ZTMT2DIV: Two-dimensional Joint Inversion of ZTEM and MT Plane-Wave EM Data Including Topography

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First Presented at EEGS SAGEEP 2014 Conference, Boston, Mass., March 16-20, 2014
Outline

• Introduction
• ZTEM and MT Basic Principles
• ZTEM Apriori Model Effects
• Joint MT-ZTEM Inversion
• Joint MT-ZTEM Model Study
• Joint MT-ZTEM Case Study
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Introduction

- ZTEM data provide excellent mapping of lateral resistivity contrasts – Fast and Low Cost.
- Quantitative resistivity model attained with suitable constraints (resolution depends on apriori start model).
- MT method provides quantitative resistivity independently due to E-fields and H-fields.
- Full airborne MT remains a technological challenge – Ground MT acquisition Slow and High Cost.
- Motivated to examine improvement to ZTEM resolution (depth, resistivity) by incorporating sparse MT measurements + Joint Inversion code.
ZTEM & MT – Basic Principles

- MT and ZTEM in same family of plane-wave EM techniques.
- Measurement of electric (E) and/or magnetic (H) fields close to the Earth's surface
- MT stands for Magnetotellurics – ground EM method
- ZTEM stands for Z-axis Tipper Electromagnetics – airborne EM method
- Magnetotellurics - ground version of ZTEM (plus electric fields).
- Frequency range determines depth of investigation
- ZTEM: 720-30 Hz (up to 2km), MT-AMT: 10,000-0.0001Hz (surface down to upper mantle)
ZTEM & MT – Basic Principles

ZTEM-MT Tipper Comparison  ZTEM-MT 3D Inversion Comparison

Highlighting Identical Nature of ZTEM & MT Measurements and Relative Accuracy Demonstrated in 3D Inversion Results

Figure: Components of tipper, estimated from ZTEM and MT at one station

Figure: Tx real part from ZTEM (left) and MT (right)

(after Hubert et al, PDAC 2013)
ZTEM BASIC PRINCIPLES OF OPERATION – How it’s Similar Yet Different From HTEM

**HTEM:** Primary EM Field Comes from Transmitter Current-Loop (Fields Mainly Vertical – Up)

- Receiver Loops Measure Secondary Hz & Hx +/- Hy Fields in Off Time

(After Witherly, PDAC 2011)

**ZTEM:** Primary EM Field Comes from World-Wide Thunderstorms (Fields Horizontal – Lateral)

- Receiver Loop Measures Hz/Hx & Hz/Hy Ratios (Mix of Primary & Secondary fields)

(Principle of ZTEM: EM Induction after Witherly, PDAC 2011)
Inversion for ZTEM profile along ground surface over brick.

Inversion with Air Layer Ignored

Inversion with 3200 ohm-m Apriori.

Returns Shallower Target

Inversion with 3200 ohm-m Apriori

Returns Deeper Target

Inversion with 320 ohm-m Apriori

Returns Shallower Target

Examples of ZTEM 2D Inversion and Effects of Apriori Parameters on Model Accuracy

(after Wannamaker, PDAC 2009)
Joint MT/ZTEM 3D Inversion shows marked improvement over stand-alone models (after Holtham and Oldenburg, 2010).
Joint MT-ZTEM 2D Model Study
2D Synthetic Forward Reference Model

- 75 ZTEM Sites - 100m Spacing (30-720Hz)
- 50 Ωm Bodies
- 2000 Ωm Half-space
- 9 MT Sites – 750m Spacing (1-1000Hz)

- ZTEM Only Data Inversion – 2000 Ωm Apriori
  - Returns Reasonable Target Depths & Resistivities
  - Gaussian Error: 0.01 ZTEM 3log10% MT Rho 2degMT Phase
TM Mode MT Only Data Inversion
- Returns Good Target Depths But Incorrect Resistivities

TE Mode MT Only Data Inversion
- Returns Good Target Depths & Resistivities But Smooth X-Z
Tipper MT Only (TE Mode) Data Inversion

- Returns Poor Target Locations & Incorrect Resistivities

Joint ZTEM-TM Mode MT Inversion

- Returns Best Target Depths & Resistivities
ZTEM Only Data Inversion – 400 Ωm Apriori

- Returns Shallow Target Depths & Low Resistivities

Joint ZTEM-TM Mode MT Inversion – 400 Ωm Apriori

- Returns Good Target Depths & Resistivities
75 ZTEM Sites
3 MT Sites

Joint ZTEM-MT 3 Site Only Inversion – 400 Ωm Apriori

- Returns Reasonable Target Depths & Resistivities

ZTEM Only Data Inversion – 10,000 Ωm Apriori

- Returns Distorted Target Depths & High Resistivities
75 ZTEM Sites
9 MT Sites

Joint ZTEM-MT Inversion – 10,000 Ωm Apriori
➤ Returns Good Target Depths & Resistivities

75 ZTEM Sites
3 MT Sites

Joint ZTEM-MT 3 Site Only Inversion – 10,000 Ωm Apriori
➤ Returns Reasonable Target Depths & Resistivities
Unconformity Uranium ZTEM-MT Case Study – East Athabasca Basin

ZTEM & MT Profile Site Map

- Airborne EM Apparent Resistivity Image
- Ground Moving Loop EM Conductors (basement graphites)
- ZTEM & MT Survey Lines

ZTEM 2D Resistivity Model

Possible Sandstone Clay Alteration

Possible Sandstone Clay Alteration

ZTEM & MT Survey Lines

Athabasca Type Unconformity Uranium Deposit Style
Unconformity Uranium ZTEM-MT Case Study – East Athabasca Basin

2D APRIORI INVERSION MODEL TESTS

ZTEM - 3k Ω-m
Target well Resolved

ZTEM - 1k Ω-m
Target Poorly Resolved

ZTEM - 10k Ω-m
Target well Resolved (but higher RMS error)

MT - 2D Inversion
Target/Reference Model

Showing effect of Half-space Start model on target depth in 2D Inversions (2009)
24 MT Sites Here

MT TM Mode

Only Data Inversion

- Returns Central Conductors Only & Wider Resistivity Range

ZTEM Only Data Inversion – 2000 Ωm Apriori

- Returns Shallower Depths, Smooth Targets & Narrow Resistivity Range

197 ZTEM Sites

2-D Model - jnlk2000

2-D Model - jnlk-trmi

24 MT Sites Here

MT TM Mode Only Data Inversion

- Returns Central Conductors Only & Wider Resistivity Range
MT TM-TE Mode Only Data Inversion

- Returns Widest Resistivity Range but doesn’t Detect South Conductor
- Similar with Central and South Conductors Better Defined

Joint ZTEM-MT TM-TE Mode Inversion

- Similar with Central and South Conductors Better Defined
Joint ZTEM MT TM Mode Inversion

- Better Defined Central and South Conductors

Joint ZTEM-MT TM Mode 3 Site Only Inversion

- Reasonably Defined Central and South Conductors
ZTEM Only Data Inversion – 500 Ωm Apriori

- Targets have Moved to Shallower Depth
- Reasonably Defined Central and South Conductors

Joint ZTEM-MT 3 Site Only Inversion – 500 Ωm Apriori

- Reasonably Defined Central and South Conductors
Conclusion

• Algorithm ZTMT2DIV can compute accurate 2D inversion images through separate or joint inversion of ZTEM and MT including ‘smooth’ topography.

• Joint inversion is mutually beneficial for each data type:
  • Inclusion of MT data should constrain resistivity baseline values to improve resolution of ZTEM structure (depth, $\rho$).
  • Detailed lateral resolution of contrasts by ZTEM data should provide control between possibly sparser MT stations.

• Some consideration must be given to relative placement of ZTEM and MT sites in the finite element mesh (Best if MT Sites Widely Distributed across Survey Extents)
Acknowledgements

Our thanks to:
Geotech and Denison Mines (Saskatoon), for allowing us to present these results.

First Presented at EEGS SAGEEP 2014 Conference, Boston, Mass., March 16-20, 2014