Application of 3D CSAMT Inversion to Various Data Components and Its Enhancement

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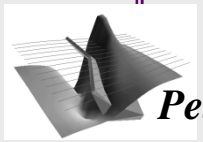
TOPICS

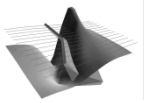
- Forward simulation
- A trust-region inversion technique
- First Synthetic Example
- Second Synthetic Example
- Inversion with striking and dipping grid cells
- A real data example
- Conclusions and Future Work



Petroseikon

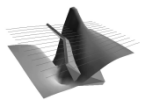
Forward simulation

- The algorithm is not limited by assumption regarding the farfield. Take into consideration of the TX current bipole geometry.
- utilize a controlled source approach utilizing the specifics of the grounded transmitter incorporating not only the injected currents but also the induced fields from the transmitted magnetic fields.
- Based on a Localized Non-Linear (LN) approximator in (Habashy et al, 1993) and (Murray et al, 1999) when scattering is controlled principally by either injected or induced currents in the host structures.
- The technique is efficient and stable in simulating three-dimensional electromagnetic scattering



Inversion technique
- a constrained trust-region method

- solves a least-squares minimization problem with simple bound constraints and has a fast rate of convergence.
- a quadratic model within a region, defined by the trust-region radius, is trusted to be an adequate representation of the objective function. The trust-region method then calculates the step to the approximate minimum of the model in this region.
- We utilized a projected gradient method to determine an initial point with sufficient reduction of the quadratic model. The projected gradient method is more efficient as several bound constraints can be added simultaneously.
- As the second stage of the step computation, a further reduction of the quadratic model is sought to enhance the convergence of the inversion with the additional restriction that the bounds on the parameters are kept fixed throughout the second process.



Objective function

minimize $\phi = \phi_d + \mu\phi_m$

$\vec{K} = (\rho_1, \rho_2, \cdots, \rho_M)^T$ resistivity model vector

Constraints: $l_i \le \rho_i \le u_i$

$\vec{d}_0 = (d_1^0, d_2^0, \cdots, d_N^0)$ observed data

$\vec{d} = (d_1, d_2, \cdots, d_N)$ predicted data

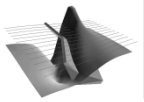
$\phi_d = \left\| W_d(\vec{d} - \vec{d}_0) \right\|^2$ data misfit

$W_d = diag(1/\sigma_1, 1/\sigma_2, \cdots, 1/\sigma_N)$

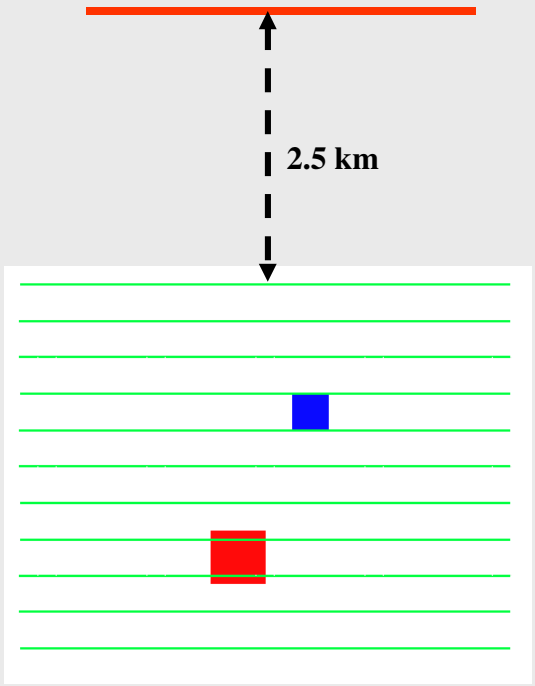
σ_i is the standard deviation of the *i*-th datum

μ is a regularization parameter

ϕ_m measures the smoothness of the resistivity distribution



First synthetic example -Survey configuration

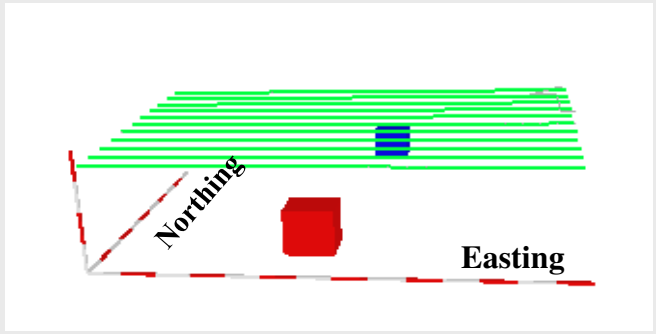


Survey area: 1350 x 1000 m, 11 lines, 308 stations

Station separation: 50 m

Line spacing: 100 m

Transmitter is 2.5 km from the survey area and has a length of 1 km



model properties:

Body 1

Dimension: cube of side 150 m

Depth to top: 200 m

resistivity : 2 Ωm

Body 2

Dimension: cube of side 100 m

Depth to top: 50 m

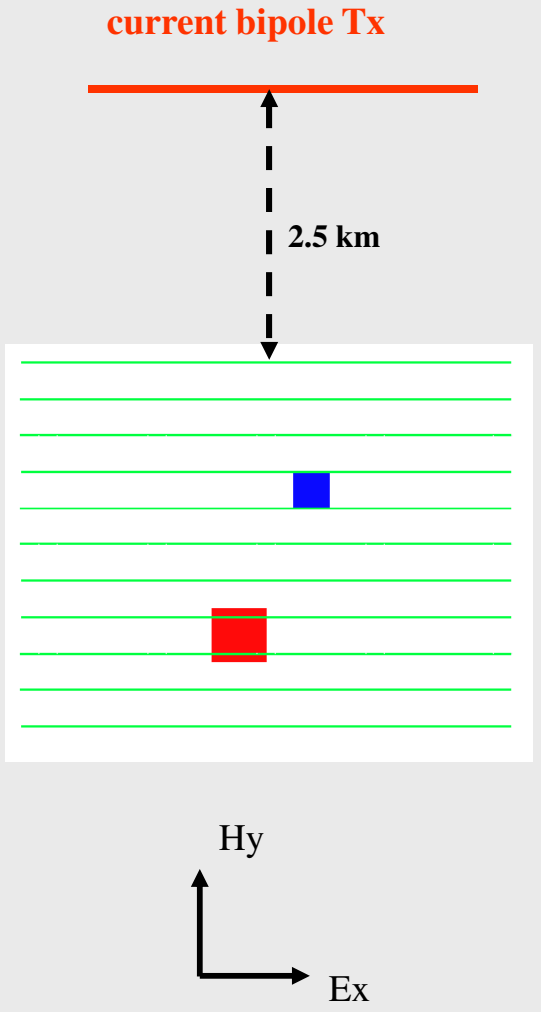
resistivity : 1000 Ωm

Background layered earth model: uniform 100 Ωm

Synthetic data generation

- Simulated Ex and Hy
- 3 frequencies (Hz): 16, 64, 512
- Ex: simulated with voltage bipole of length 50 m
- The simulated data were added noise of 2% of the datum magnitude

Computed impedance: $Z_{xy} = E_x / H_y$



Inversion setting

-regular grid

3D inversion region: 1600 x 1300 x 600 m

Grid cell size: 50 x 50 x 50 m

Grid cell number: 32 x 26 x 12

Starting model: uniform half-space of 100 Ωm

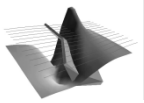
Constraints: $1 \leq \rho_i \leq 100$ Ωm

3 Frequencies used (Hz): 16, 64, 512

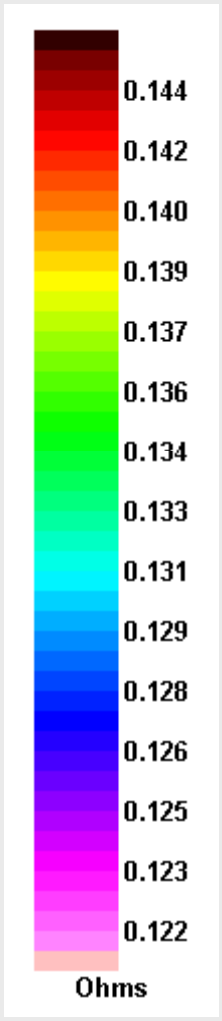
smoothing coefficients:

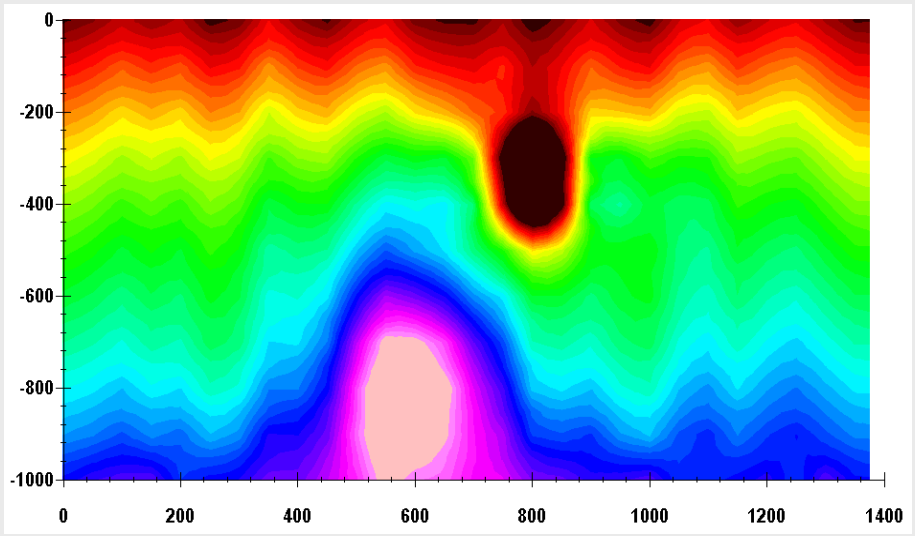
EW: 3, NS: 3, Vertical: 8

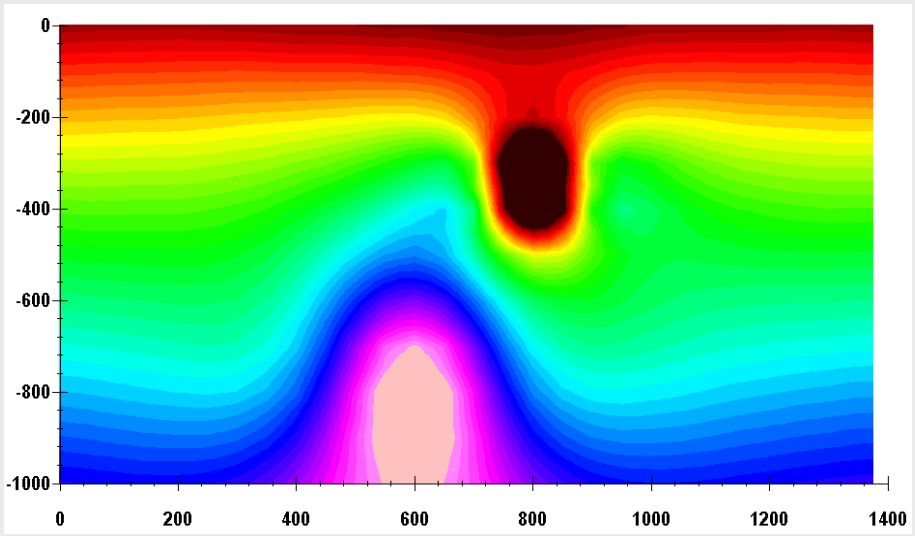
Inversion on apparent resistivity and phase



Gridded predicted data VS “true” data







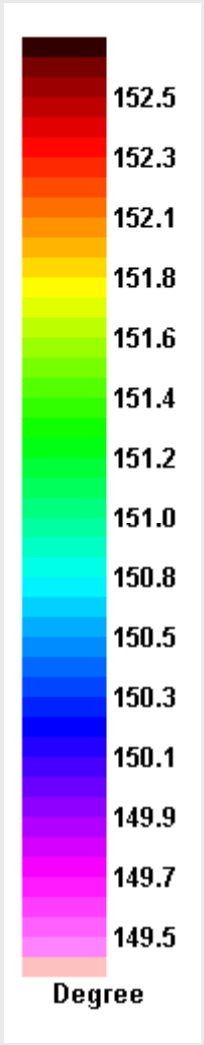
”*true*” data

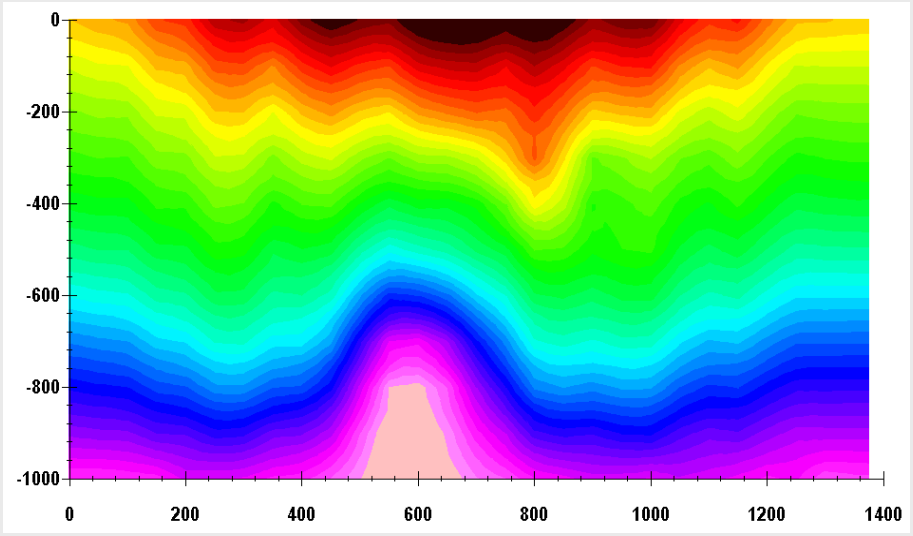
16 Hz data

Apparent resistivity

predicted data

Gridded predicted data VS “true” data

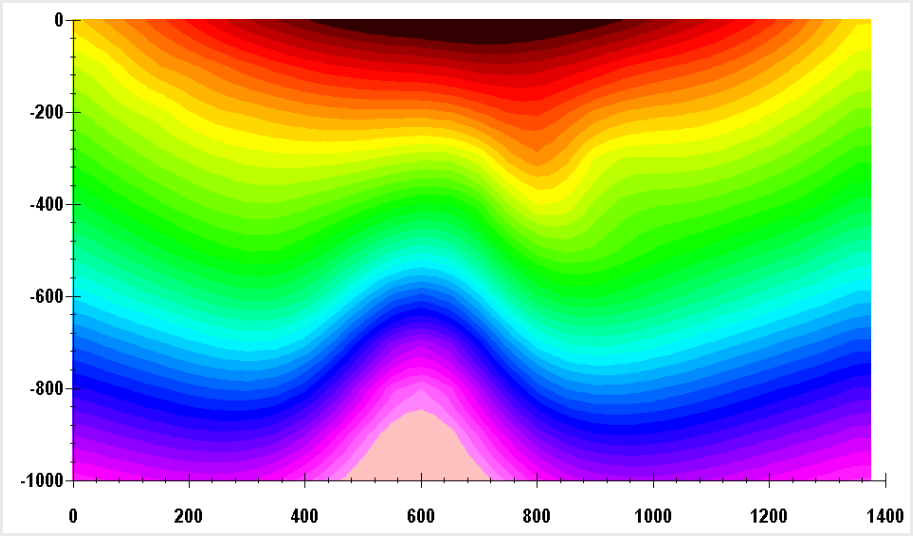




”*true*” data

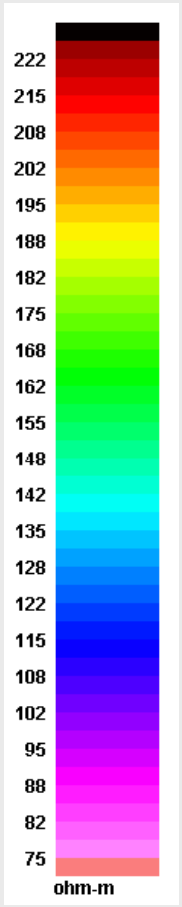
16 Hz data

phase

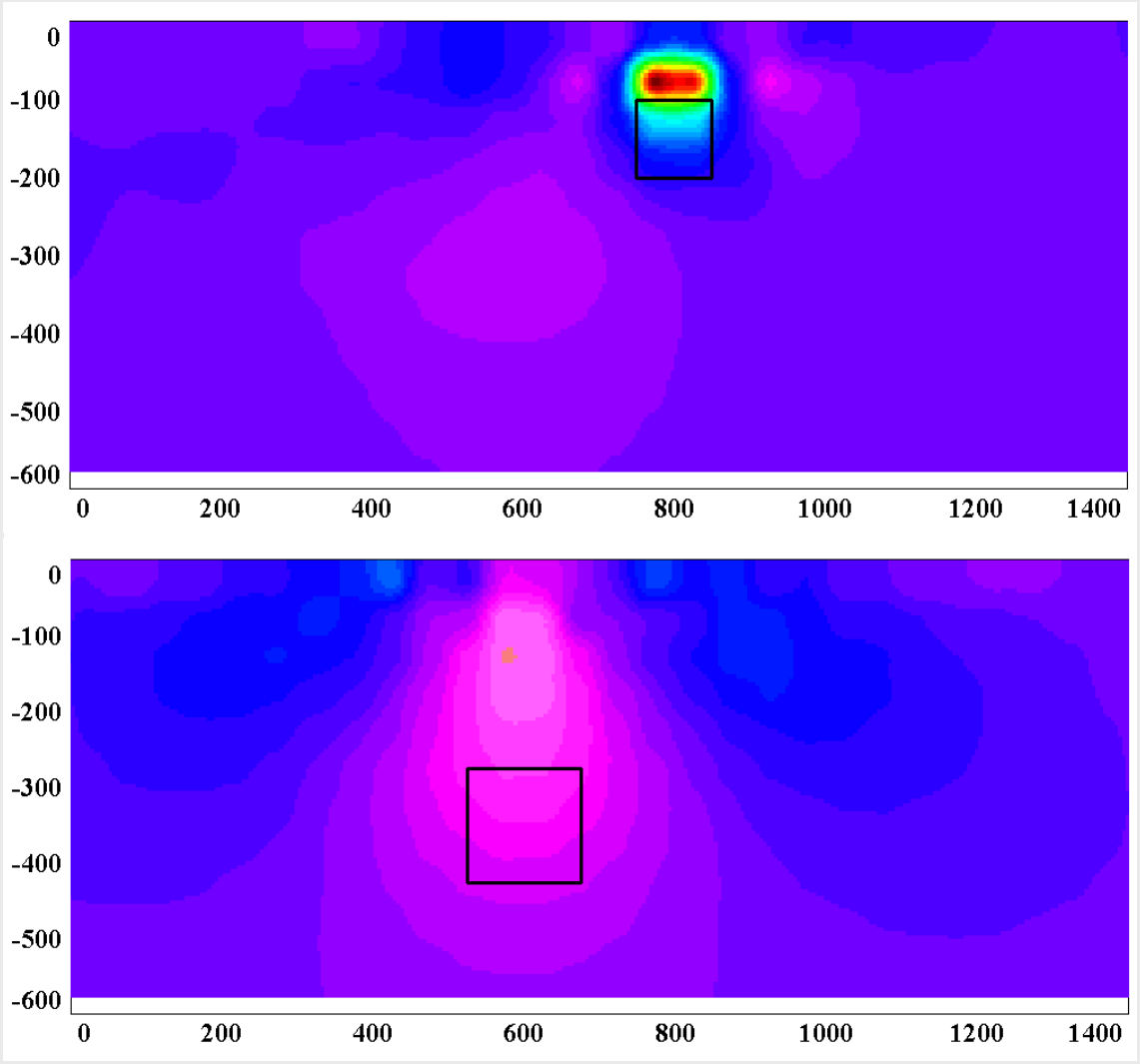


predicted data

Recovered model



Z(m)



slice at

y=-350

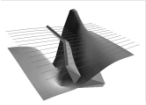
through the
center of Body 2

slice at

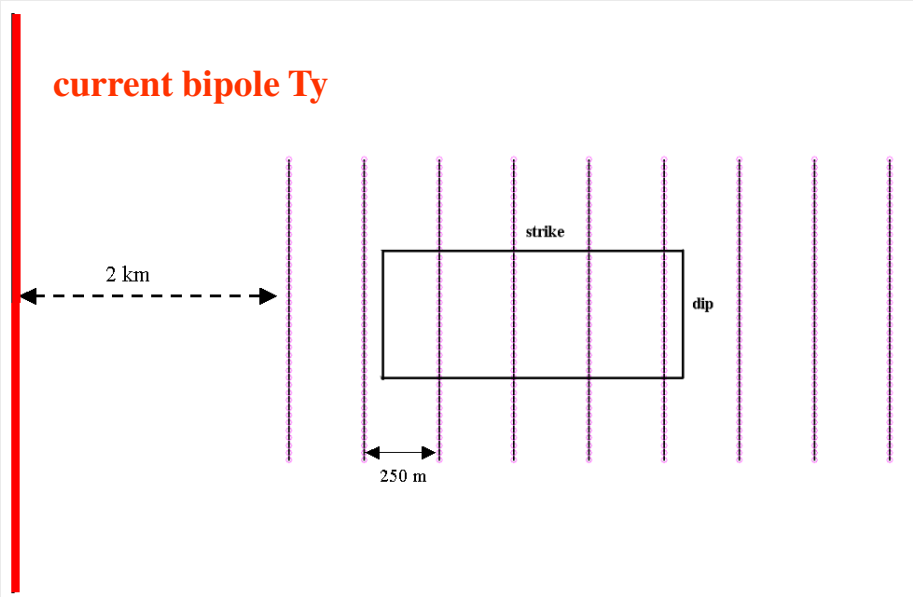
y=-750

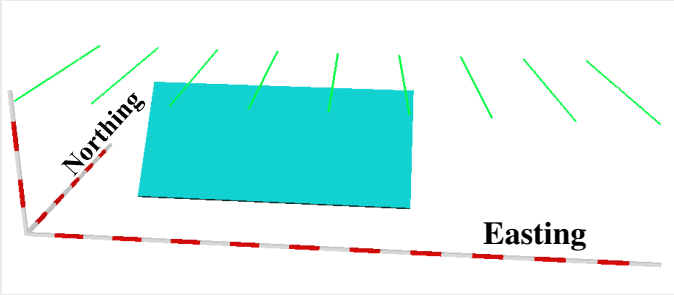
through the
center of Body 1

Easting (m)



Survey configuration





Survey area: 2000 x 1000 m, 9 lines, 369 stations

Station separation: 25 m

Line spacing: 250m

Transmitter is 2km from the survey area and has a length of 2km

Background layered earth model:

uniform 1000 Ωm

model properties:

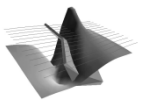
slab-type anomaly: 1000 x 500 x 10 m,

Dipping: 45 degrees

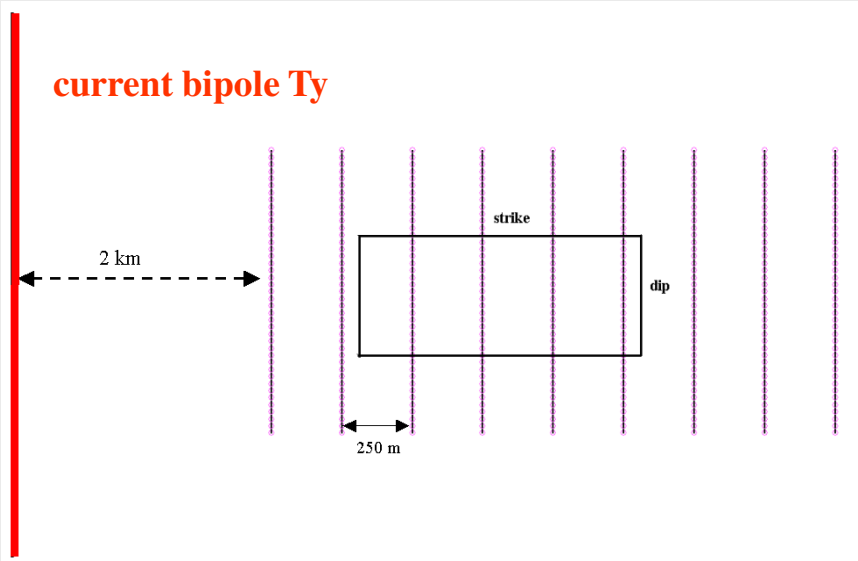
Striking: east-west

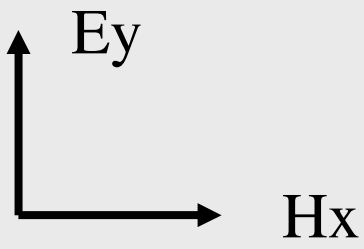
Depth to top: 75 m

resistivity : 10 Ωm



Synthetic data generation





- Simulated Ey and Hx
- 9 frequencies (Hz): 1, 10, 60, 100, 600, 1k, 3k, 6k, 10k
- Ey: simulated with voltage bipole of length 50 m
- The simulated data were added noise of 3% of the datum magnitude

Computed impedance: $Z_{yx} = E_y / H_x$

Inversion setting

-regular grid

3D inversion region: 2200 x 1100 x 600 m

Grid cell size: 125 x 25 x 50 m

Grid cell number: 18 x 44 x 12

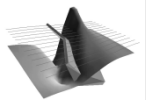
Starting model: uniform half-space of 1000 Ωm

Constraints: $1 \leq \rho_i \leq 1000$ Ωm

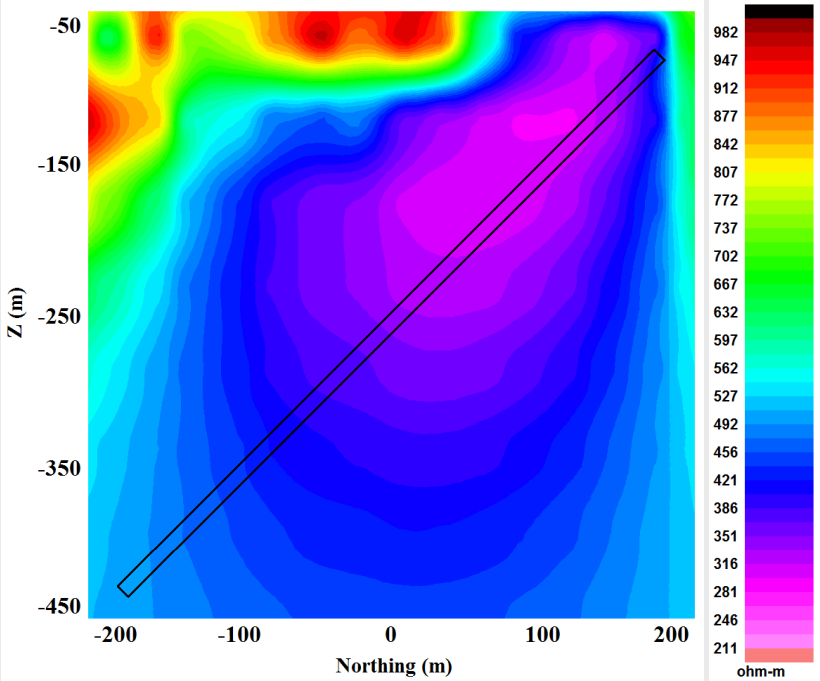
9 Frequencies used (Hz): 1, 10, 60, 100, 600, 1k, 3k, 6k, 10k

smoothing coefficients:

EW: 3, NS: 0.1, Vertical: 8



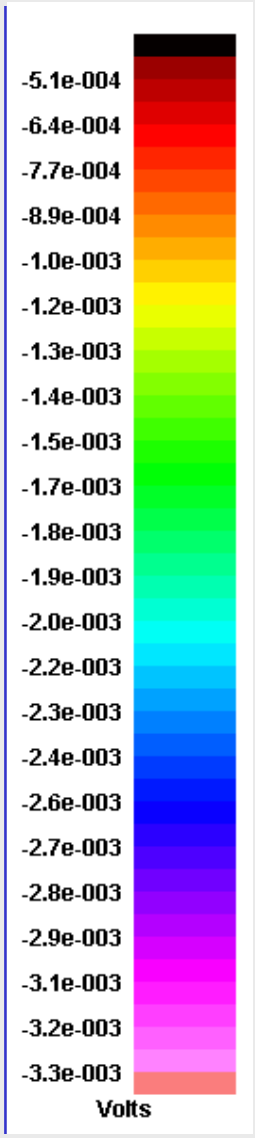
Recovered model – electric field inversion

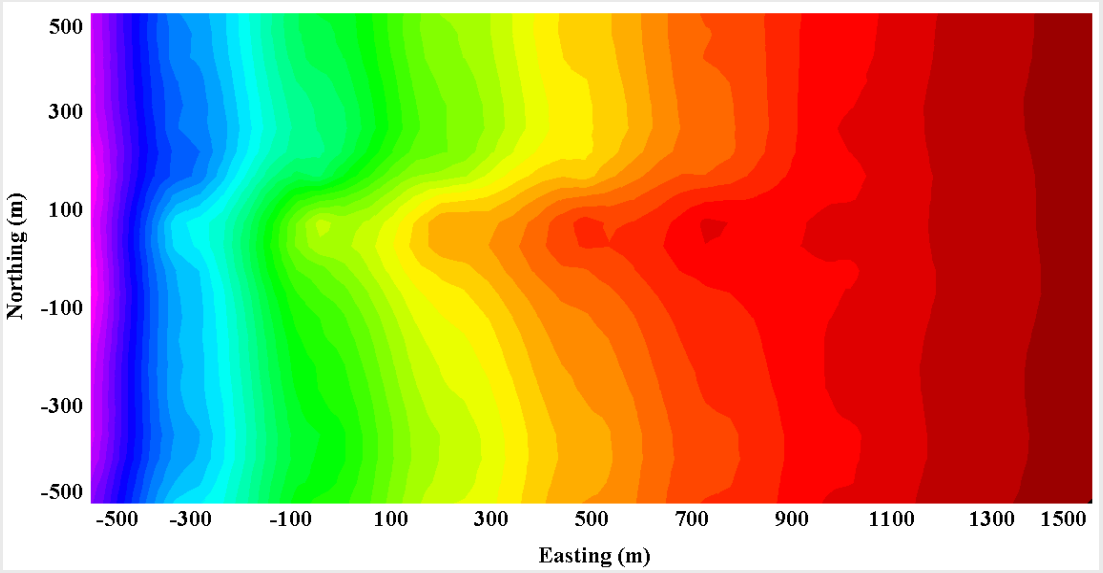


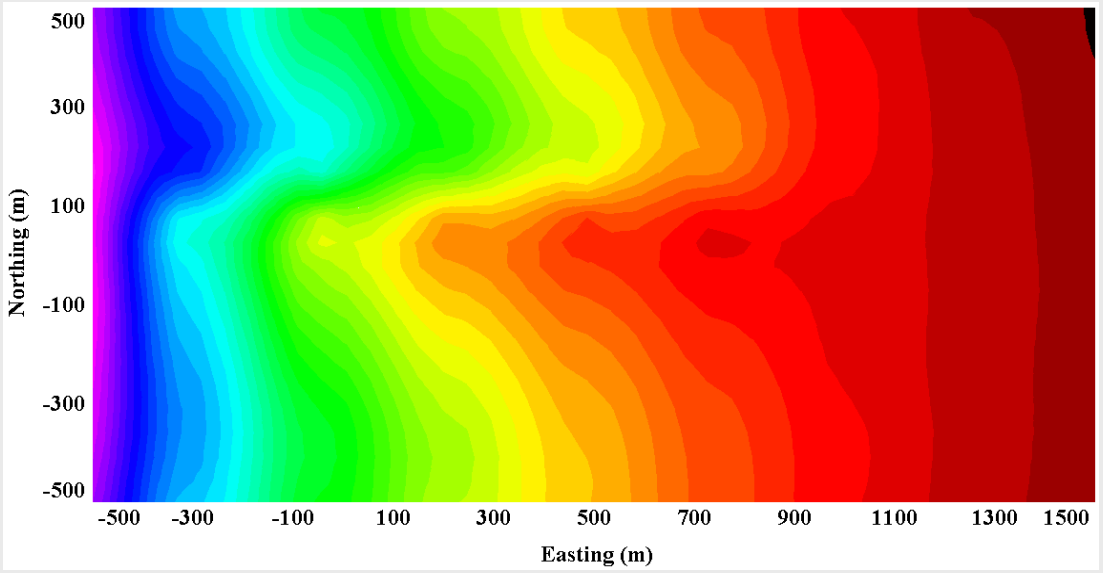
vertical slice of the inverted model through the center of the true model (at x= -50)

The conductive features in the inverted resistivity distribution models outline a dipping structure, although becoming smooth and broad at greater depths.

Gridded predicted data VS “true” data







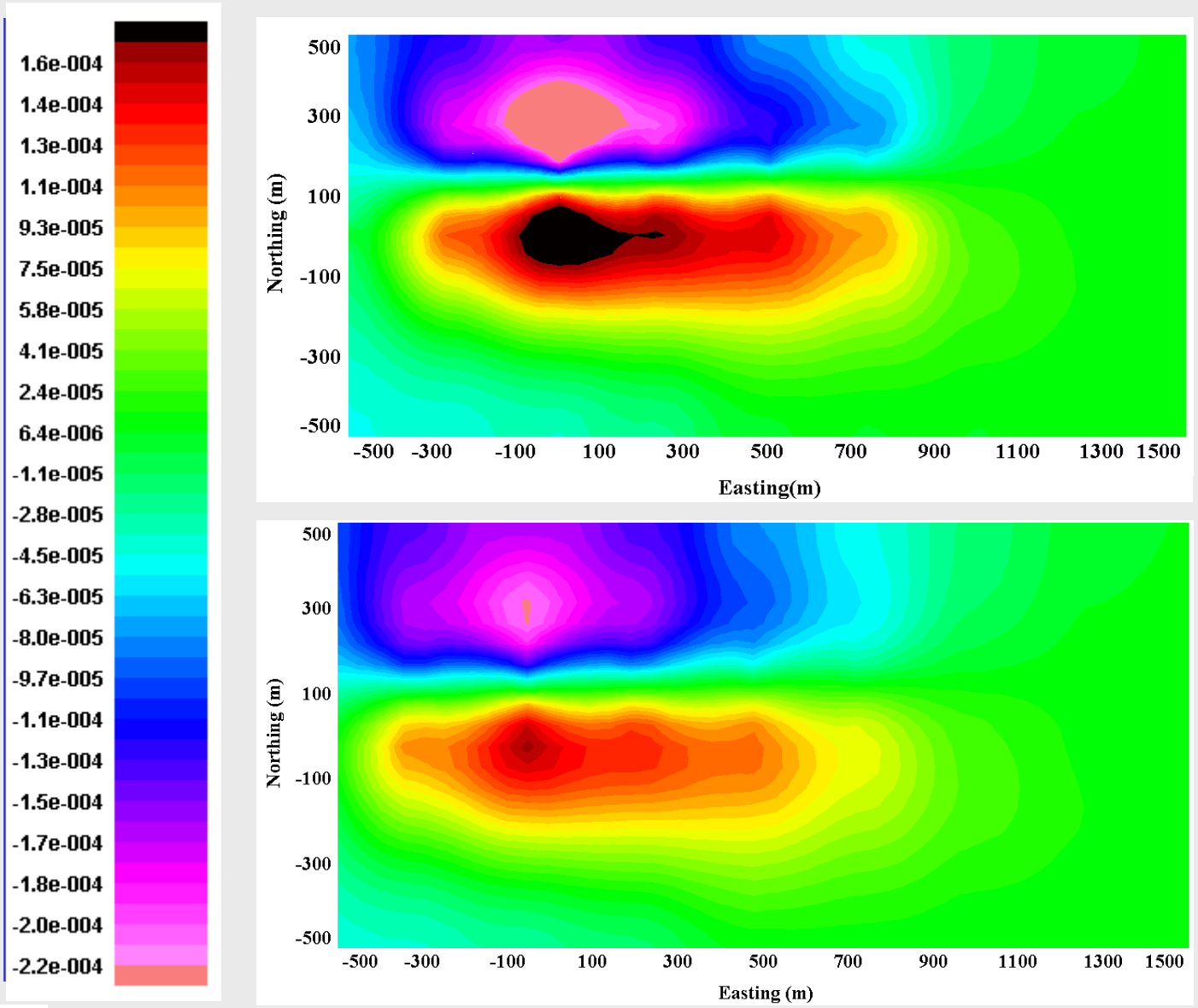
”*true*” data

1 kHz data

real part

predicted data

Gridded predicted data VS “true” data



”*true*” data

1 kHz data

Imaginary part

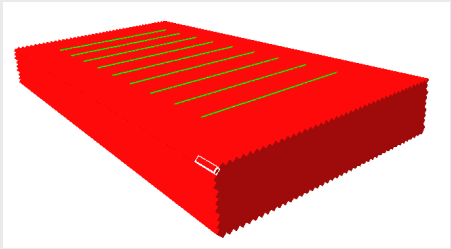
predicted data

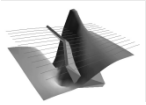
Incorporating known strike and dip into inversion

- Assume that the strike and dip of linear structures are known.
- Build a 3D mesh model according to the strike and dip
- grid cells are oriented along known strike and dip directions
- Find the resistivity distribution of the 3D mesh model.

The advantages of utilizing dipping grid cells:

- Make it easy to impose smoothing constraints along the known strike and dip direction.
- It can also improve the recovered model resolution as a dipping linear structure can be better represented with the grid cells of the same orientation.





Dipping grid inversion setting

- 3D inversion region: 2200 x 1100 x 600 m
- Each cell strikes EW and dips 45^{o} to the south
- Grid cell size: strike length of 125 m, an extent down dip 50 m, thickness 25 m
- Grid cell number: 18 x 44 x 17

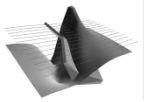
Starting model: uniform half-space of 1000 Ωm

Constraints: $1 \leq \rho_i \leq 1000$ Ωm

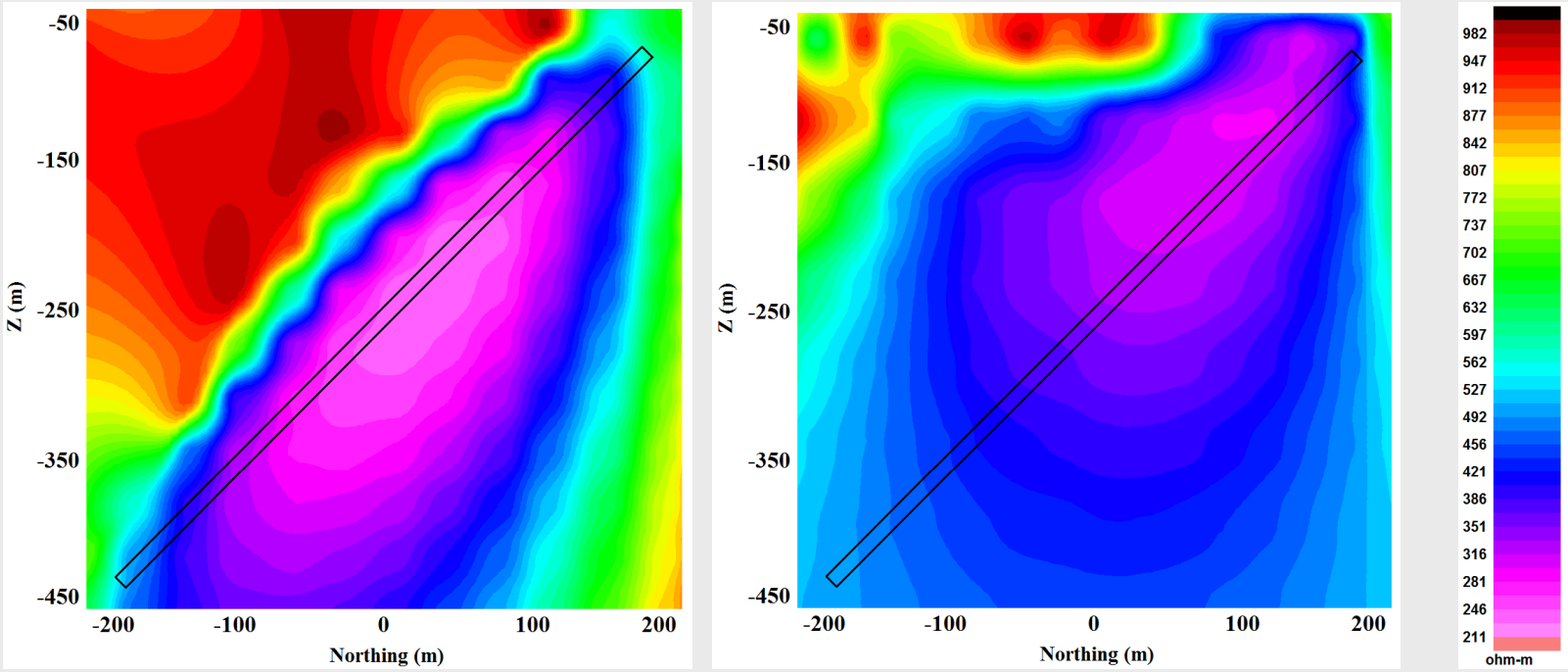
9 Frequencies used (Hz): 1, 10, 60, 100, 600, 1k, 3k, 6k, 10k

smoothing coefficients:

3 in Strike (EW), 0.1 NS, 8 in dip direction



Recovered model
from dipping grid inversion

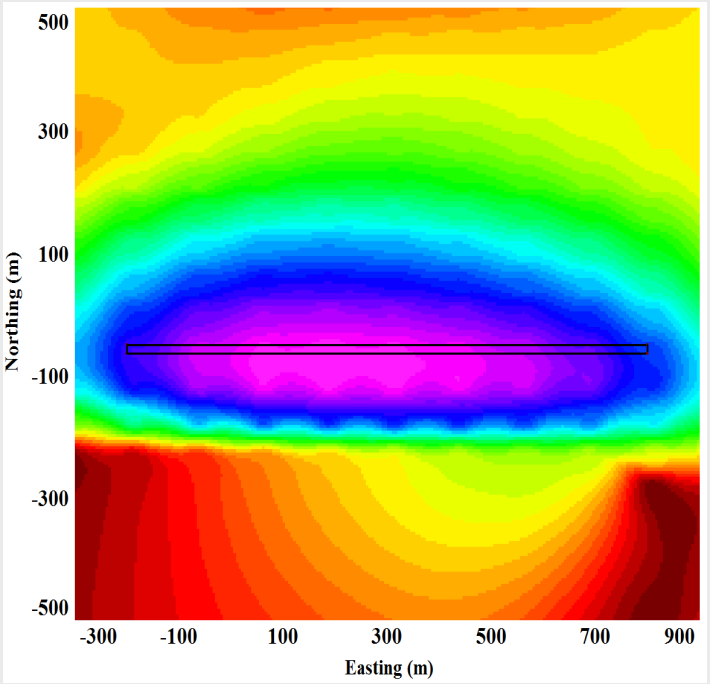


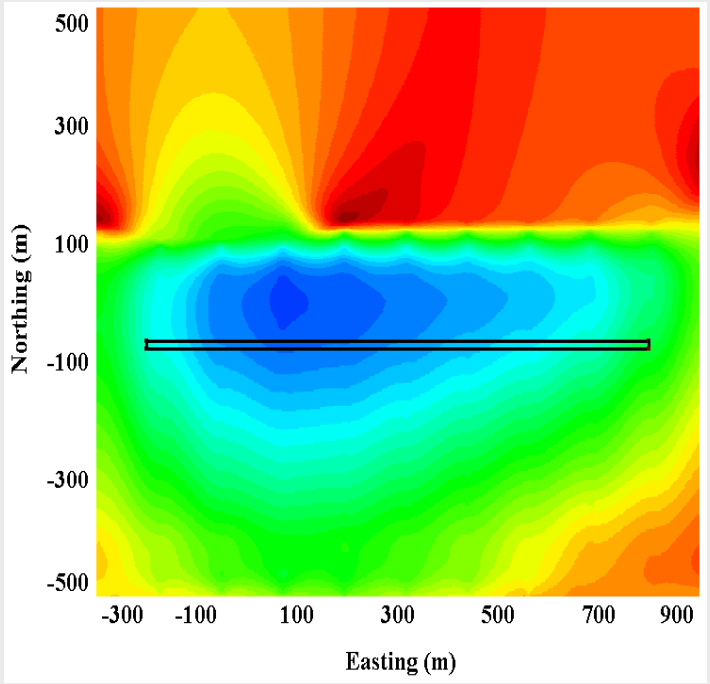
vertical slice of the inverted model through the center of the true model (at x= -50)

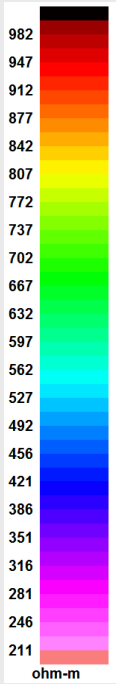
the inverted model with a dipping grid demonstrates a better recovery of the structure with higher resolution, particularly at depth

Recovered model

slice at depth 300 m



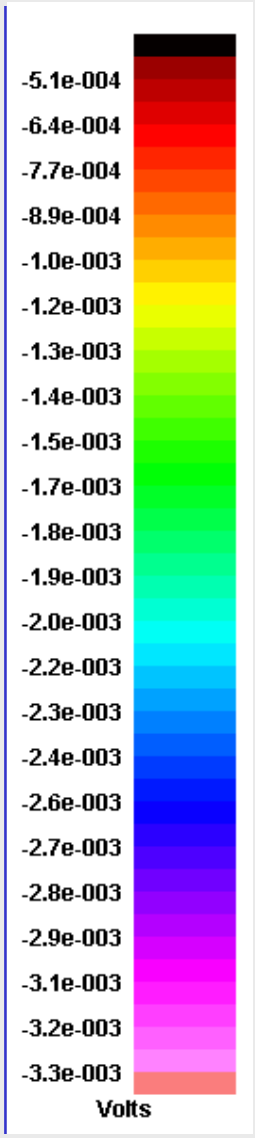


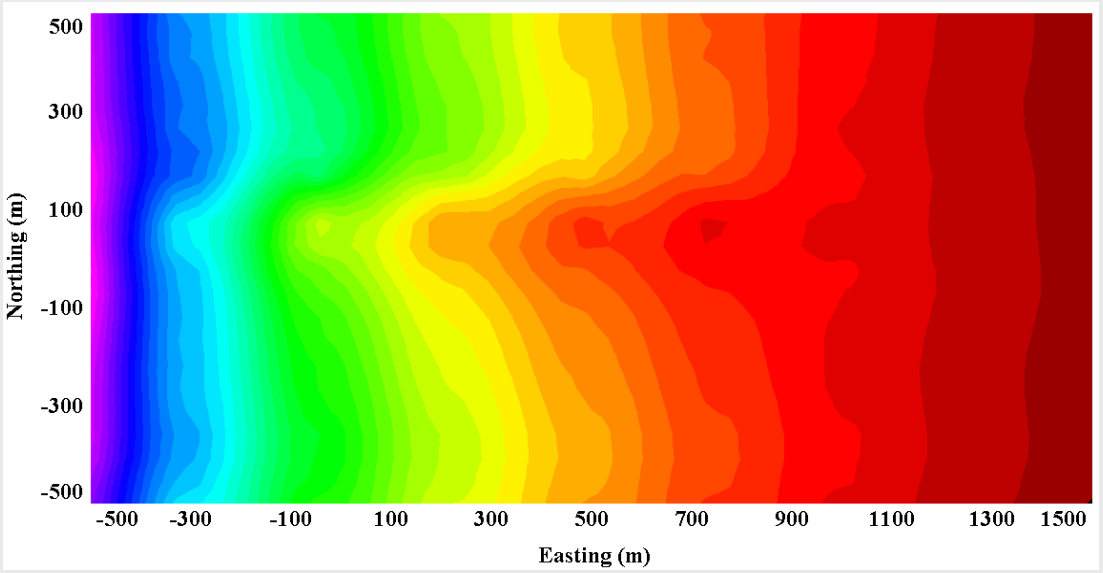


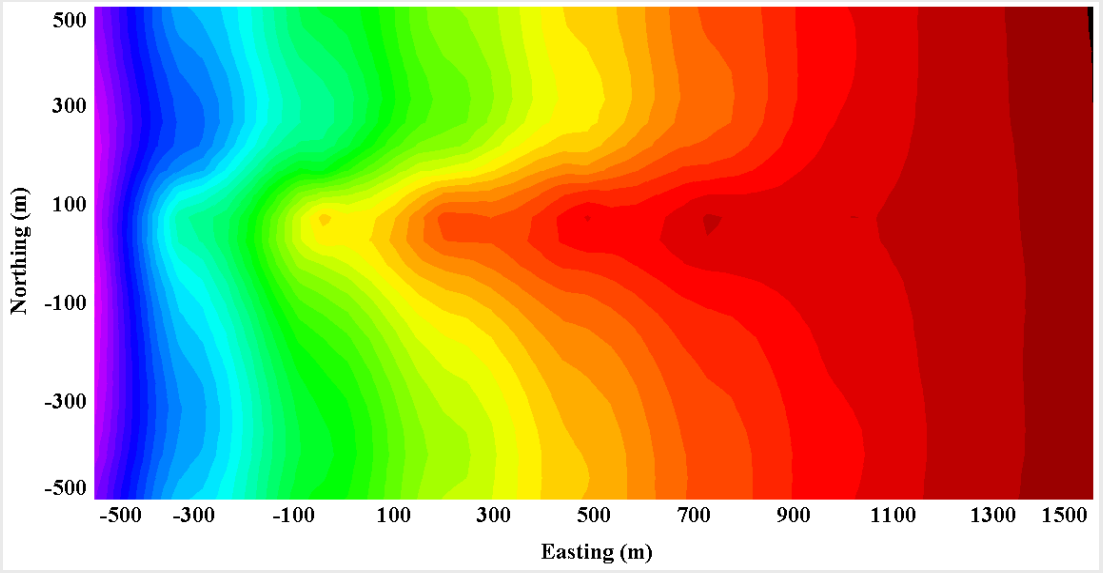
slice at depth 300 m

the inverted model with a dipping grid demonstrates a better recovery of the structure with higher resolution

Gridded predicted data VS “true” data







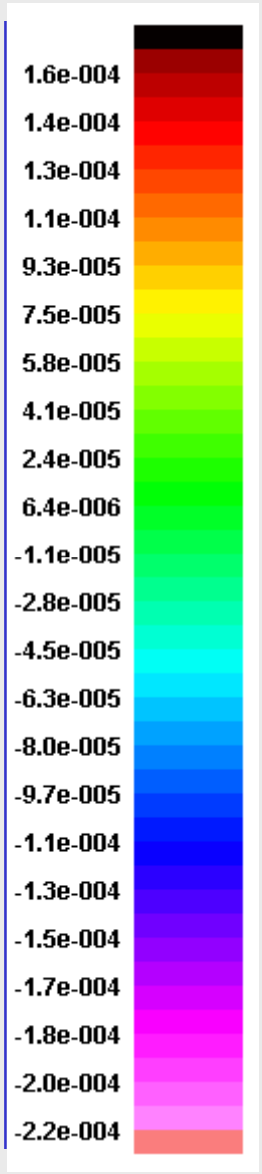
”*true*” data

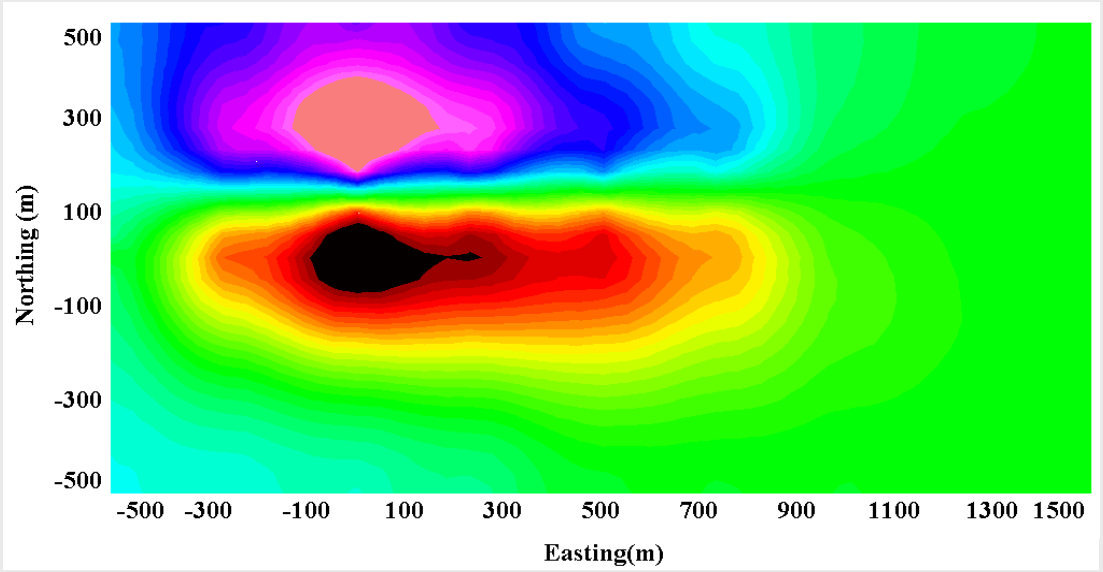
1 kHz data

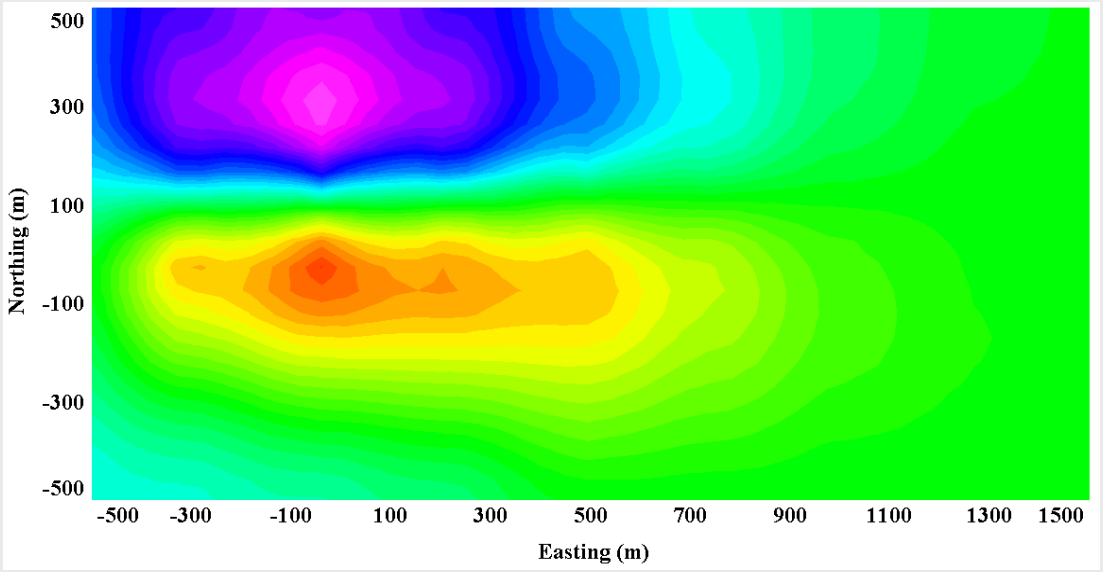
real part

predicted data

Gridded predicted data VS “true” data







”*true*” data

1 kHz data

Imaginary part

predicted data

Real data example

Current bipole

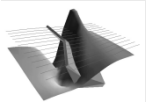
Transmitter is 8 km north and 500 m east of survey area and has a length of 1.2 km

Survey: 1 line of length 1.6 km

Station separation: 50 m

34 stations

- Ex and Hy
- 14 frequencies (Hz): 1, 4, 8 16, 64, …, 8192
- Ex: voltage bipole of length 50 m



Inversion setting

-regular grid

3D inversion region: 1600 x 800 x 1000 m

Grid cell size: 25 x 800 x 50 m

Grid cell number: 64 x 1 x 20

Each cell Sampled 8 in y direction

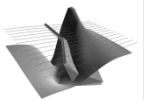
Starting model: uniform half-space of 50 Ωm

Constraints: $1 \leq \rho_i \leq 2000$ Ωm

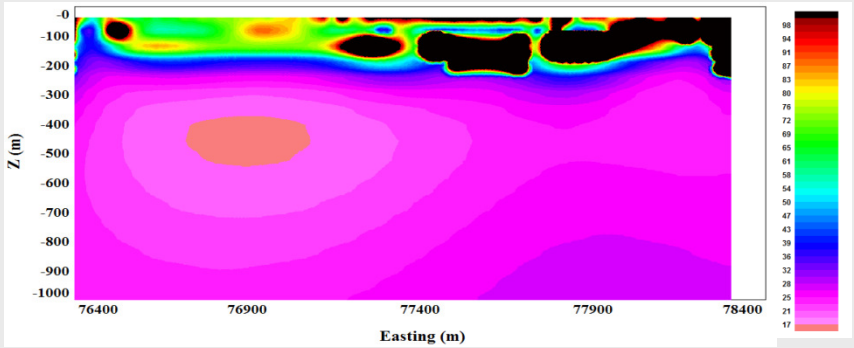
11 Frequencies used (Hz): from 8 to 128 Hz

smoothing coefficients:

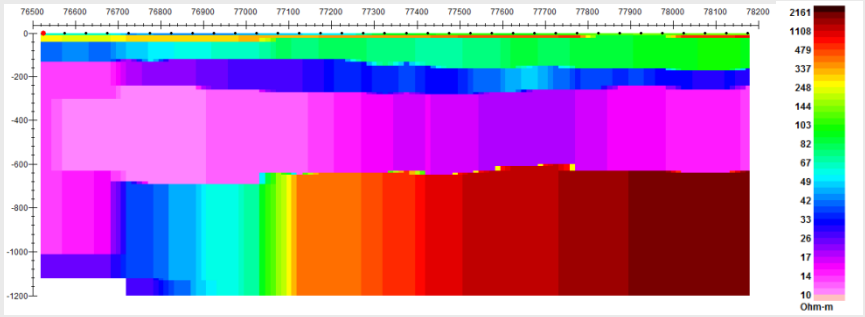
EW: 3, Vertical: 8



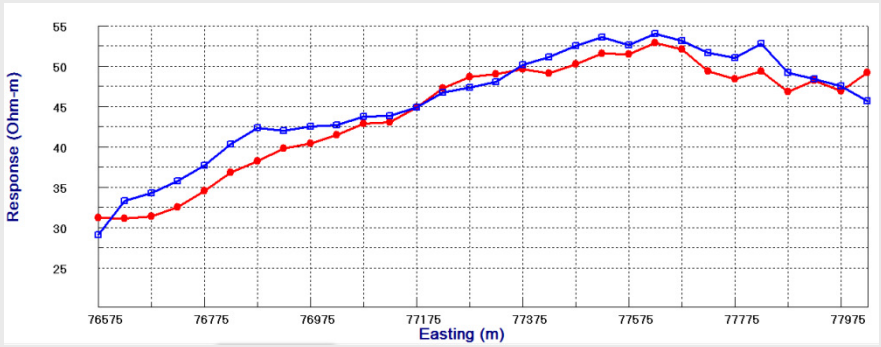
Inversion results – on apparent resistivity



3d inversion model



1d inversion model



64 Hz apparent resistivity
Red: observed data
Blue: recovered data

Conclusions and Future Work

- the resolution of the inversion can be dramatically improved by utilizing dipping and striking grid cells with the known orientation.
  - The resolution of the inverted results in the strike and dip directions can be easily controlled by the smoothing constraints in a model objective function.
  - the structure can be better represented with grid cells of the same orientation.
- The use of individual fields or the combined impedance ration provides more flexibility in structural determination as well as dealing with bad data.

Future work

•To incorporate different strike and dip angles in regions of subsurface, we may divide the 3D inversion volume into sub-regions, each of which has its own strike and dip angle.