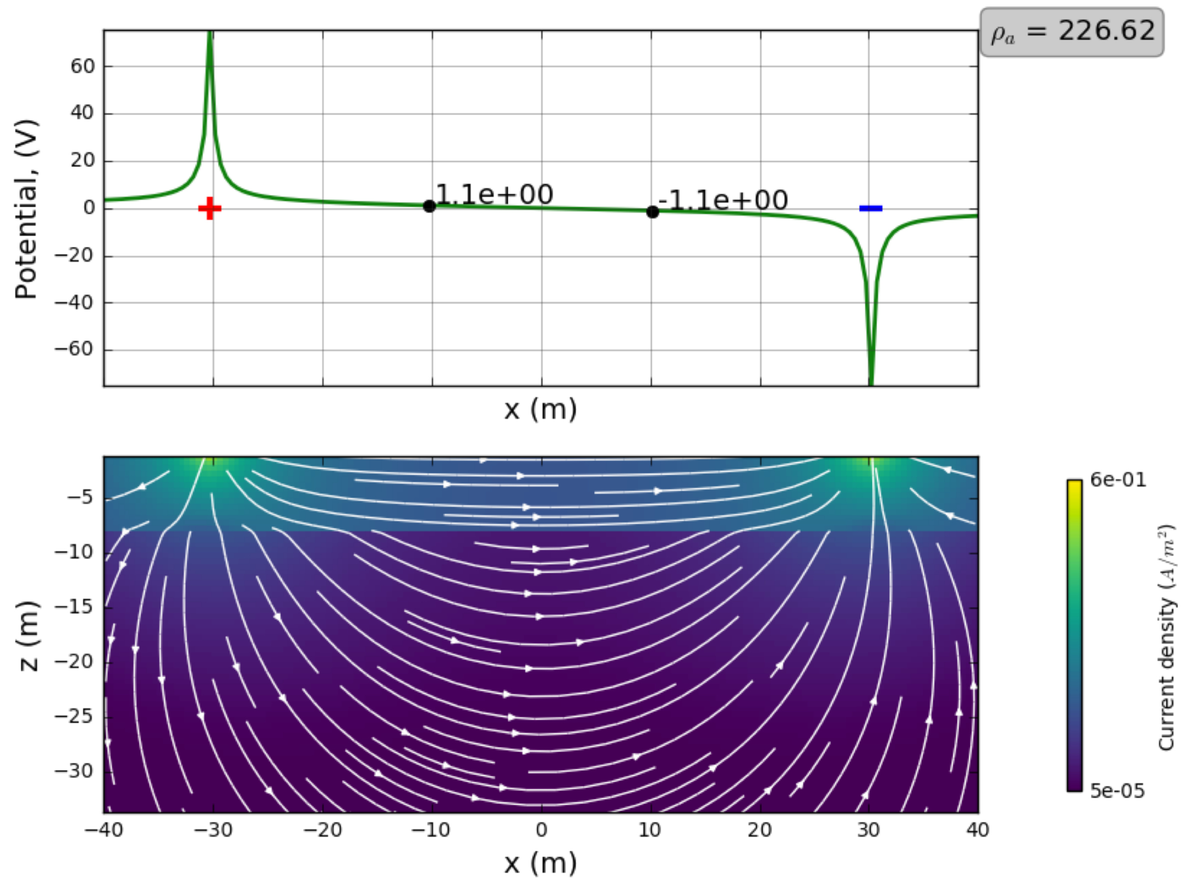


$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

Apparent resistivity

$$\rho_a = \frac{\Delta V_{MN}}{IG}$$

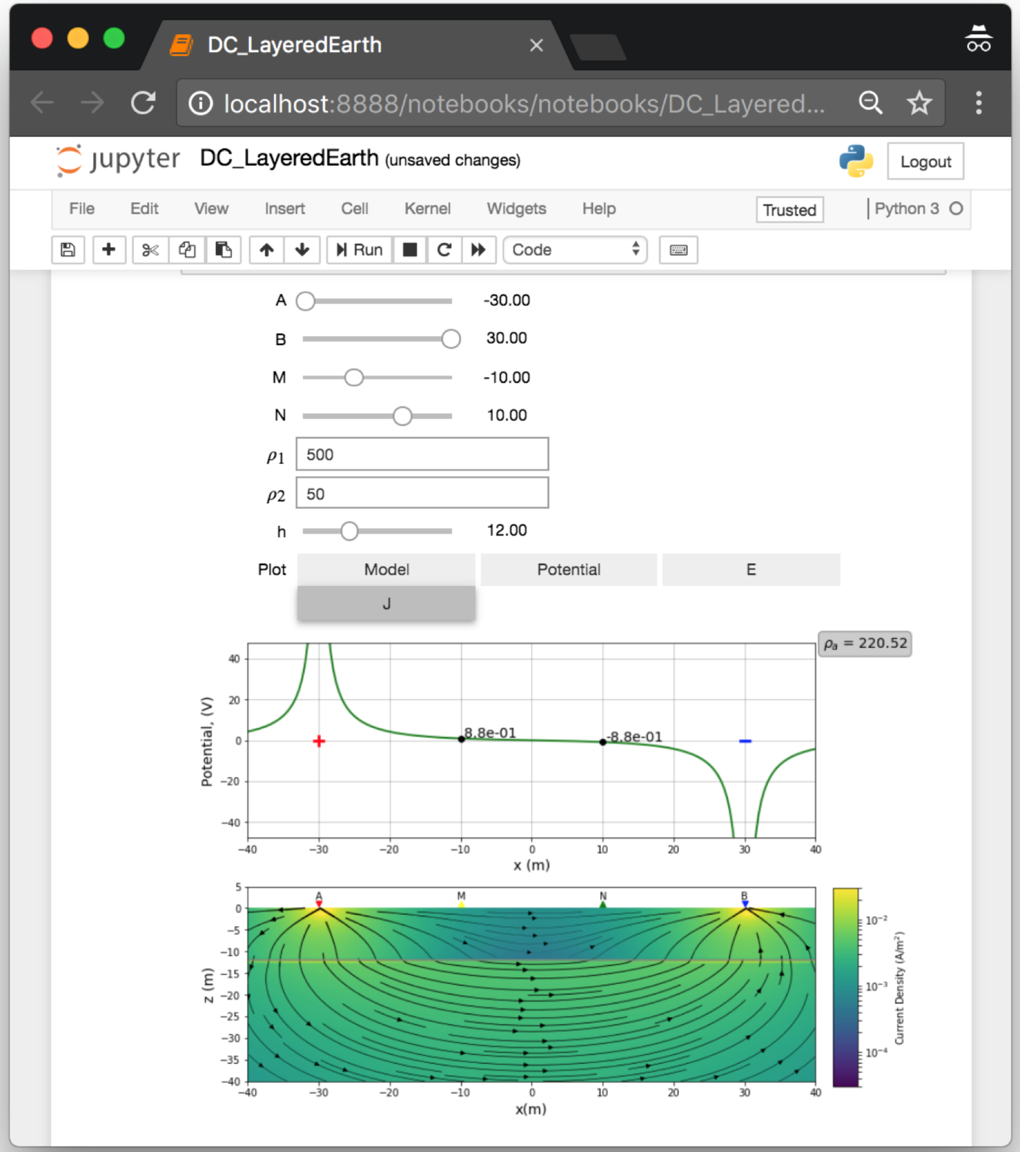
Conductive overburden (100 Ωm)



DC Layer App

Why interactive apps?

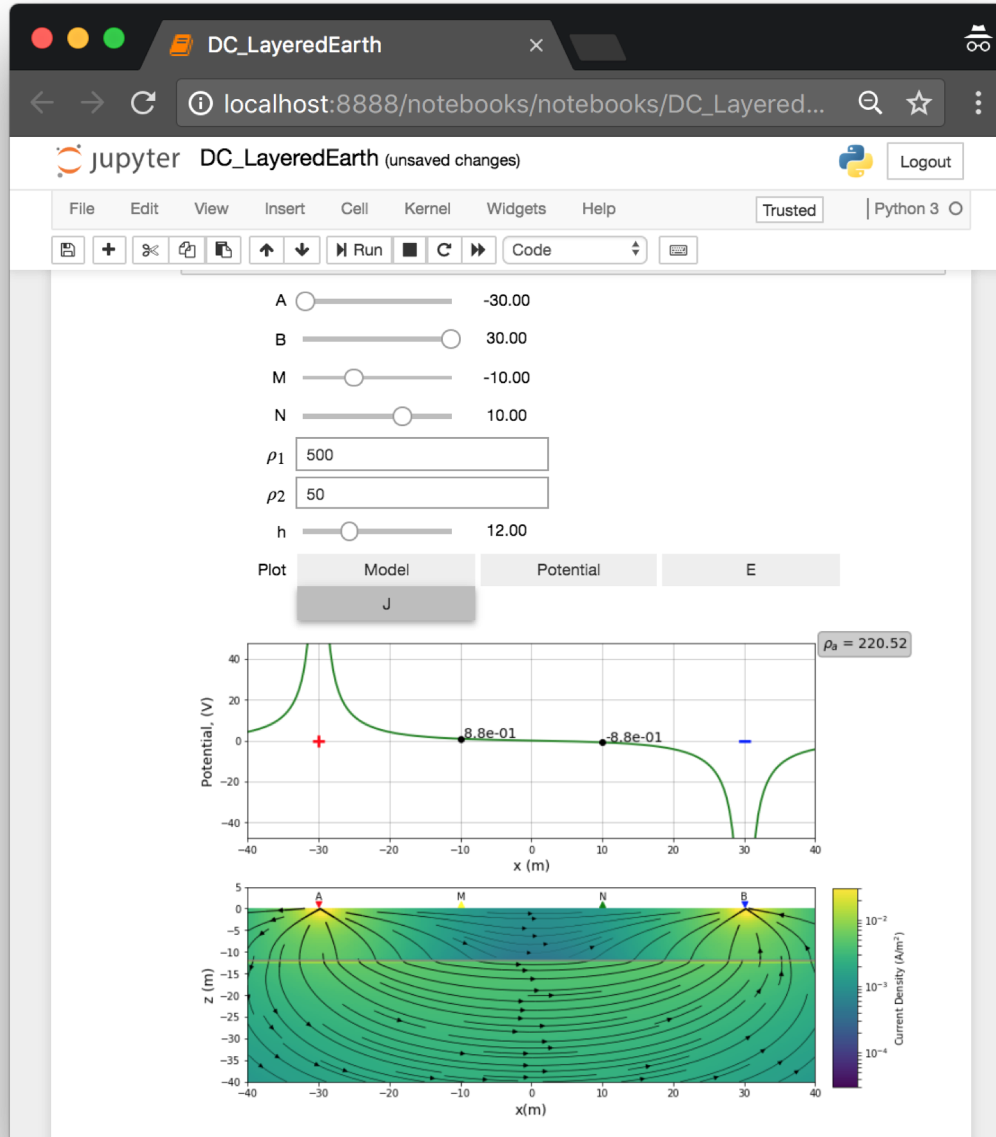
- Visualization aids understanding
- Learn through interaction
  - ask questions and investigate
- Open source:
  - Free to use
  - Welcome contributions!



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

DC Layered earth (Demo)

- DC_LayeredEarth.ipynb
- Parameters:
  - Layer resistivities
  - Layer thickness
  - Electrode locations
- View:
  - Model
  - Electric potential
  - Electric field
  - Current density

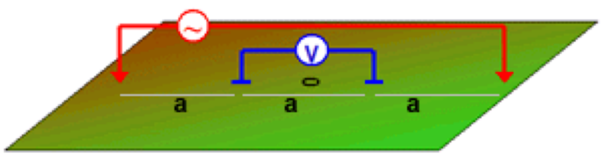


http://em.geosci.xyz/apps.html

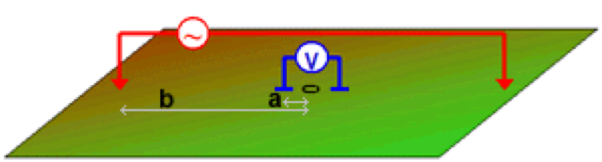
Soundings and Arrays

Geometry

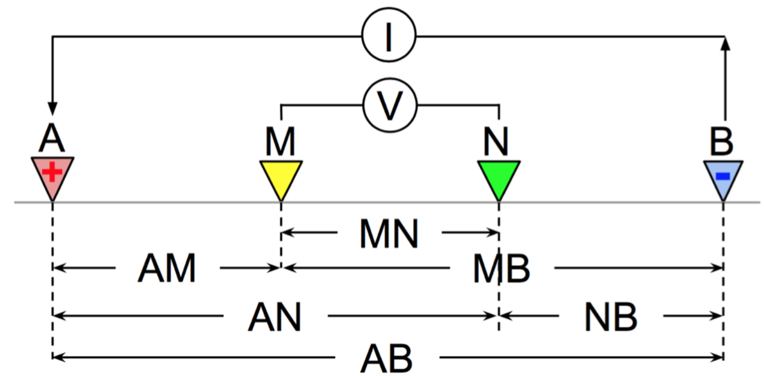
Wenner



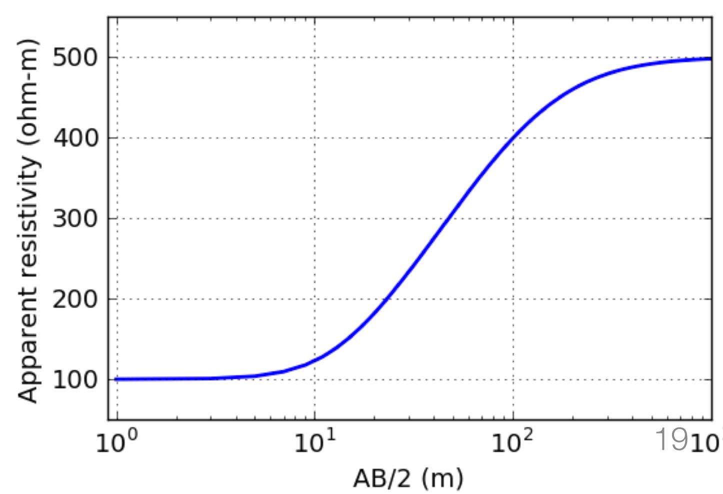
Schlumberger



4 electrode Array

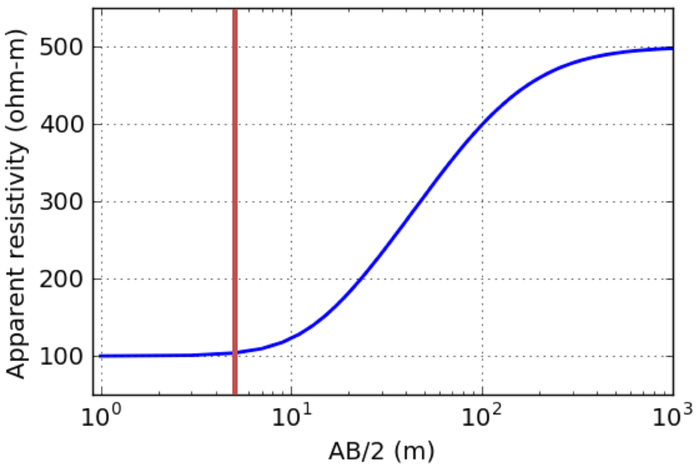


Sounding

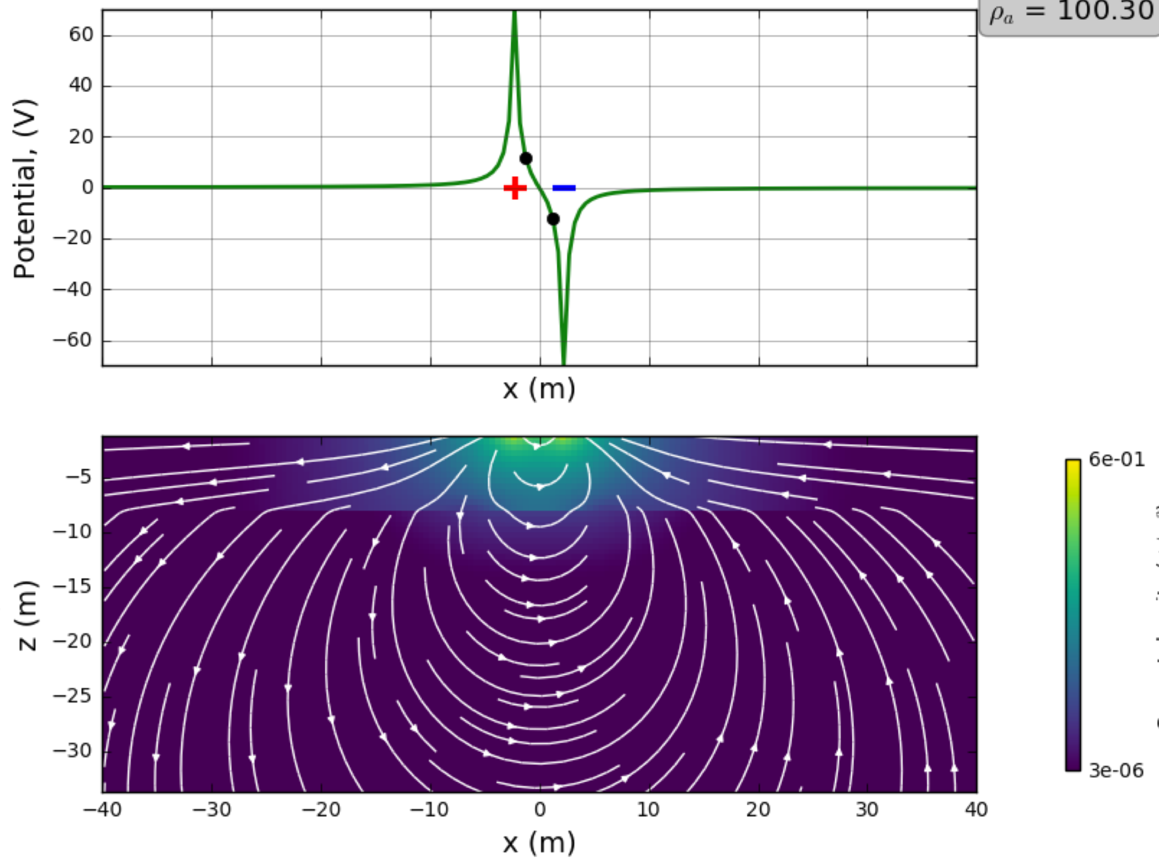


Soundings

DC Sounding curve



AB/2 = 5 m



Soundings

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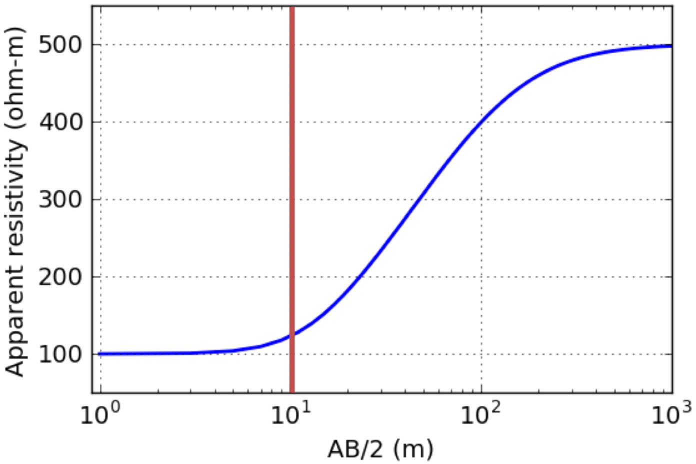
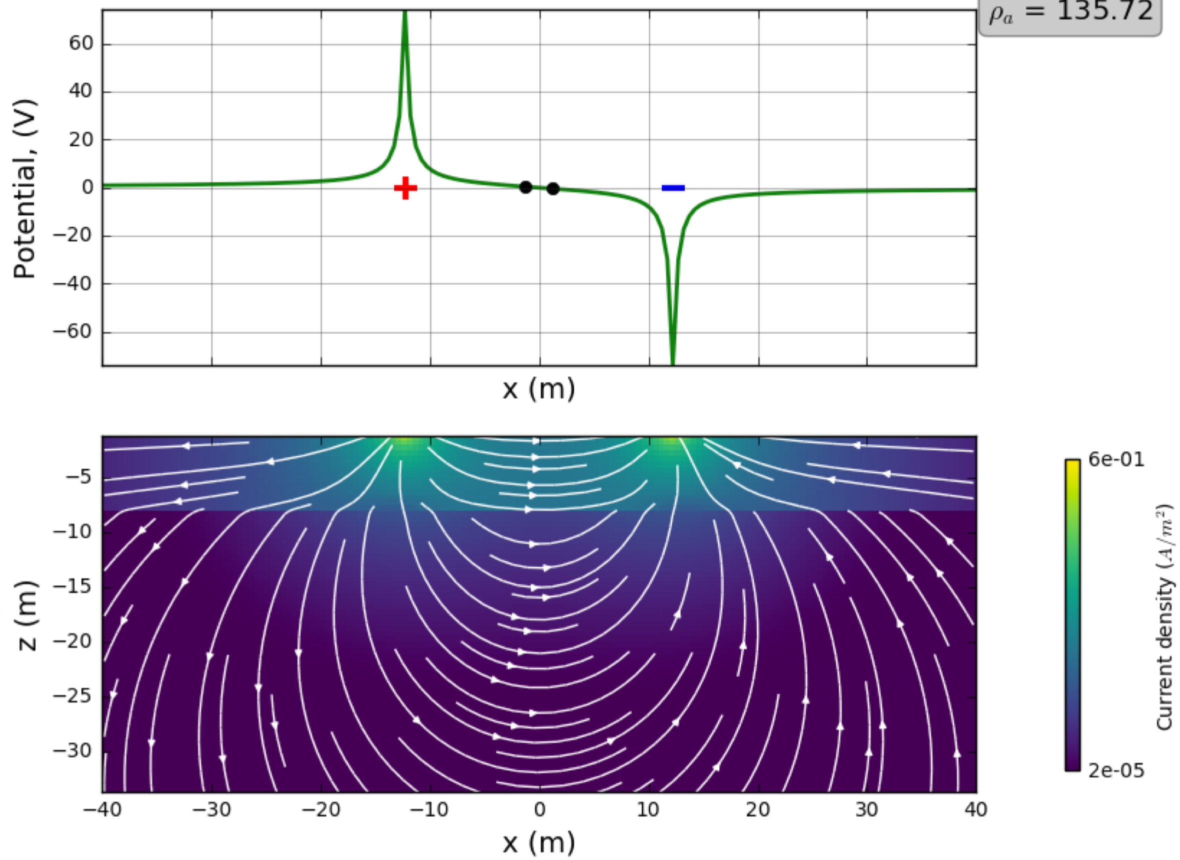
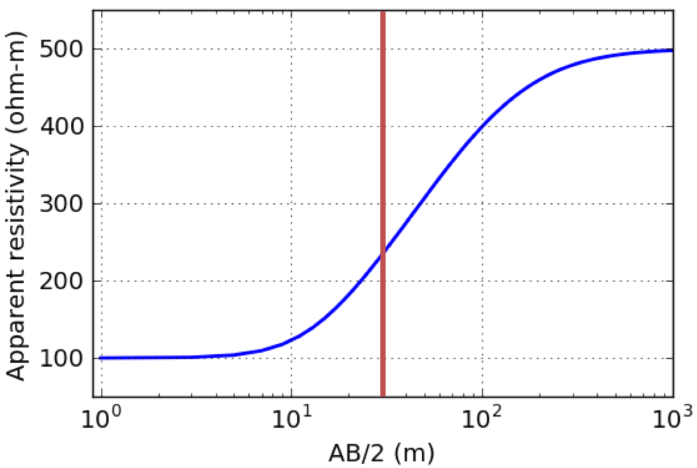


AB/2 = 10 m

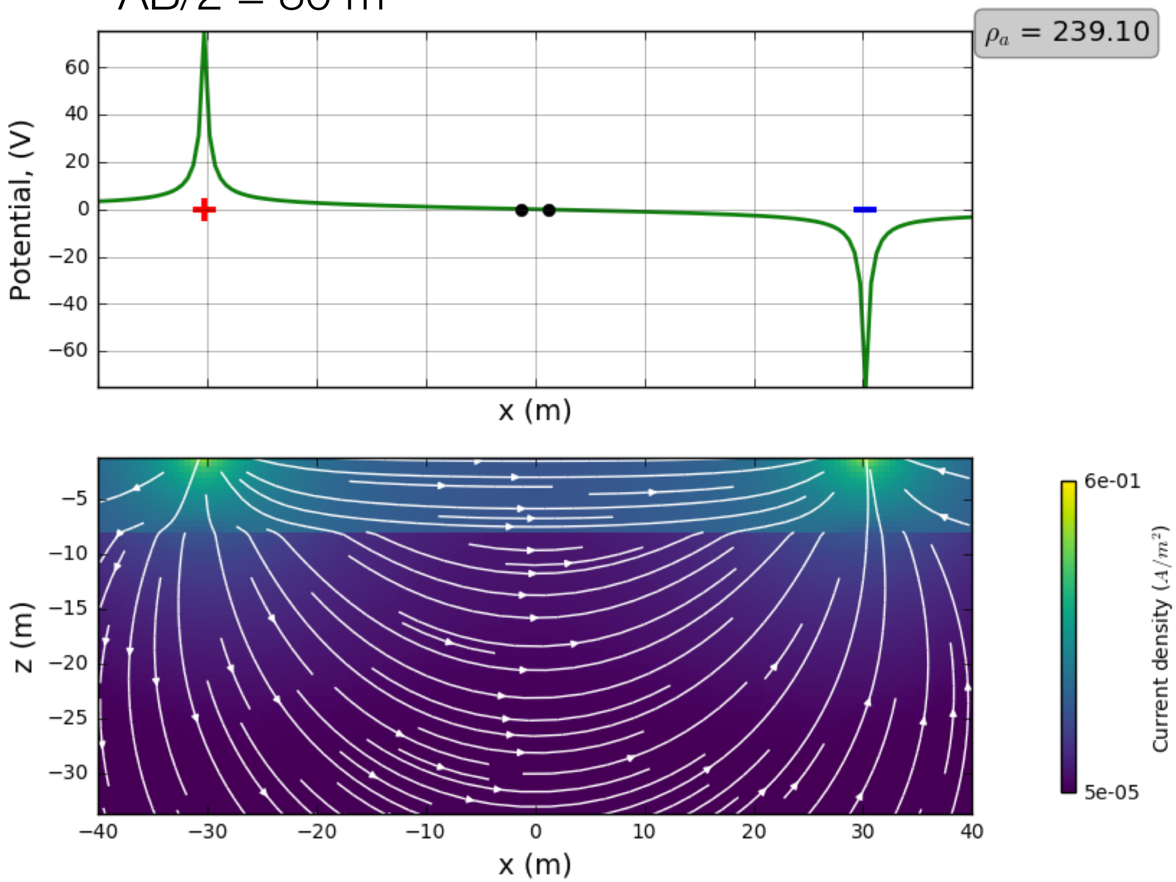


Soundings

DC Sounding curve

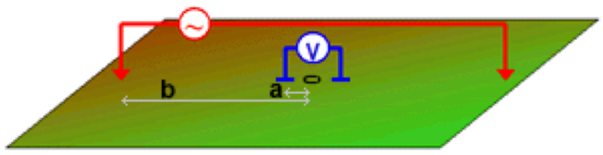


AB/2 = 30 m

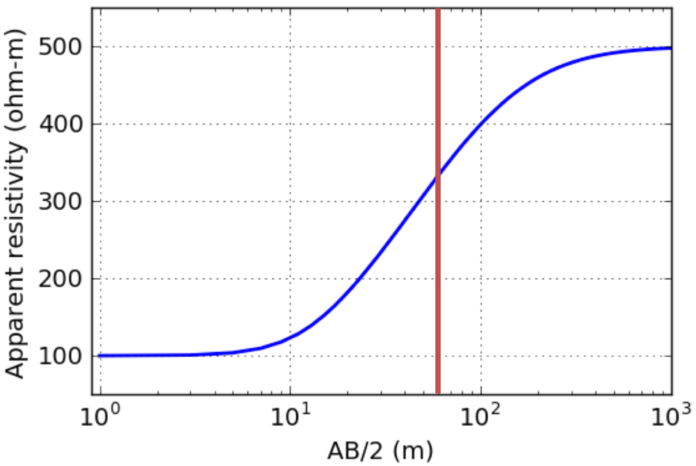


Summary: soundings

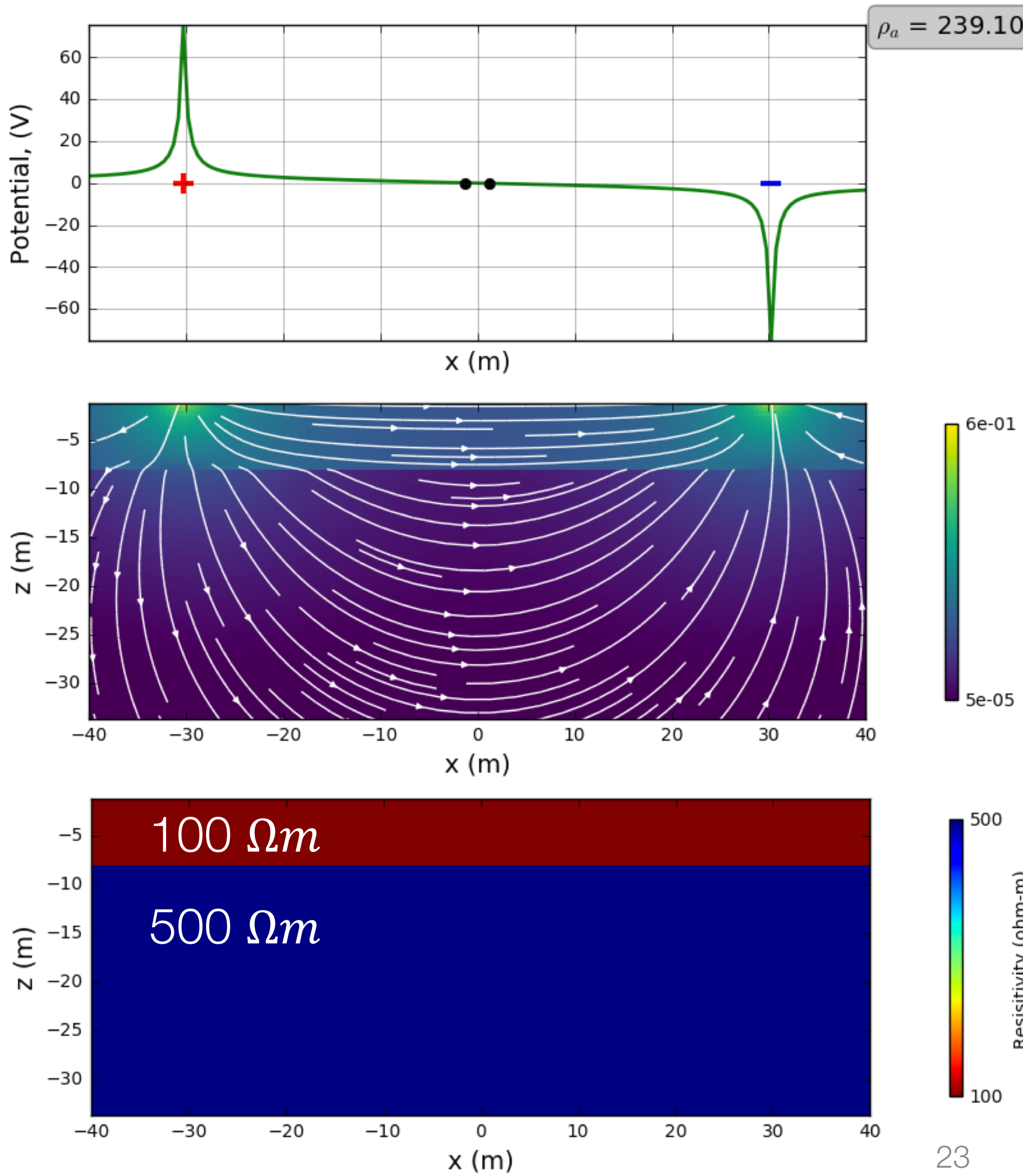
Schlumberger array



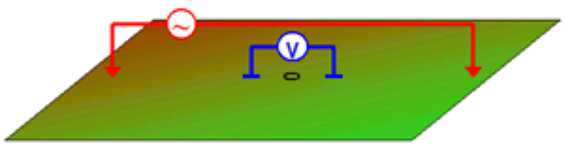
DC **Sounding** curve



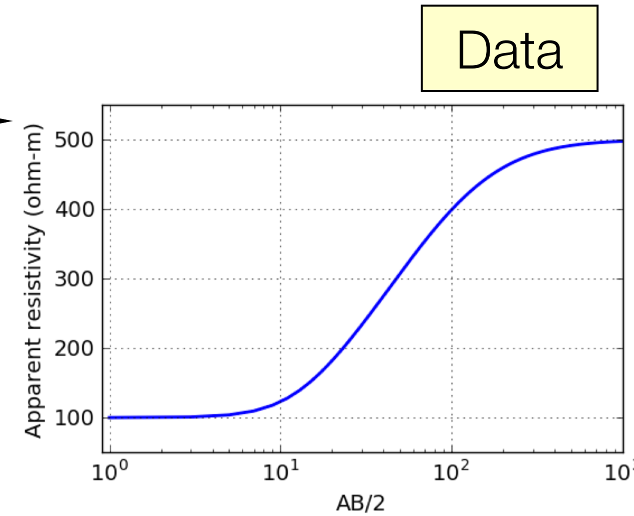
Scale length of array must be large to see deep

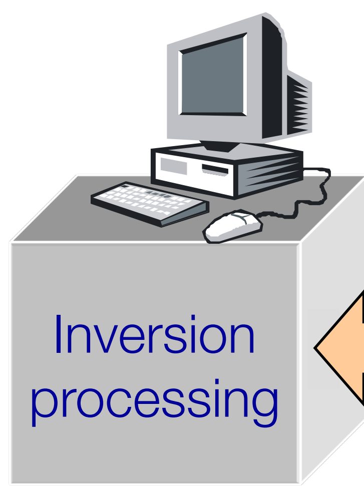


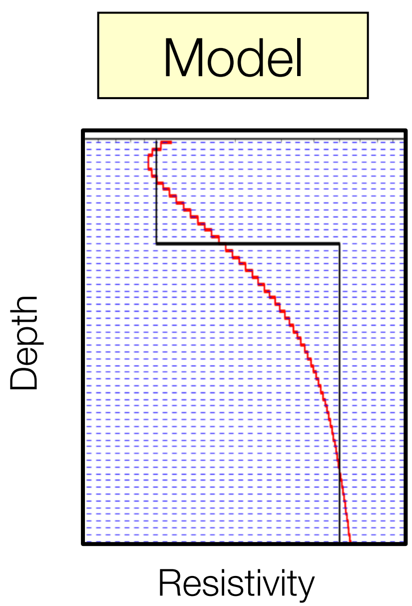
Inversion



Measurements over the Earth are data.







Inversion estimates Earth models based upon data and prior knowledge.

DCR for a confined body

- Useful to formally bring in the concept of charges

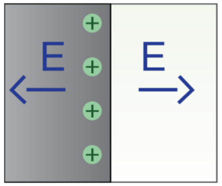
Normal component of current density is continuous

$$J_{1n} = J_{2n}$$
$$\sigma_1 E_{1n} = \sigma_2 E_{2n}$$

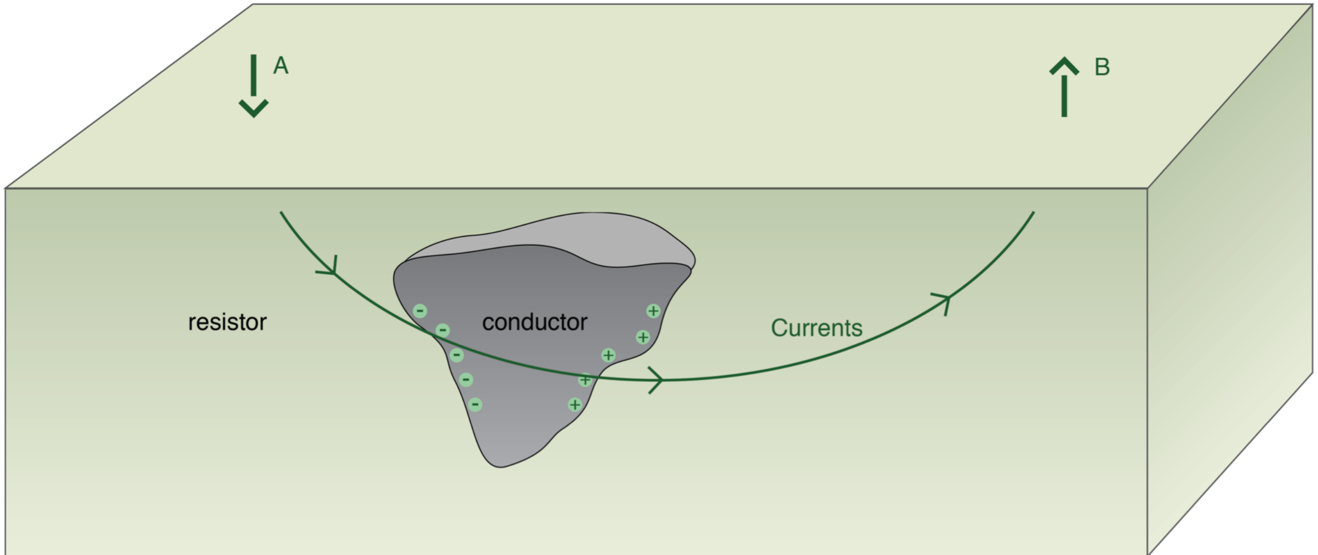
Conductivity contrast

$$\sigma_1 \neq \sigma_2$$

- Electric field discontinuous
- Charge build-up



$$\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}'|^2}\hat{\mathbf{r}}$$



Charges at conductivity contrasts

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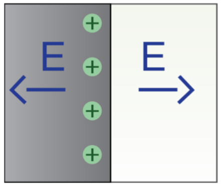
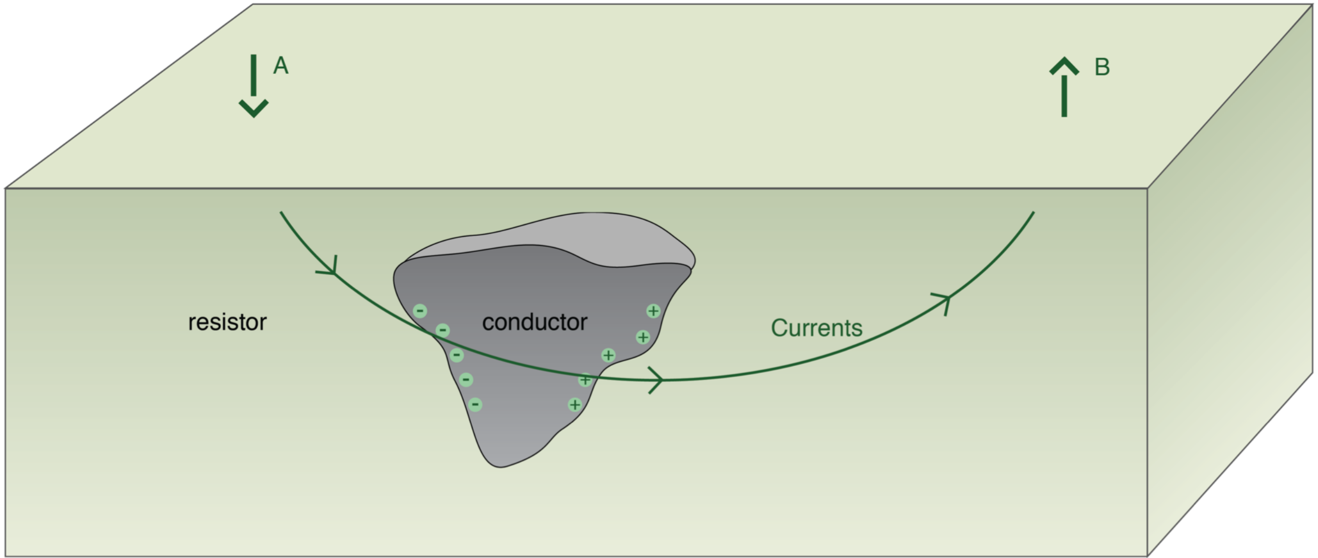
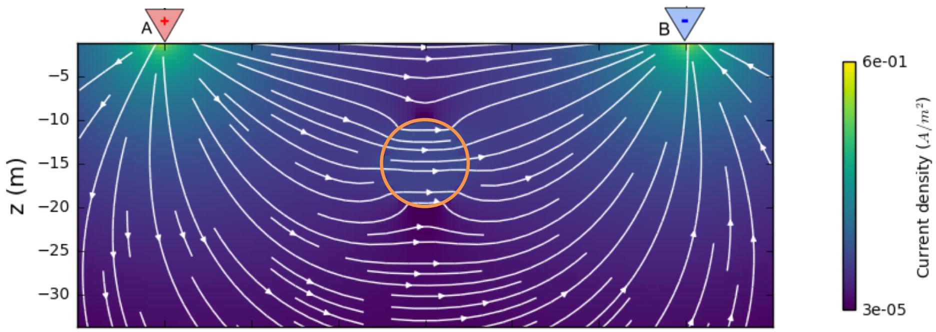


$$\tau_f = \varepsilon_0 \left(\frac{\sigma_1}{\sigma_2} - 1 \right)$$

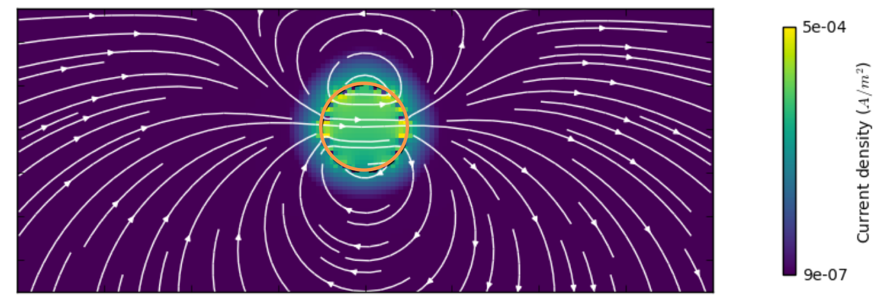


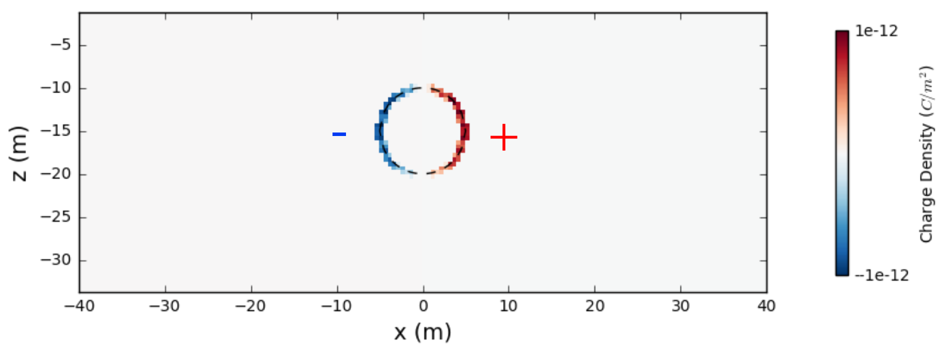
Currents, charges, and potentials

Total currents: J

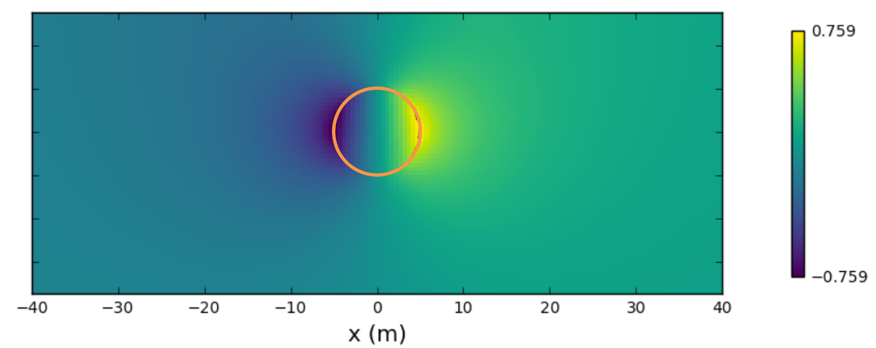


Secondary currents: J_s





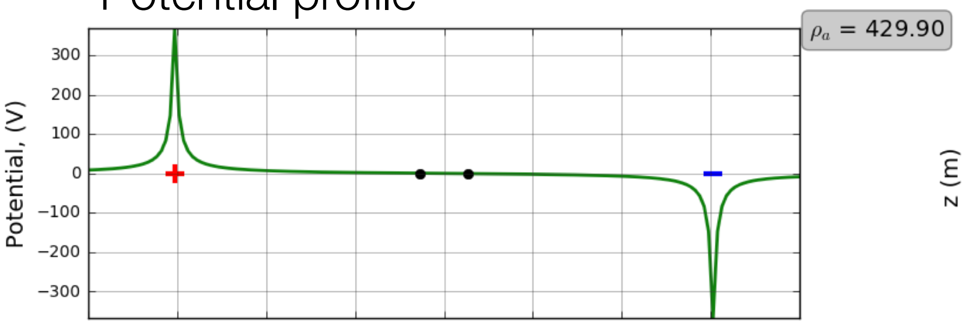
Secondary charges: Q_s



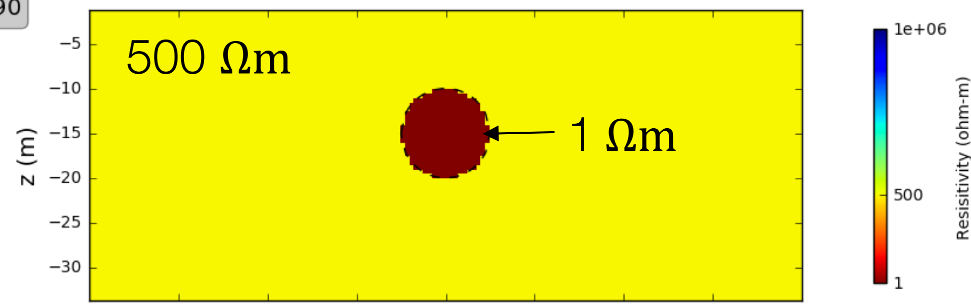
Secondary potential: ϕ_s

Measurements of DC data: gradient array

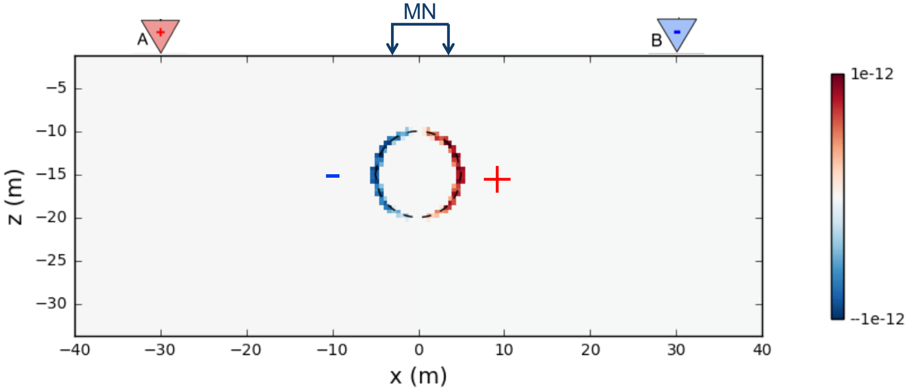
Potential profile



Resistivity model

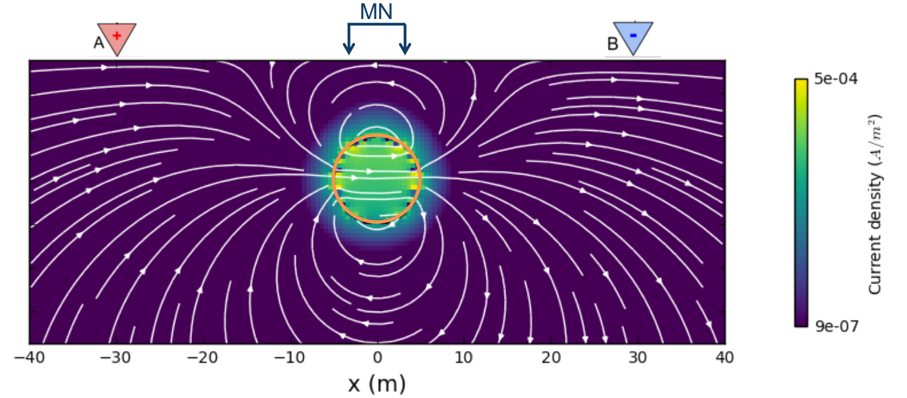


ρ_a = 430



Secondary charges: Q_s

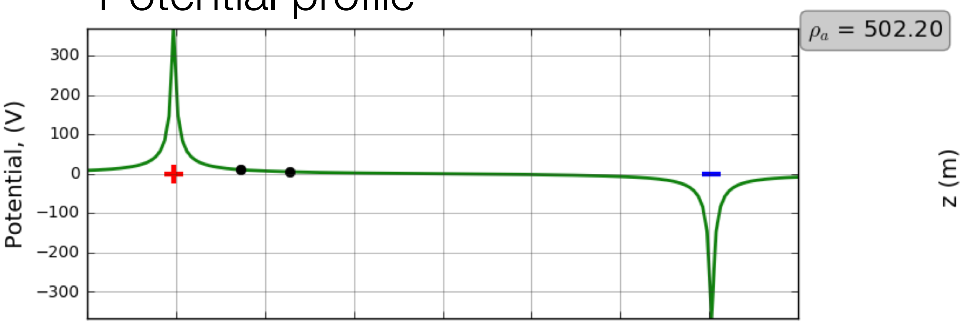
ρ_a = 430



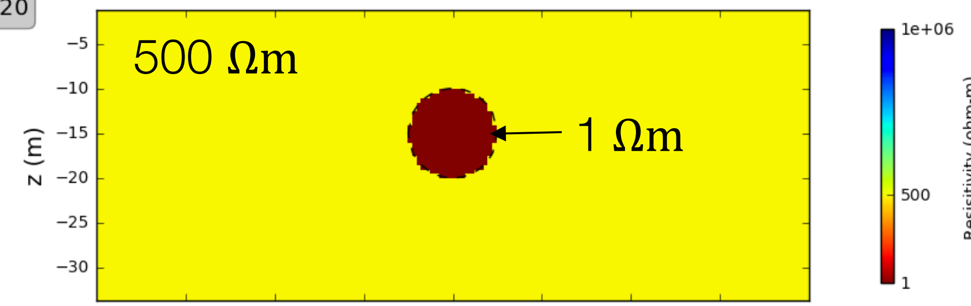
Secondary currents: J_s

Measurements of DC data: gradient array

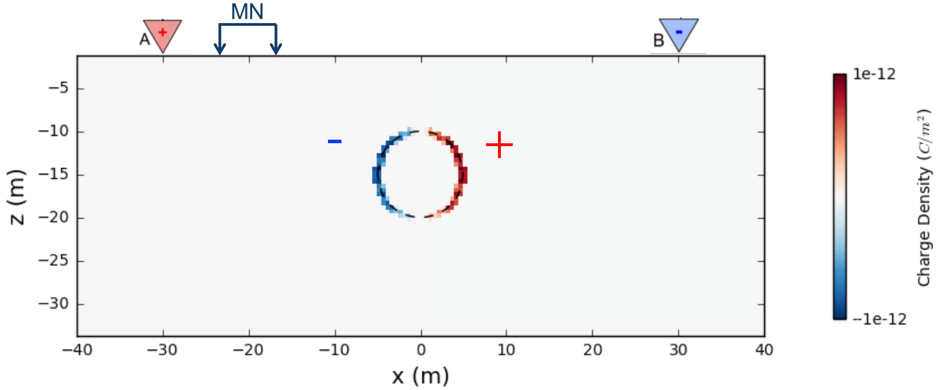
Potential profile



Resistivity model

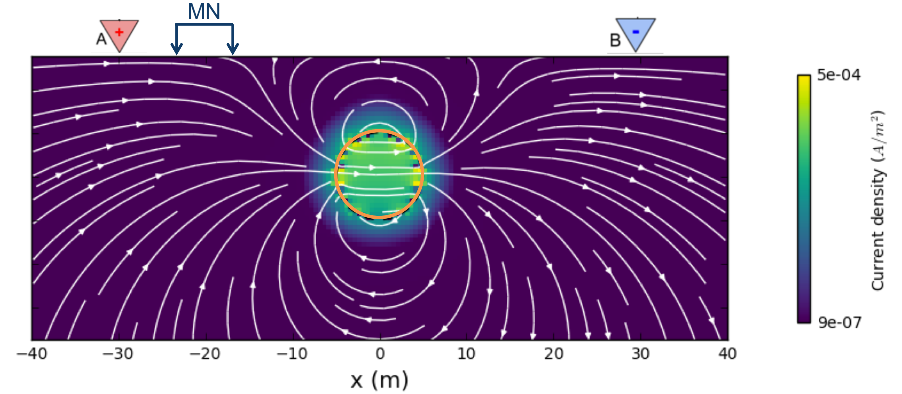


ρ_a = 502



Secondary charges: Q_s

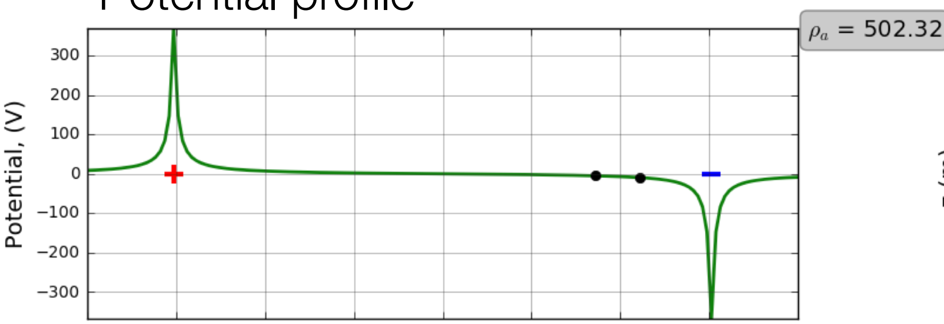
ρ_a = 502



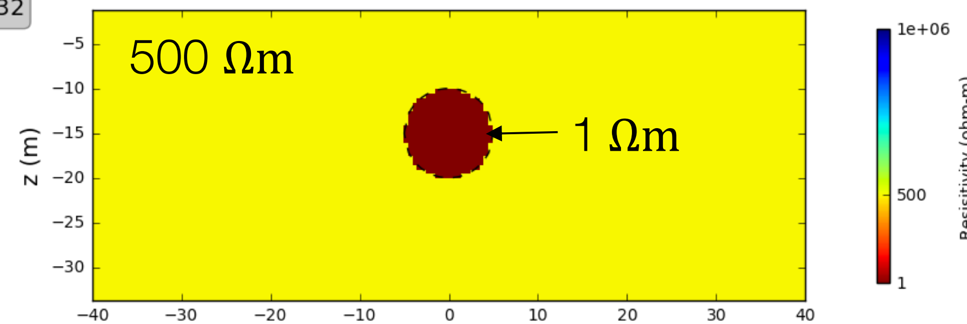
Secondary currents: J_s

Measurements of DC data: gradient array

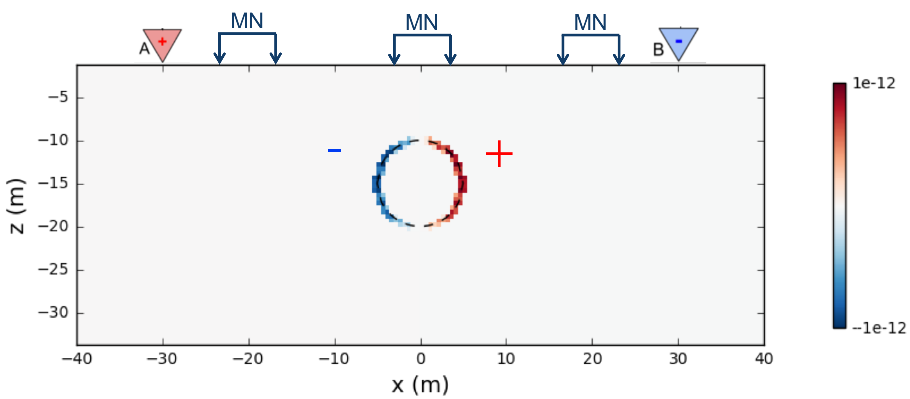
Potential profile



Resistivity model

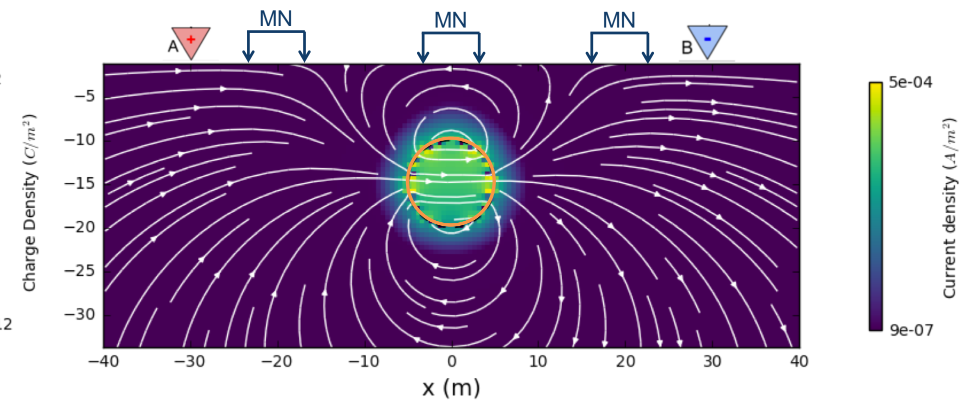


ρ_a = 502 ρ_a = 430 ρ_a = 502



Secondary charges: Q_s

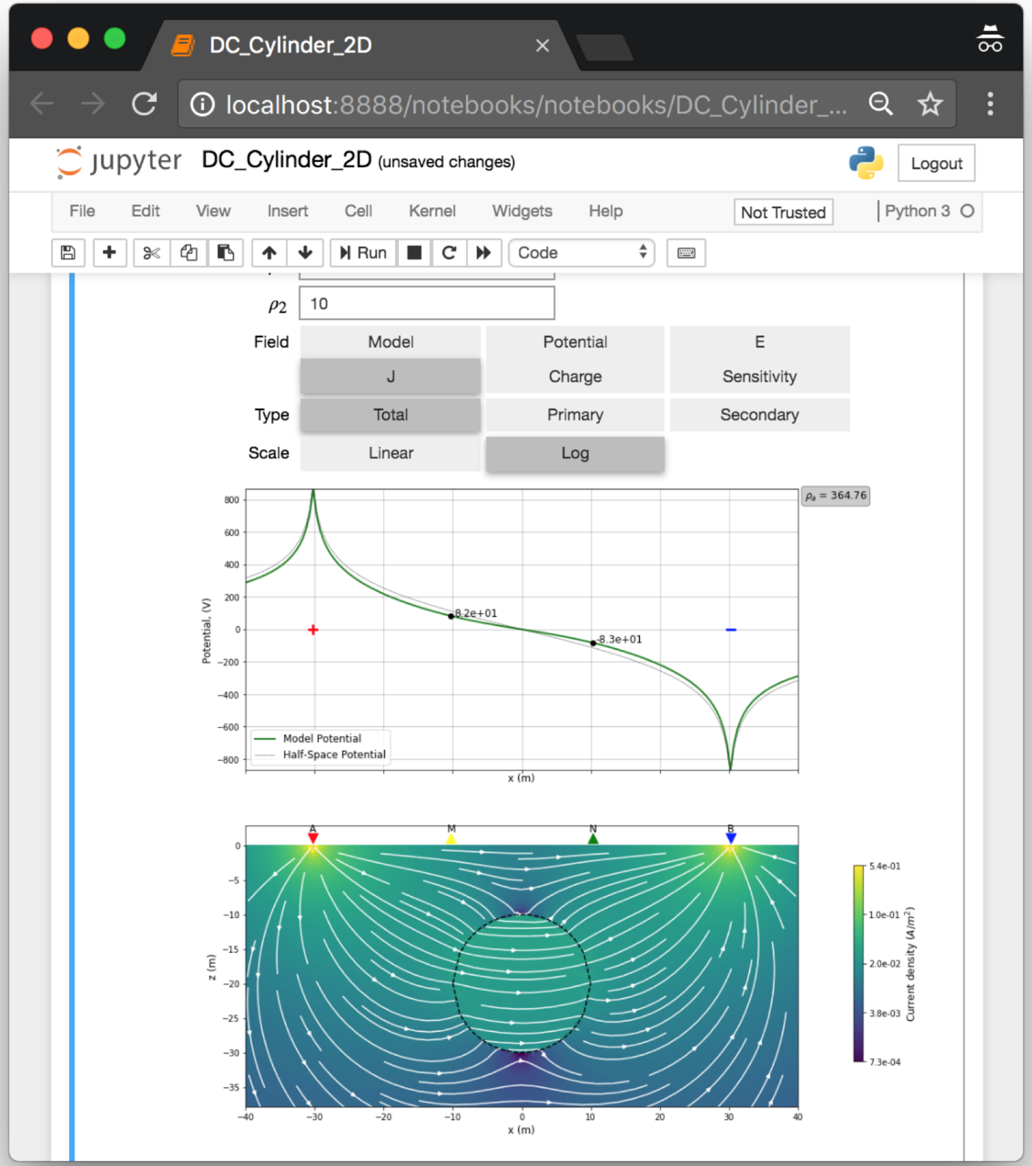
ρ_a = 502 ρ_a = 430 ρ_a = 502



Secondary currents: J_s

DC cylinder

- DC_Cylinder_2D
- Parameters:
  - Resistivity of background cylinder
  - Geometry of cylinder
  - Location of electrodes
- View:
  - Model
  - Electric potential
  - Electric field
  - Charges
  - Current density

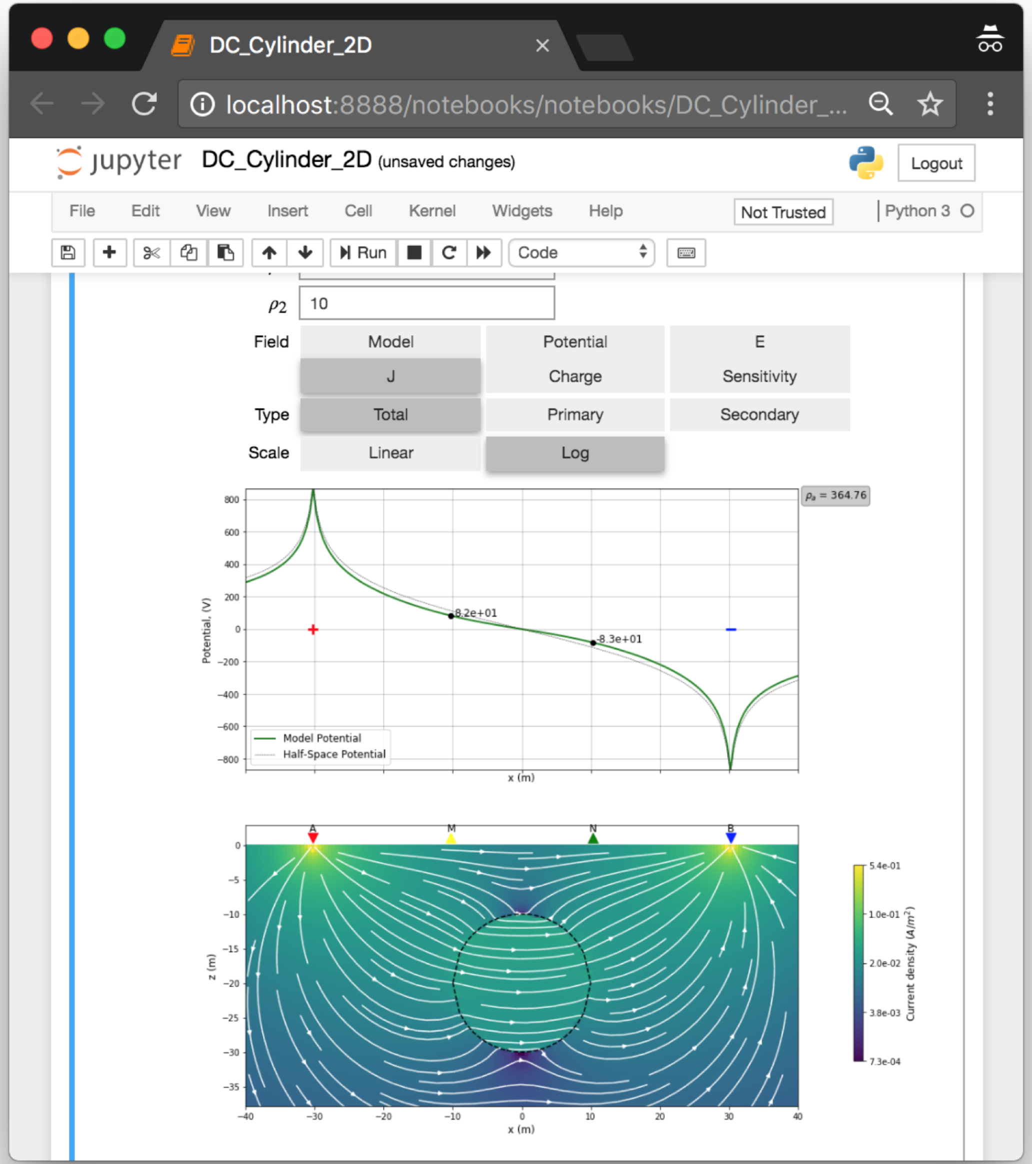


http://em.geosci.xyz/apps.html

DCR: cylinder (Demo)

- How does the charge vary with location of the current electrode?
- How does the apparent resistivity vary with source electrode location?

- Up next…
  - Profiling, sounding, and ability to see the cylinder at various depths.

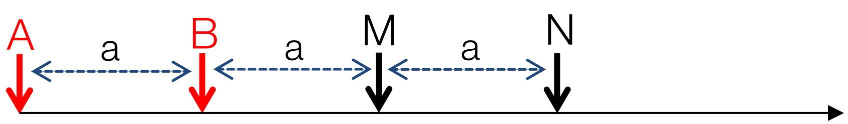


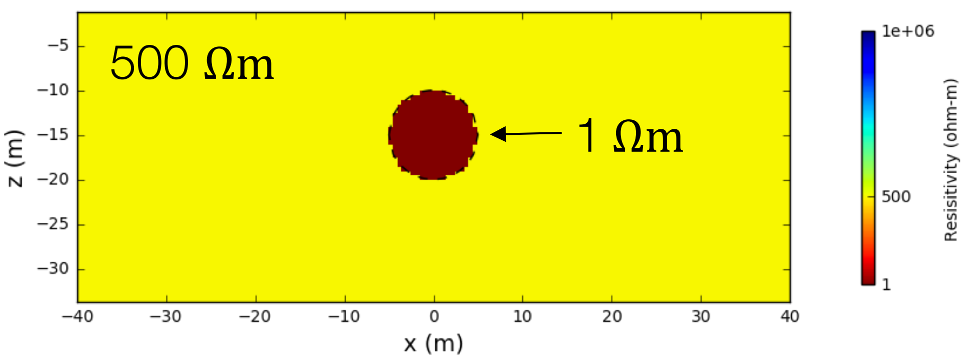
Profiling

Fixed geometry: Move laterally

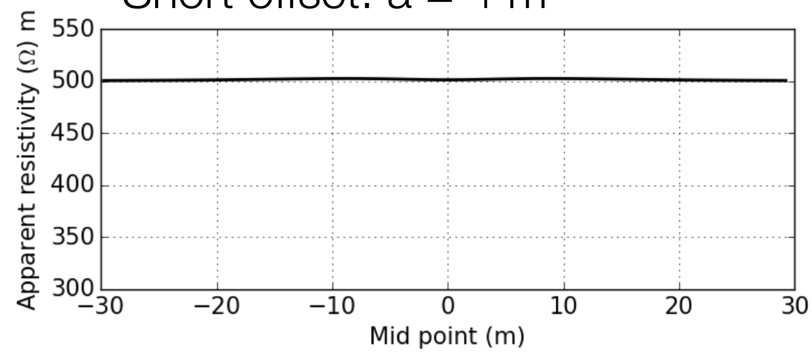
Short offset, a=4m

Long offset, a=20m

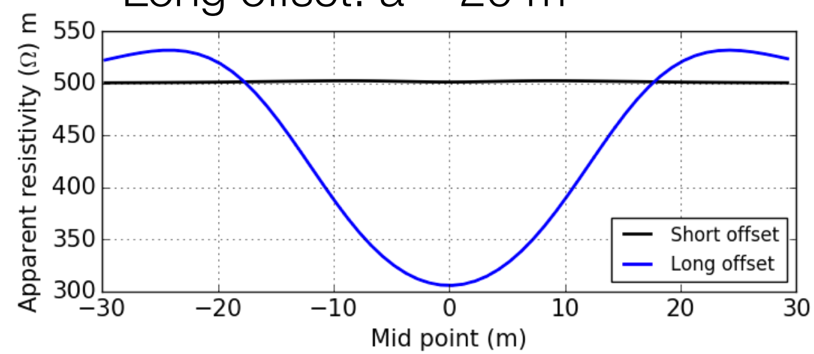




Short offset: a = 4 m



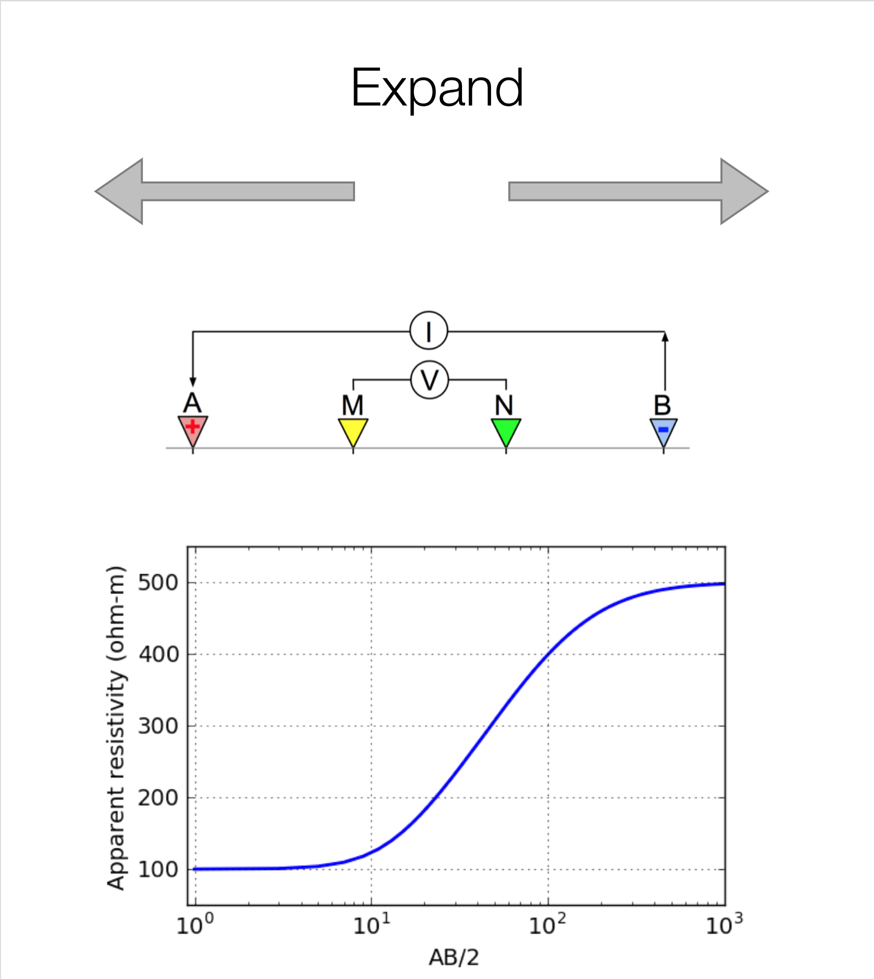
Long offset: a = 20 m



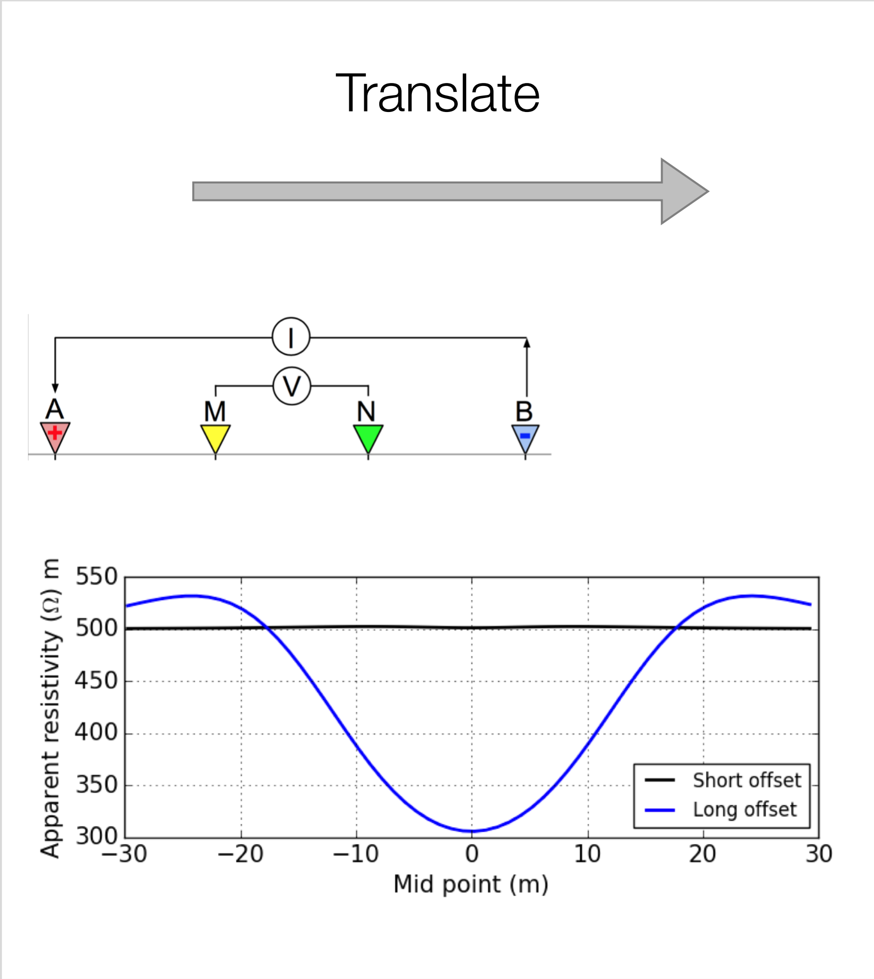
Depth of investigation depends upon offset or array length

Summary: Soundings and Profiles

Sounding

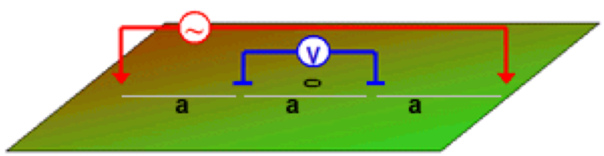


Profiling

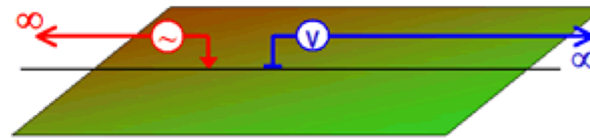


Basic Survey Setups

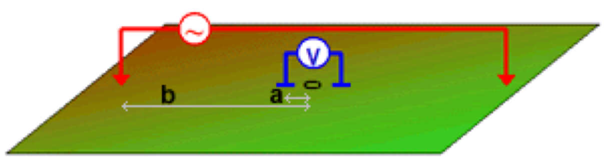
Wenner



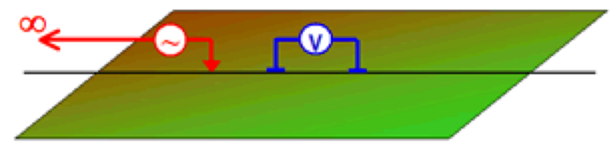
Pole-Pole



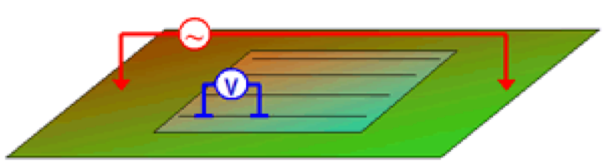
Schulmberger



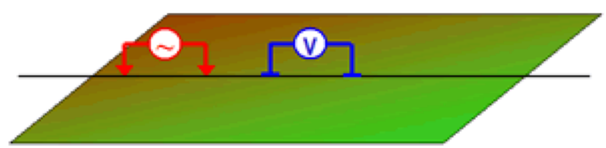
Pole-Dipole



Gradient



Dipole-Dipole



Well-logging

- Same physical principles, different geometry

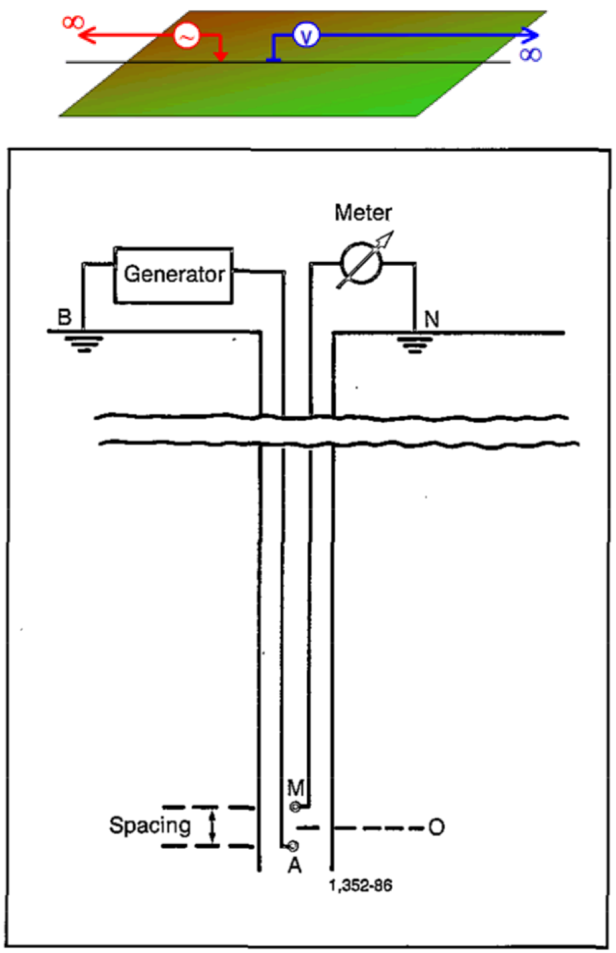


Fig. 7-1—Normal device—basic arrangement.

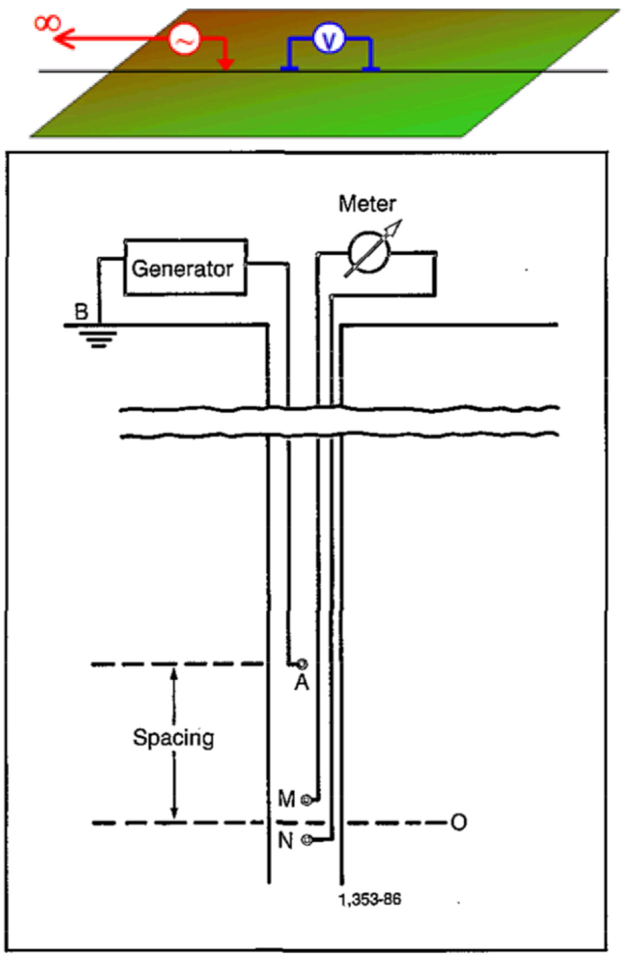
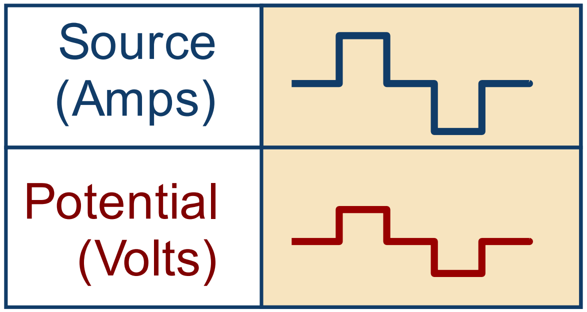
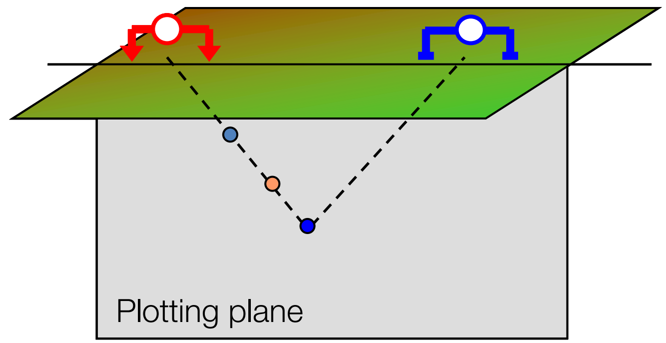


Fig. 7-2—Lateral device—basic arrangement.

From Chapter 7 of the Schlumberger Log Interpretation Principles/Applications Textbook

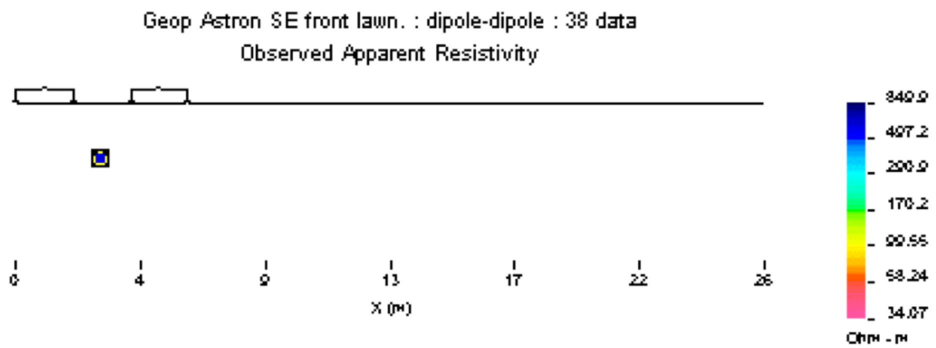
DC resistivity data





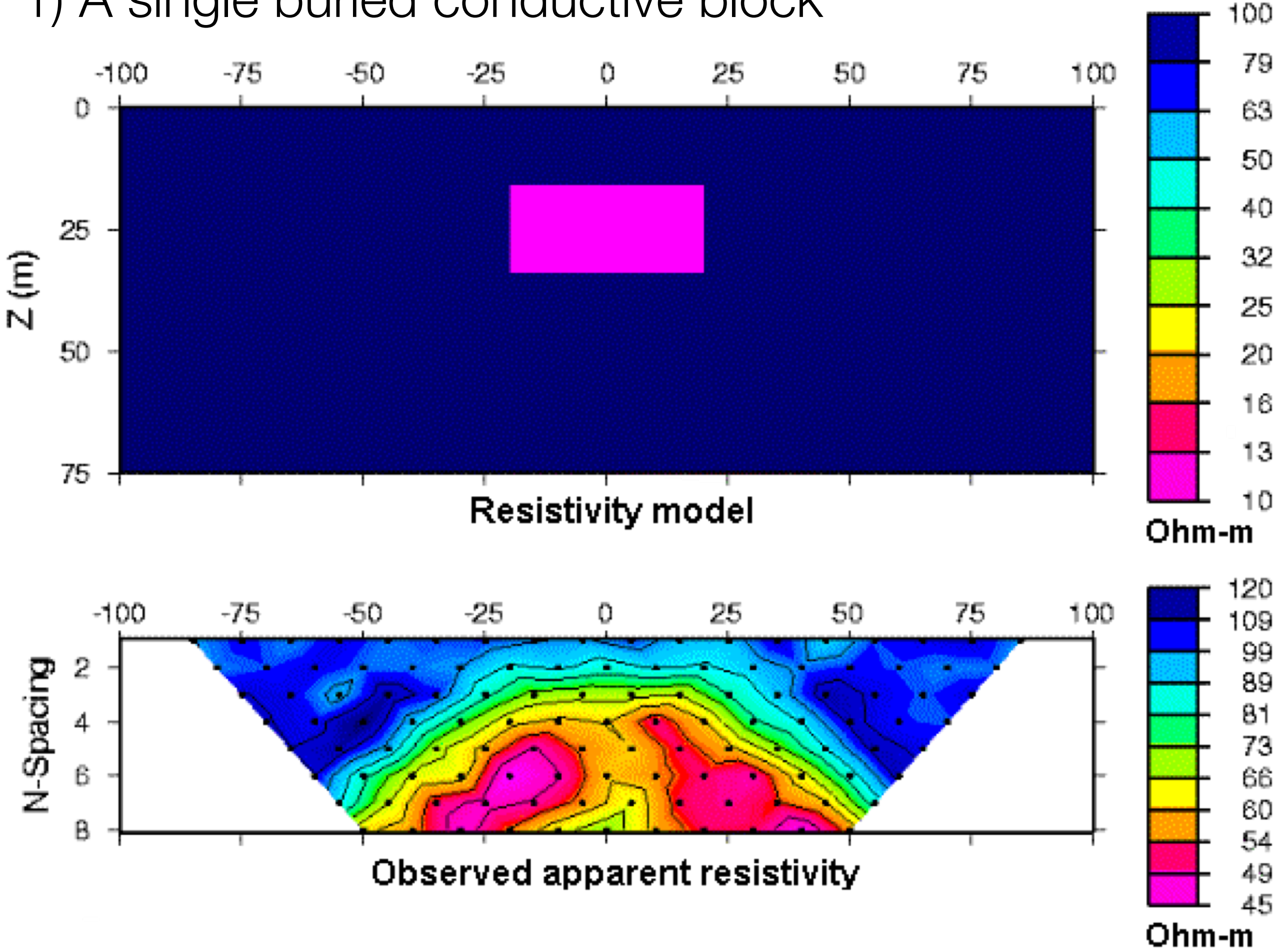
Each data point is an apparent resistivity:

$$\rho_a = \frac{2\pi\Delta V}{IG}$$

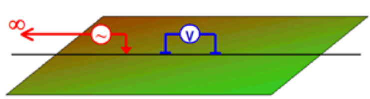


Example pseudosections

1) A single buried conductive block



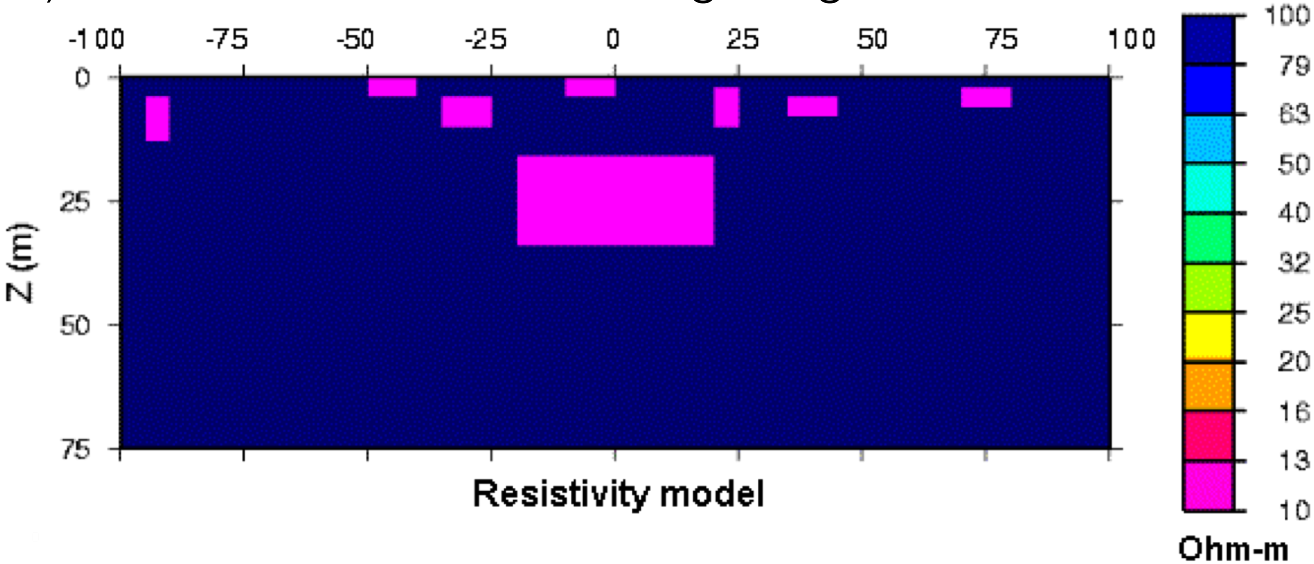
Pole-Dipole

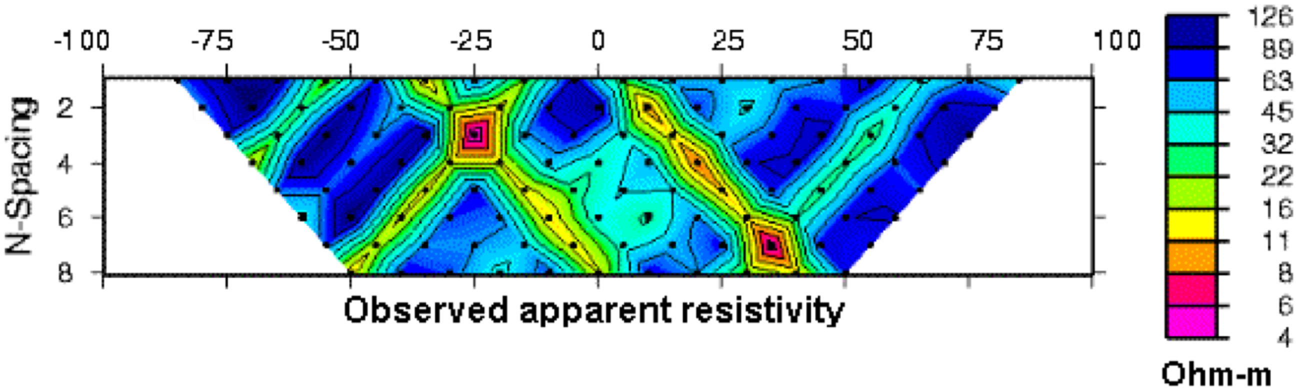


- Pole-dipole; n=1,8; a=10m; N=316

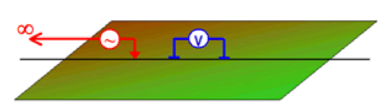
Example pseudosections

2) The conductive block with geologic noise.





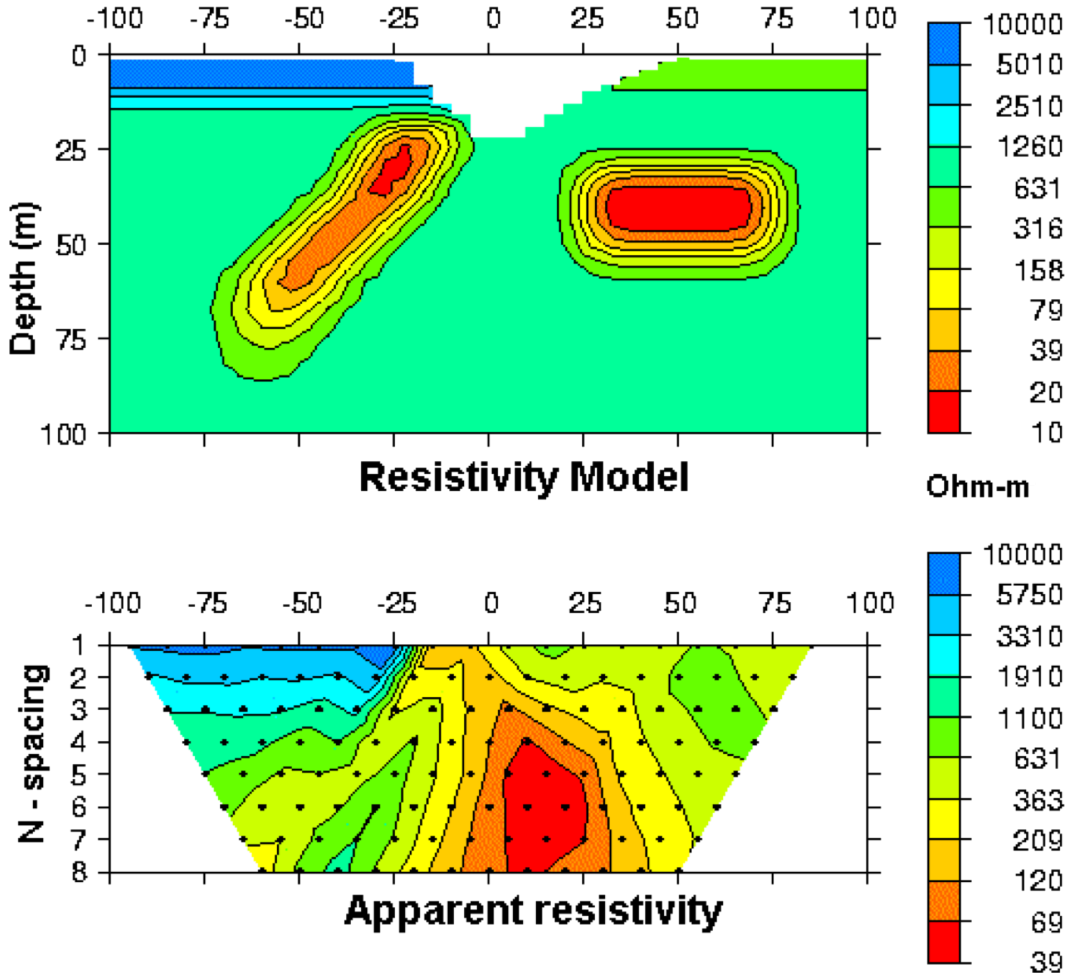
Pole-Dipole



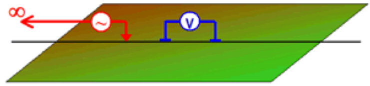
- Pole-dipole; n=1,8; a=10m; N=316

Example pseudosections

3) The "UBC-GIF model"

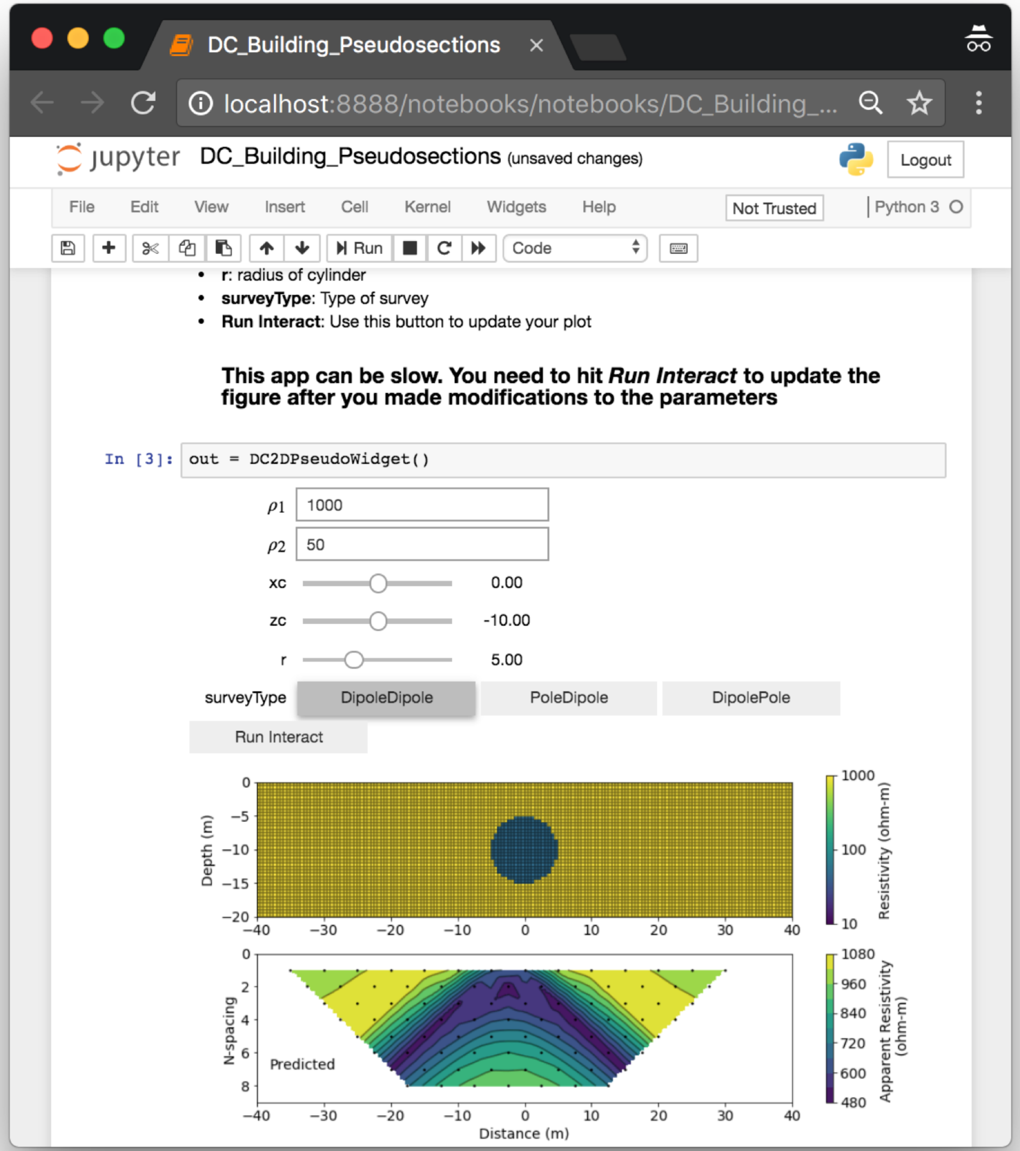


Pole-Dipole



Pseudo-section app

- DC_Building_Pseudosections
- Parameters:
  - Resistivity of background, layer, sphere
  - Geometry of sphere, layer
  - Location of electrodes
- View:
  - Model
  - Pseudosection



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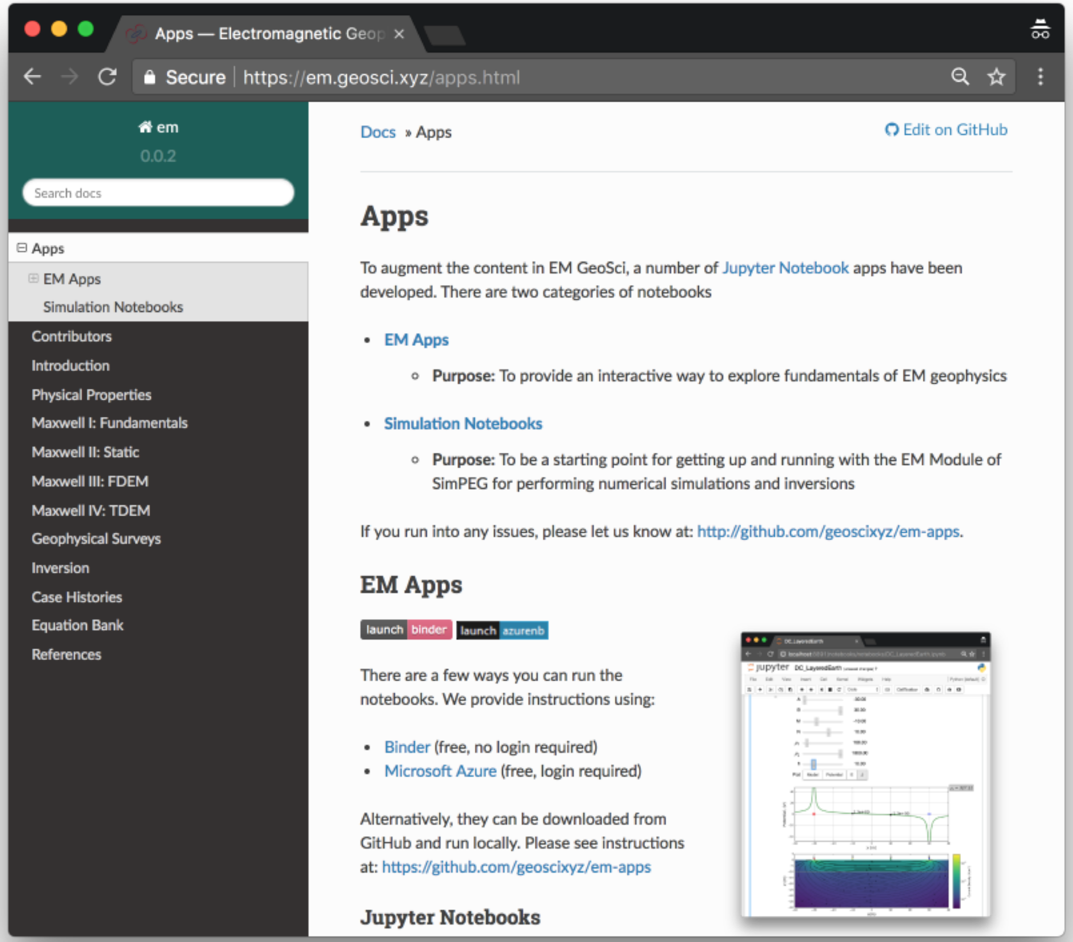
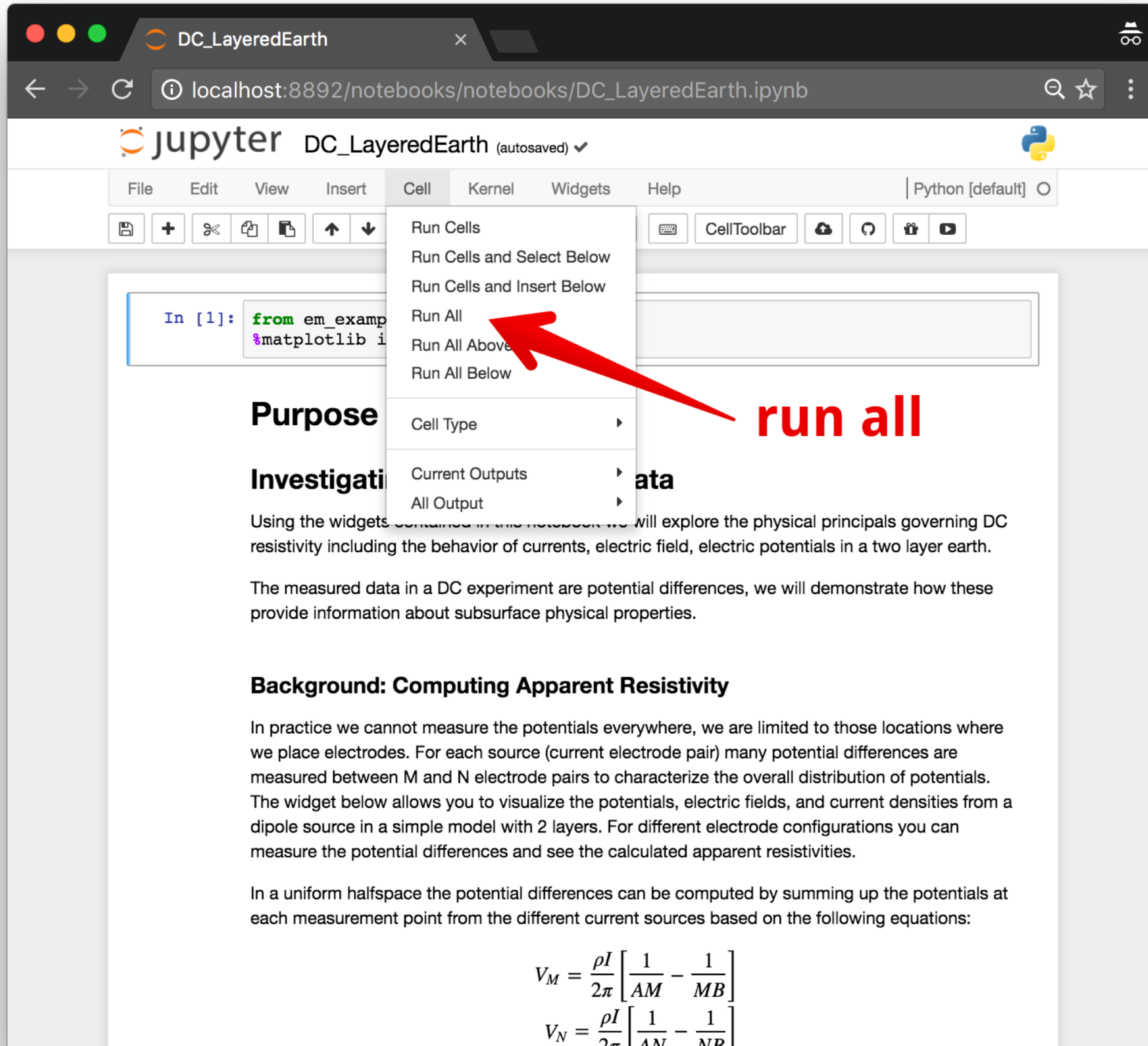
Using the apps

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



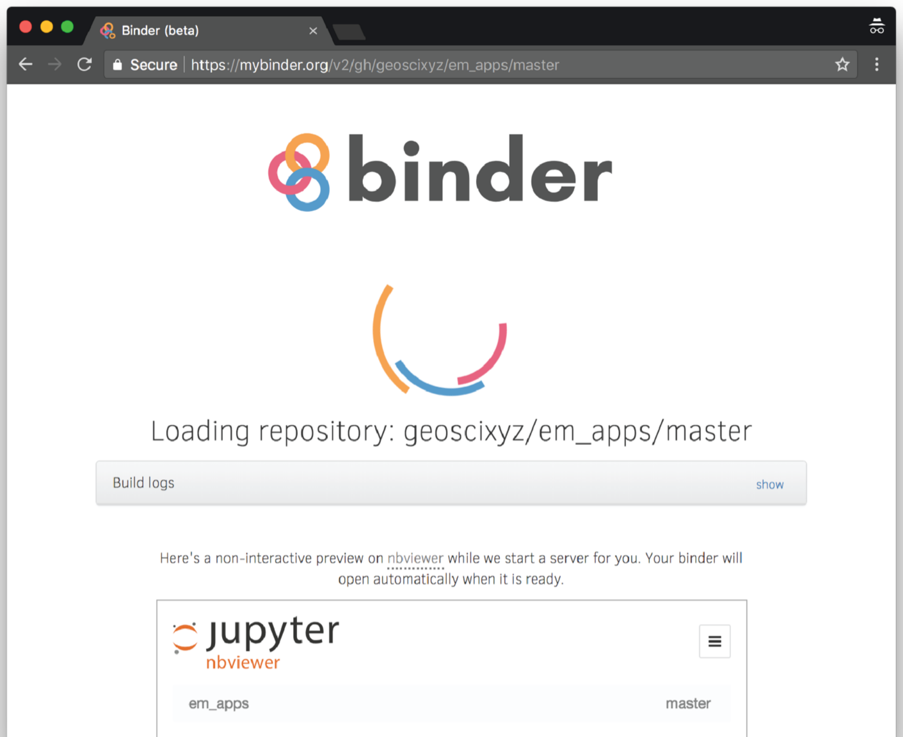
Jupyter Notebooks

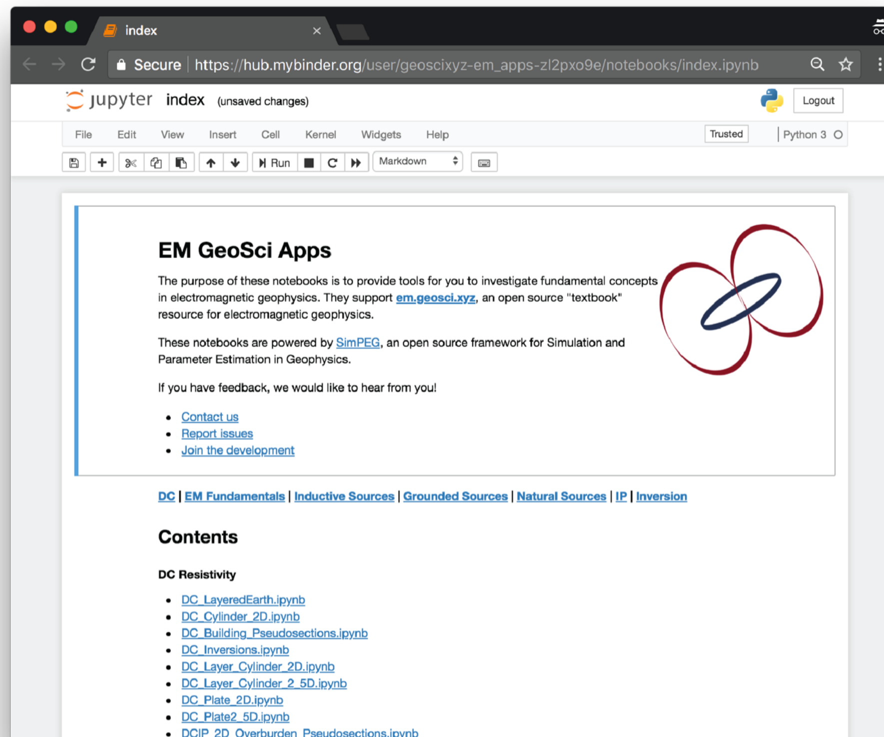


Running the Apps

launch binder

1. Load the repository (be patient...)
2. Select notebook from contents



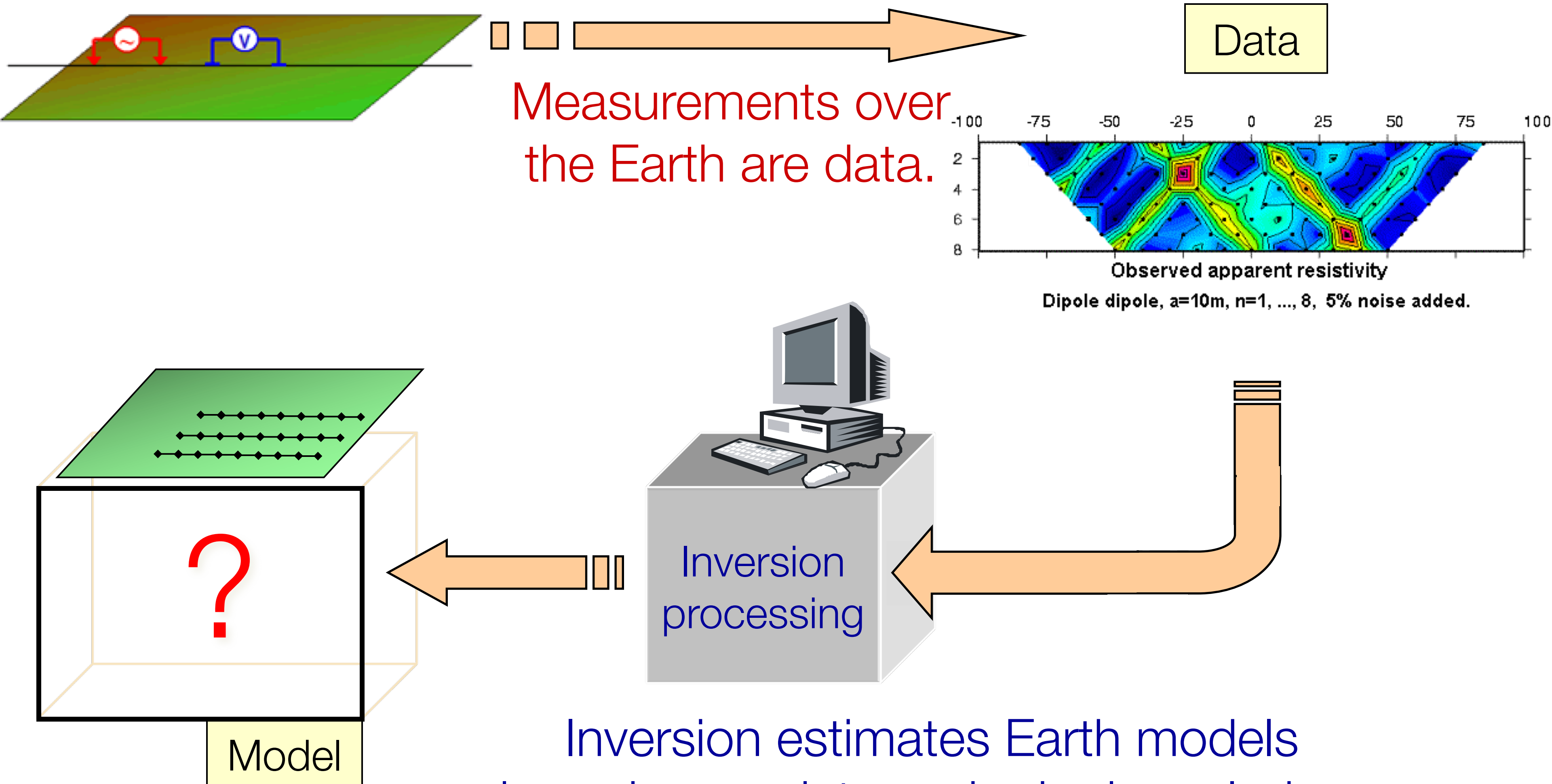


http://em.geosci.xyz/apps.html

Questions

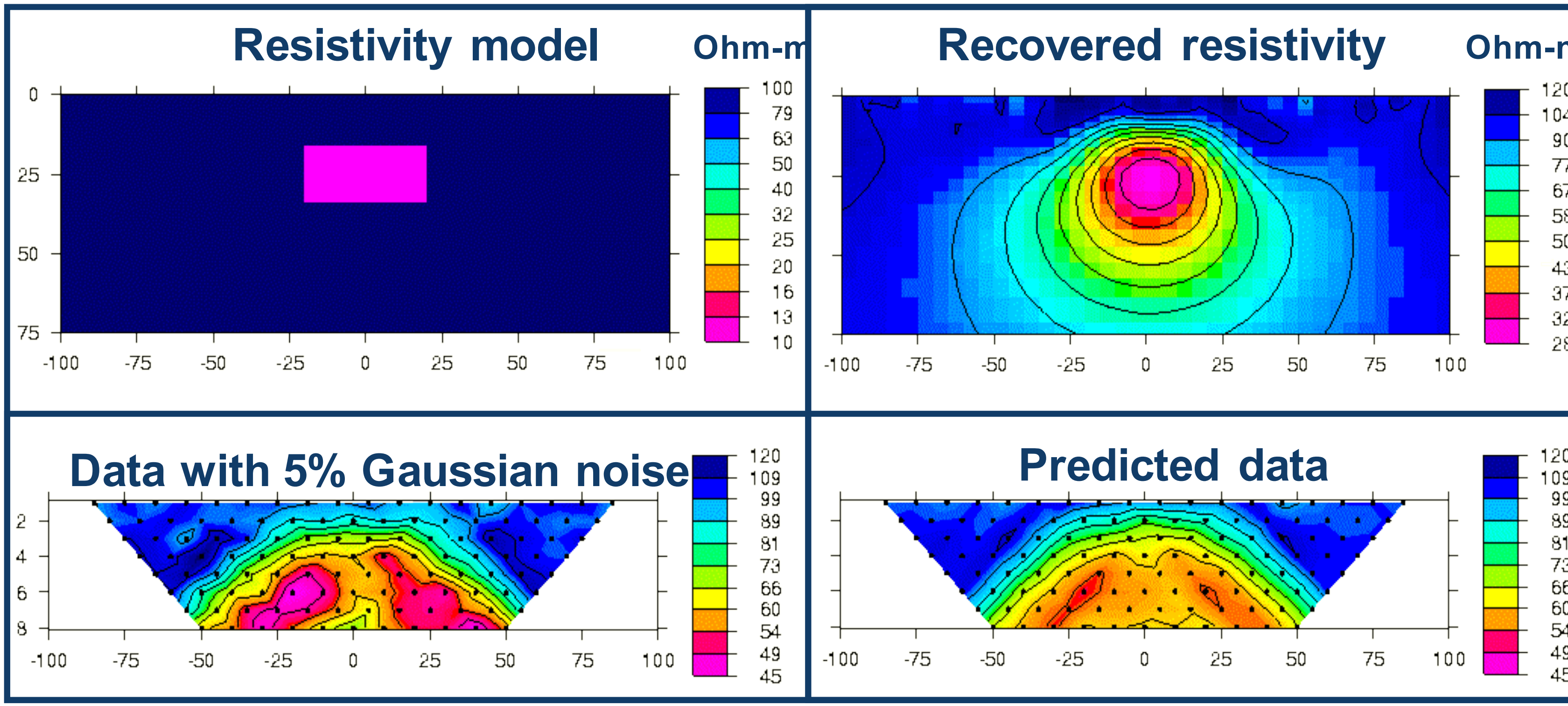
- DC_LayeredEarth
  - Start with a top layer that is conductive (50 Ωm).
    - What is the minimum A-B separation we need to see the second layer in our data?
    - What happens if the layer is more conductive / resistive?
    - What happens if the layer is thicker?
- DC_Cylinder_2D
  - You have been charged with finding 2 tunnels: (1) Filled with salty water, (2) filled with air
    - How are the charges distributed for both tunnels if you use a pole source?
    - How does the apparent resistivity vary with changing the parameters of the tunnel (resistivity, radius, depth)?
- DC_Cylinder_2D cont…
  - For a conductive cylinder (10 Ωm) in a resistive background (500 Ωm), can you generate a pole-pole example where the apparent resistivity is > 500 Ωm? How do you explain this (hint: look at the charges)
- DC_Building_Pseudosections
  - For which survey setup's are the "pant-legs" symmetric over the target? Which aren't?
  - Can you demonstrate an example of non-uniqueness? E.g. If the sphere has a radius of 2m and a resistivity of 50 Ωm, is there a model that produces similar data?

Inversion



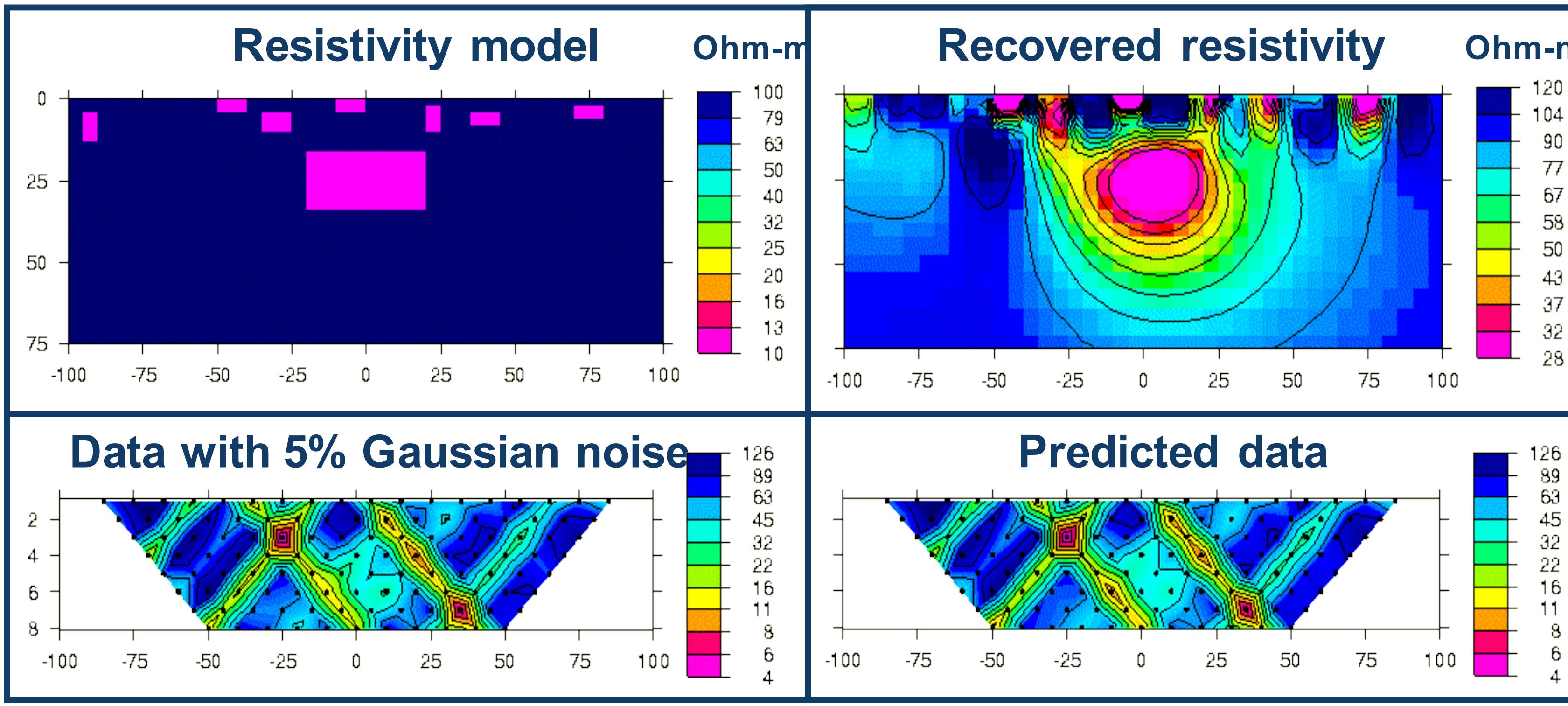
Inversion estimates Earth models based upon data and prior knowledge.

Example 1: buried prism



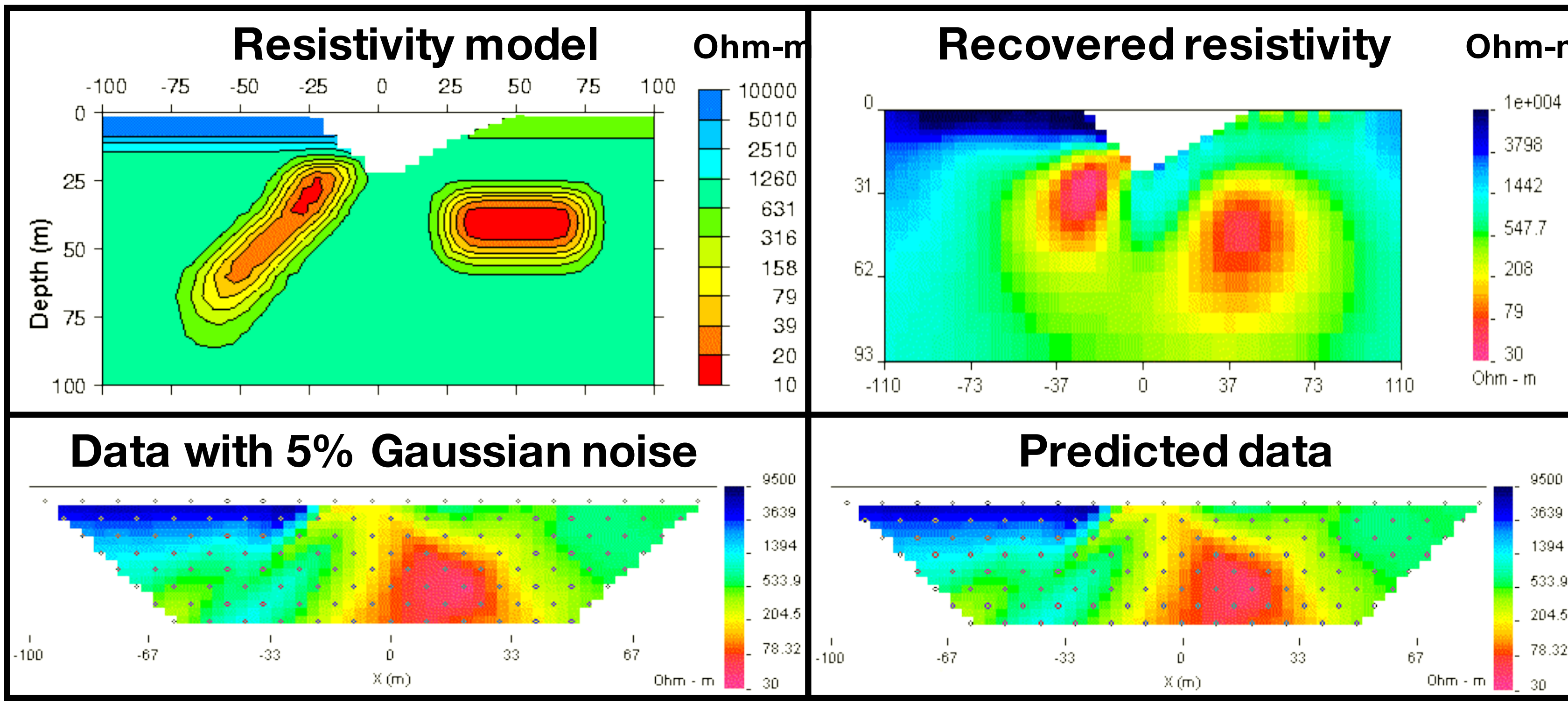
- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

Example 2: prism with geologic noise



- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

Example 3: UBC-GIF model



- Pole-dipole; n=1,8; a=10m

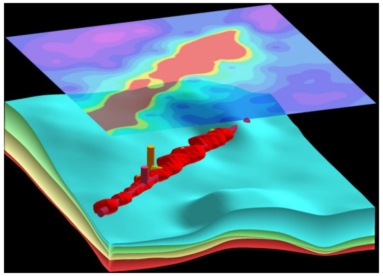
The world is 3D

- Target
  - Size, shape, depth
- Background
  - Variable resistivity
- Questions
  - Where to put currents? 2D acquisition? 3D?
  - Where to make measurements?
  - Which measurements?
  - Effects of topography?
- These are survey design questions
- Crucial element is the **sensitivity**

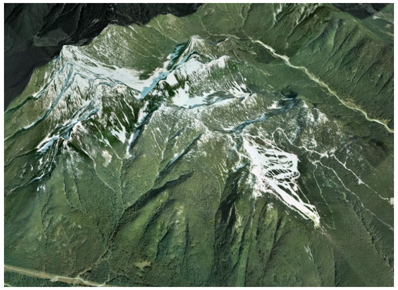
Host

Water underground

Ore body

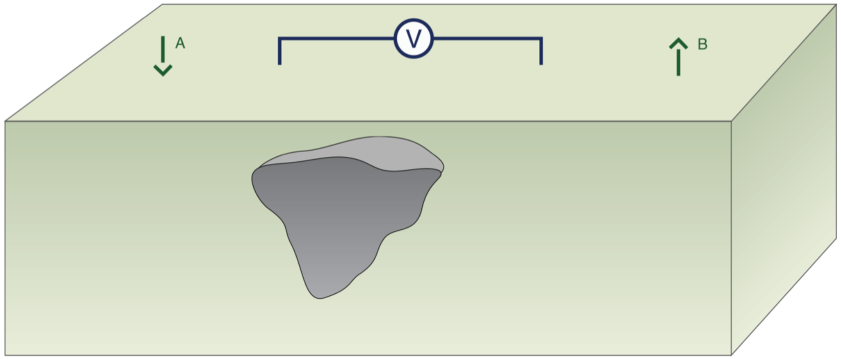


Topography



Sensitivity

Sensitivity Function



Is the measured potential *sensitive* to the target?

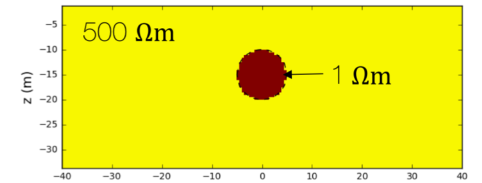
Quantified by the sensitivity

$$G = \frac{\Delta d}{\Delta p} = \frac{\text{change in data}}{\text{change in model}}$$

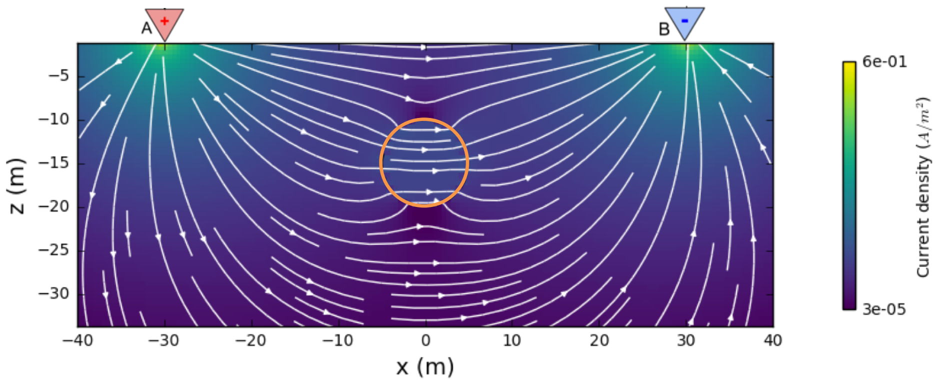
- Collect the data that are sensitive to the target
  - Need to **excite** the target
  - Need to have sensor **close** to the target

Exciting the target

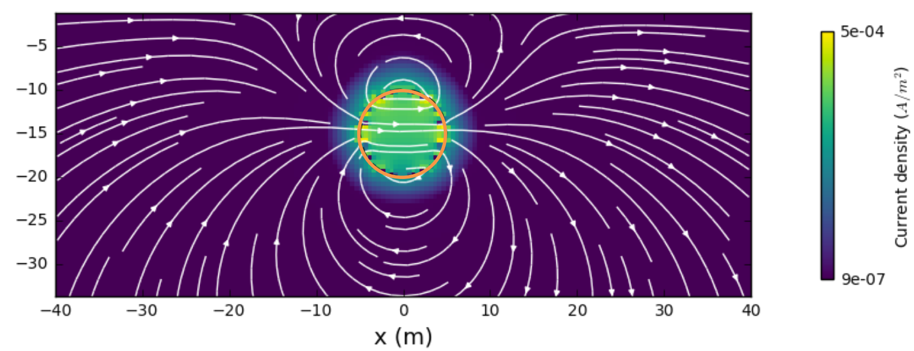
Resistivity model



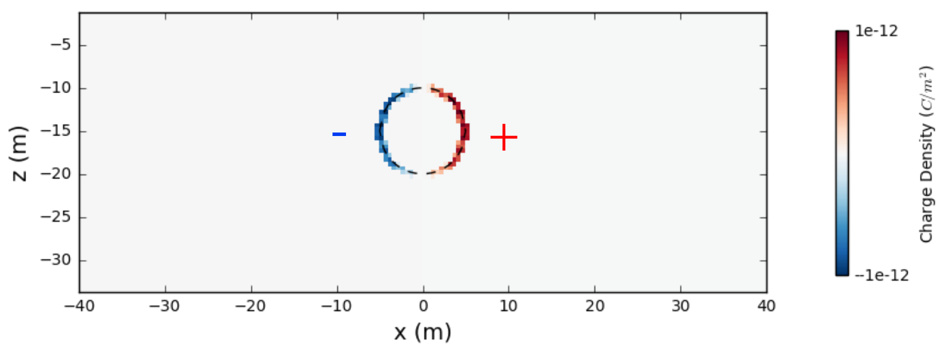
Total currents: **J**



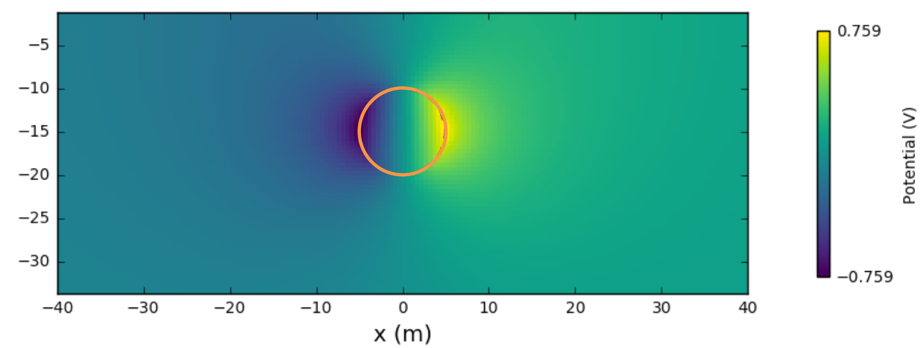
Secondary currents: $\mathbf{J}_s$



Secondary charges: Q_s

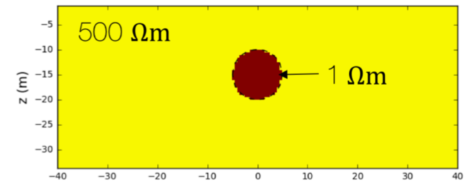


Secondary potential: ϕ_s

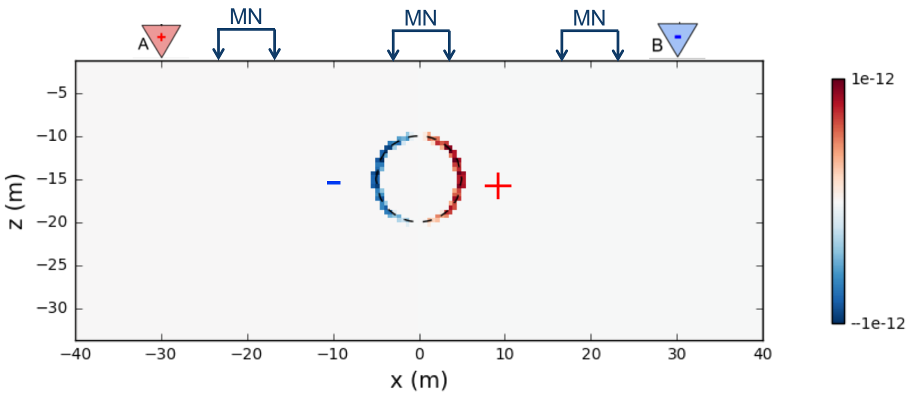


Measurements

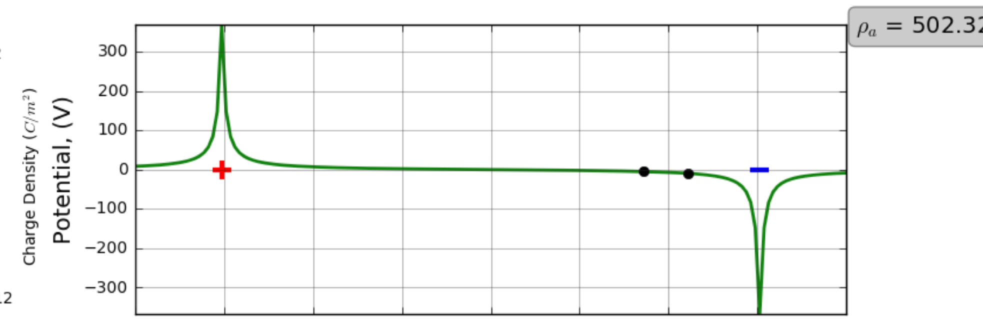
Resistivity model



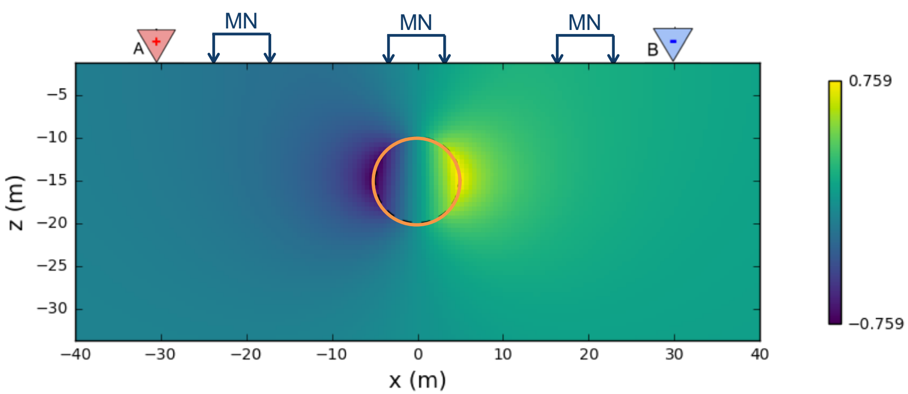
Secondary charges: Q_s



Potential profile

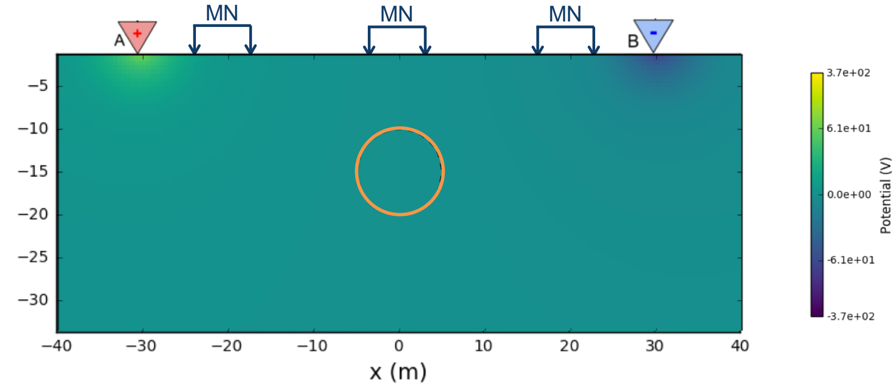


Secondary potential: ϕ_s



Total potential: ϕ

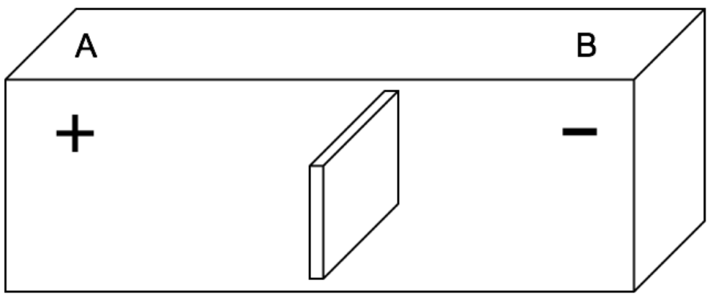
$\rho_a = 502$ $\rho_a = 430$ $\rho_a = 502$

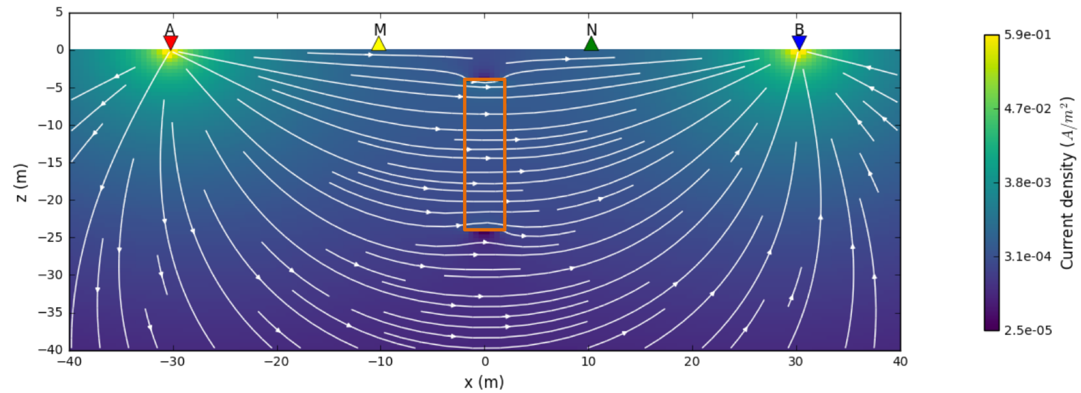


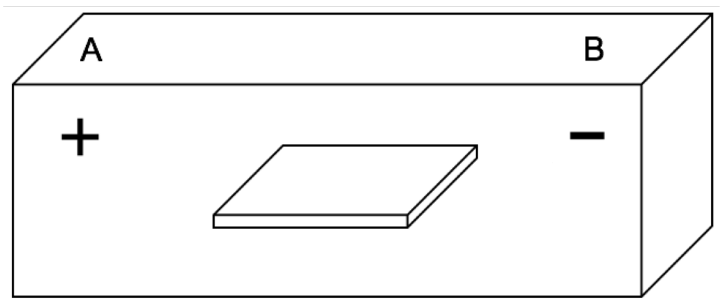
Coupling

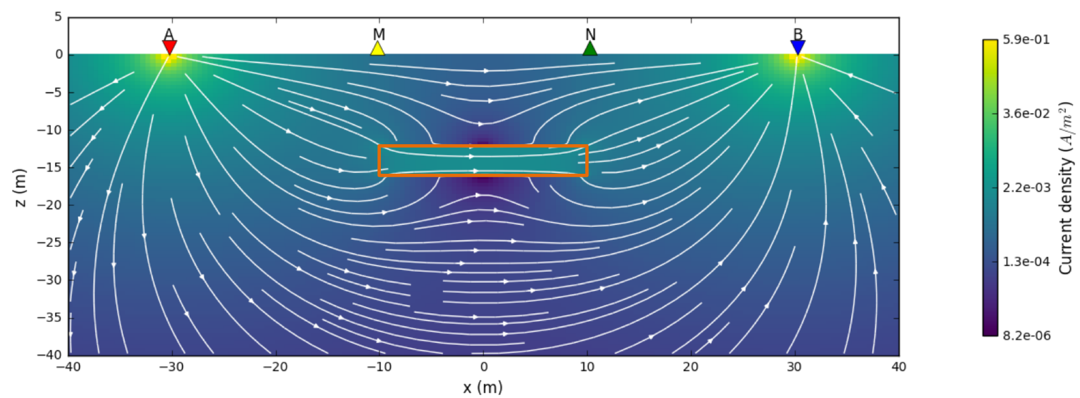
- Thin plate – different orientations
  → different data

Total currents: **J**





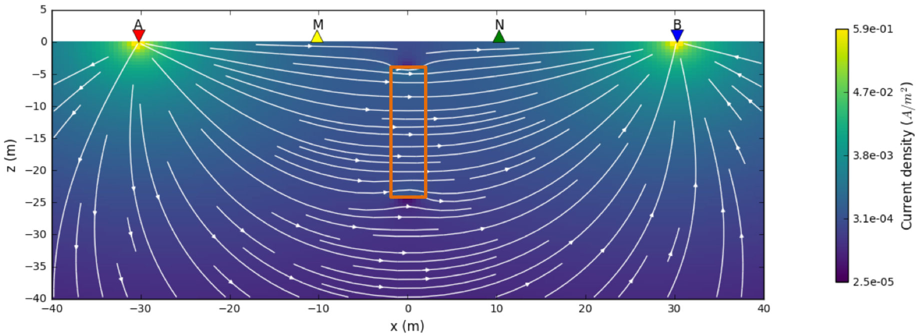




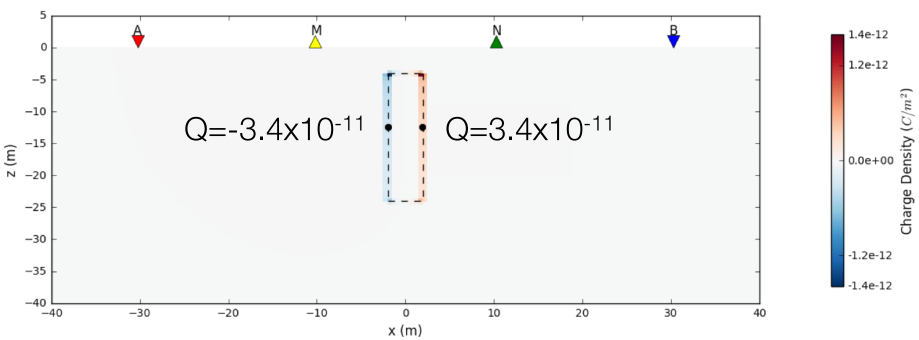
Conductive vs. Resistive Target

Conductive Target

Total currents: **J**

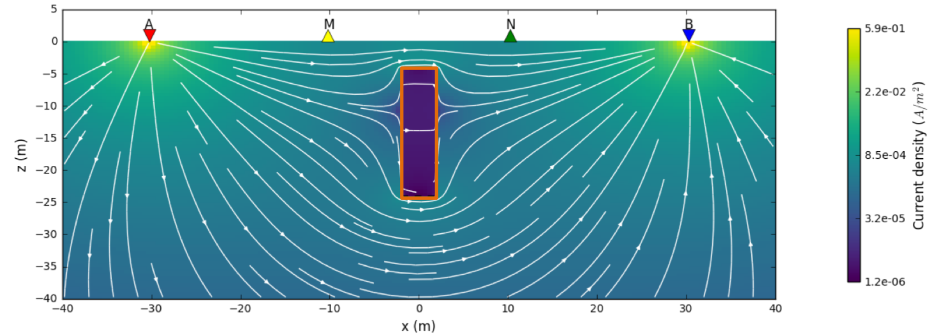


Secondary charges: Q_s

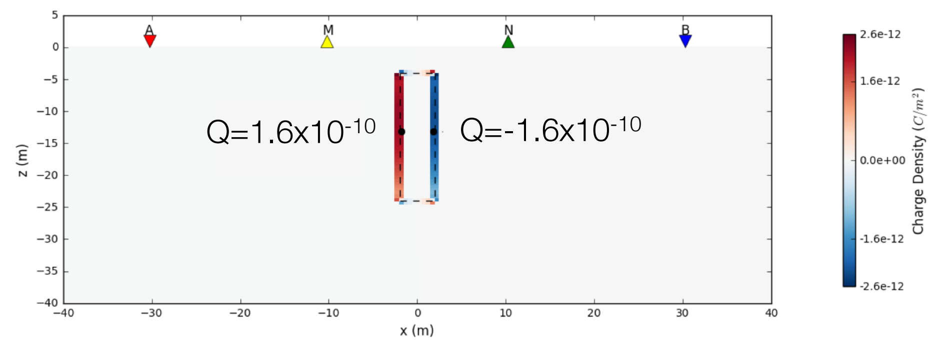


Resistive Target

Total currents: **J**

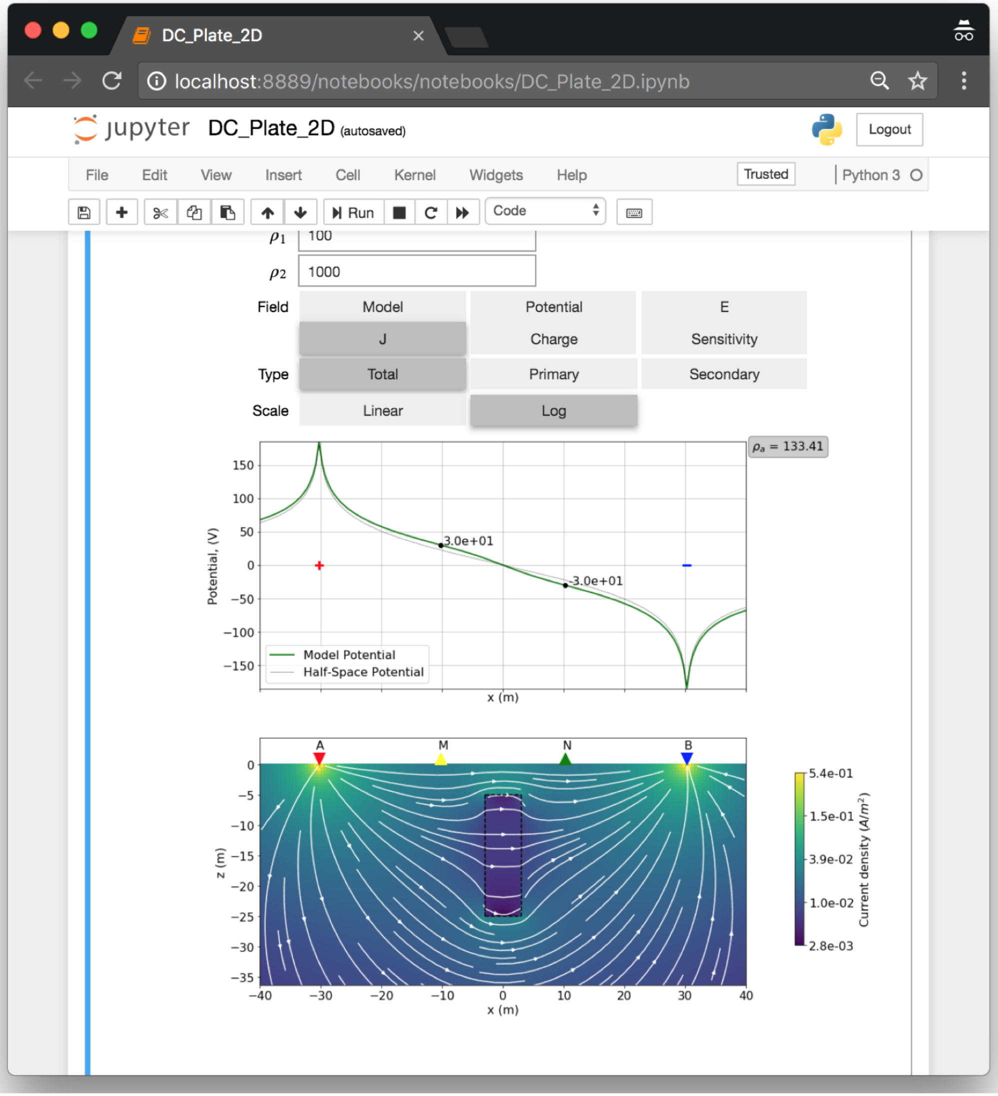


Secondary charges: Q_s



DC 2D Plate app

- DC_Plate_2D
- Parameters:
  - Resistivity of background, plate
  - Geometry and location of plate
  - Location of electrodes
- View:
  - Model
  - Electric potential
  - Electric field
  - Charges
  - Current density



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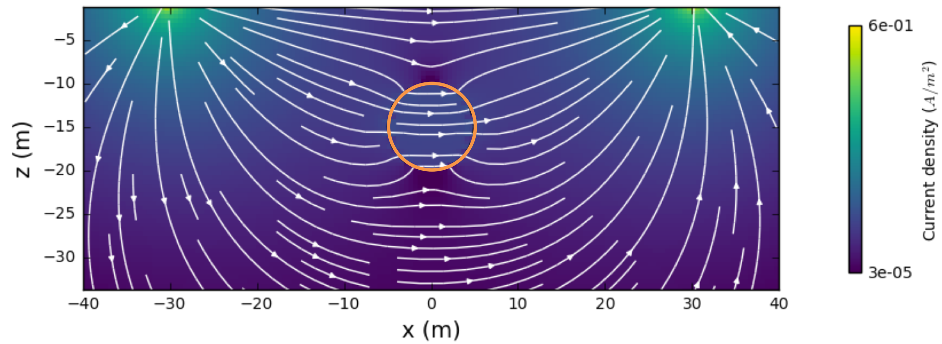
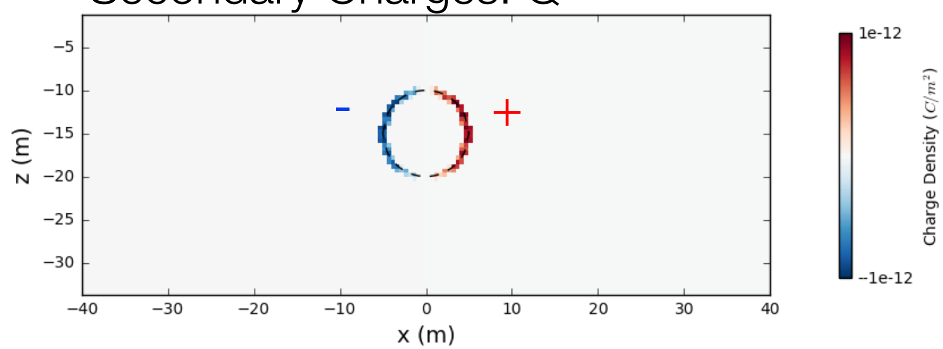
Summary: Sensitivity

- “Excite” the target
  - Drive currents to target
  - Need good coupling with target
- Measuring a datum
  - Proximity to target
  - Electrode orientation and separation
- Background resistivity is important

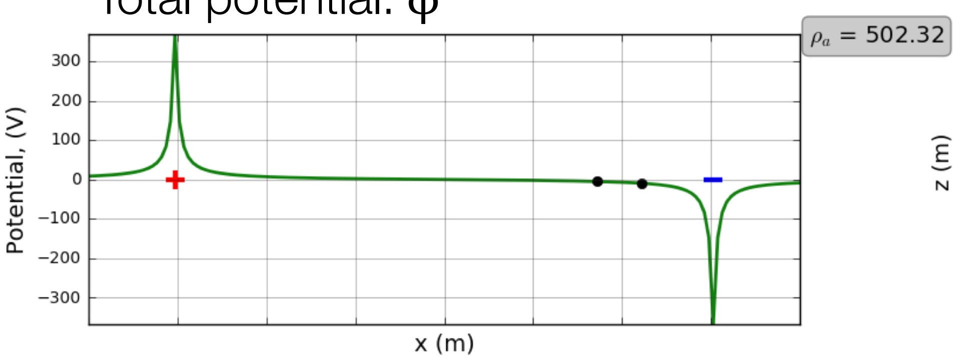
Total currents: J



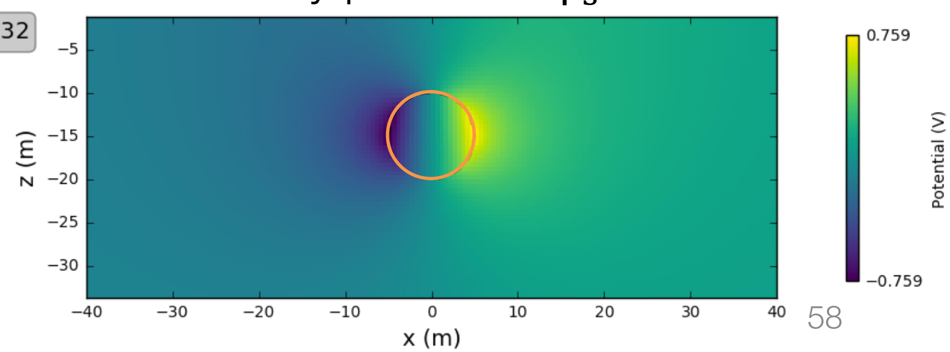
Secondary Charges: Q



Total potential: ϕ

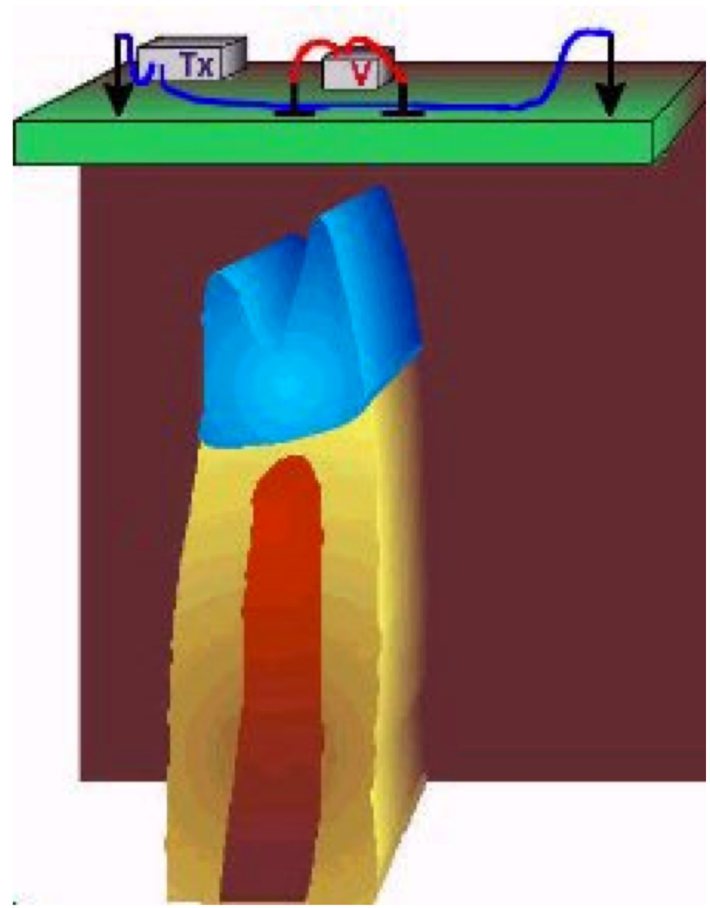


Secondary potential: ϕ_s



Survey Design: Questions

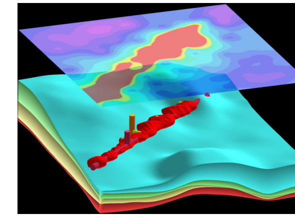
- What is objective?
  - Layered earth (1D)
    → do a sounding
  - Target body (2D)
    → profile, sounding perpendicular to geology
  - Target body (3D)
    → need 3D coverage



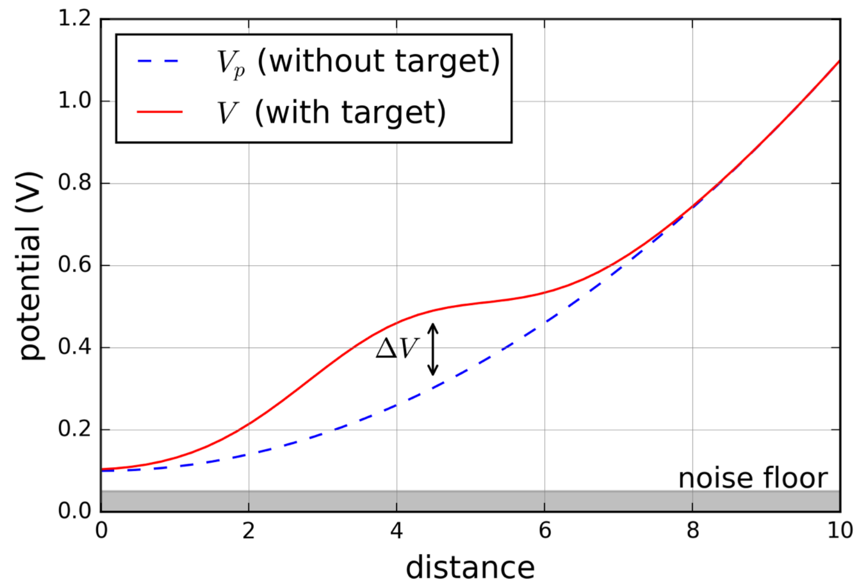
- What is the background resistivity?

- What are the noise sources? fences, power lines, …

Survey Design: in general



- Numerical simulation – can we **see** the target?
- Steps:
  - Define a geologic model
  - Assign physical properties
  - Select a survey
  - Simulate with (V) and without (V_p) target
- Best practice
  - Assign uncertainties to simulated data
  - Invert with code you will use for the field data



Signal from target

$$\Delta V = V - V_p$$

Need

$$\Delta V > floor$$

$$\frac{\Delta V}{V_p} > \%|V|$$

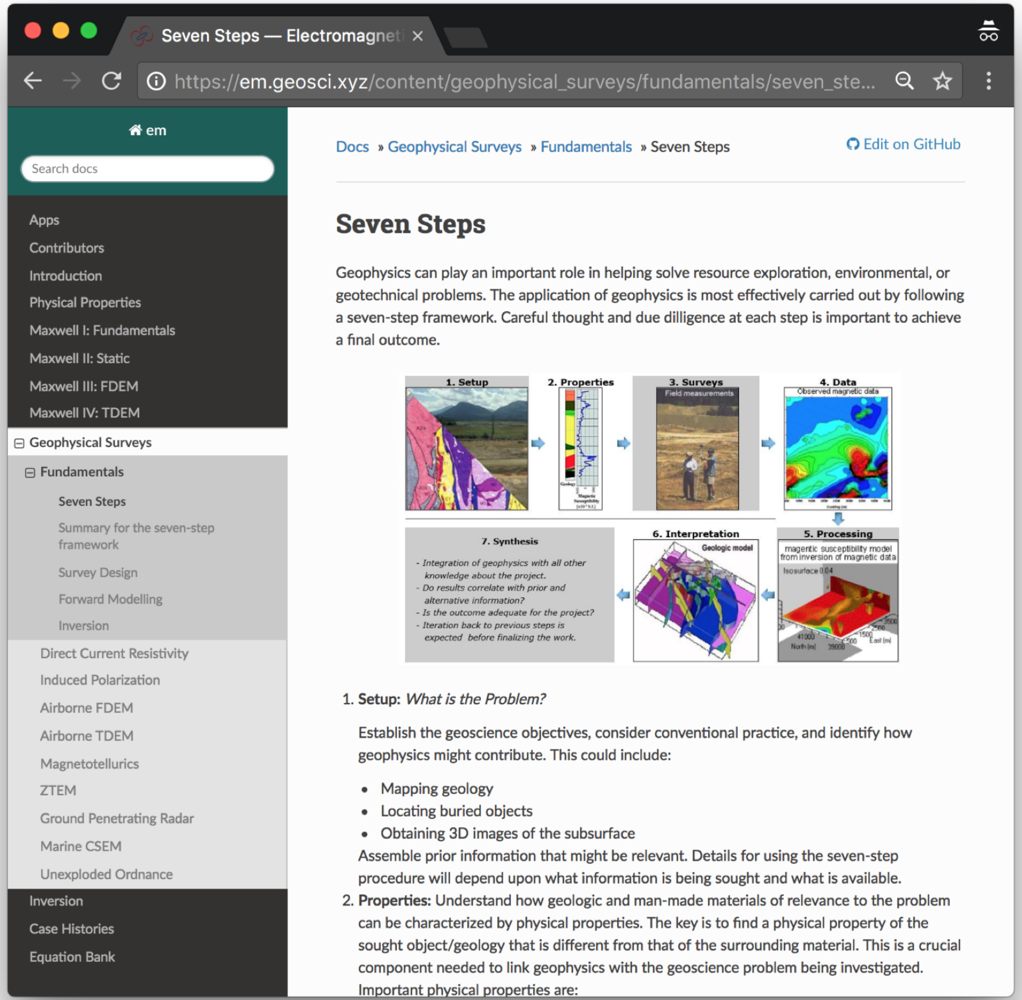
Outline

- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- Case History – Mt Isa
- Case History – Reservoir monitoring for oil sands

- Steel casing + DC
- Working with the apps
- Effects of background resistivity

Geophysical Surveys using EM.GeoSci

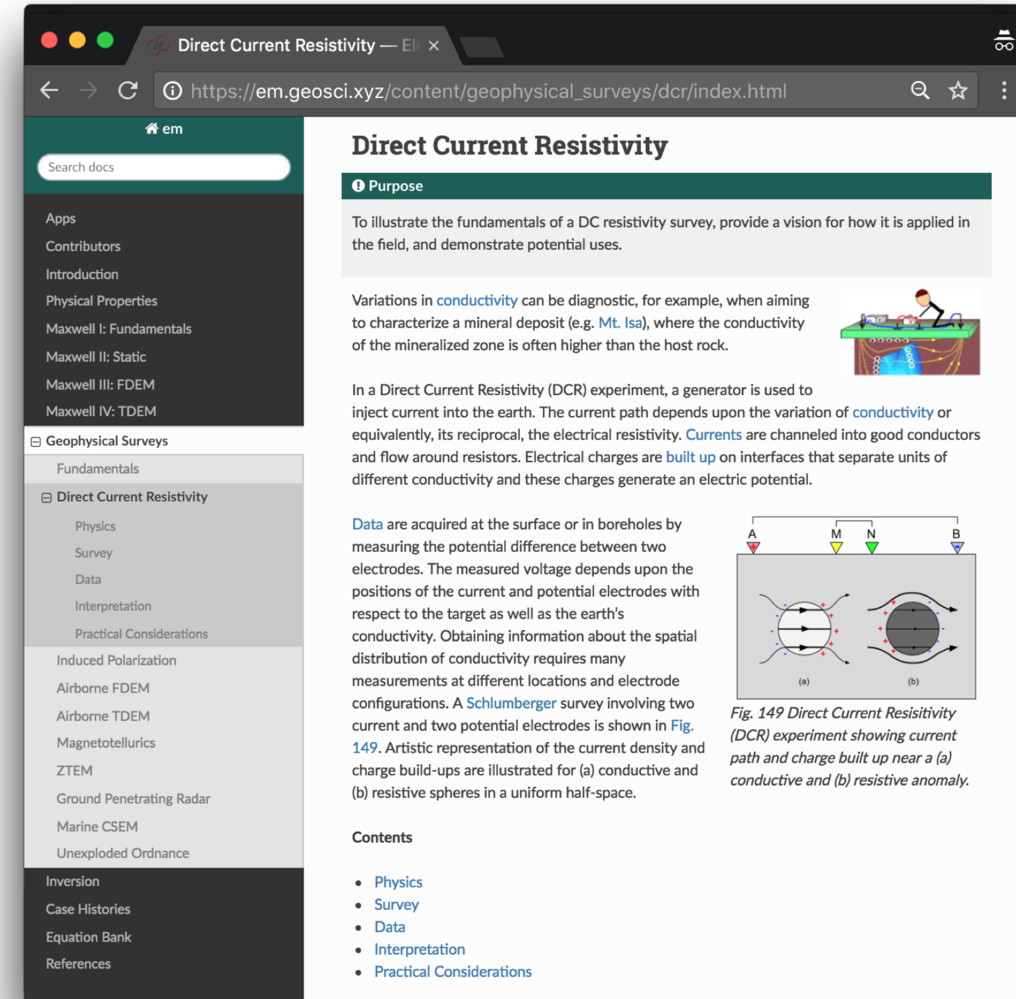
- Geophysical Surveys
  - Fundamentals
  - Seven Step Framework for case histories
  - Survey Design Considerations
  - Forward Modelling



https://em.geosci.xyz/content/geophysical_surveys/index.html

DC Surveys using EM.GeoSci

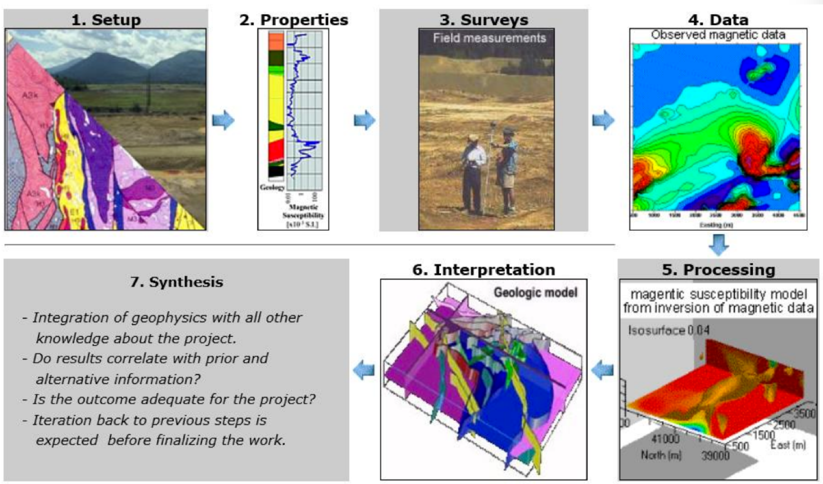
- Geophysical Surveys: Direct Current Resistivity
- Contents:
  - Physics
  - Survey
  - Data
  - Interpretation
  - Practical Considerations

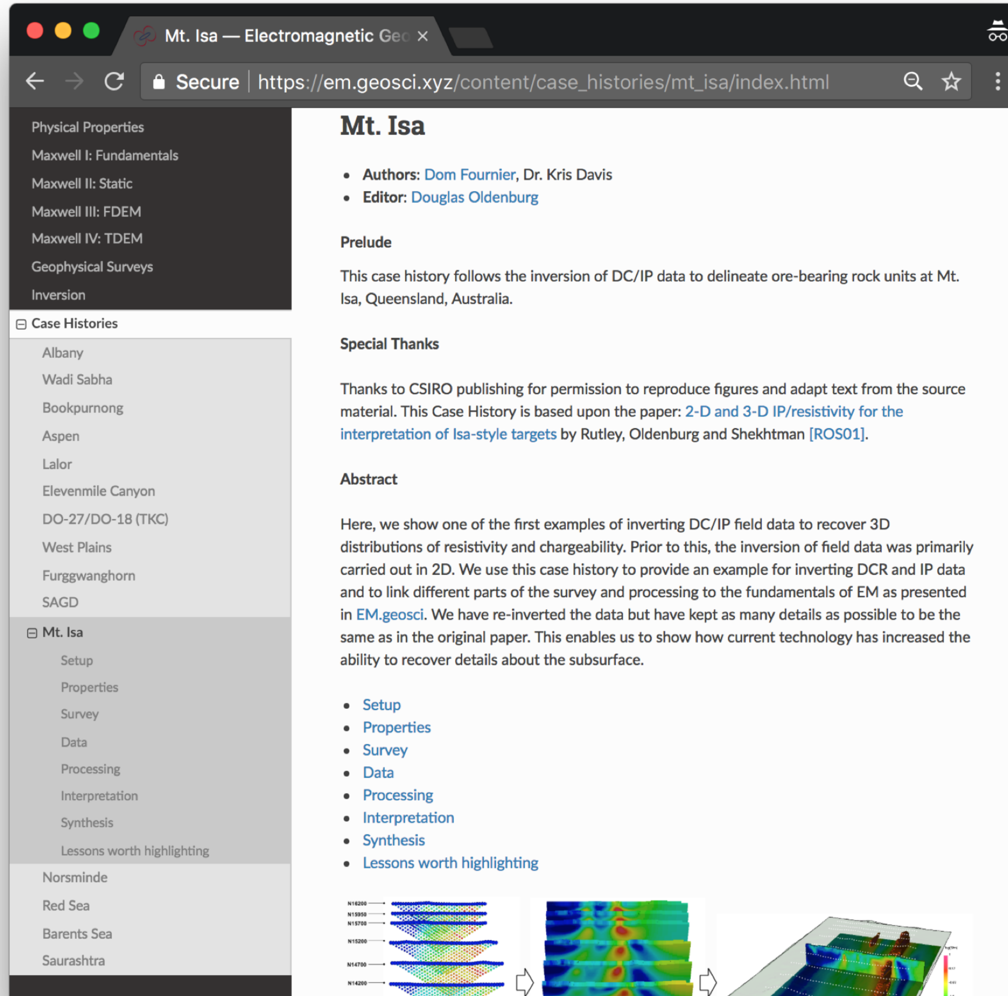


https://em.geosci.xyz/content/geophysical_surveys/dcr/index.html

Case History using EM.GeoSci

- All case histories follow 7-step framework

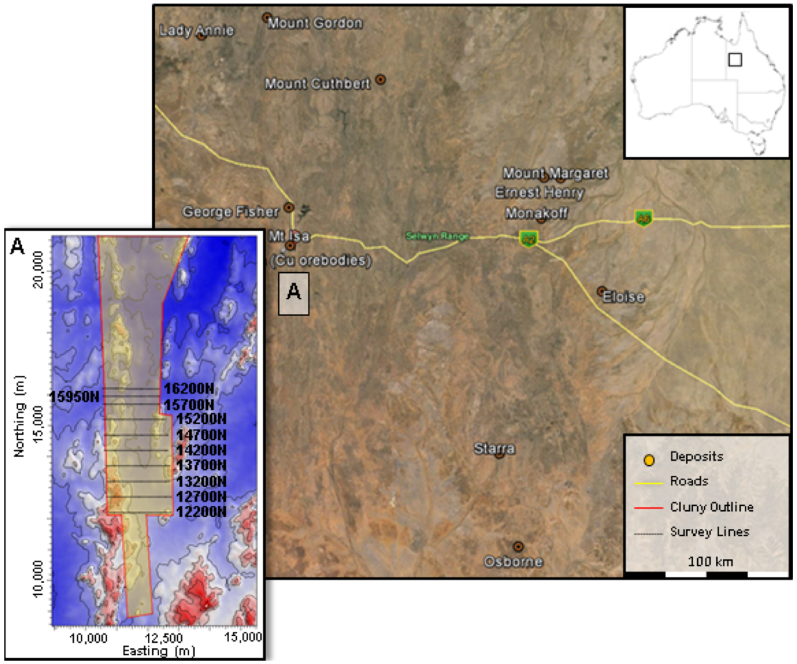




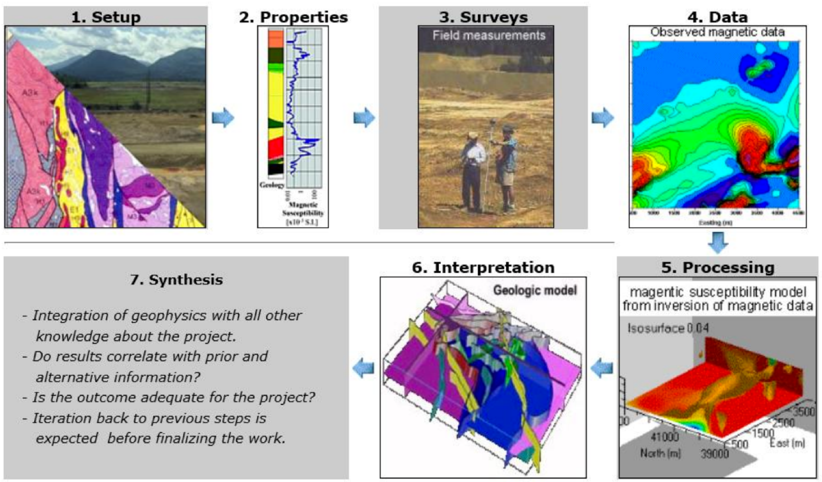
https://em.geosci.xyz/content/case_histories/mt_isa/index.html

Mt. Isa

Mt. Isa (Cluny prospect)

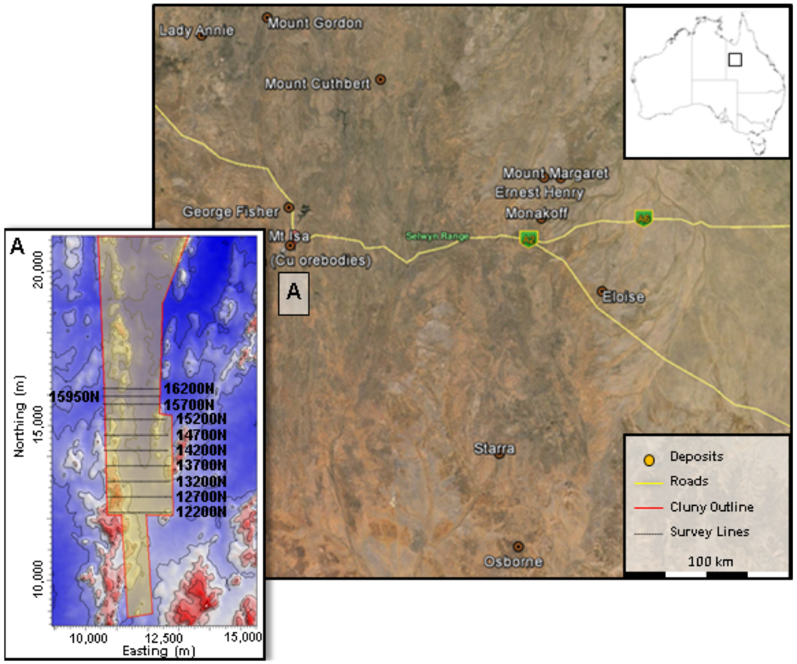


Seven Steps

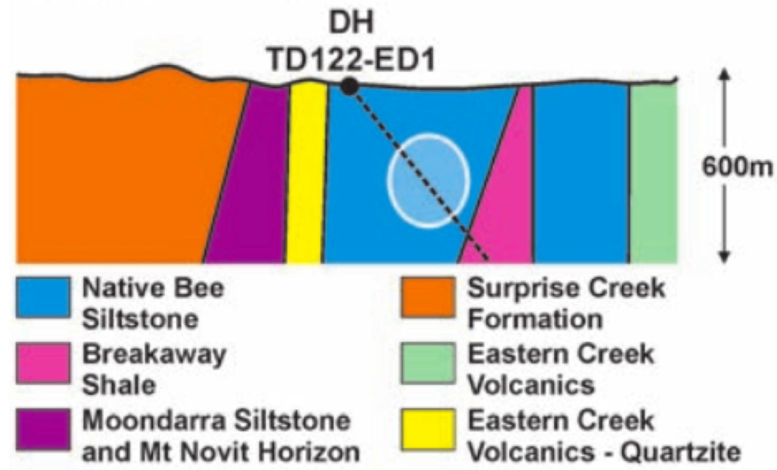


Setup

Mt. Isa (Cluny prospect)



Geologic model

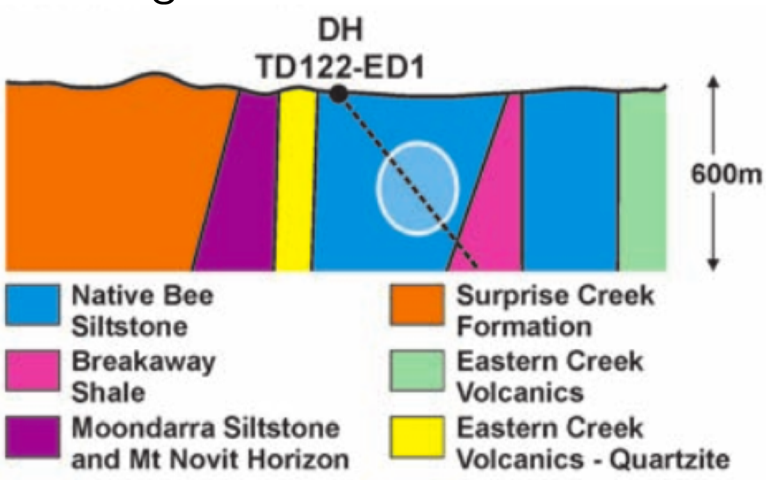


Question

- Can conductive units, which would be potential targets within the siltstones, be identified with DC data?

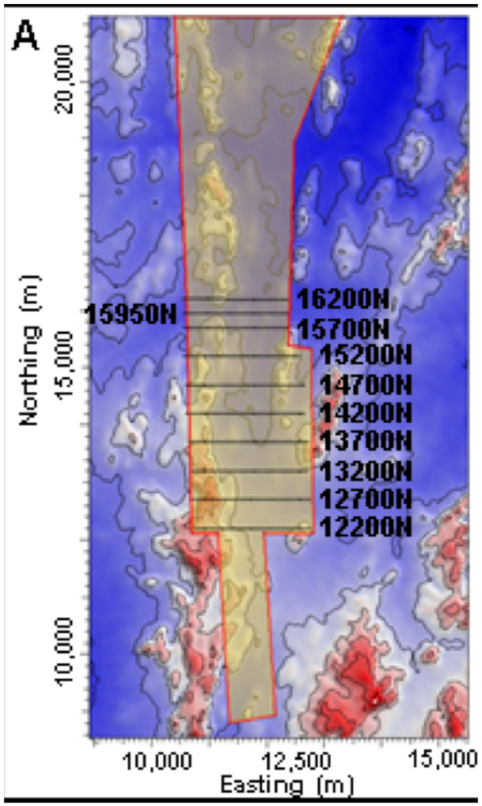
Properties

Geologic model



Rock Unit	Conductivity
Native Bee Siltstone	Moderate
Moondarra Siltstone	Moderate
Breakaway Shale	Very High
Mt Novit Horizon	High
Surprise Creek Formation	Low
Eastern Creek Volcanics	Low

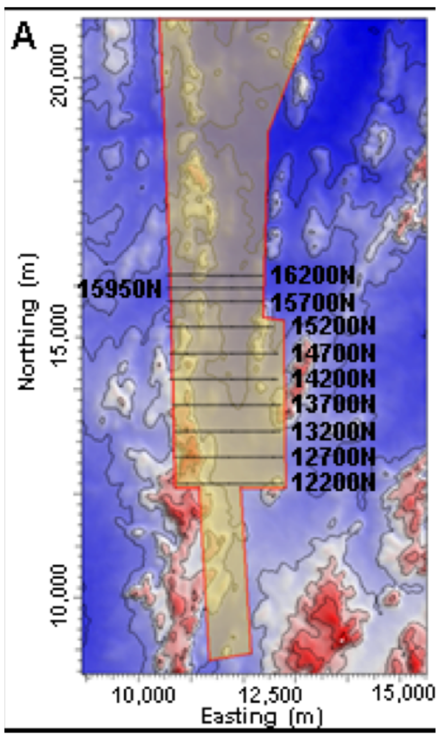
Surface topography

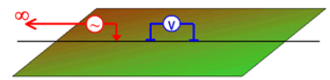


Survey and Data

- Eight survey lines
- Two survey configurations.

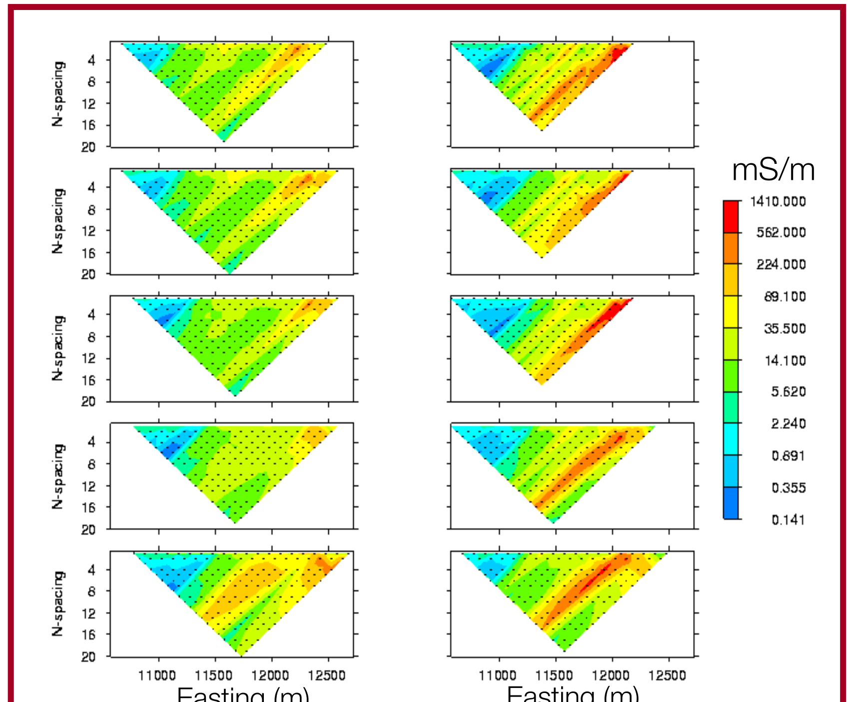
Surface topography





Data set #1:

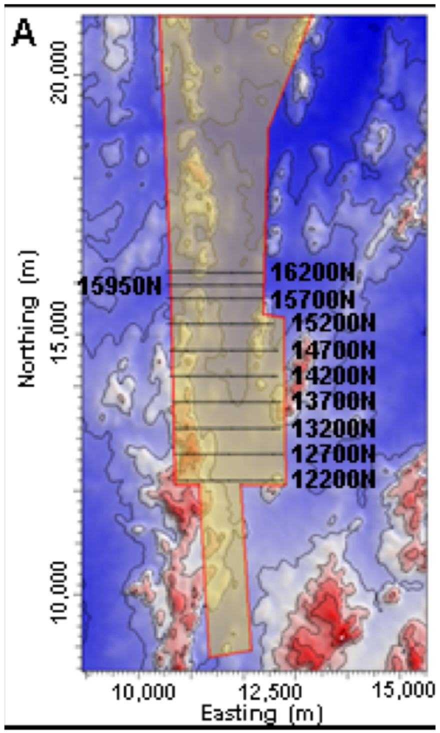
Apparent resistivity, pole - dipole.



Survey and Data

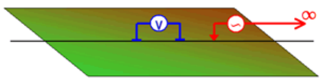
- Eight survey lines
- Two survey configurations.

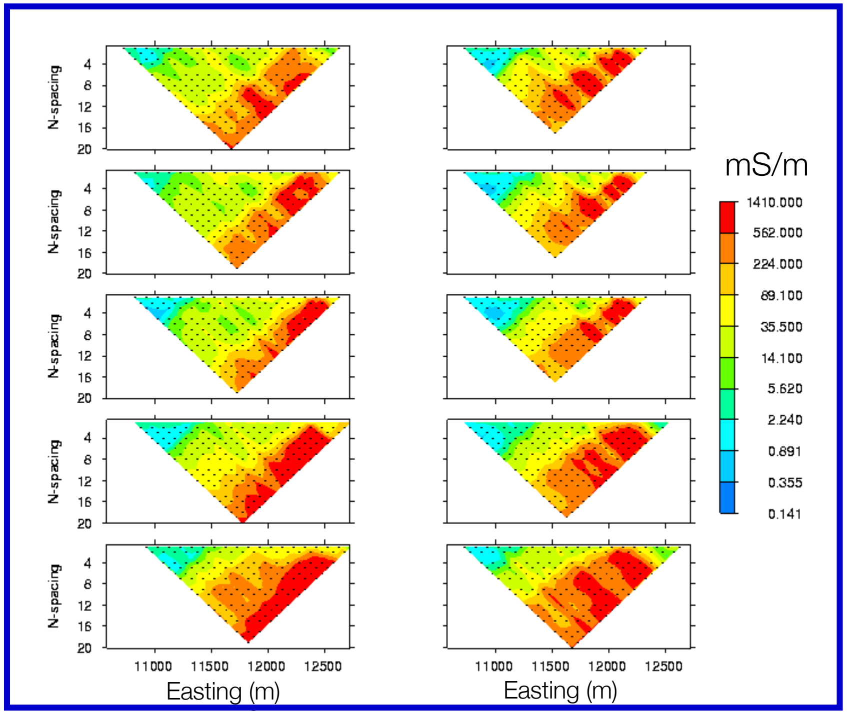
Surface topography



Data set #2:

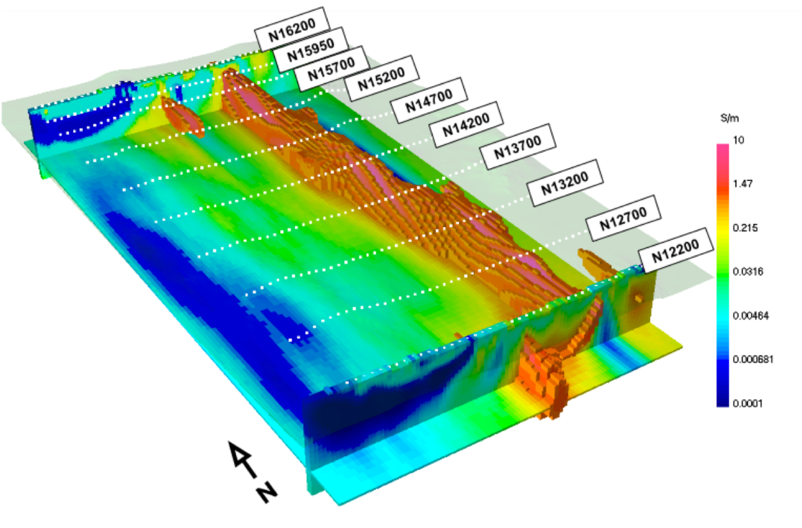
Apparent resistivity, dipole - pole



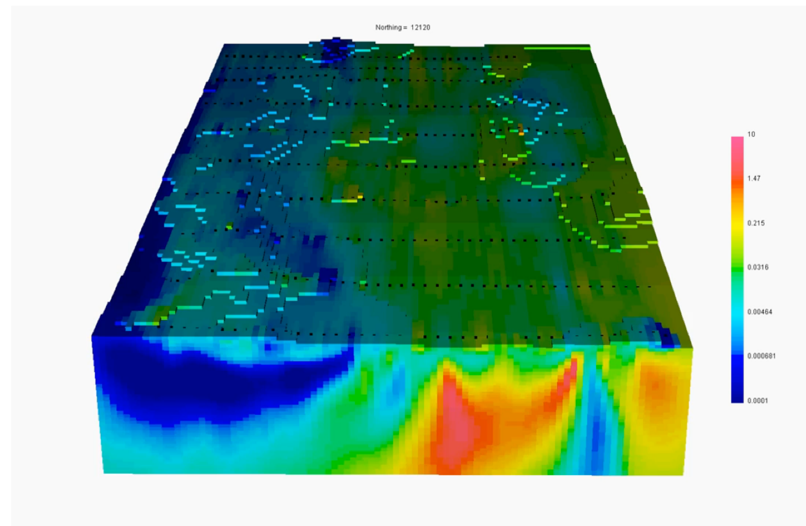


Processing and interpretation

3D resistivity model



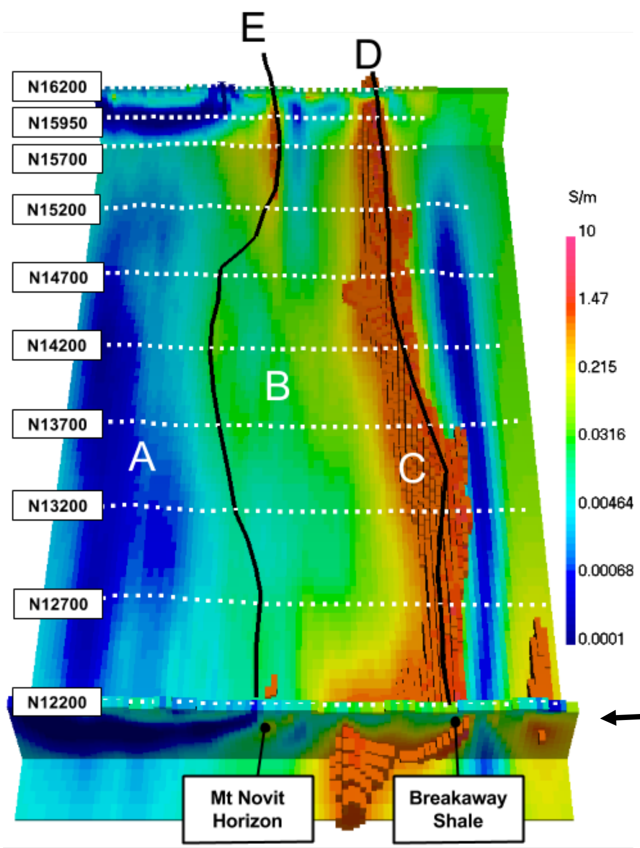
Animation



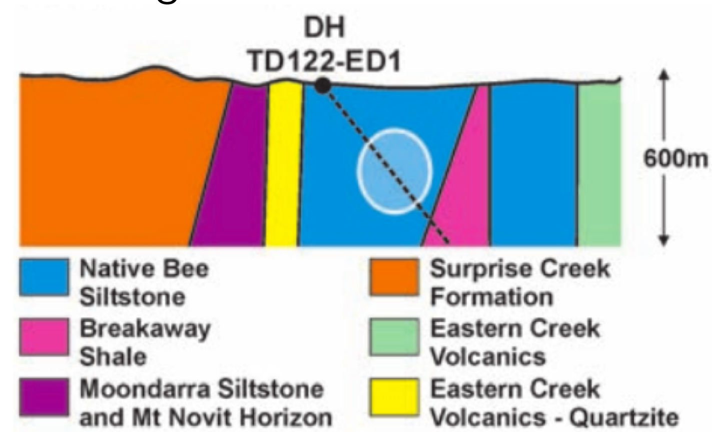
Synthesis

- Identified a major conductor → black shale unit
- Some indication of a moderate conductor

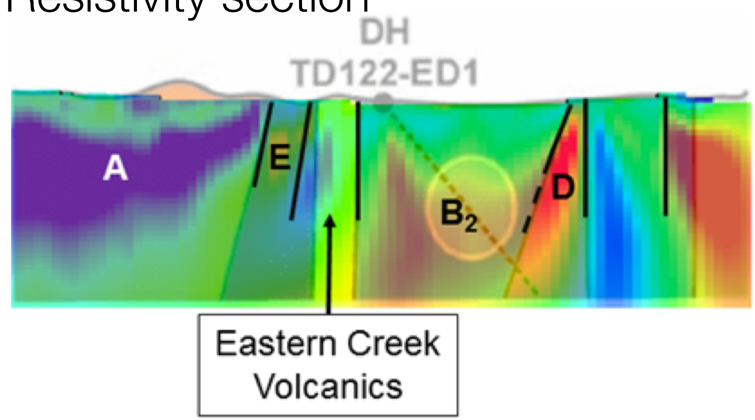
3D resistivity model



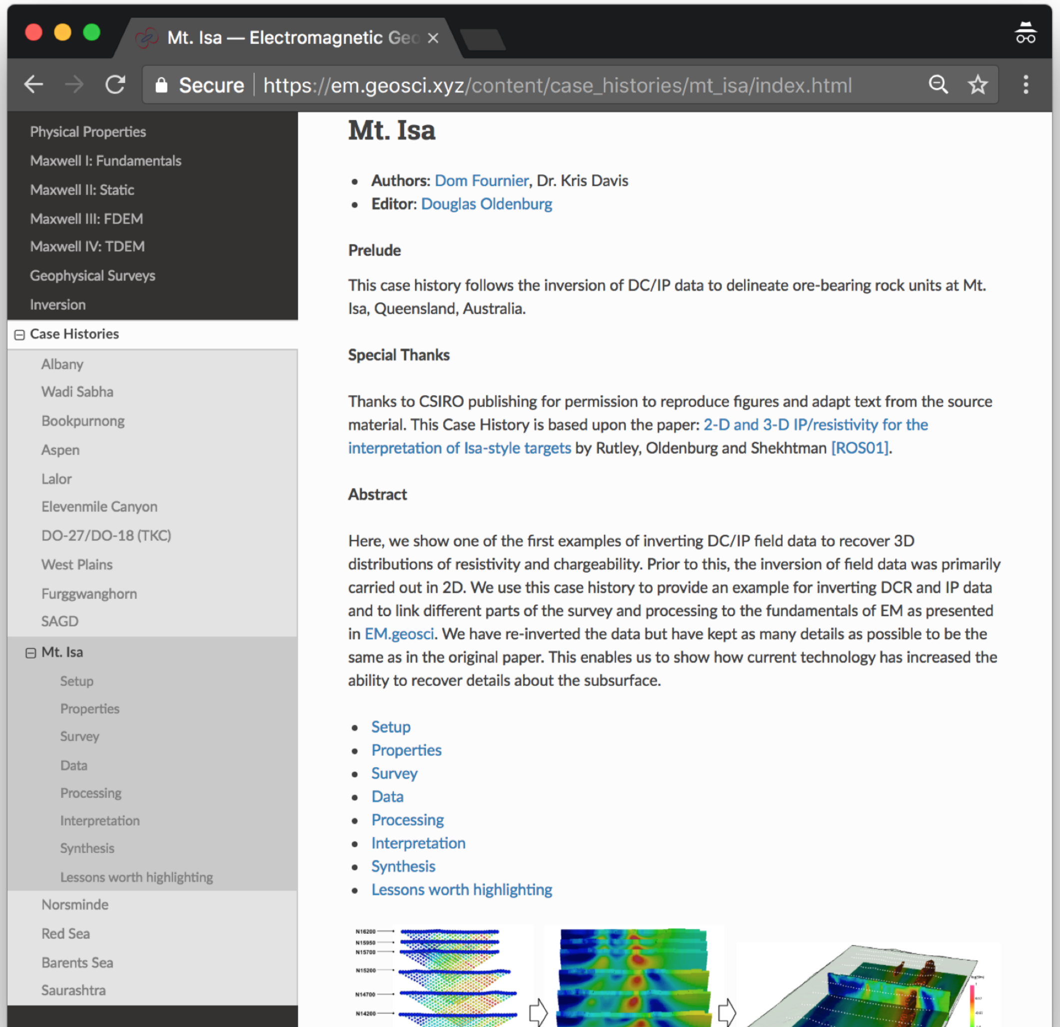
Geologic section



Resistivity section



Mt. Isa in em.geosci.xyz



Outline

- Basic experiment
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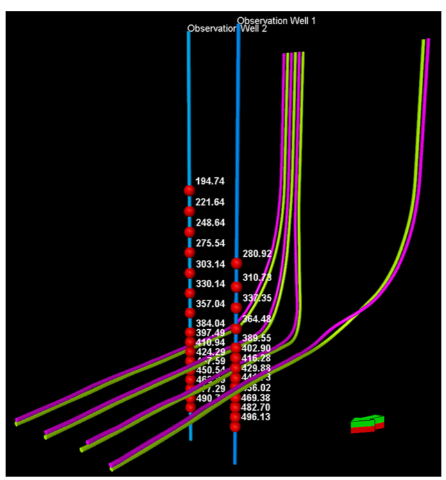
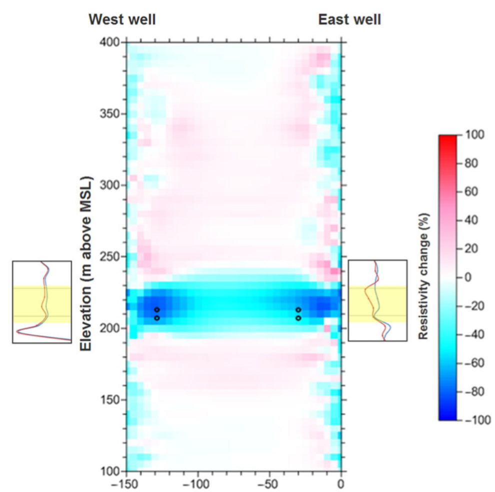
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- Case History – Mt Isa

- Case History – Reservoir monitoring for oil sands
- Steel casing + DC
- Working with the apps
- Effects of background resistivity

Case History: Crosswell ERT monitoring

Tondel et al. 2014

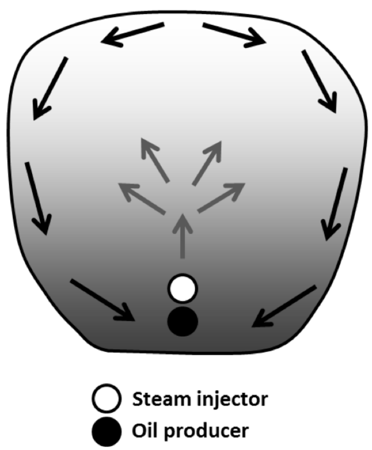


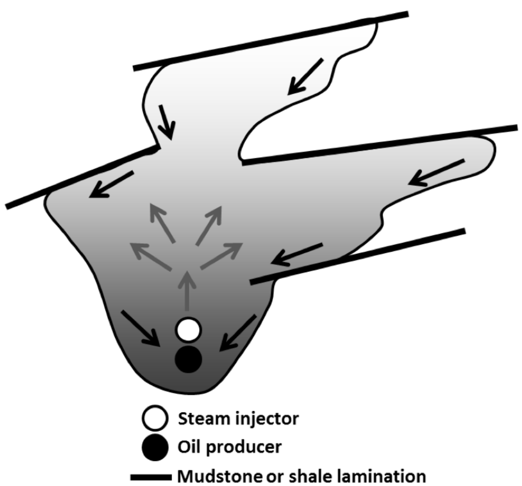


Setup

- Athabasca Oil Sands
  - The largest oil sand region in North America
- Facility for steam-assisted gravity drainage (SAGD)
- Statoil purchased North American Oil sand Corporation (2007)
- Developing Leismer Demonstration Area
  - Research initiatives
  - E.g. “Which crosswell surveys should be used to map SAGD?”

Steam assisted gravity accelerated drainage (SAGD)



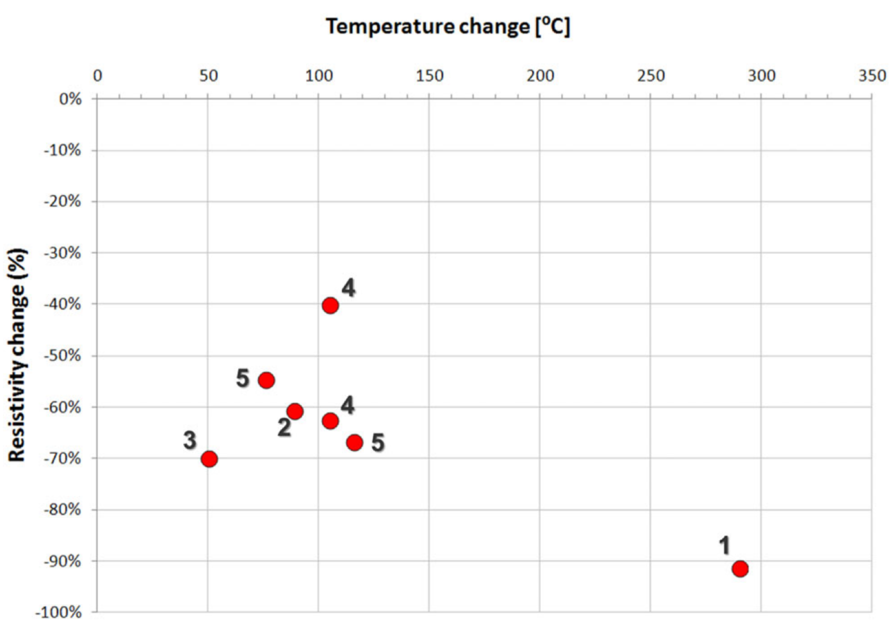


- In-situ recovery process used to extract bitumen from the Athabasca oil sands
- Uses two horizontal wells drilled at the bottom of the reservoir
- Top well (injection): produces a steam chamber
- Bottom well (production)
- Bottleneck: inhomogeneity in the reservoir

Want to know extent of the steam

Properties

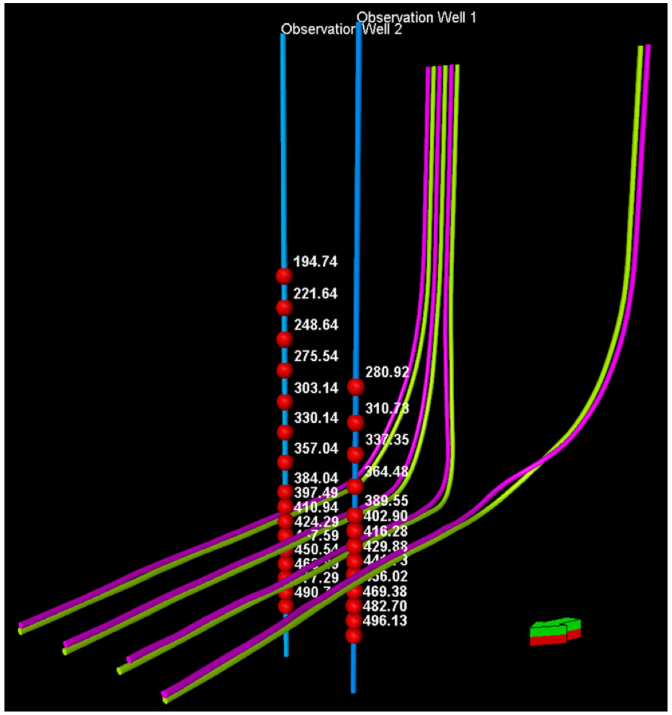
- Temperature can exceed 250°C
- Resistivity decrease indicates
  - Temperature increase
  - Replacement of produced oil by brine
- Resistivity increase indicates
  - Condensed steam → dilutes brine



1: Englemark (2007)
2: Mansure (2003)
3: Martinez (2012)
4: Ramirez (1993)
5: Ranganyaki (1992)

Which crosswell surveys to monitor steam?

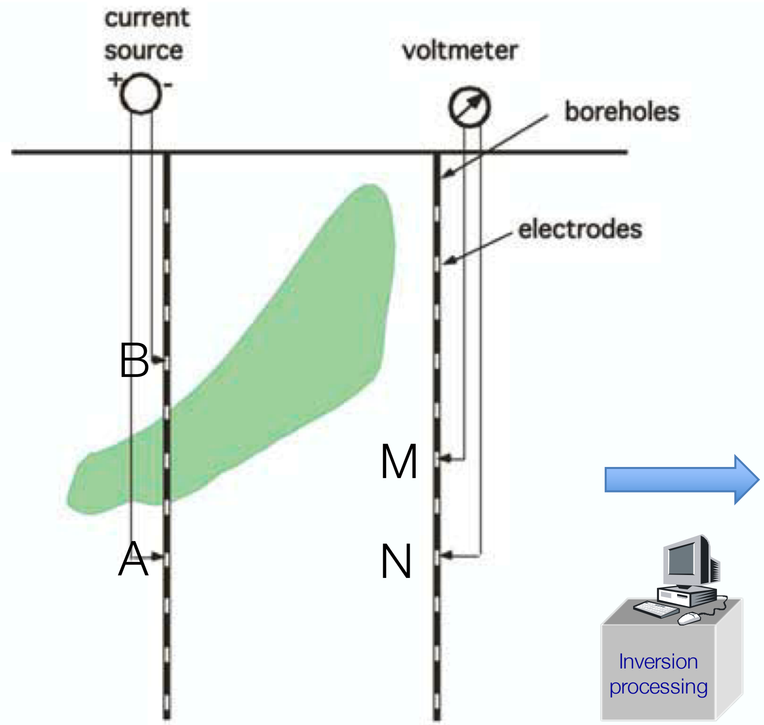
- Options to consider:
  - 3D vertical seismic profile (VSP)
  - Crosswell seismic tomography
  - Crosswell EM
  - Crosswell DC (or ERT)



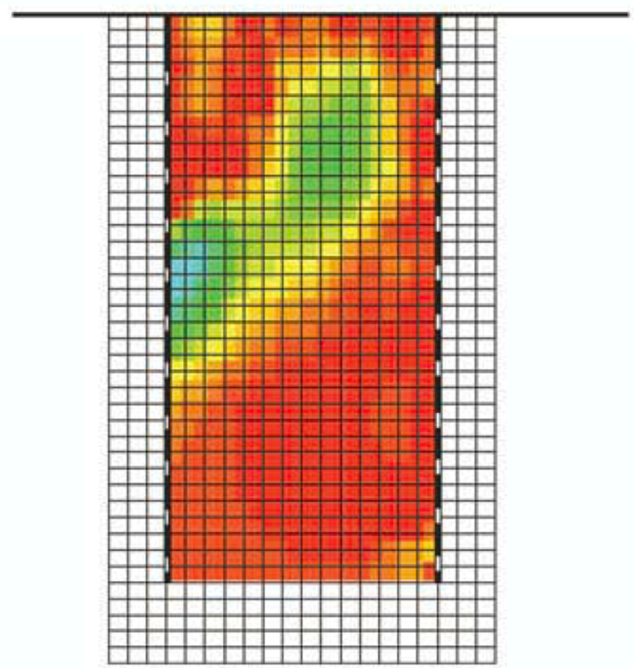
- Challenges:
  - High temperature (up to 250°C)
  - Steel casing (often imperfectly insulated)
  - Repeatability

Our focus is crosswell DC

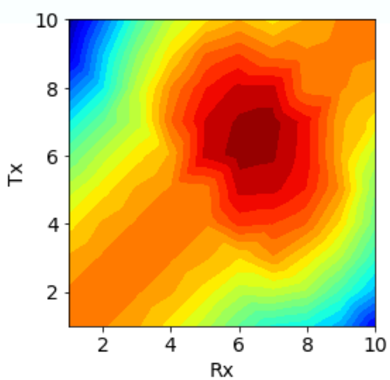
Crosswell DC survey



Recovered resistivity

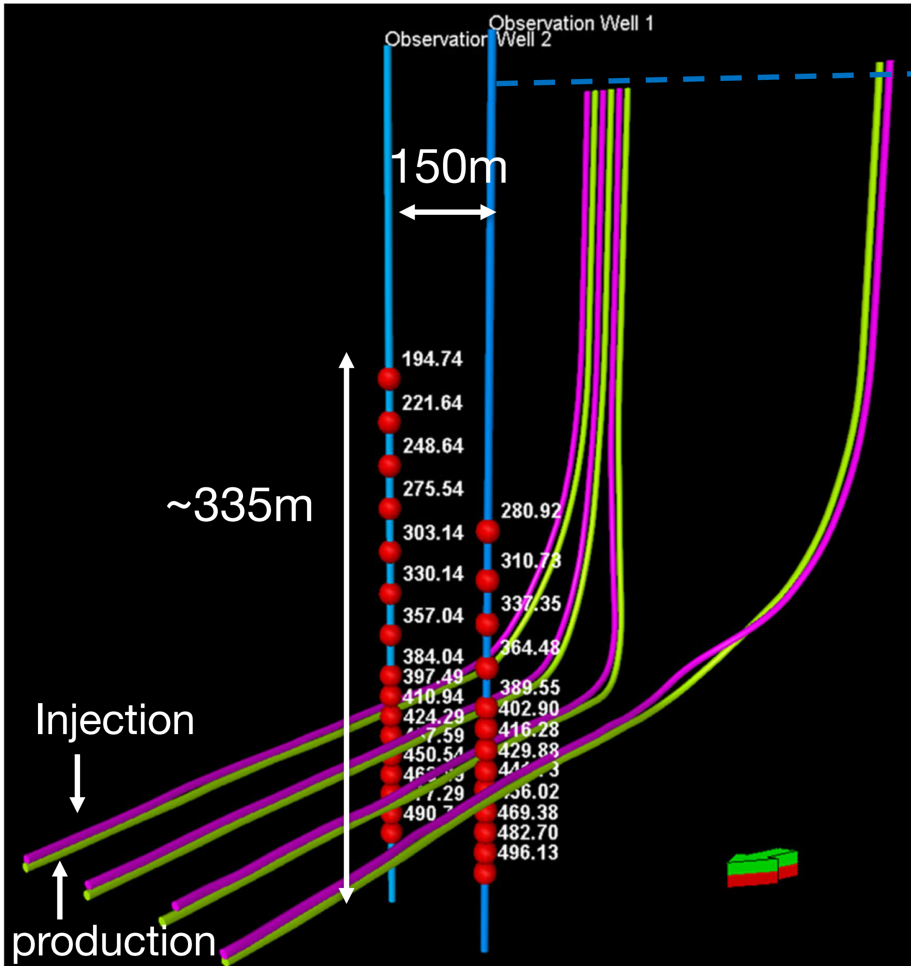


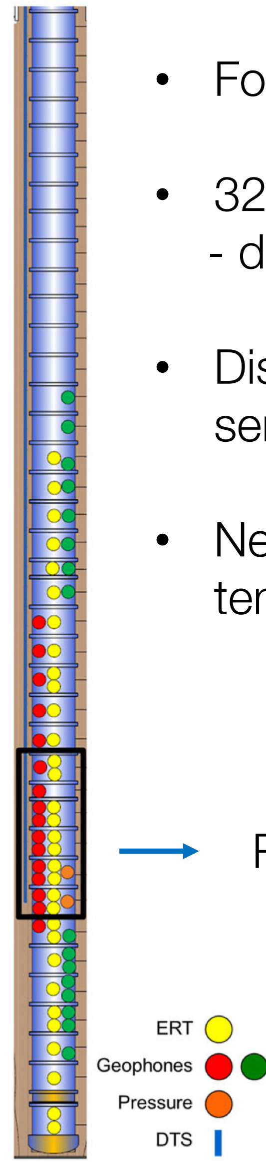
Apparent resistivity



Crosswell DC survey for SAGD

Observation, injection, and production wells

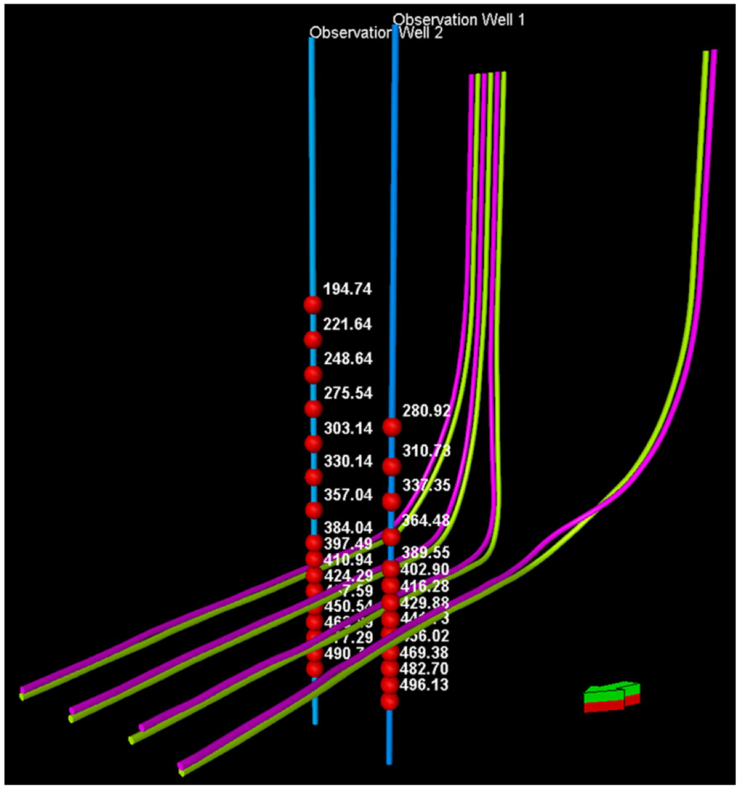




- For each observation well
- 32 electrodes
  - denser at reservoir
- Distributed temperature sensing (DTS) system
- Need to endure high temperature

Reservoir

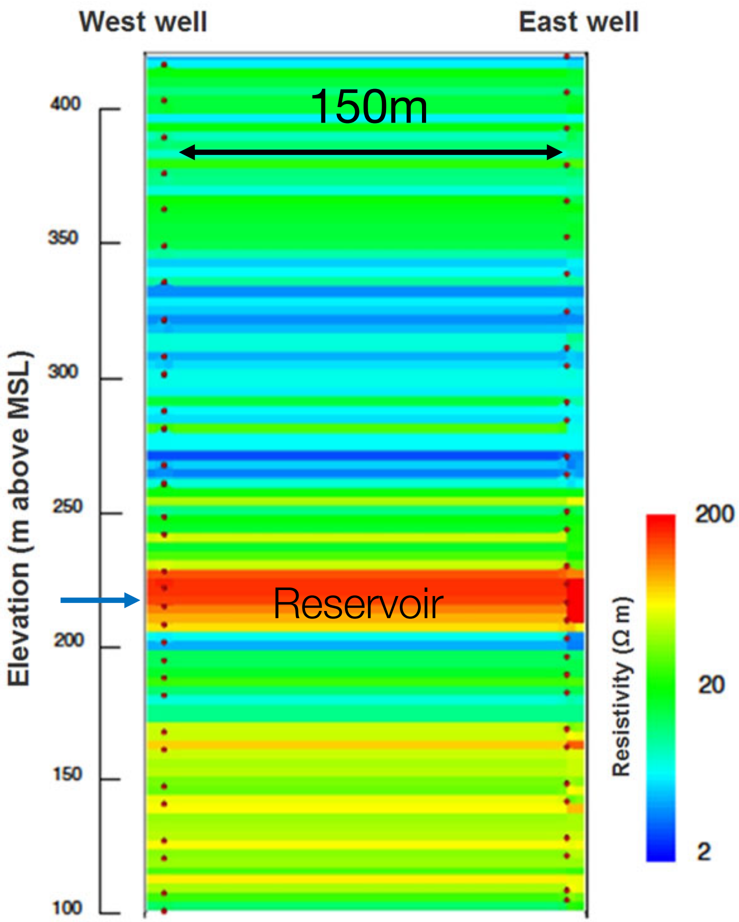
Autonomous setup for monitoring



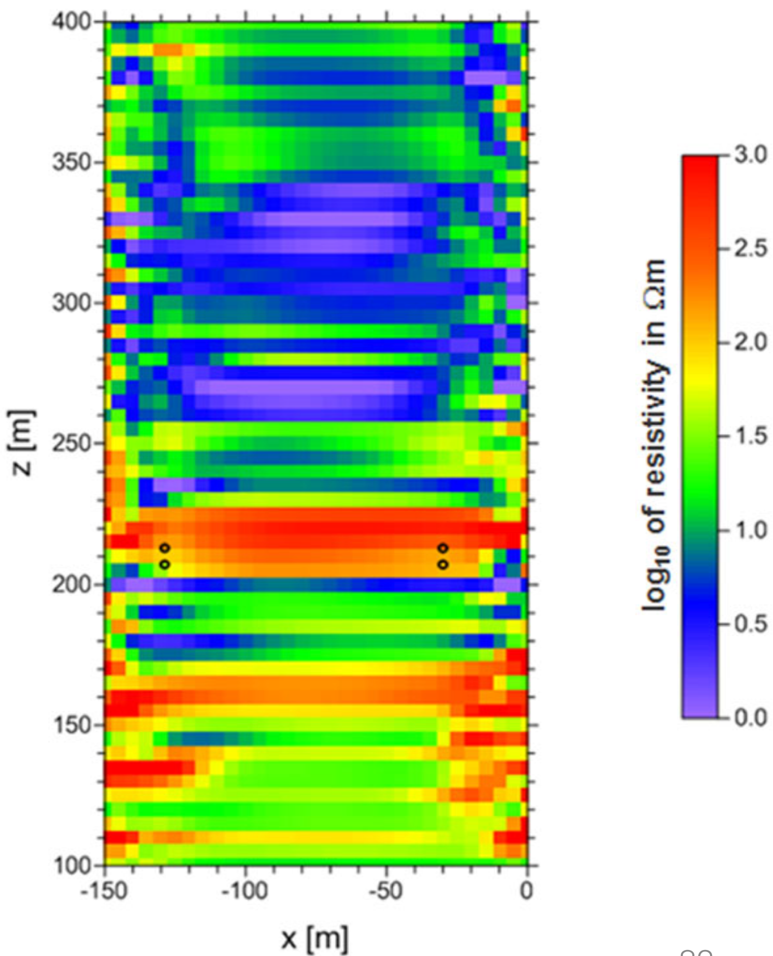
- Fully autonomous system
  - Nobody in the field
- Measure 2 full DC data per day
- High quality data
  - ~2% error

Inversion: baseline (March 2011)

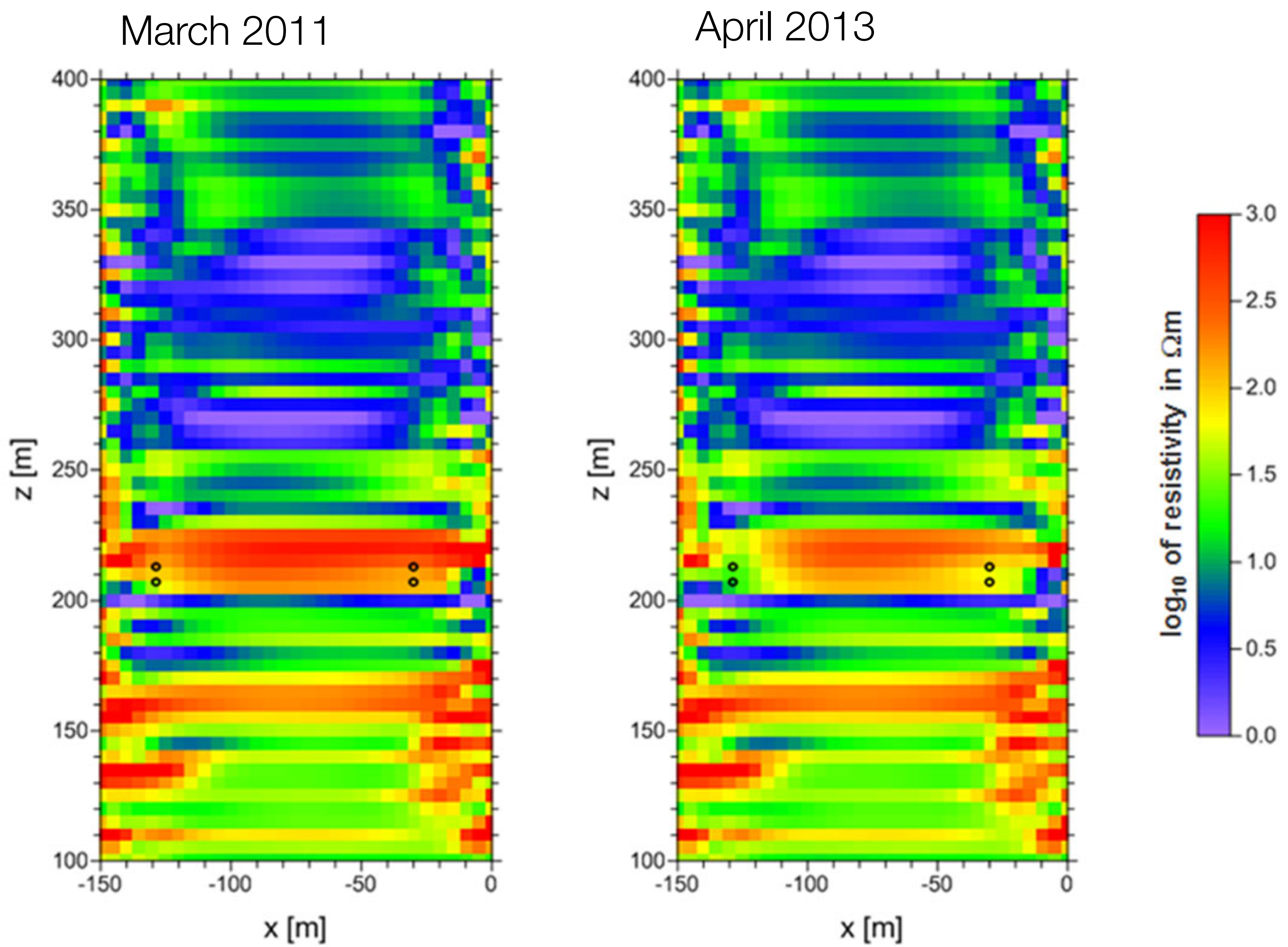
Initial model from well logs + geology



Recovered resistivity (March 2011)

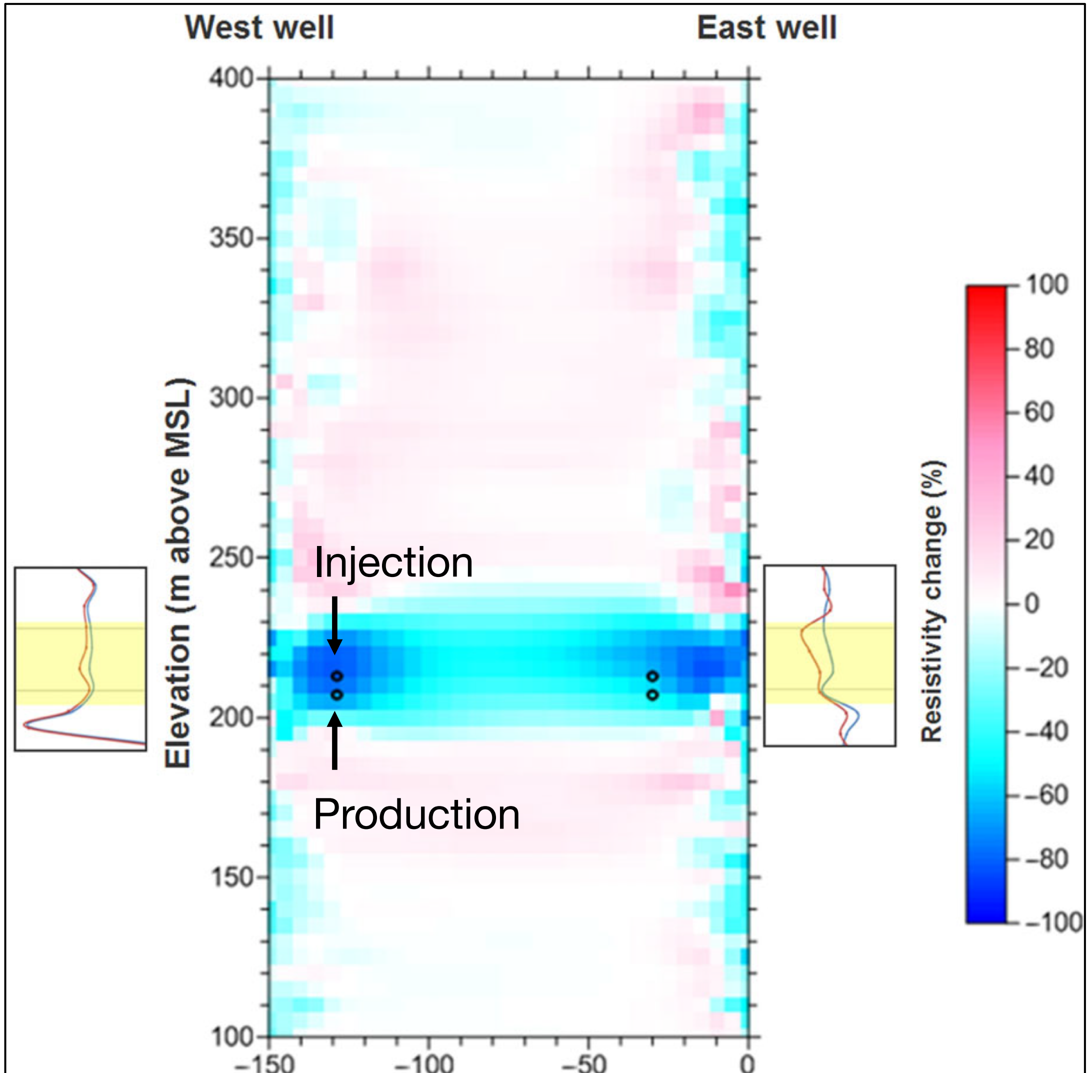


Inversion: time-lapse

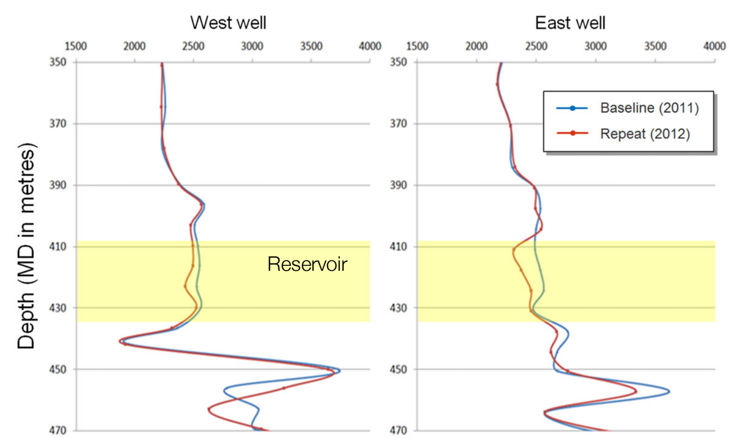


Around electrodes: artefacts due to current leakages to steel casing(?)

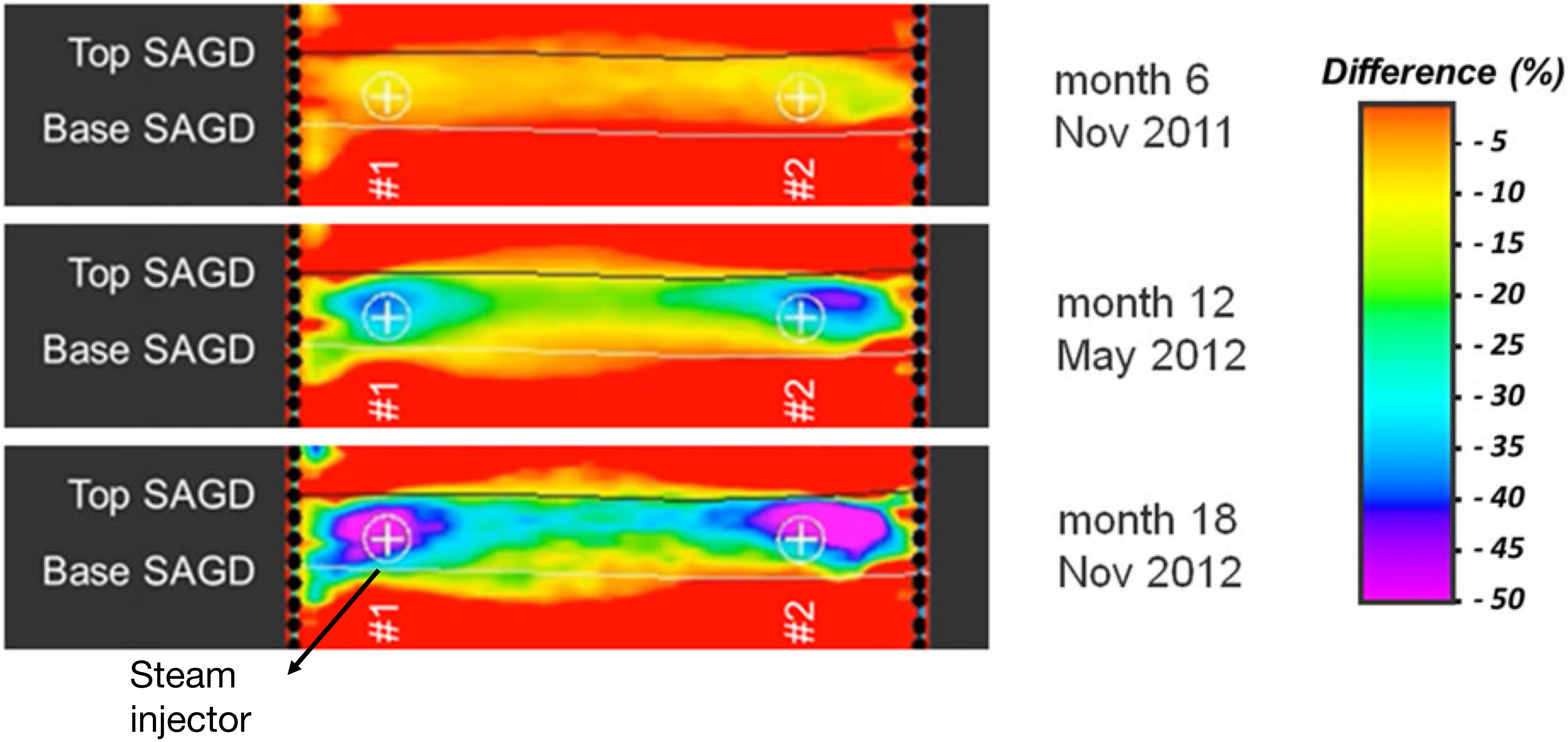
Interpretation: resistivity difference



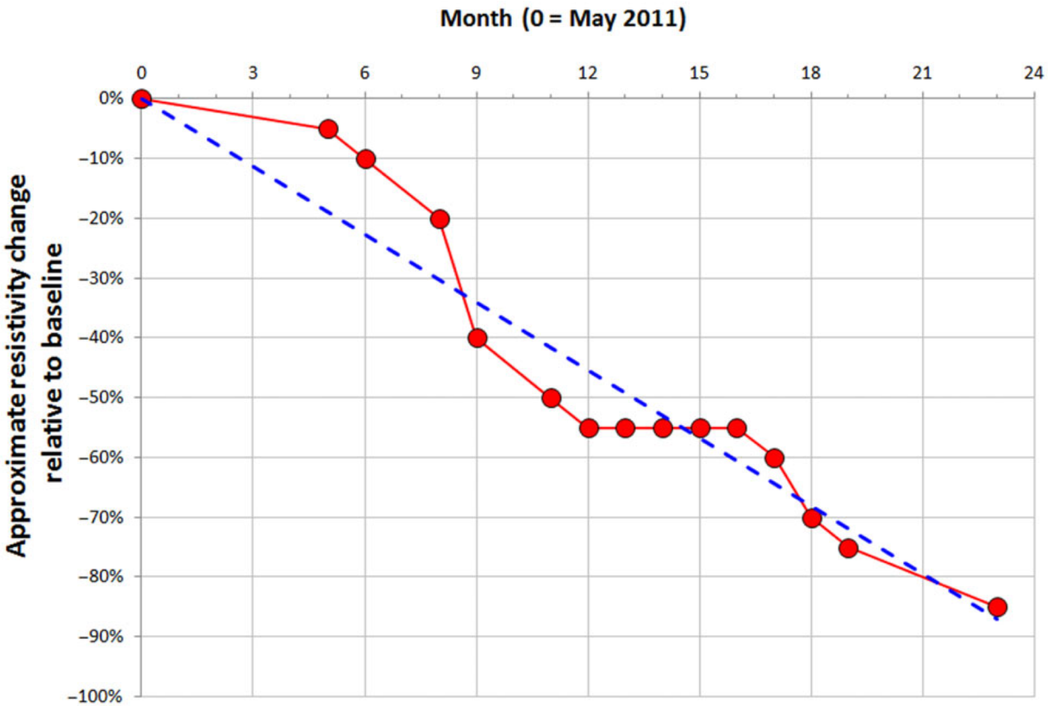
- Significant changes at the reservoir
- Maximum resistivity change: -85%
- Match with VSP

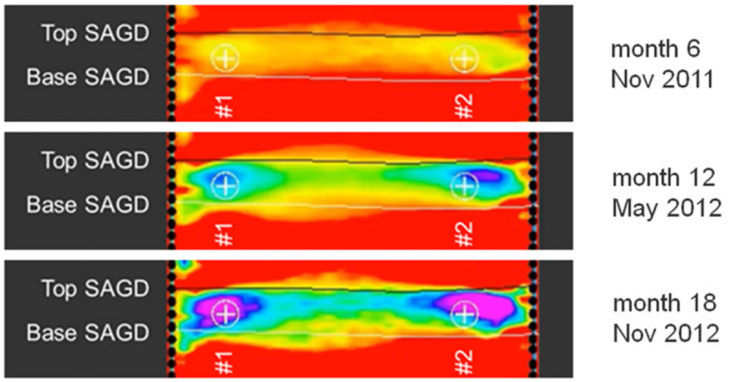


Interpretation: resistivity difference



Synthesis



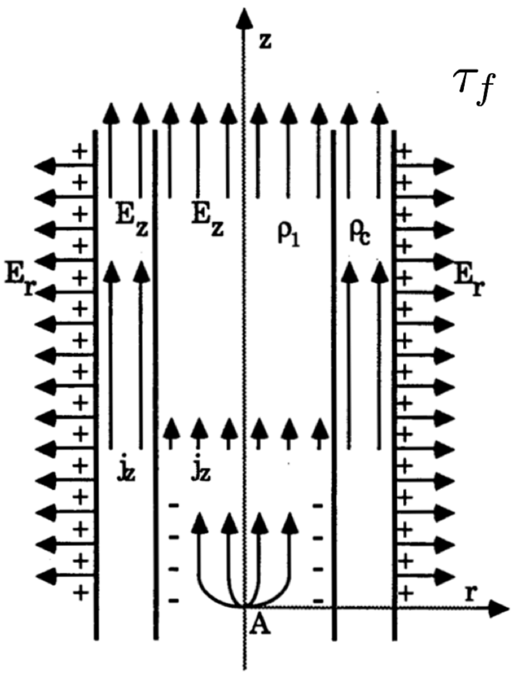


- Can see changes in the reservoir
  - Nearly linear changes (-4% per month)
  - Maximum resistivity difference is -85%
- Crosswell DC can be an effective option for monitoring SAGD
  - Great repeatability + endurance for temperature + low cost

DC Resistivity with steel cased wells

Initial work: Logging through steel-cased wells

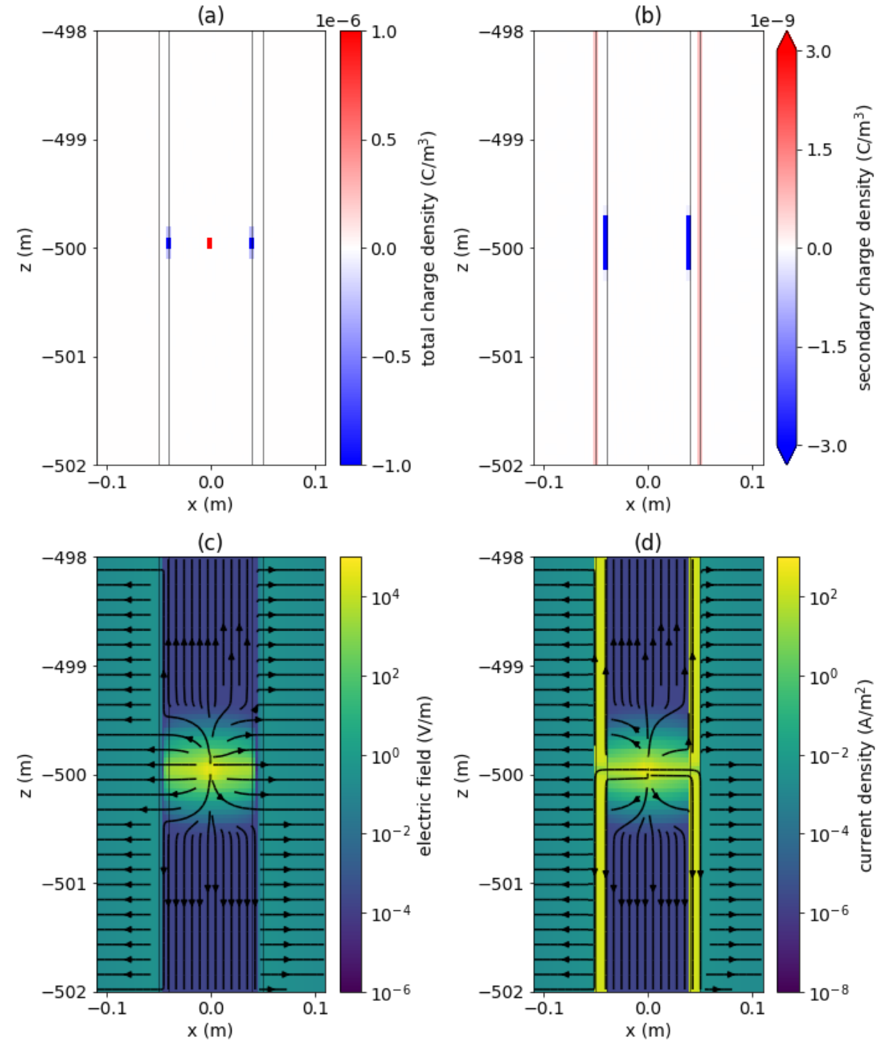
- Kaufman, 1990
  - Currents vertical within casing
  - Positive charges on outside surface of casing
  - Electric field radial outside casing



$$\tau_f = \varepsilon_0 \left(\frac{\sigma_1}{\sigma_2} - 1 \right)$$

(Kaufman, 1990)

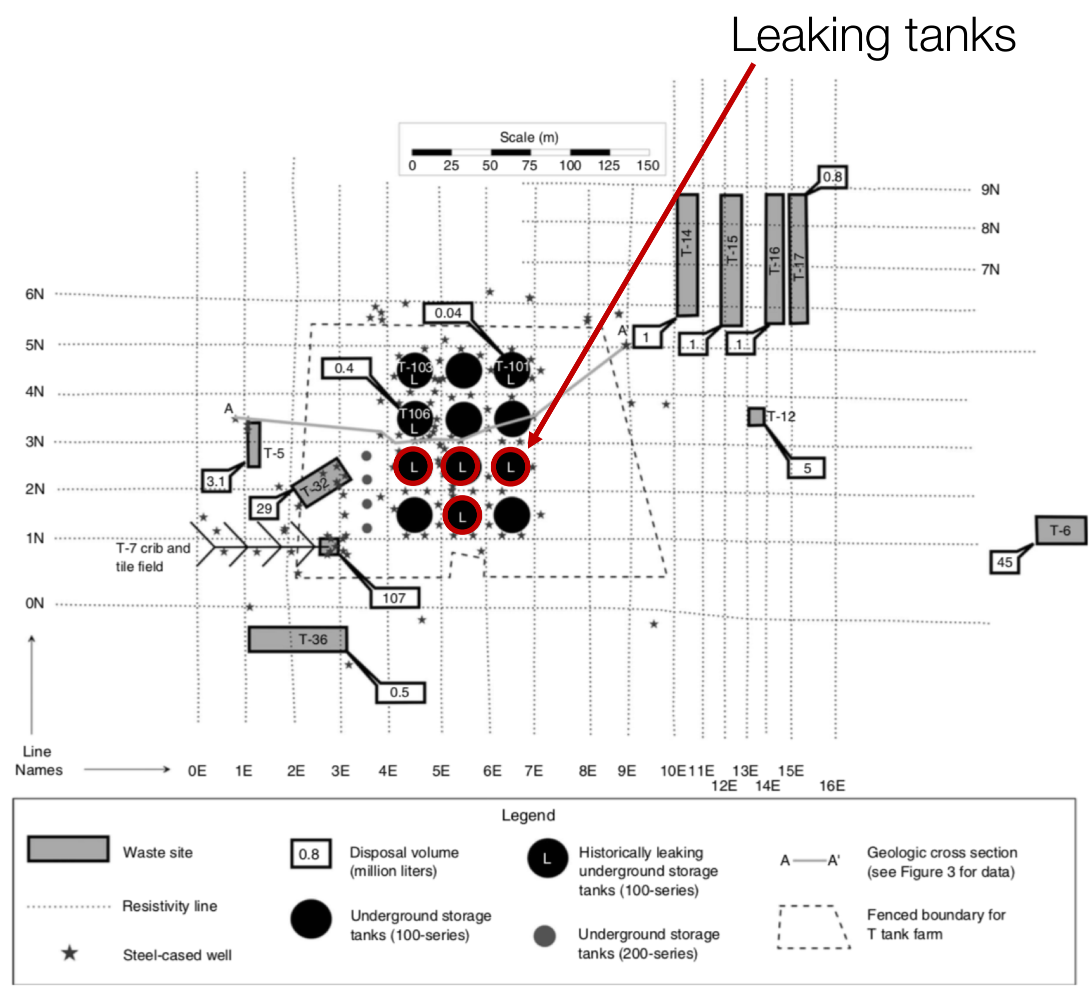
- Now we can solve numerically



(Heagy & Oldenburg, 2018)

Using steel casing as an "Extended Electrode"

- Fracturing, enhanced oil recovery, carbon capture and storage, Small targets, etc.
  - Deep
  - Steel cased wells
- Previous studies:
  - E.g. (Rucker, 2010): Detecting leaks from underground storage tanks
  - Use wells to get beneath conductive near surface & surface infrastructure



Using steel casing as an "Extended Electrode"

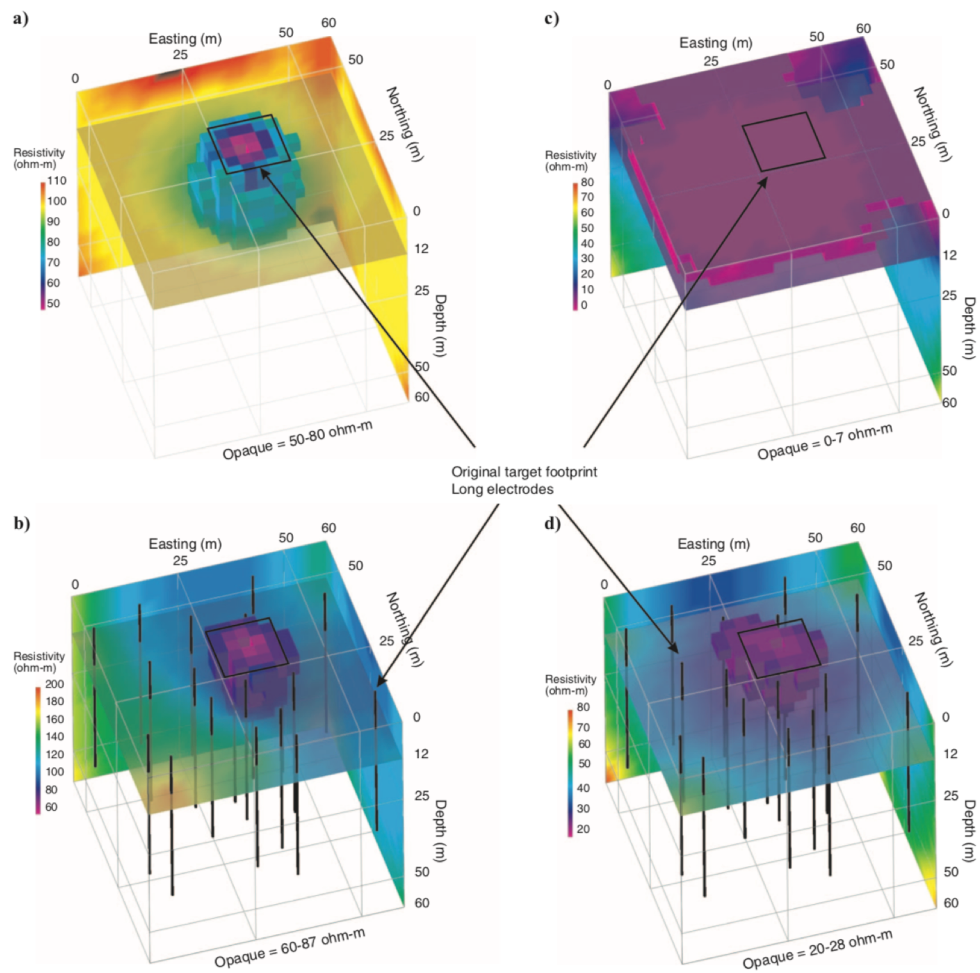
- Synthetic inversion example: conductive block

Conductive block in halfspace

Conductive block + conductive overburden

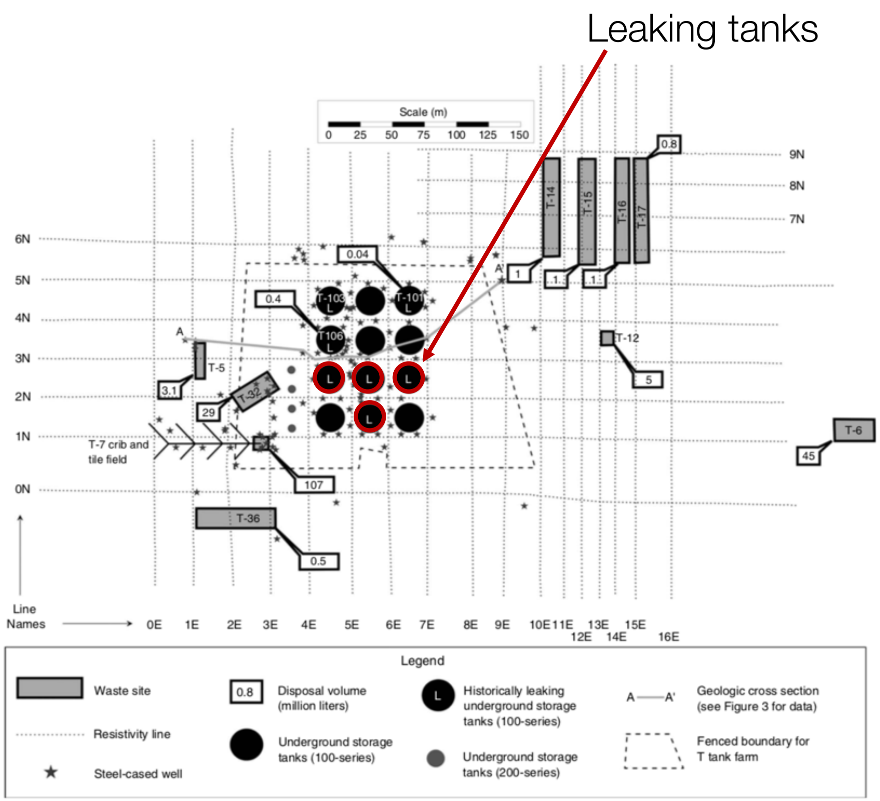
Surface electrodes

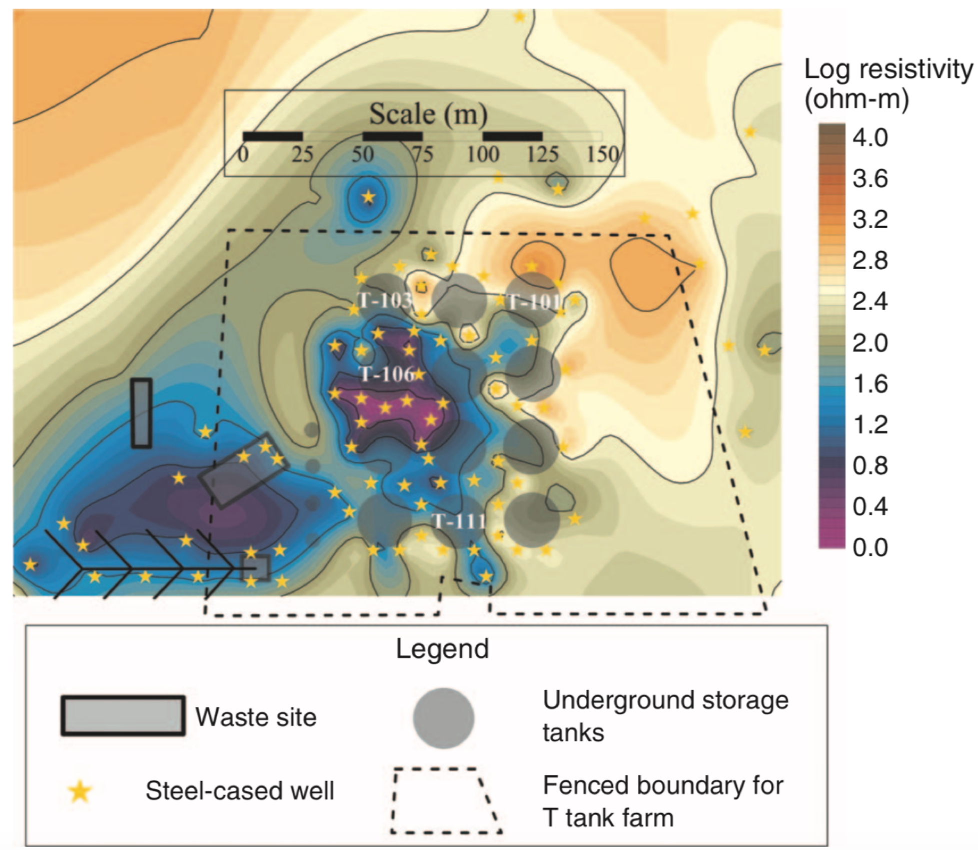
Steel-casing electrodes



Using steel casing as an “Extended Electrode”

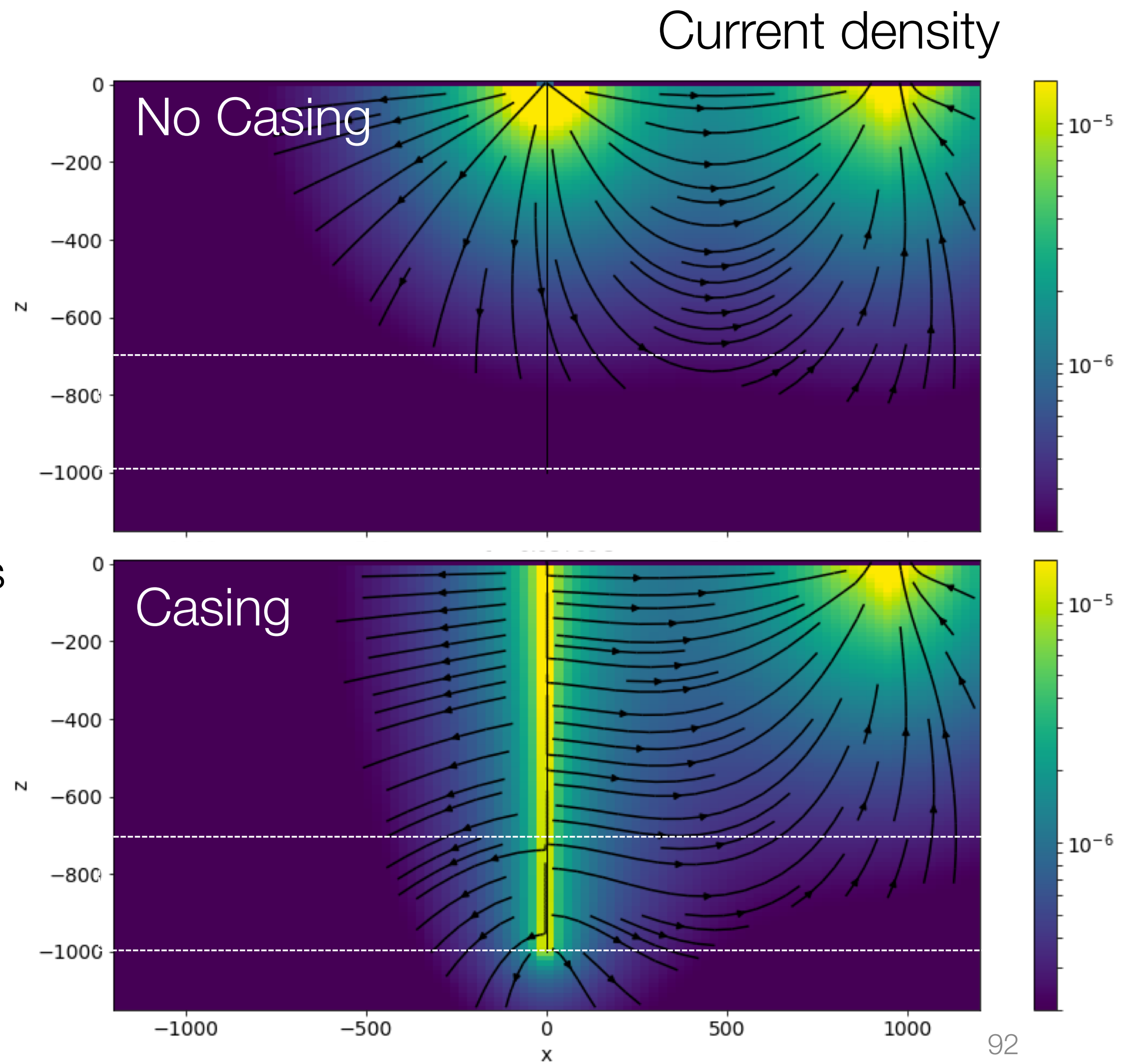
- Field study: imaged conductive waste beneath leaking tanks





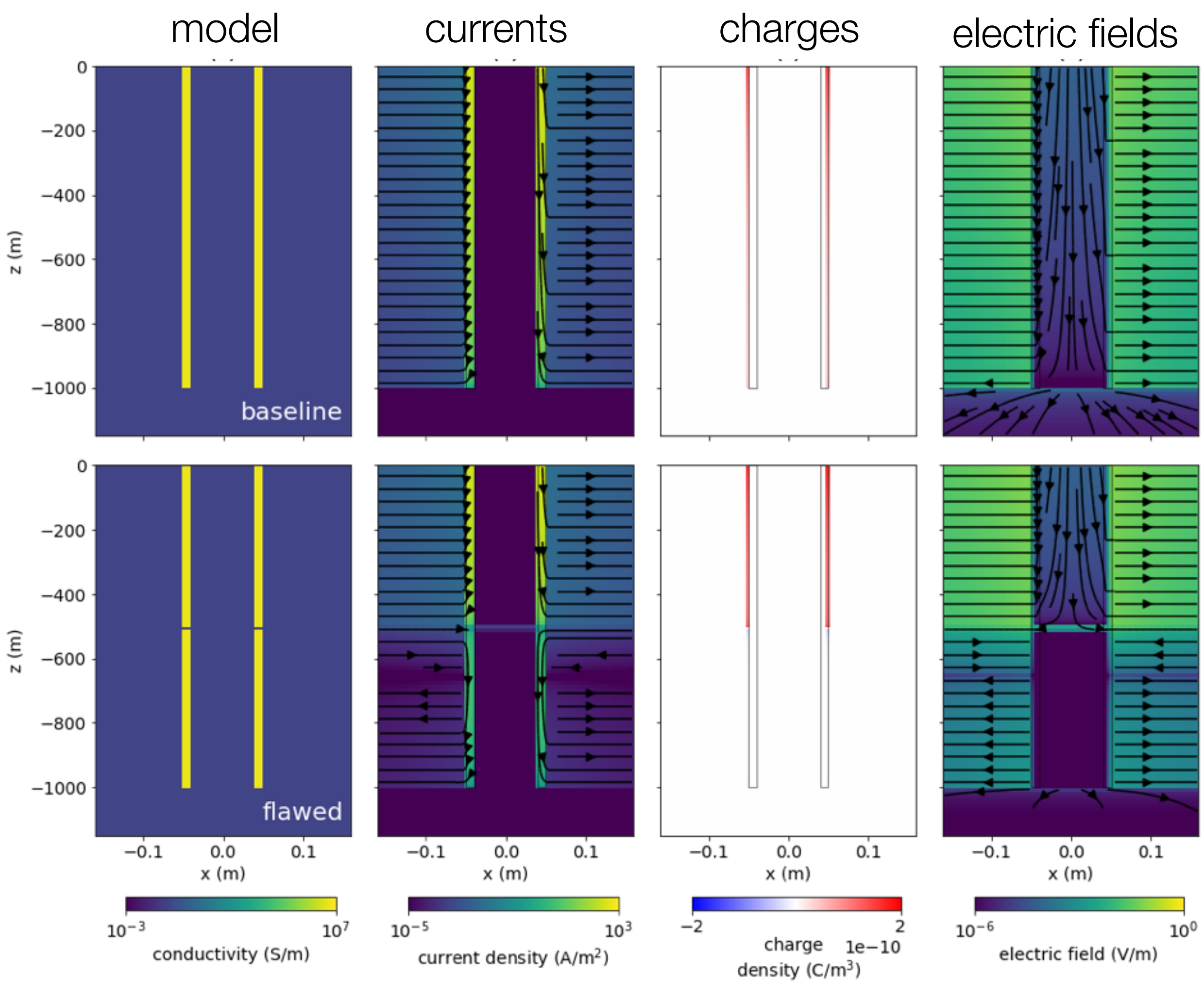
Using steel casing as an “Extended Electrode”

- Fracturing, enhanced oil recovery, carbon capture and storage, …
  - Small targets
  - Deep
  - Steel cased wells
- Use casing to deliver current to depth



Casing integrity

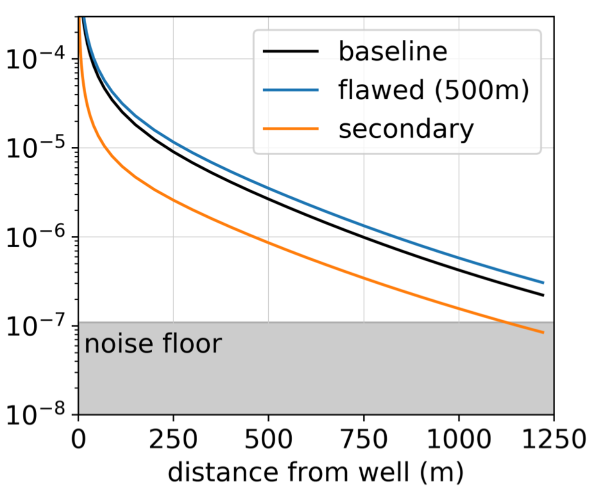
- Can we detect flaws in the casing from the surface?
  - e.g. corrosion

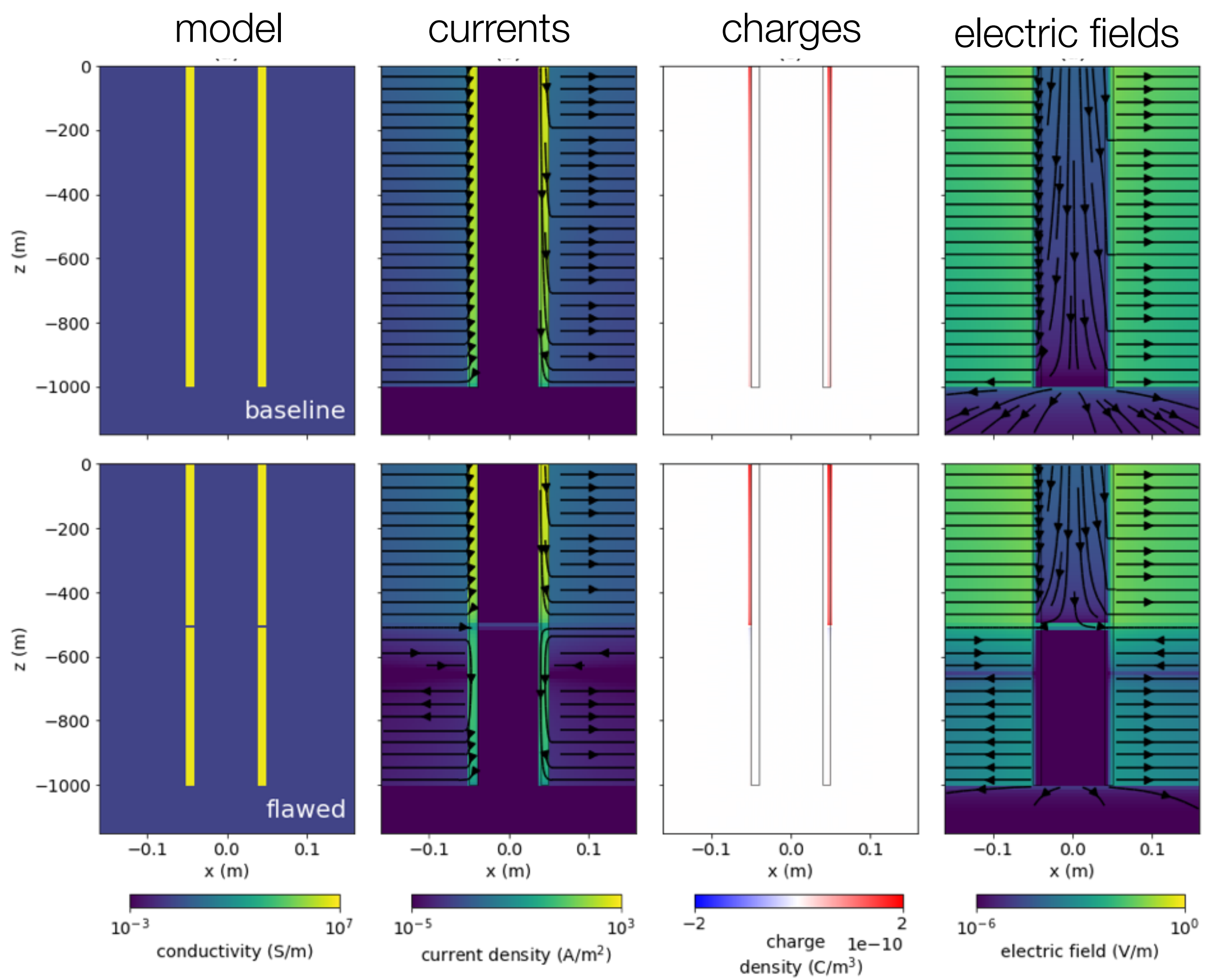


Casing integrity

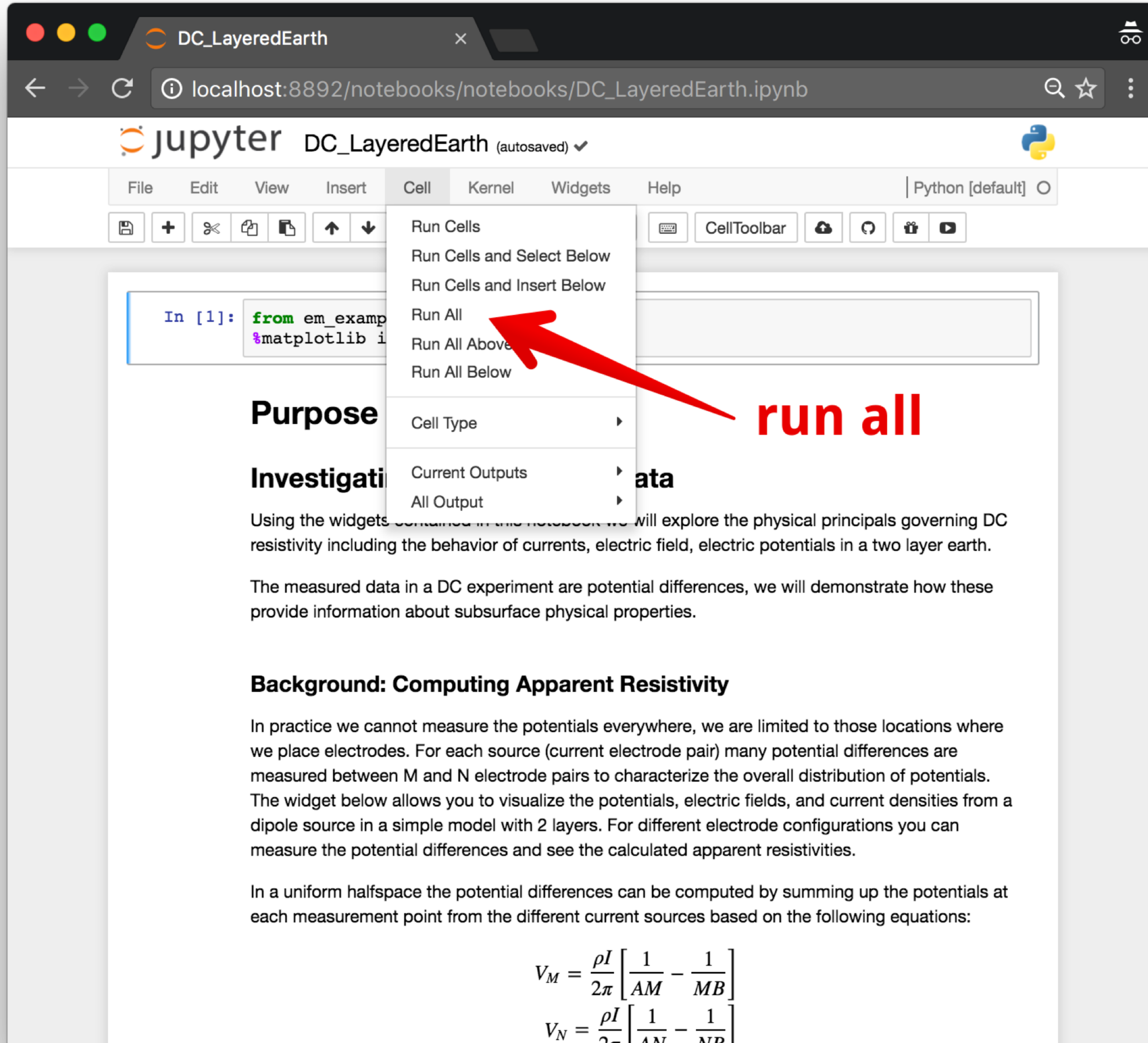
- Can we detect flaws in the casing from the surface?
  - e.g. corrosion

Electric field at surface



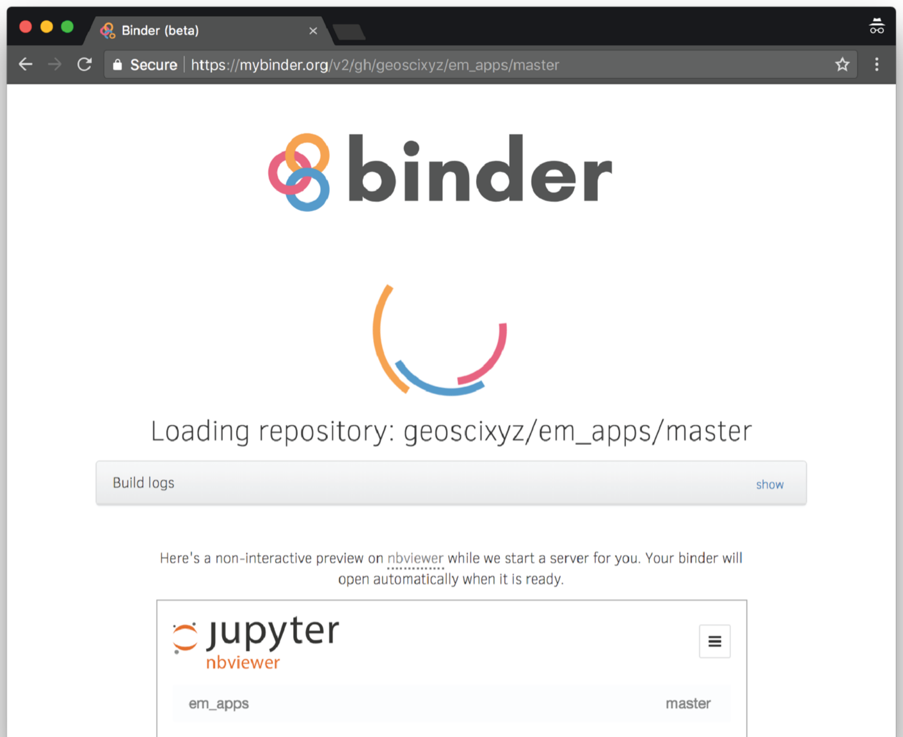


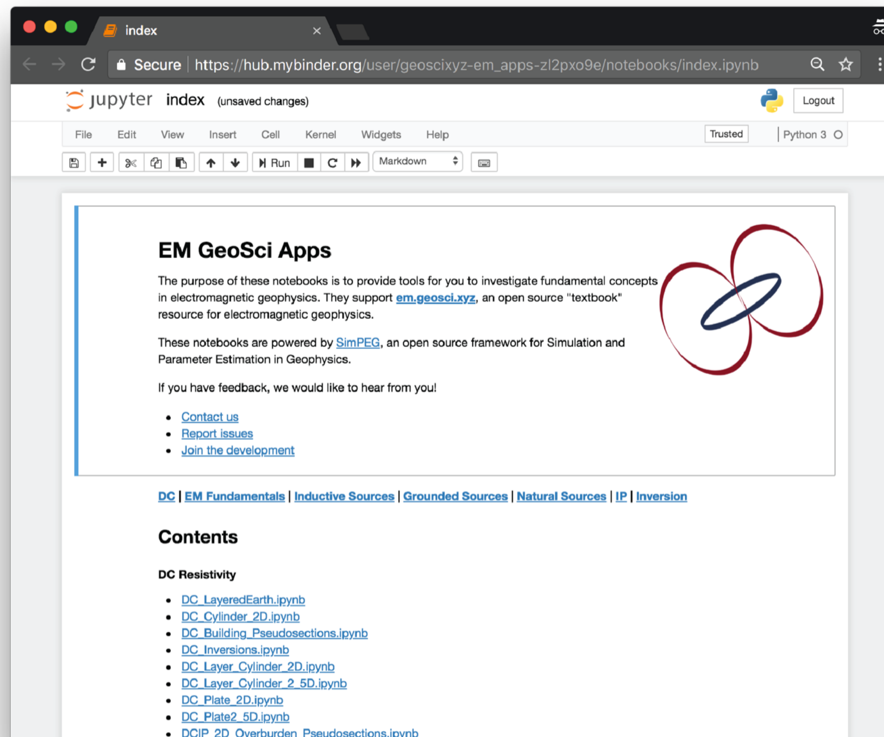
Jupyter Notebooks



Running the Apps

1. Load the repository (be patient...)
2. Select notebook from contents





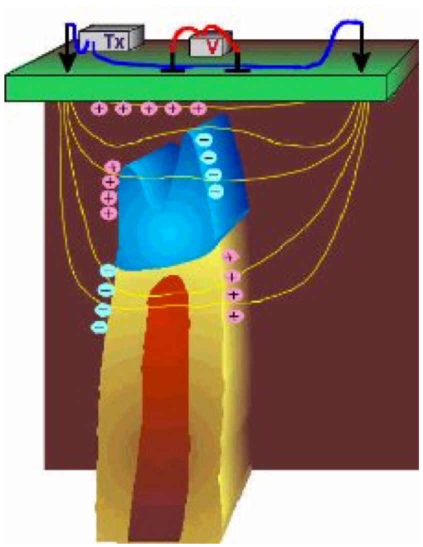
http://em.geosci.xyz/apps.html

Questions

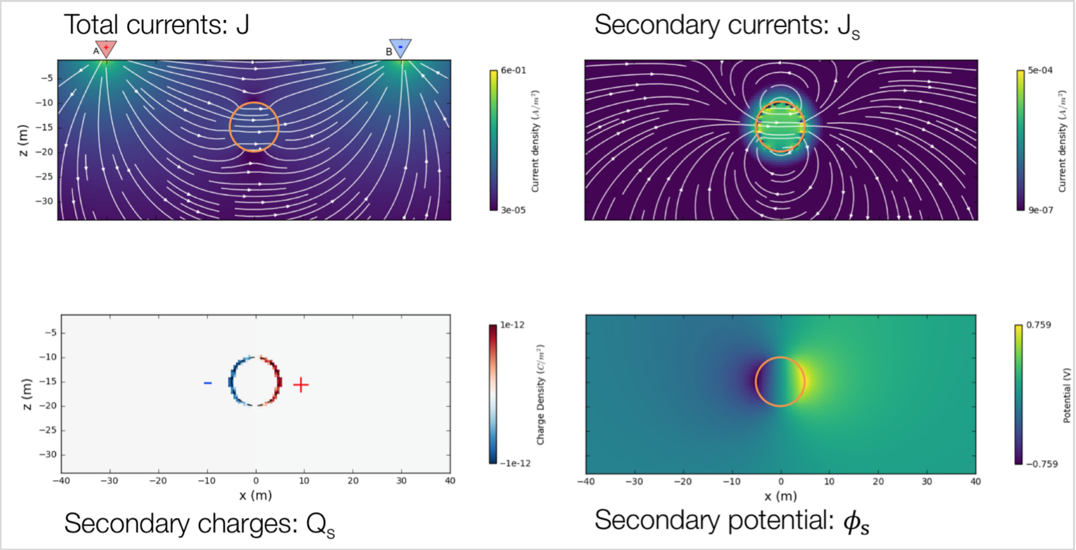
- DC_LayeredEarth
  - Start with a top layer that is conductive (50 Ωm).
    - What is the minimum A-B separation we need to see the second layer in our data?
    - What happens if it is more conductive / resistive?
    - What happens if the layer is thicker?
- DC_Cylinder_2D
  - You have been charged with finding 2 tunnels: (1) Filled with salty water, (2) filled with air
    - How are the charges distributed in each of these cases?
    - How are the charges distributed if you use a pole source?
- DC_Cylinder_2D cont…
  - For a conductive cylinder (10 Ωm) in a resistive background (500 Ωm), can you generate a pole-pole example where the apparent resistivity is > 500 Ωm? How do you explain this (hint: look at the charges)
- DC_Building_Pseudosections
  - For which survey setup's are the "pant-legs" symmetric over the target? Which aren't?
  - Can you demonstrate an example of non-uniqueness? E.g. If the sphere has a radius of 2m and a resistivity of 50 Ωm, is there a model that produces similar data?

Summary

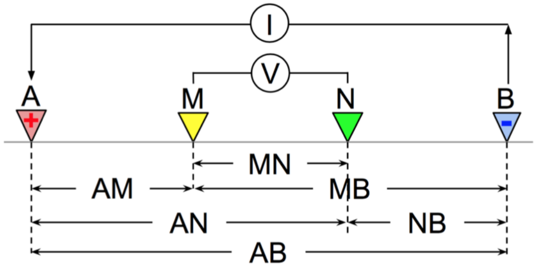
Basic experiment and physics



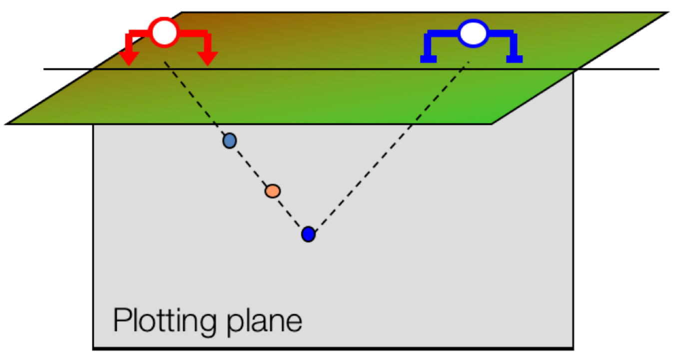
Confined targets



Soundings and arrays

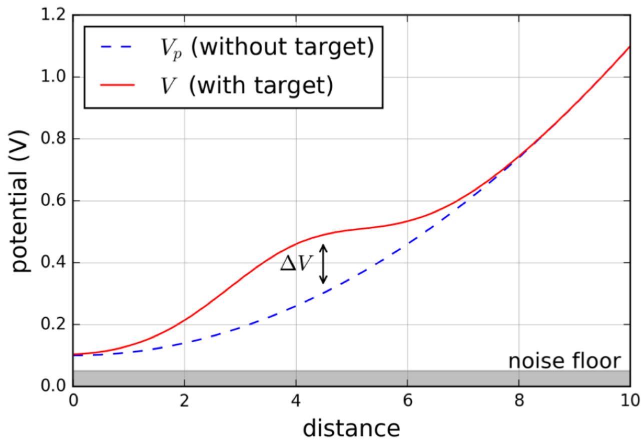


Pseudosections



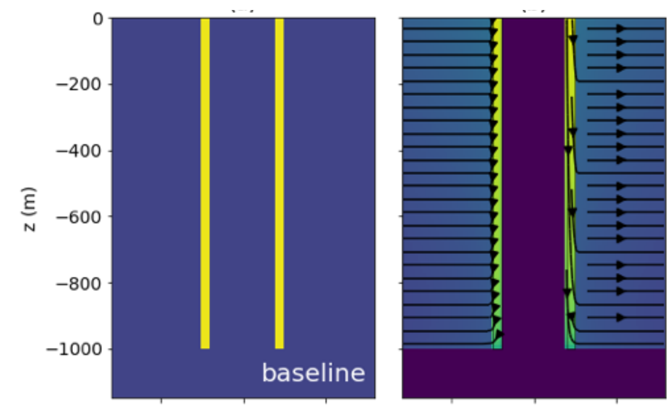
Summary

Sensitivity + survey design

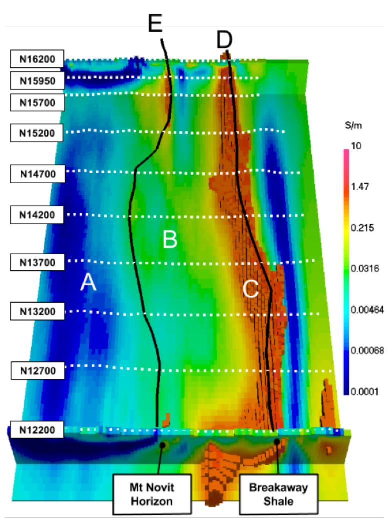


DC with steel cased wells

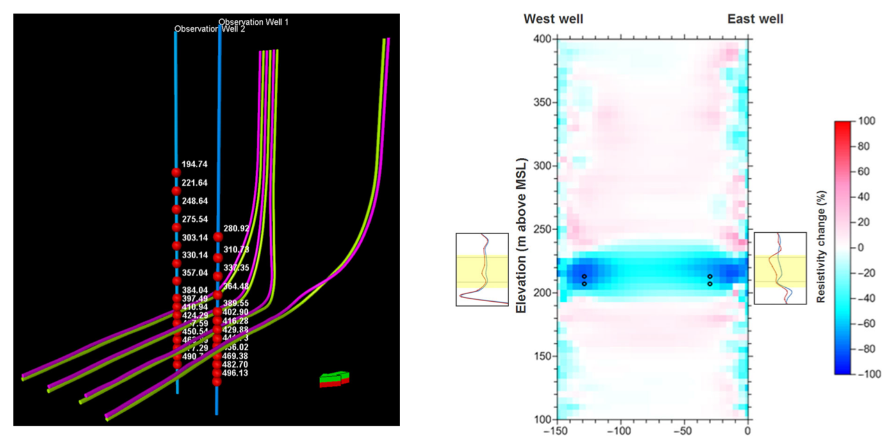
model currents



Case History: Mt. Isa

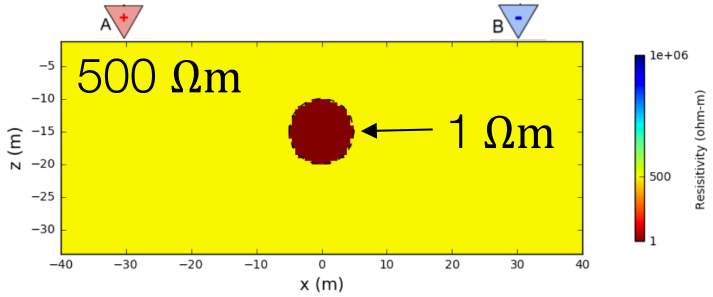


Case History: Reservoir Monitoring



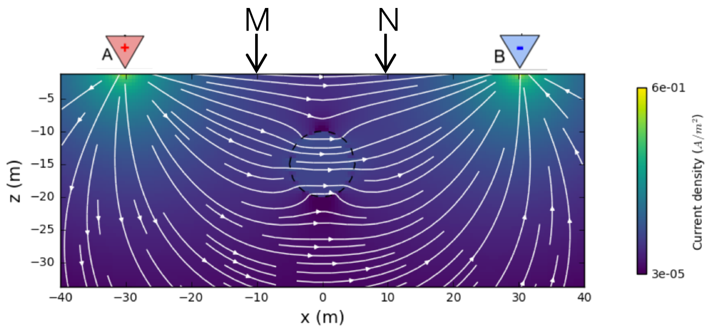
Effects of background resistivity

Resistivity models (thin resistive layer)



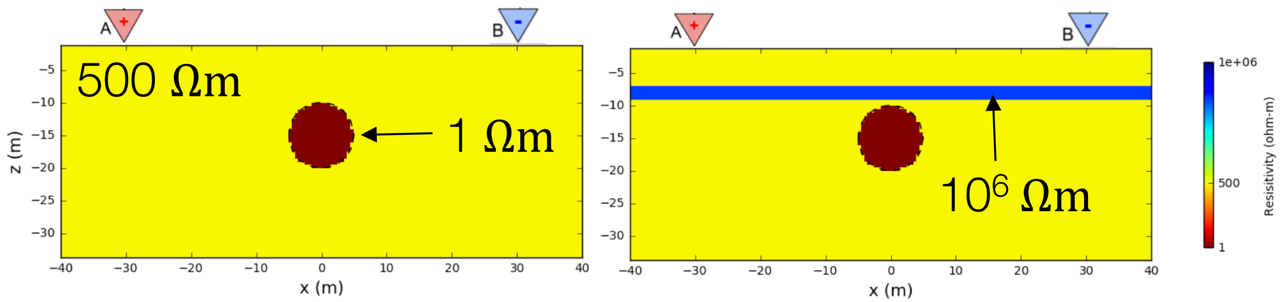
Currents and measured data at MN

ρ_a = 430 Ωm



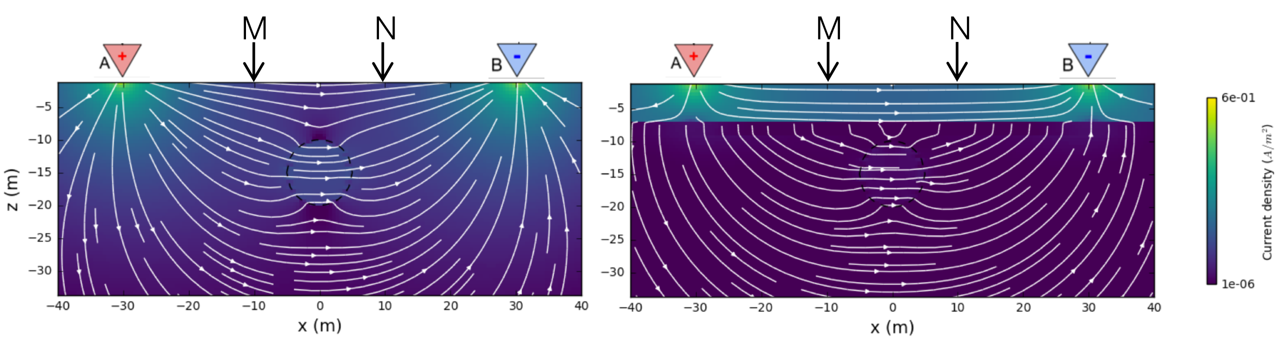
Effects of background resistivity

Resistivity models (thin resistive layer)



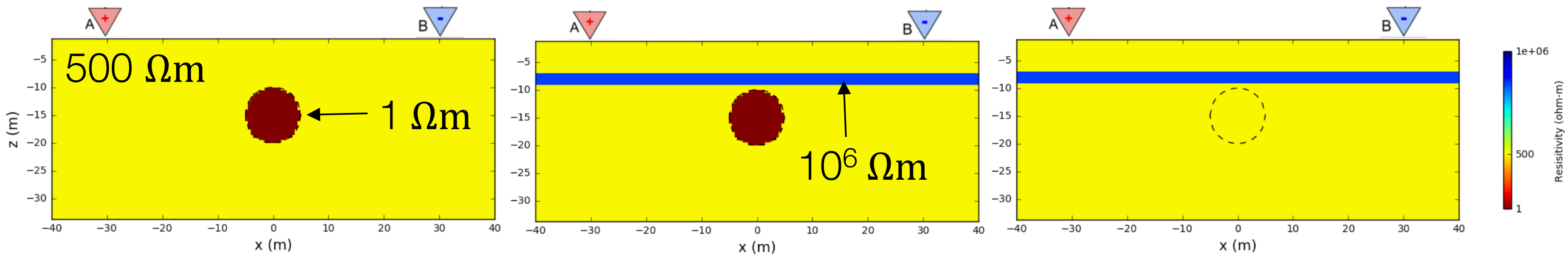
Currents and measured data at MN

ρ_a = 430 Ωm ρ_a = 1652 Ωm



Effects of background resistivity

Resistivity models (thin resistive layer)

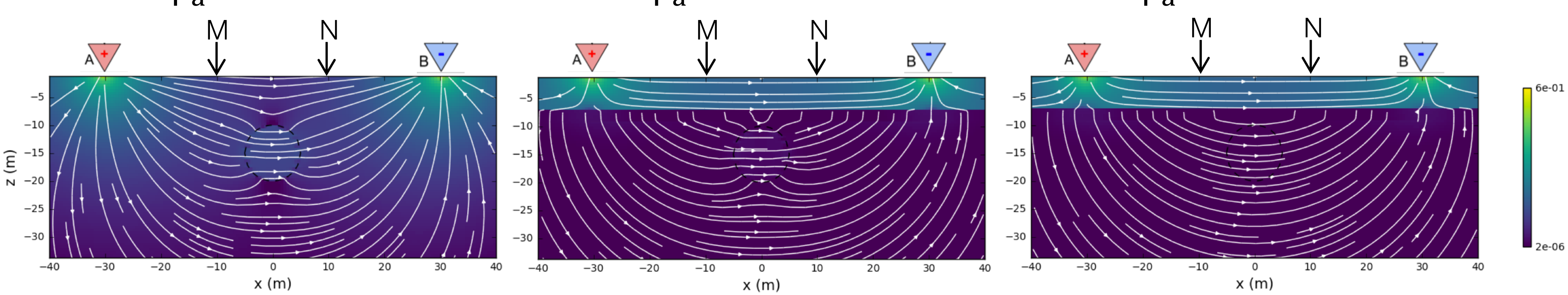


Currents and measured data at MN

ρ_a = 430 Ωm

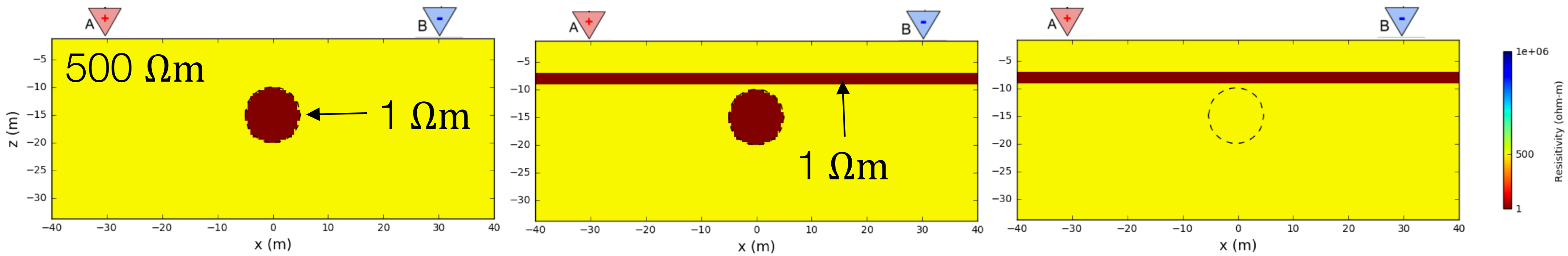
ρ_a = 1652 Ωm

ρ_a = 1654 Ωm

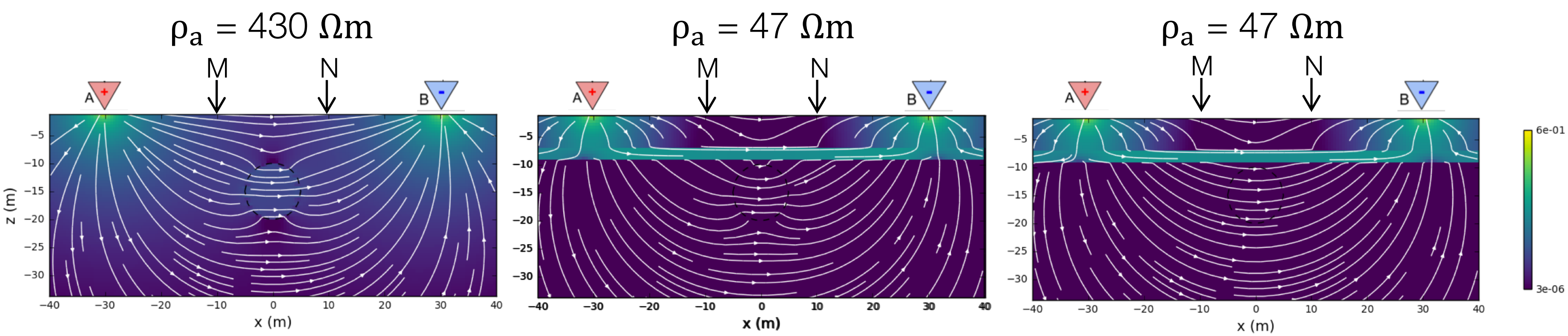


Effects of background resistivity

Resistivity models (thin conductive layer)

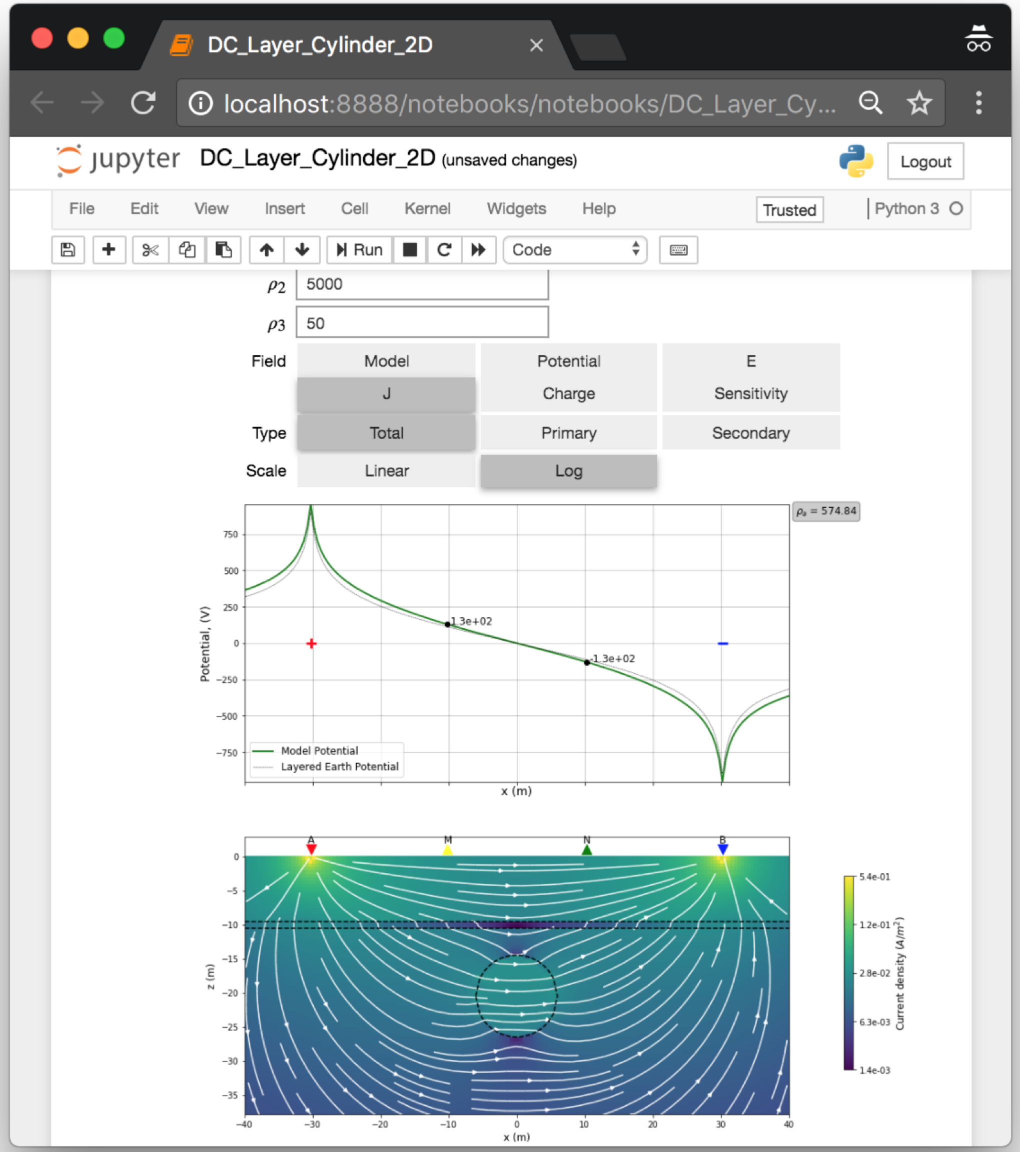


Currents and measured data at MN



DC Layered earth + cylinder

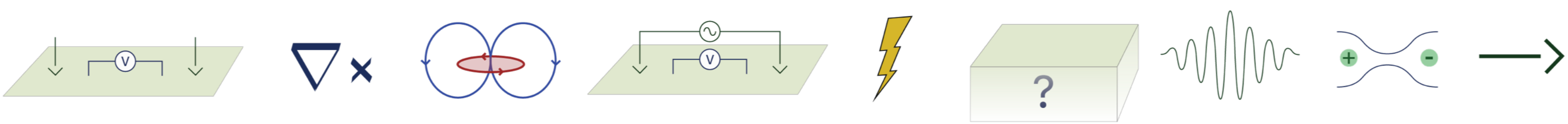
- DC_Layer_Cylinder.ipynb
- Parameters:
  - Resistivity of background, layer, sphere
  - Geometry of cylinder, layer
  - Location of electrodes
- View:
  - Model
  - Electric potential
  - Electric field
  - Charges
  - Current density



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

End of DCR

Next up



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