Airborne Natural Source Electromagnetics for an Arbitrary Base Station

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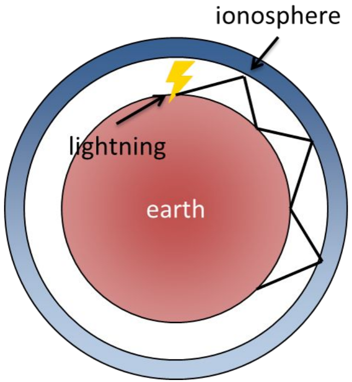
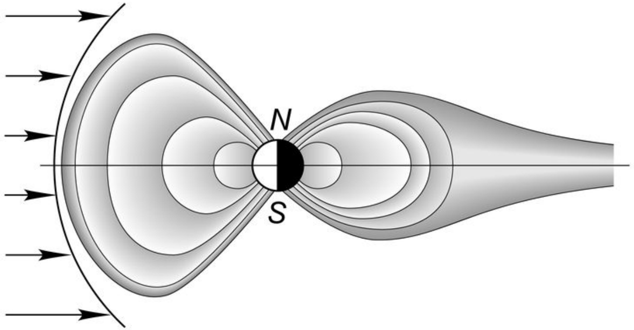
Presentation Outline

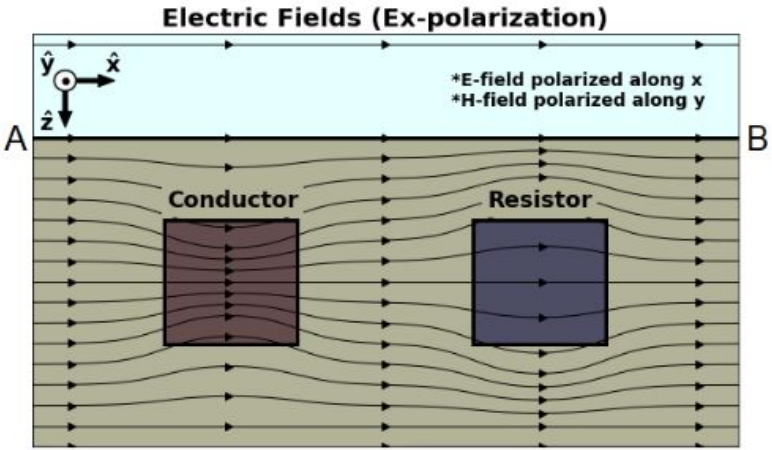
1. Introduction to NSEM
2. Motivation
3. Understanding airborne NSEM anomalies
4. Unconstrained inversion of airborne NSEM data
5. Future considerations

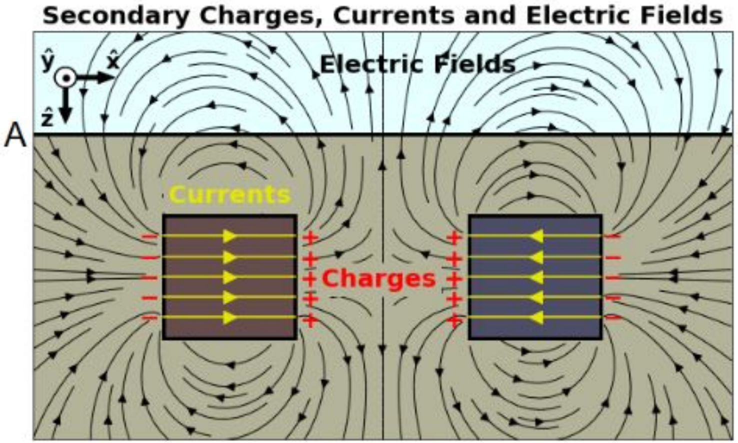
NSEM Fundamentals

Natural sources









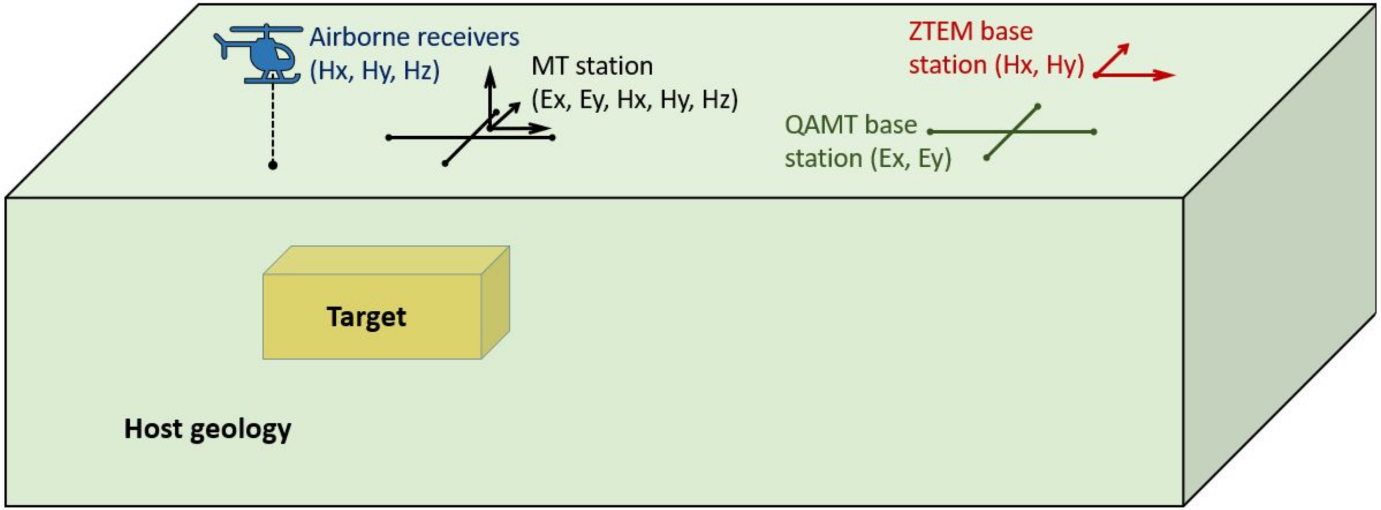
- Lightning and solar wind
  → Incoming planewave

- Conductor and resistors
  → Anomalous currents

- Anomalous electric and magnetic fields

NSEM Survey Geometry

- Magnetic fields (Hx, Hy, Hz) measured in air or on surface
- Electric fields (Ex, Ey) measured on surface
- Systems include: MT, AFMag, ZTEM, QAMT and MobileMT



Magnetotellurics

- Measure fields Ex, Ey, Hx, Hy and Hz at many surface locations

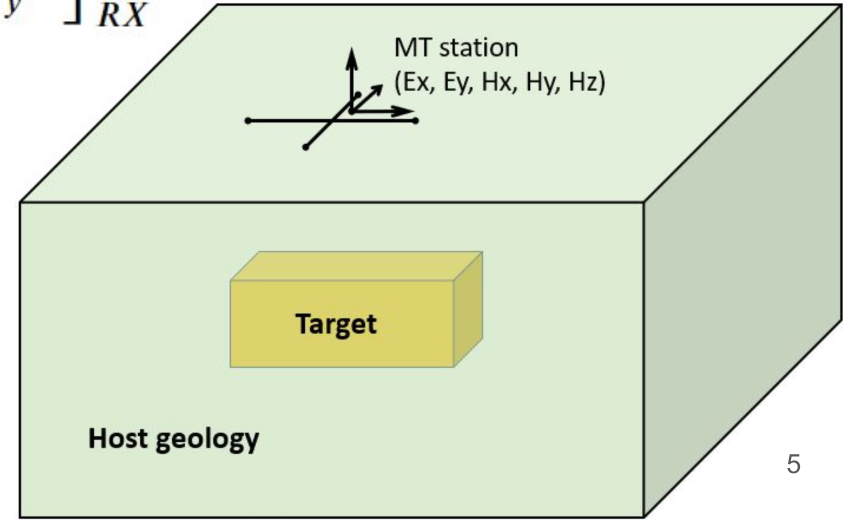
- Compute impedances, such that

$$\begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} = \begin{bmatrix} E_x^{(x)} & E_x^{(y)} \\ E_y^{(x)} & E_y^{(y)} \end{bmatrix}_{RX} \begin{bmatrix} H_x^{(x)} & H_x^{(y)} \\ H_y^{(x)} & H_y^{(y)} \end{bmatrix}_{RX}^{-1}$$

- Directly sensitive to subsurface conductivity

$$\sigma_{app} = \frac{\mu\omega}{\left|Z_{ij}\right|^2}$$

- Expensive and time-consuming



AFMag and ZTEM

- Compute **tipper data** which relates the vertical field (Hz) to the horizontal fields (Hx, Hy).

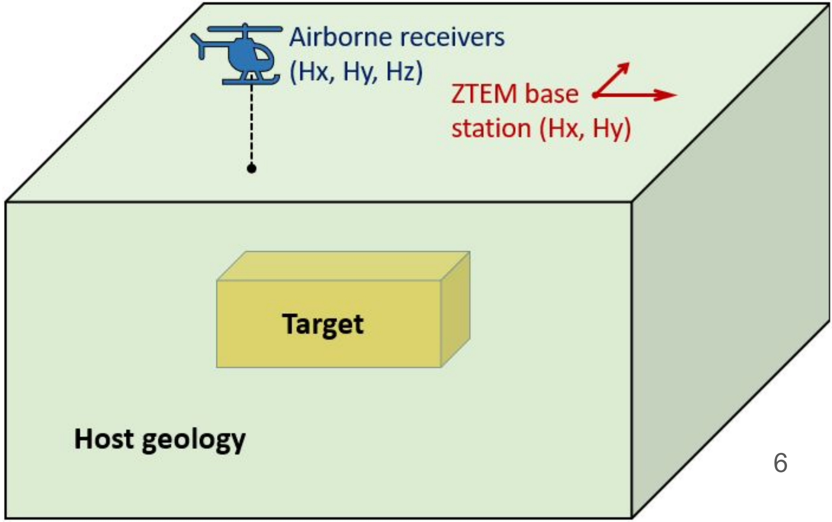
- **ZTEM** measures Hx, Hy at a base station

$$\begin{bmatrix} T_{zx} \\ T_{zy} \end{bmatrix} = \begin{bmatrix} H_x^{(x)} & H_y^{(x)} \\ H_x^{(y)} & H_y^{(y)} \end{bmatrix}_{BS}^{-1} \begin{bmatrix} H_z^{(x)} \\ H_z^{(y)} \end{bmatrix}_{RX}$$

- Not directly sensitive to subsurface conductivity

- Sensitive to conductivity contrasts along vertical interfaces

- Anomalies driven by magnetic fields



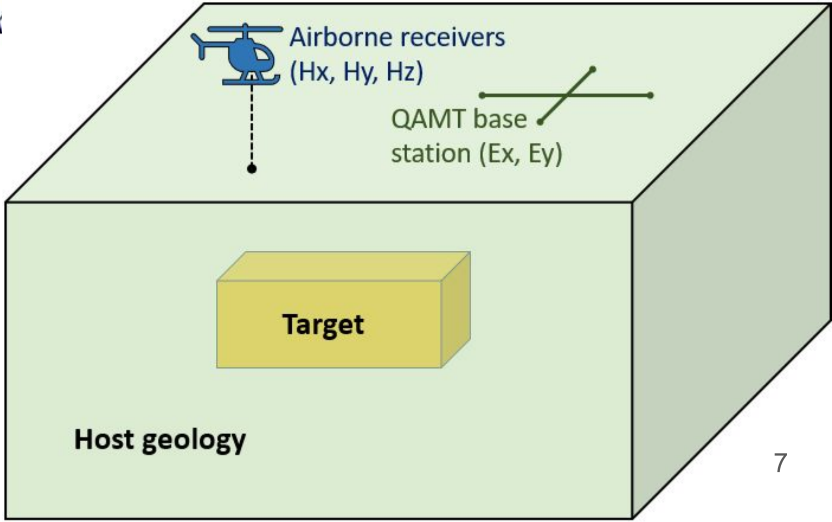
QAMT and MobileMT

- Airborne Hx, Hy, Hz at many locations and surface Ex, Ey at base station
- **QAMT impedances:**

$$\begin{bmatrix} Q_{xx} & Q_{xy} \\ Q_{yx} & Q_{yy} \end{bmatrix} = \begin{bmatrix} E_x^{(x)} & E_x^{(y)} \\ E_y^{(x)} & E_y^{(y)} \end{bmatrix}_{BS} \begin{bmatrix} H_x^{(x)} & H_x^{(y)} \\ H_y^{(x)} & H_y^{(y)} \end{bmatrix}_{RX}^{-1}$$

- **MobileMT data:**

$$\sigma_{mmt} = \frac{\mu\omega}{|det(\mathbf{Q})|}$$



To Summarize

- Three main flavours:
  - Magnetotellurics (ground-based)
  - Tipper (airborne)
  - QAMT / MobileMT (airborne)

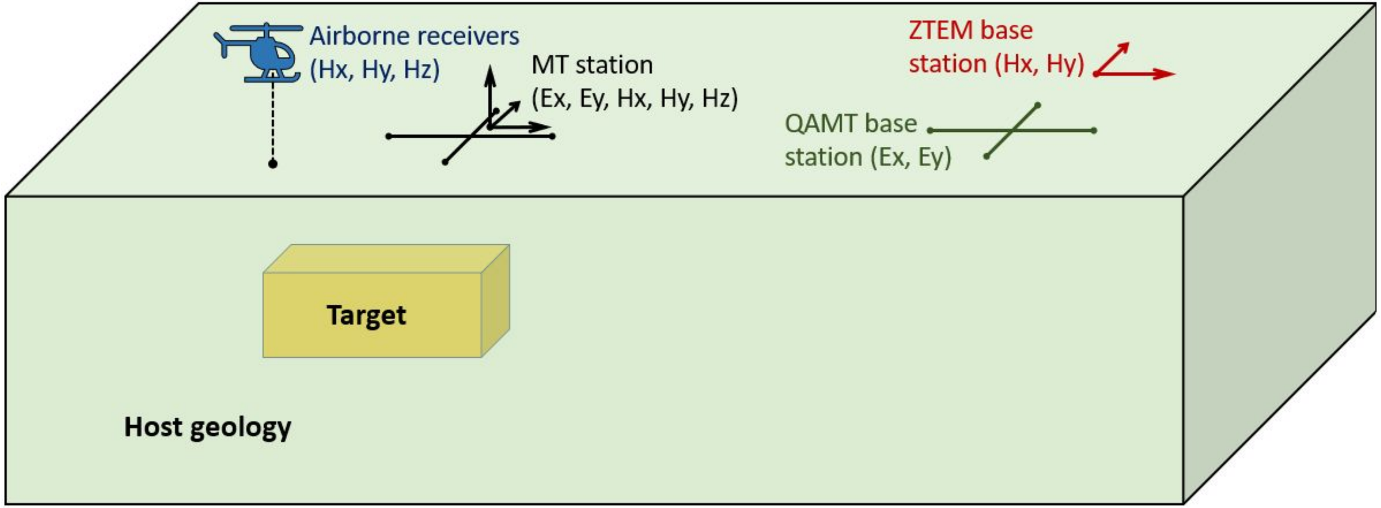
- Each system defines data according to a different transfer function

  → Collects different information about the Earth

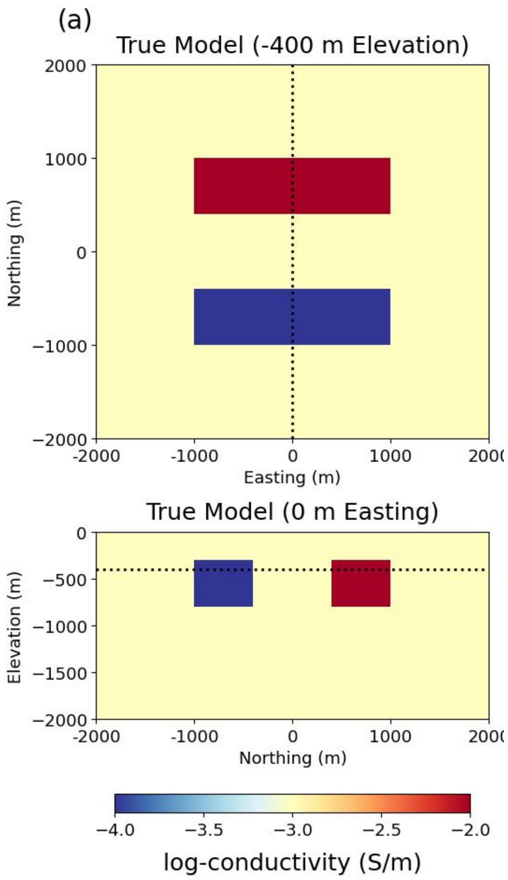
2. Motivation

Understanding Airborne NSEM

- Multitude of airborne NSEM systems
- Desire to recover models using inversion
- Limited literature (especially QAMT and MobileMT)

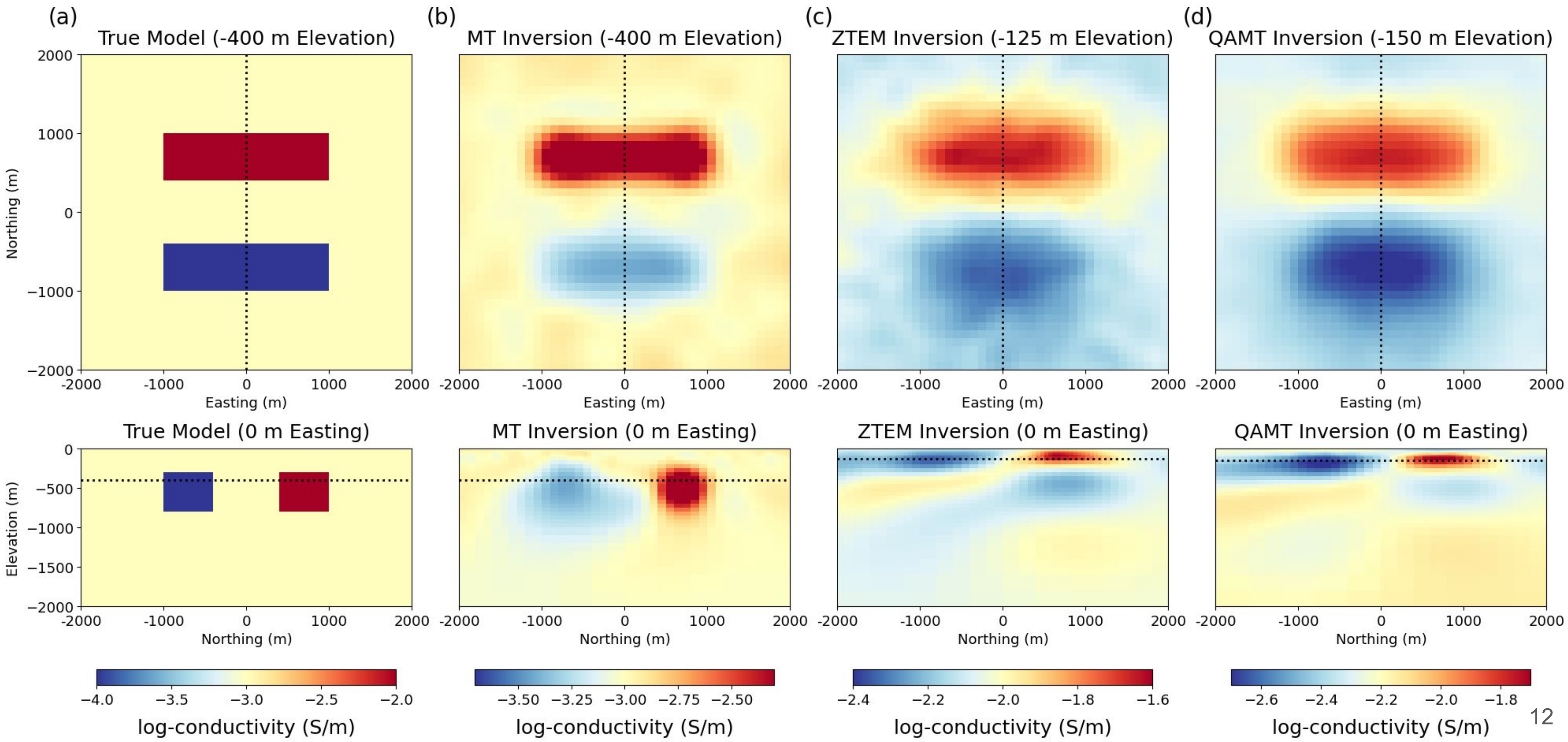


Why Is This Important?



- Inverting different data → different recovered models
- True model:
  - 0.001 S/m host
  - 0.0001 S/m resistor
  - 0.01 S/m conductor
- Generate MT, ZTEM and QAMT data
- Carry out smoothest inversion
- Invert with 0.01 S/m starting model (overestimated!!!)

Smoothest Model Inversion Results



Biggest Questions

Understanding Airborne NSEM Anomalies:

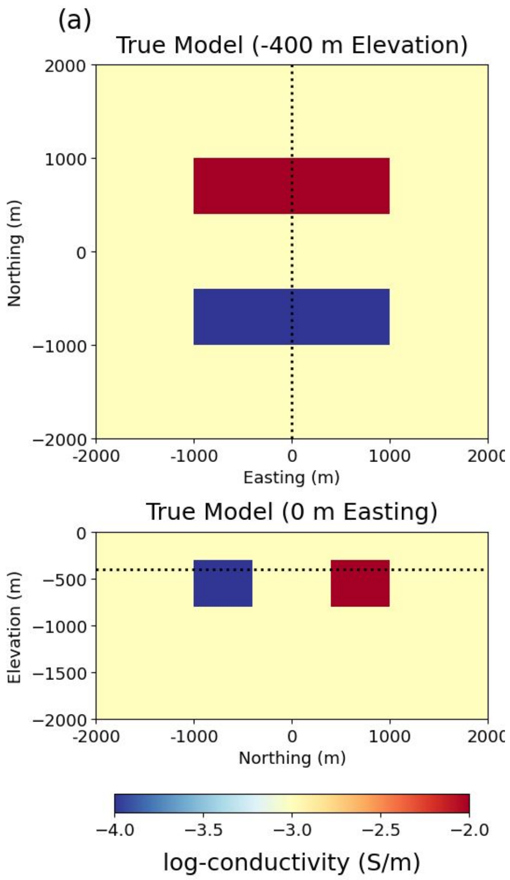
- How are MT and QAMT impedances different?
- What is the influence of the conductivity at the base station on ZTEM and QAMT data?

Understanding Airborne NSEM Inversion:

- How are inversion results influenced when the base station and host conductivity differ significantly?
- How does the inversion naturally recover features to fit the data?

3. Understanding Airborne NSEM Anomalies

MT vs QAMT Impedances



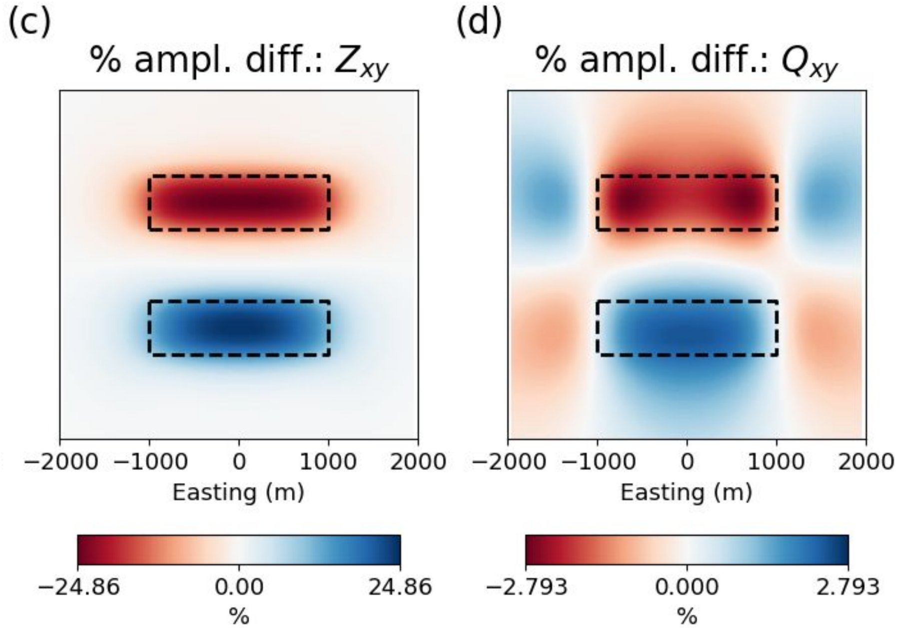
- How does structure impact MT and QAMT impedances?

- Here we:
  - Compute 0.001 S/m halfspace data
  - Compute block model data
  - Compute % difference in amplitude

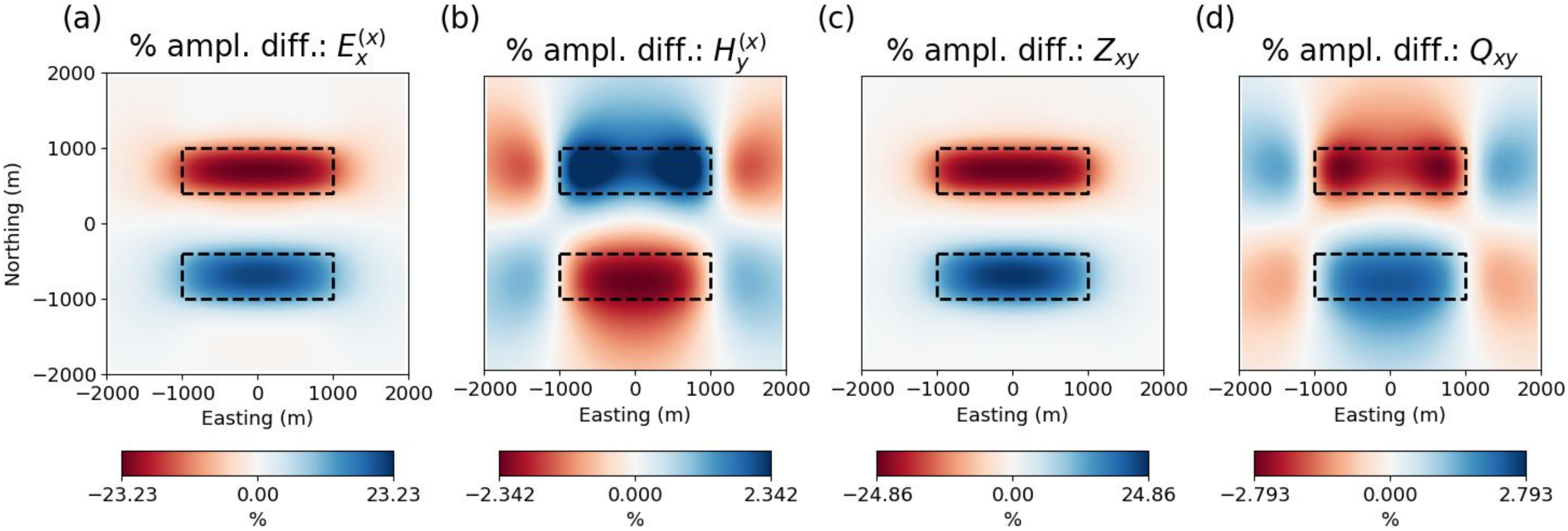
$$100\% \times \left(\frac{|f(\sigma_{block})| - |f(\sigma_{hs})|}{|f(\sigma_{hs})|} \right)$$

- Assume QAMT base station characterized by 0.001 S/m halfspace

MT vs QAMT Impedances



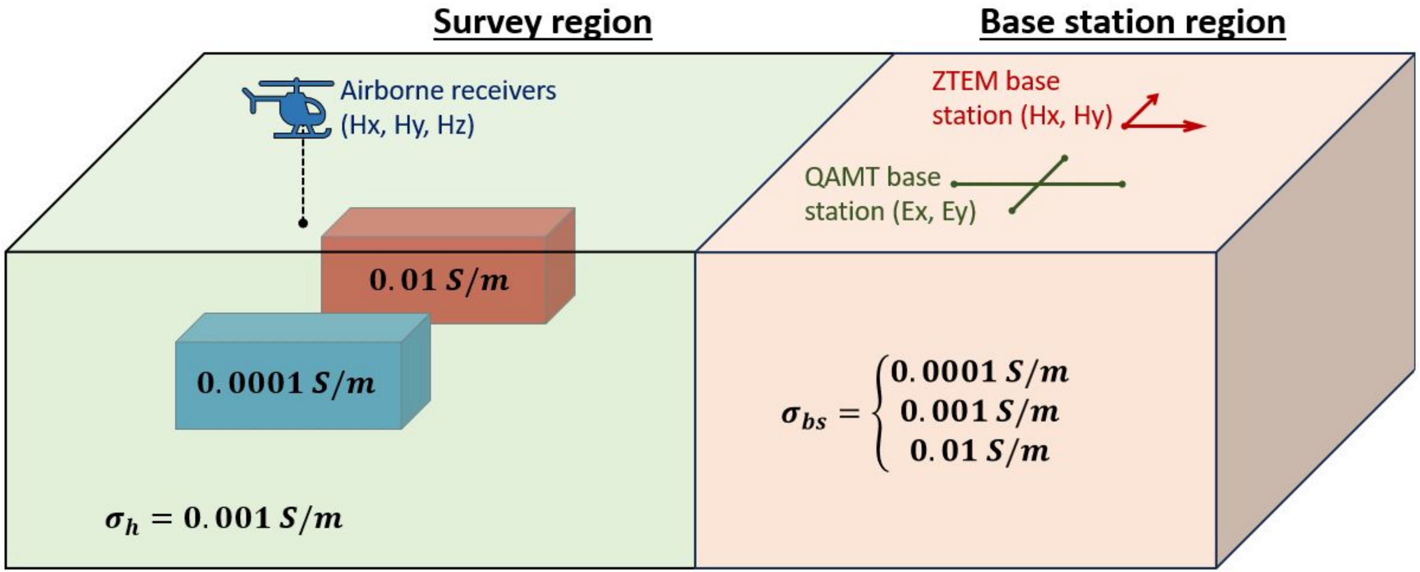
MT vs QAMT Impedances



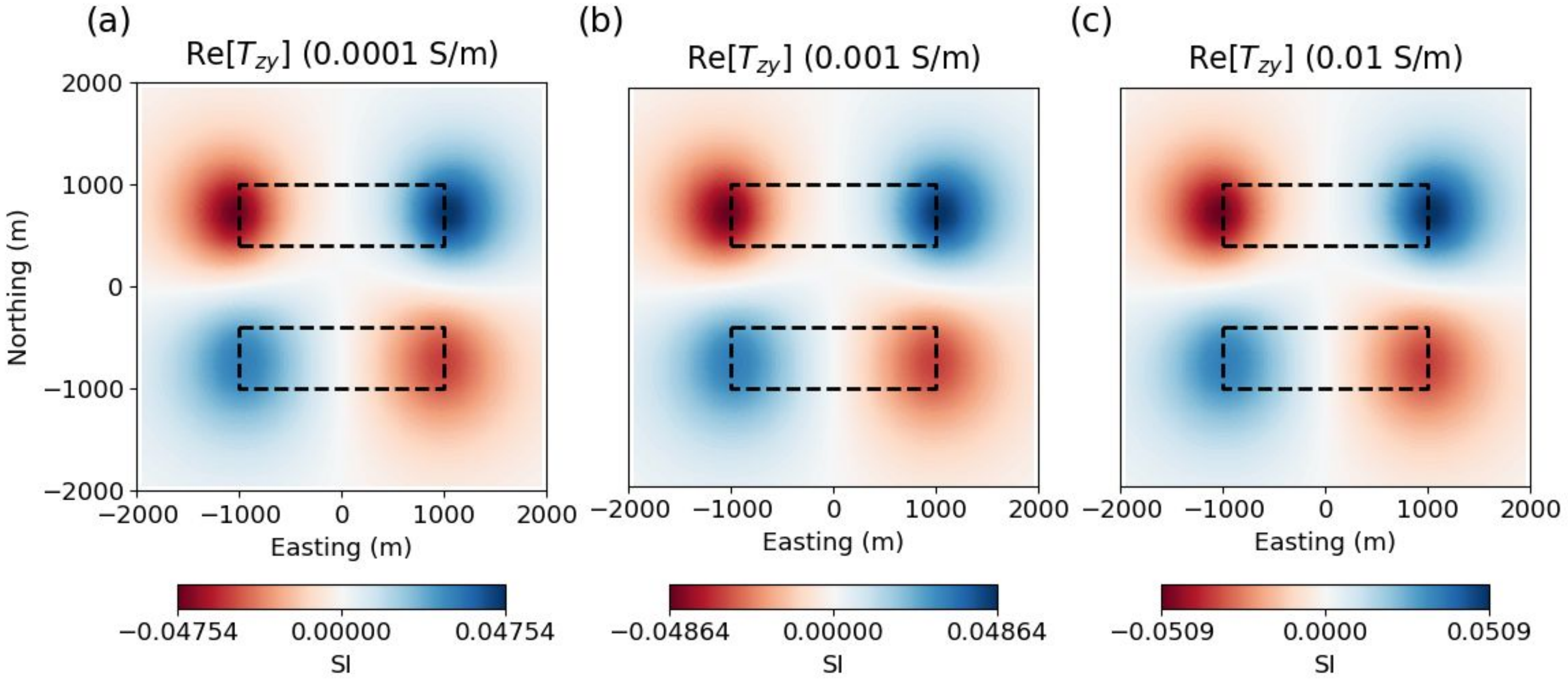
- MT driven by anomalous electric fields
- QAMT (and MobileMT) driven by anomalous magnetic fields
- Same behaviours observed for phase

Impact of Base Station Conductivity

- ZTEM and QAMT both measure fields at a base station
- What if base station conductivity very different from host conductivity?
- Assume base station a local half-space
- Impact on ZTEM and QAMT anomalies

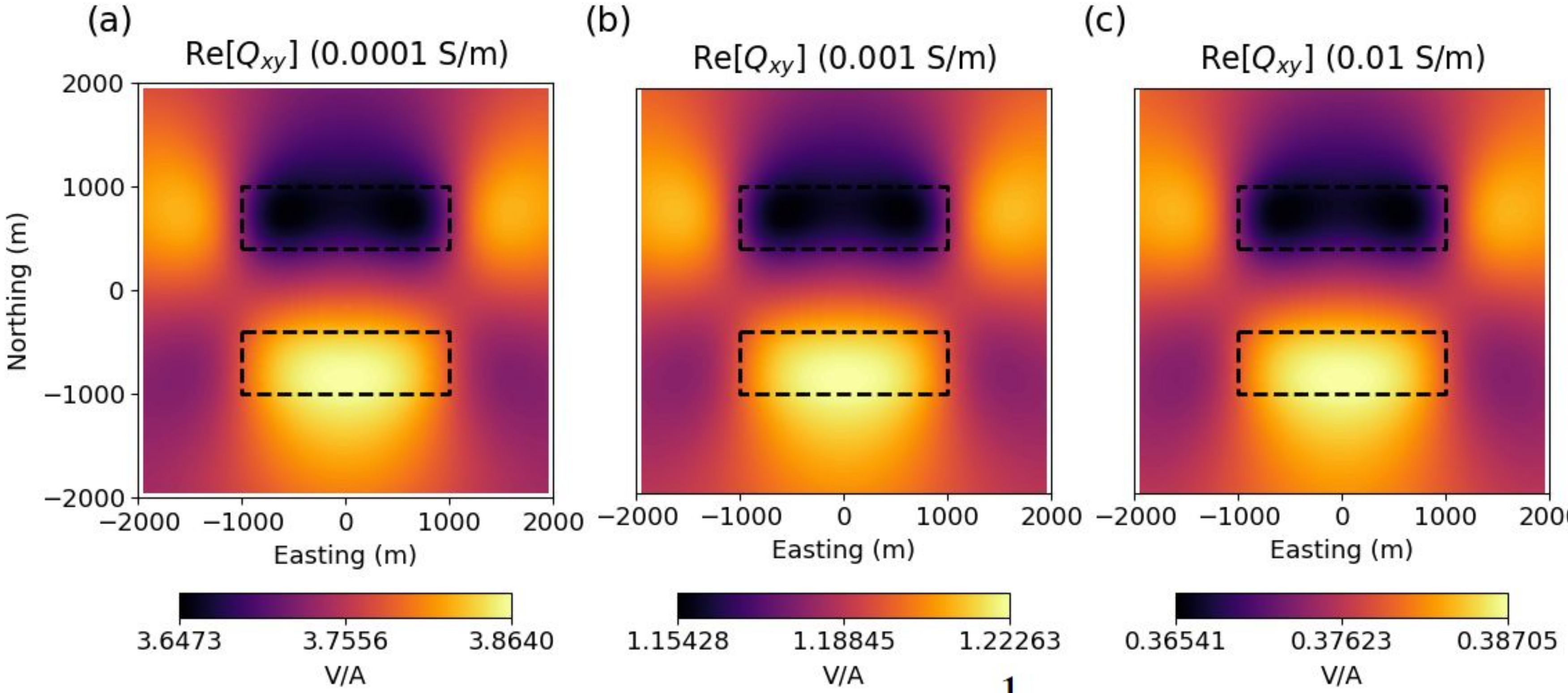


Impact of Base Station Conductivity



Consistent anomaly amplitude!!!

Impact of Base Station Conductivity



Proportional to $\frac{1}{\sqrt{\sigma_{bs}}}$

Section Summary

- **MT**
  - Directly sensitive to subsurface conductivity throughout survey region
  - Anomalies driven by anomalous electric fields

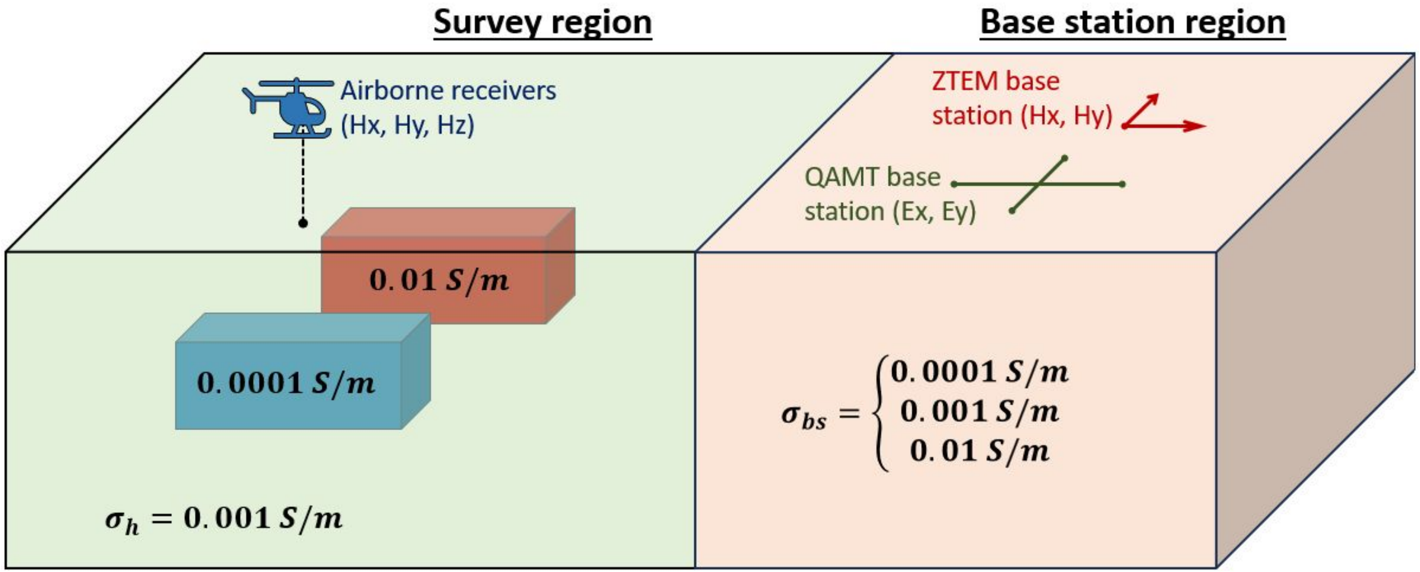
- **ZTEM**
  - Not directly sensitive to subsurface conductivity
  - Anomalies driven by anomalous magnetic fields from vertical interfaces

- **QAMT**
  - Directly sensitive to conductivity at base station
  - Anomalies driven by anomalous magnetic fields

4. Unconstrained Inversion of Airborne NSEM Data

Setup

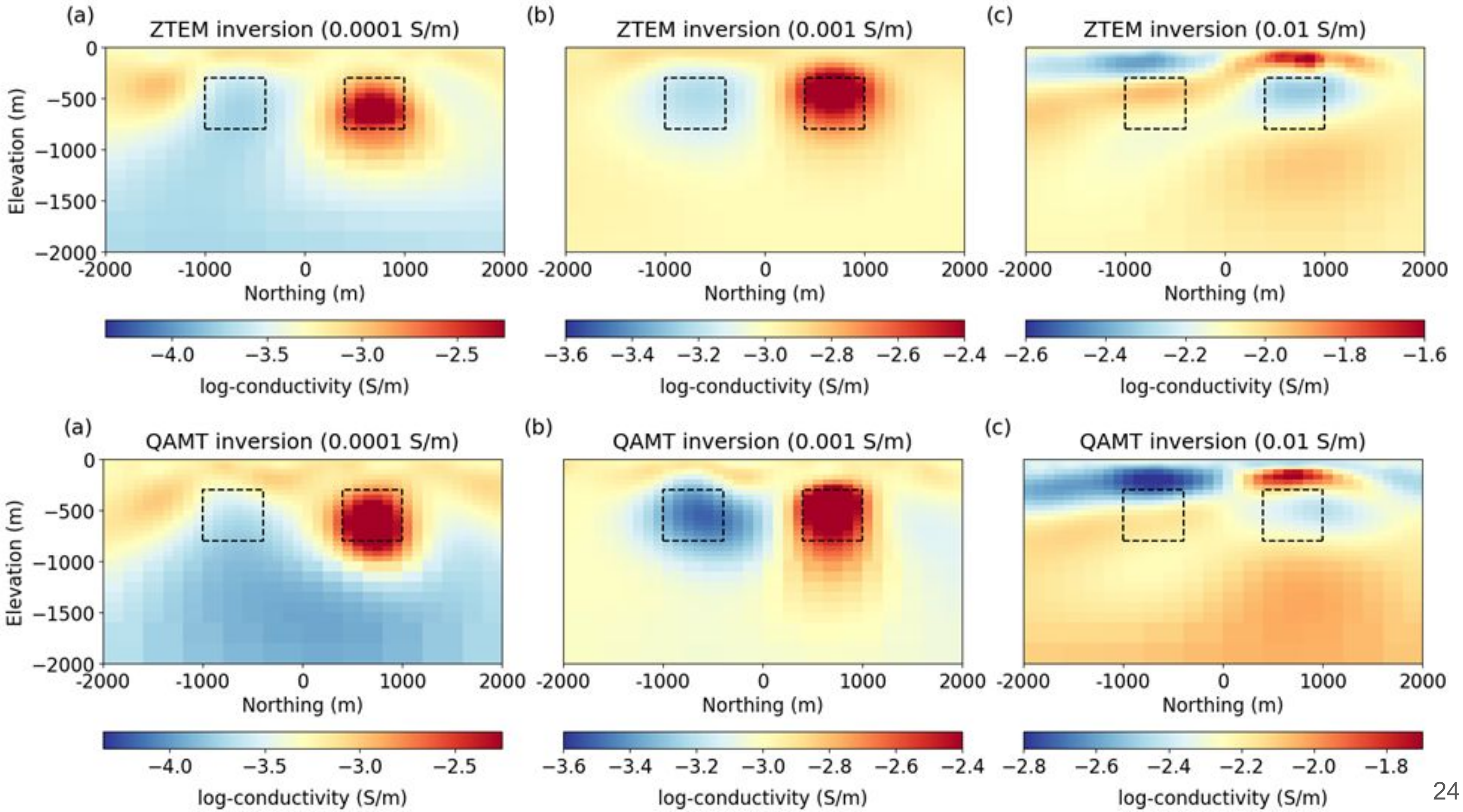
- Host and base station conductivity different
- Generate and invert synthetic ZTEM and QAMT data
- Use base station or host conductivity as starting model?



Inversion with Base Station Conductivity

ZTEM

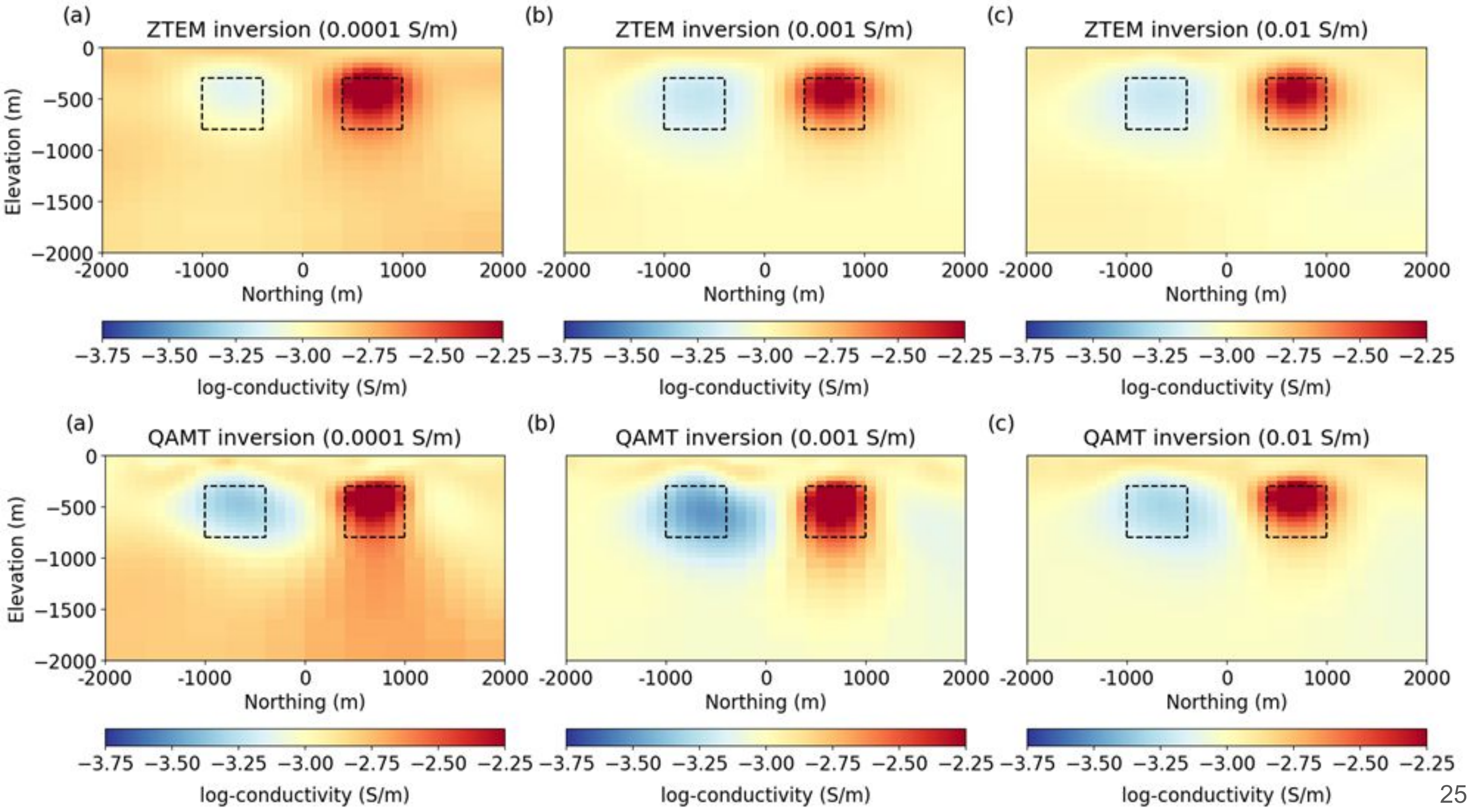
QAMT



Inversion with Host Conductivity

ZTEM

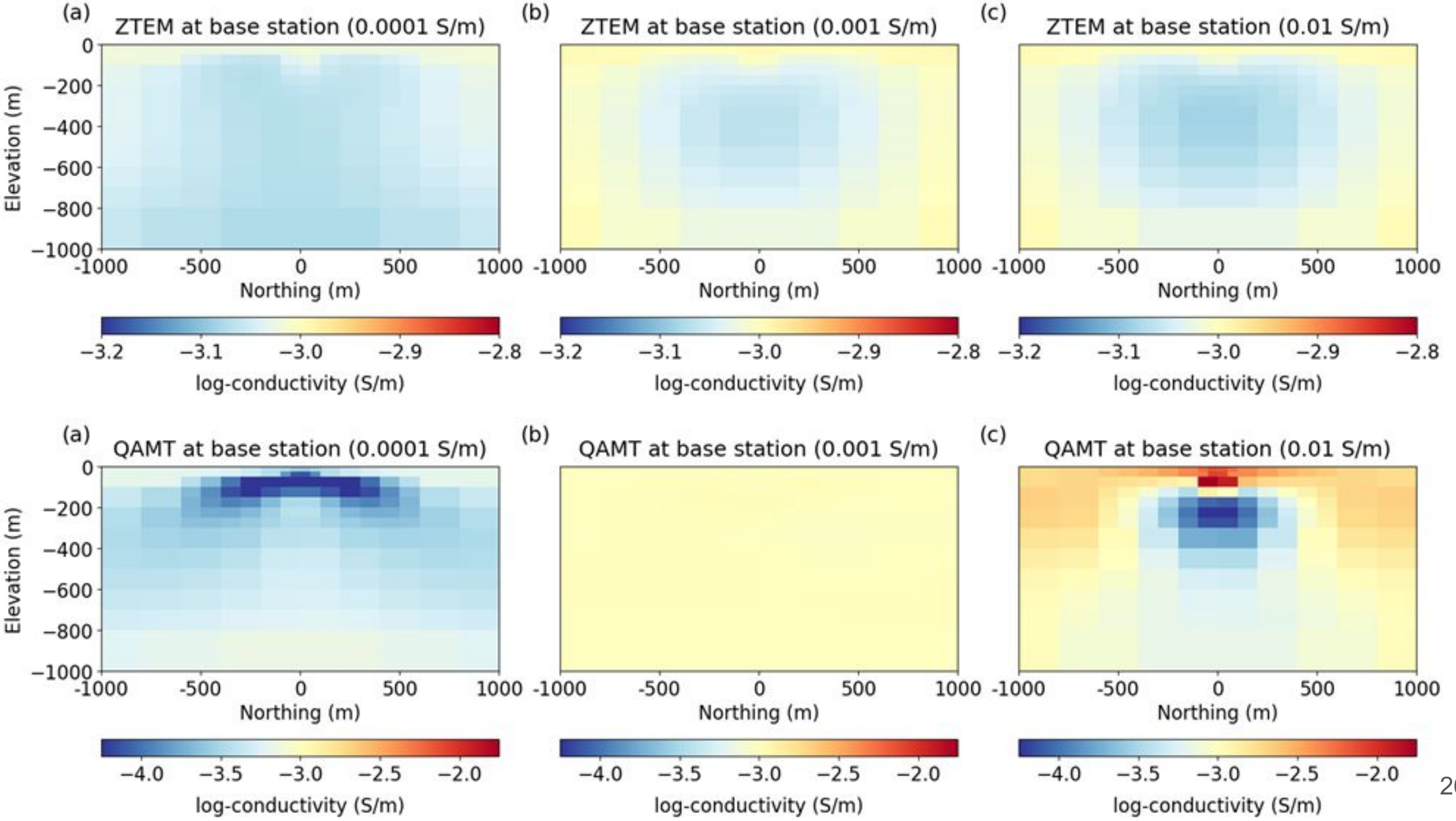
QAMT



Inversion with Host Conductivity (Base Station)

ZTEM

QAMT



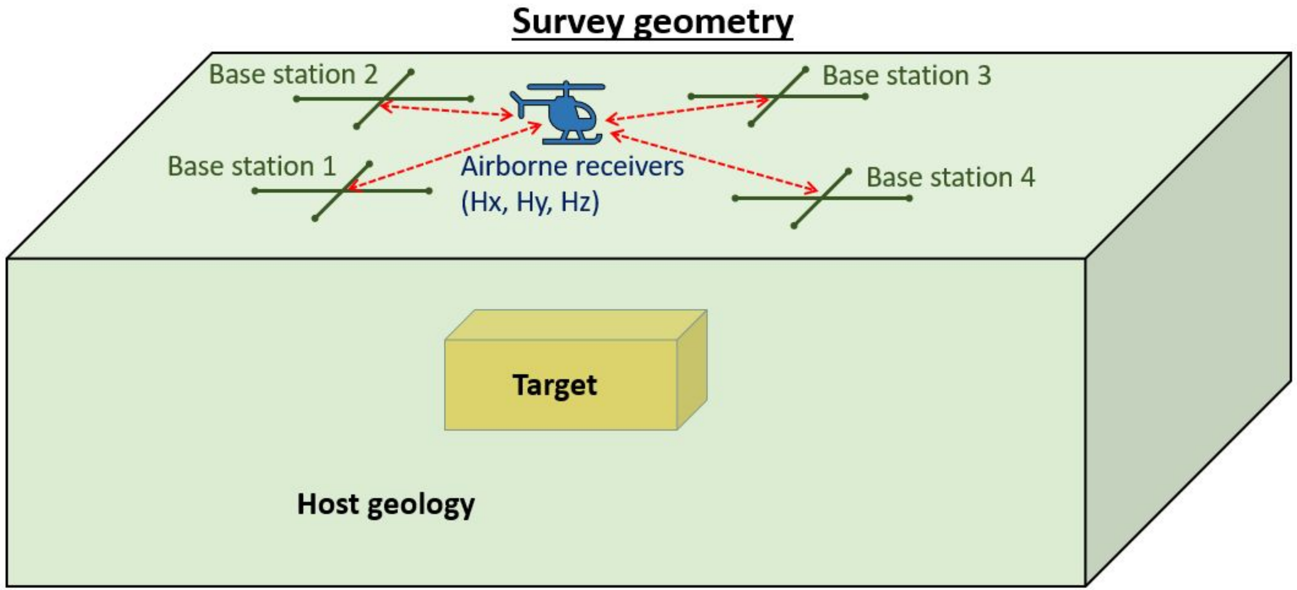
Section Summary

- Choice in starting model impacts both ZTEM and QAMT inversion
- Best to use host conductivity as starting model
- Significant structures recovered at base station
- Base station structures important in fitting data

5. Future Considerations

Survey Design

- Optimum base station location
- Add several MT stations
- Sync multiple base stations to airborne measurements (below)



Inversion Methodology

- Starting/reference model strategies
- Regularization
- Uncertainties
- Mitigating artifacts at base station

Thank you!