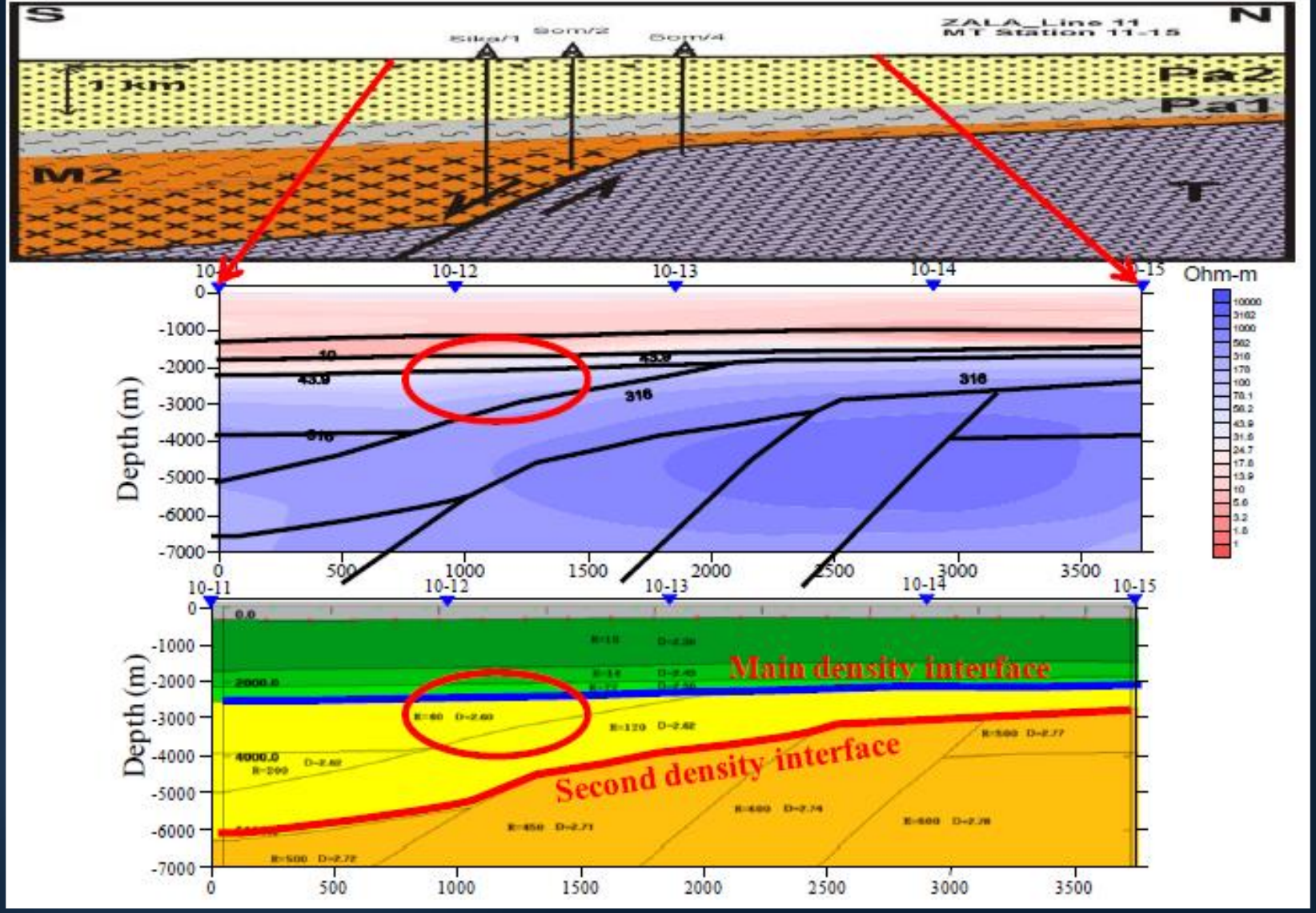
Magnetotellurikus mélyszerkezet kutatás egy kanadai és egy magyarországi példán keresztül

NÁDASI ENDRE

2019. Szeptember 5.
Eötvös Loránd Szakmai Öröksége a Miskolci Egyetemen c. előadói nap



Kurt Martin Strack, Norman C. Allegar, Gang Yu, Helga Tulinius, László Ádám, Adrian Gunnarsson, Ling Feng He, Zhi El Segundo He: **Exploring for geothermal reservoirs using broadband 2-D MT and gravity in Hungary.** SEG Technical Program Extended Abstracts 27(1) · June 2008

Outline

- Introduction
- Theoretical background
- Case study 1(Western Superior Region, Canada)

Geological setting, Station map, Data analysis, Anisotropy study, Inversion results, Comparison, Conclusion

- Case study 2 (Irota, Cserehát, North Eastern Hungary)

Geological setting, Station map, Data cleaning, Inversion results, Conclusion

Theoretical background

- MT Forward modeling problem
- $d = \begin{bmatrix} cZ^{reg} \\ W \end{bmatrix} = A(\sigma)$
- $Z = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix}$
- $W = \begin{bmatrix} W_{zx} \\ W_{zy} \end{bmatrix}$
- $E = E^b + E^a$
- $H = H^b + H^a$
- $E^a(r_j) = G_E[\Delta\sigma(r)E] = \iiint_D \hat{G}_E(r_j|r)\Delta\sigma(r)\left(E^b(r) + E^a(r)\right)dv$
- $H^a(r_j) = G_H[\Delta\sigma(r)E] = \iiint_D \hat{G}_H(r_j|r)\Delta\sigma(r)\left(E^b(r) + E^a(r)\right)dv$

Theoretical background 2

- Tikhonov regularization
- Regularized Gauss-Newton (RGN) method
- $P(\sigma, c) = \|W_d(cA(\sigma) - d)\|^2 + \alpha\|S\|^2 \rightarrow min$
- $S = \begin{bmatrix} S_\sigma \\ S_c \end{bmatrix} = \begin{bmatrix} D(\sigma - \sigma_0) \\ c - c_0 \end{bmatrix}$
  - d – vector of data
  - A – forward modeling operator based on integral equations
  - W_d – diagonal matrix of data weights, based on data variance
  - α – regularization parameter
  - σ_0 - vector of a reference conductivity model
  - c_0 – 2 x 2 identity matrix, corresponding to no distortion case
  - D – matrix of the finite difference first derivative operator

Theoretical background 3

- The GN method converges much faster than the steepest descent or even the conjugate gradient methods, but each iteration requires more computations (inversion of large Hessian matrix)
- The data-space implementation of the method needs the inversion of a much smaller matrix, than the model space GN method

$$\Delta m_k = -(H^\alpha)^{-1} l^\alpha(m_k)$$

$$H^\alpha = F_w^* F_w + \alpha C_m$$

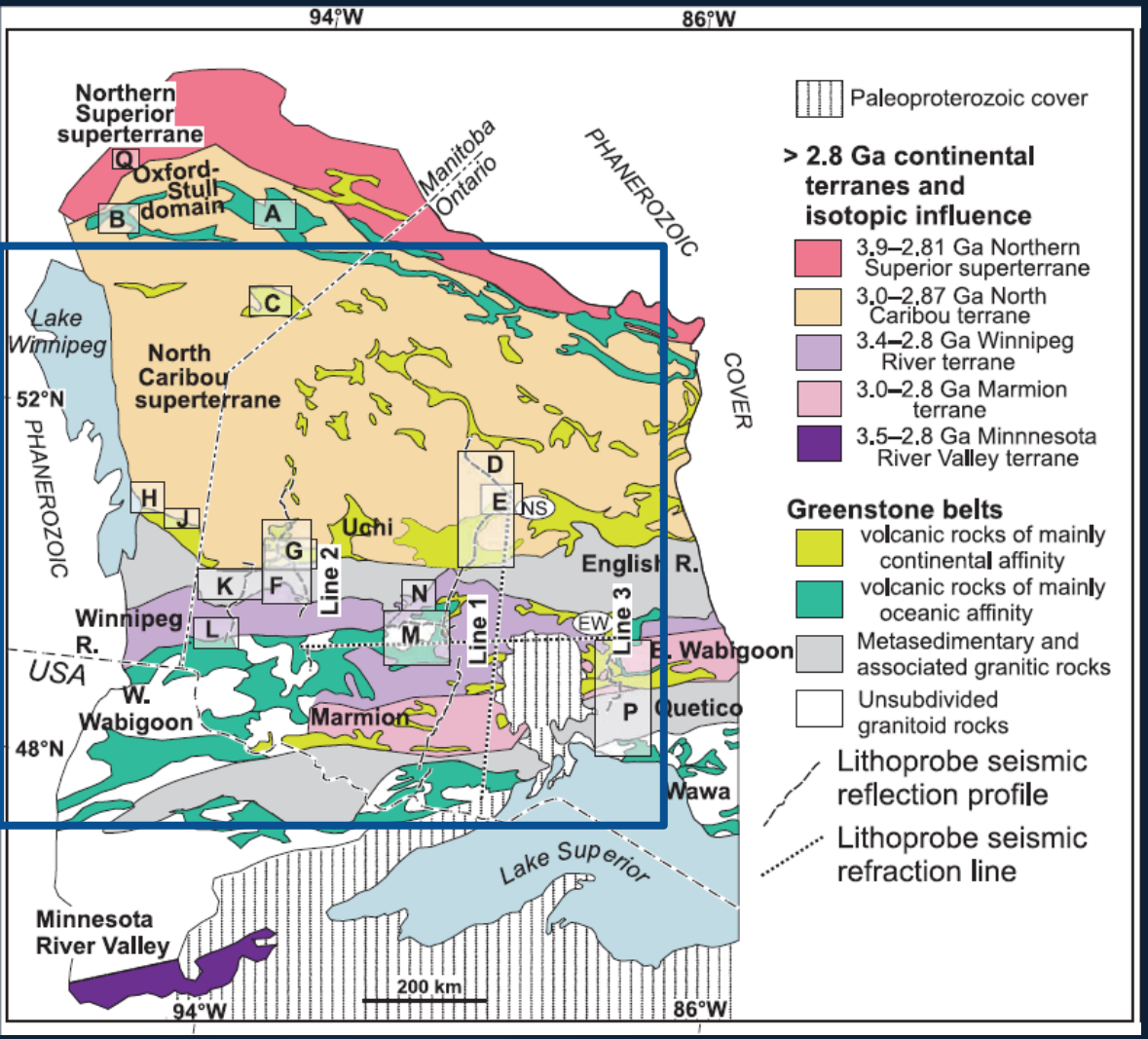
$$m_{k+1} = C_m^{-1} F_w^* (F_w C_m^{-1} F_w^* + \alpha I)^{-1} \left[F_w\left(m_k - m_{apr}\right) - r_w\right]$$

Case study 1
Western Superior Province, Canada

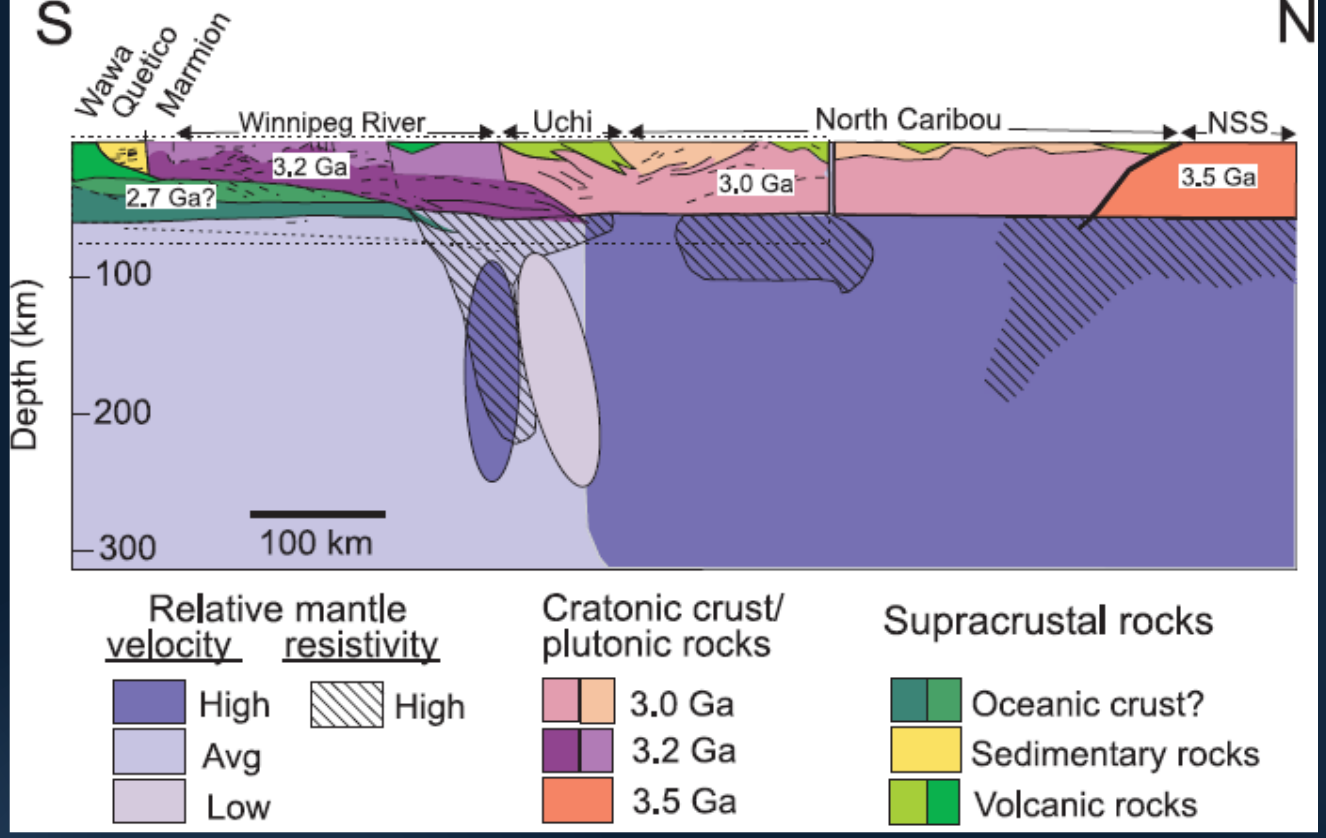
Introduction

- 3D MT inversion of a subset of Lithoprobe and EarthScope data
- Regularized Gauss-Newton method
- Data-space implementation
- MT impedace and tipper data
- Western Superior region
- Part of Canadian shield

Geological setting

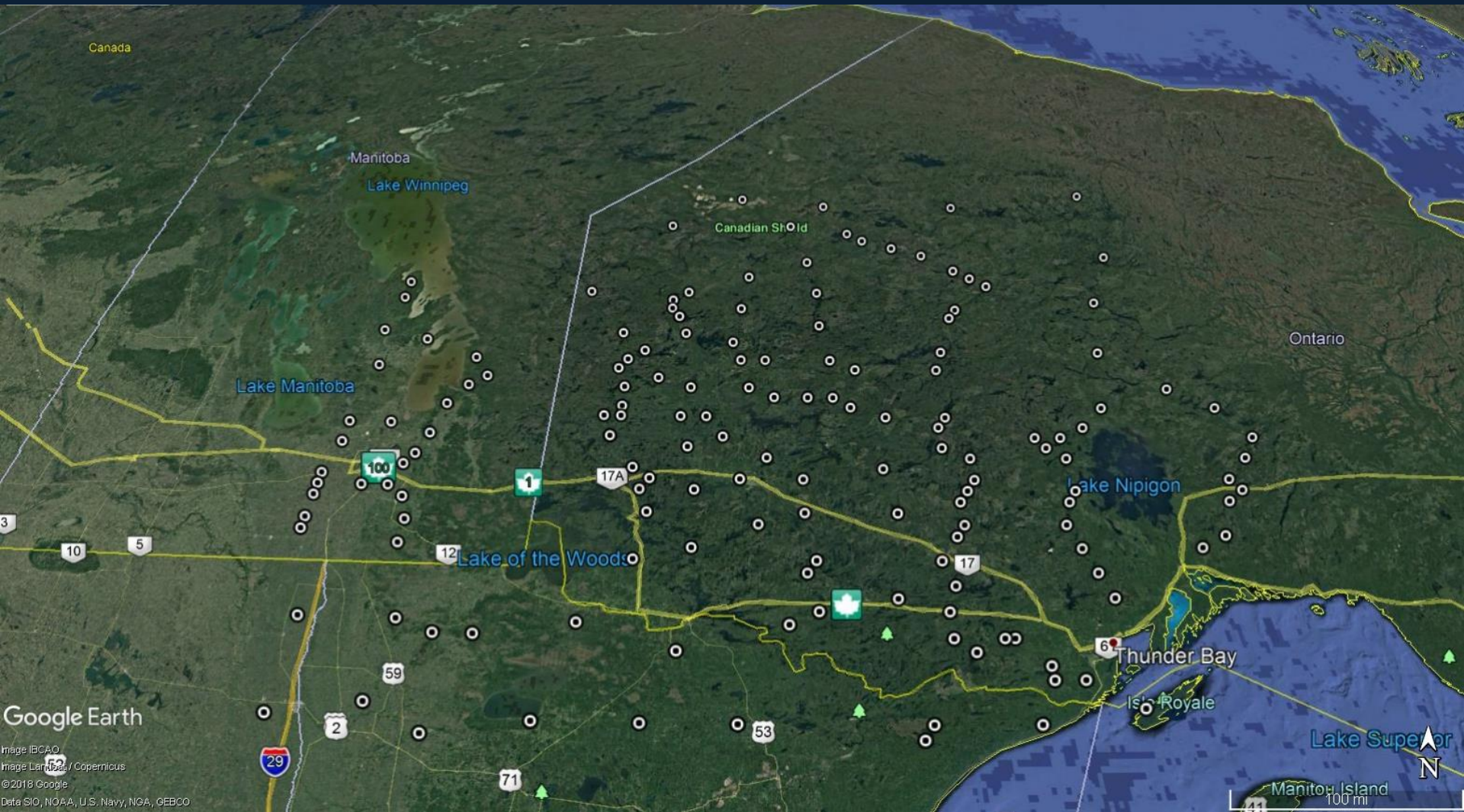


- Nucleus of the North American continent
- Largest Archaen craton of the Earth
- Rich gold and base metal depostis
- Orogenic processes, successive accretion of oceanic crust, island arcs, continental fragments (Percival et al, 2012)



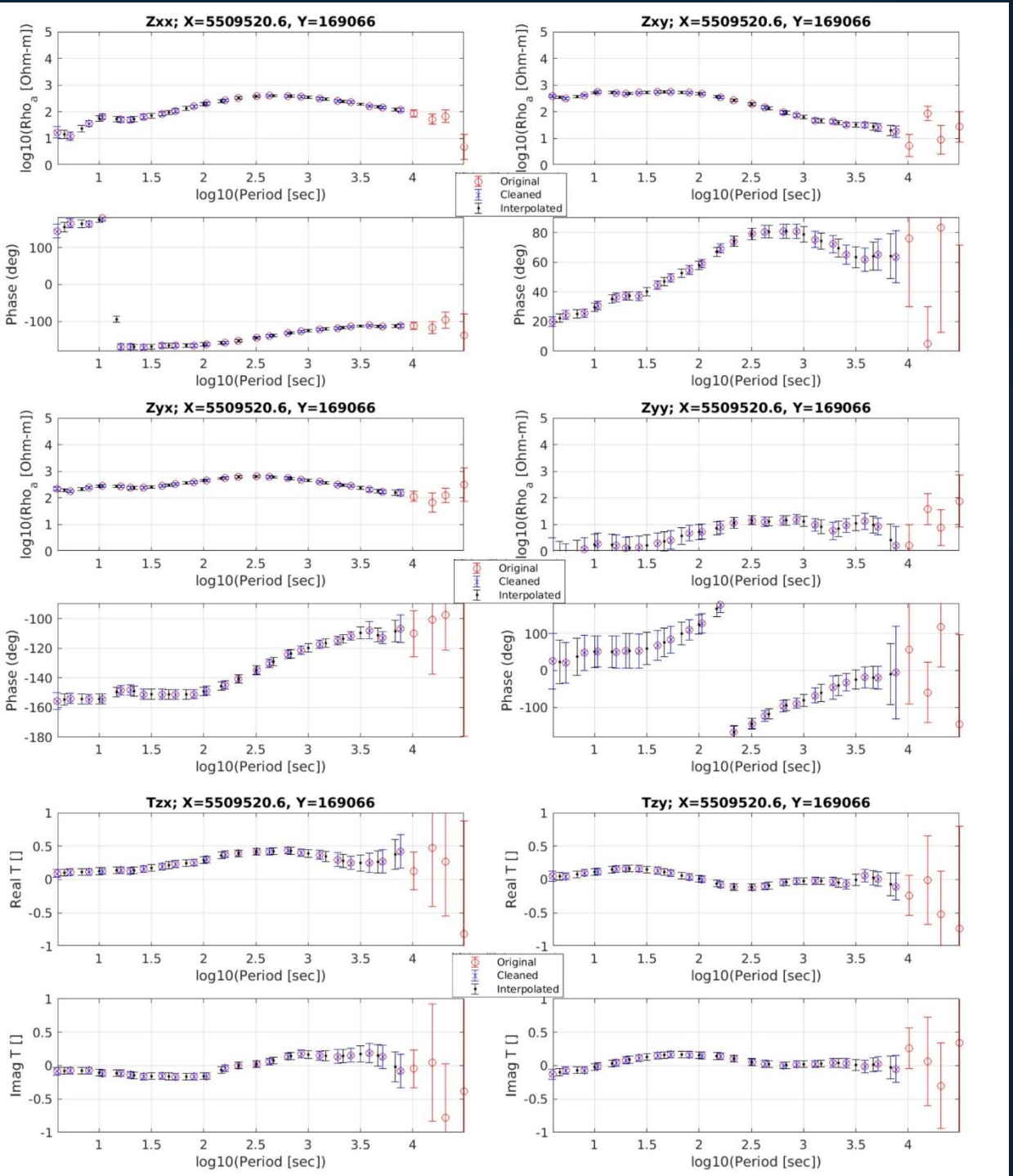
- 8% azimuthal Vp anisotropy in the lower crust; 6% in the upper mantle (Musacchio, 2004)
- North Caribou characterized by relatively high velocity (Kendall et al, 2002)
- Deep electrical anisotropy is present at the Canadian Precambrian Shield (Wannamaker, 2005)

Station map


Canada
Manitoba
Lake Winnipeg
Canadian Shield
Ontario
Lake Manitoba
Lake Nipigon
Lake of the Woods
Thunder Bay
Isle Royale
Lake Superior
Manitou Island
100 mi
N
Google Earth
Image IBCAO
Image Landsat / Copernicus
©2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Data preparation

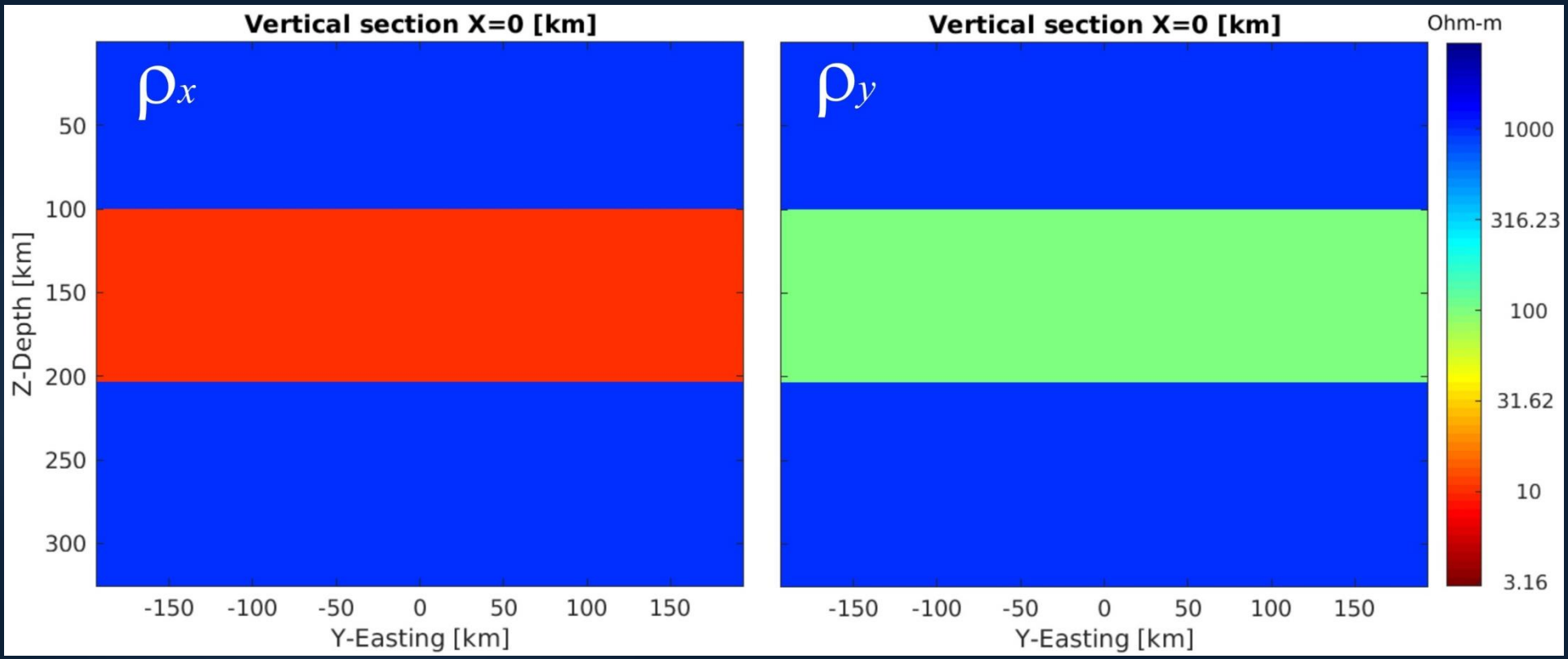
- Total of 180 MT stations downloaded from IRIS website
- Ontario, Manitoba (Canada); Minnesota, North Dakota (USA)
- Irregular spacing between stations
- 21 stations were rejected due to a proximity to another station or poor data quality
- 159 sites were utilized (Lithoprobe: 143, EarthScope: 16)
- With data cleaning, outliers were removed as well as points with large data errors
- Cleaned data were interpolated on a common set of peroids from 3.16 to 1,000 sec

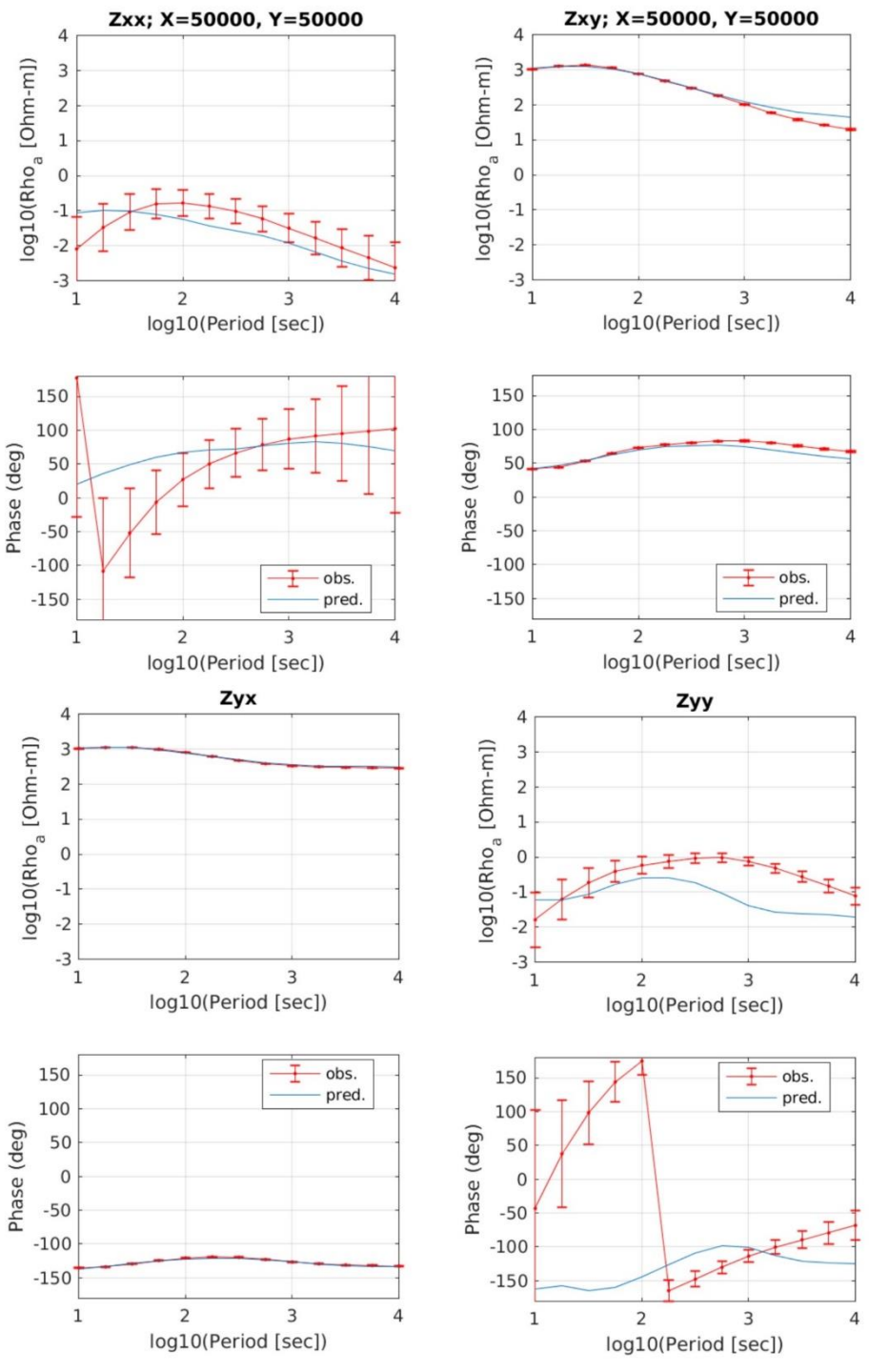

Zxx; X=5509520.6, Y=169066
Zxy; X=5509520.6, Y=169066
Zyx; X=5509520.6, Y=169066
Zyy; X=5509520.6, Y=169066
Tzx; X=5509520.6, Y=169066
Tzy; X=5509520.6, Y=169066
log10(Rho$_a$ [Ohm-m])
Phase (deg)
Real T []
Imag T []
log10(Period [sec])
Original
Cleaned
Interpolated

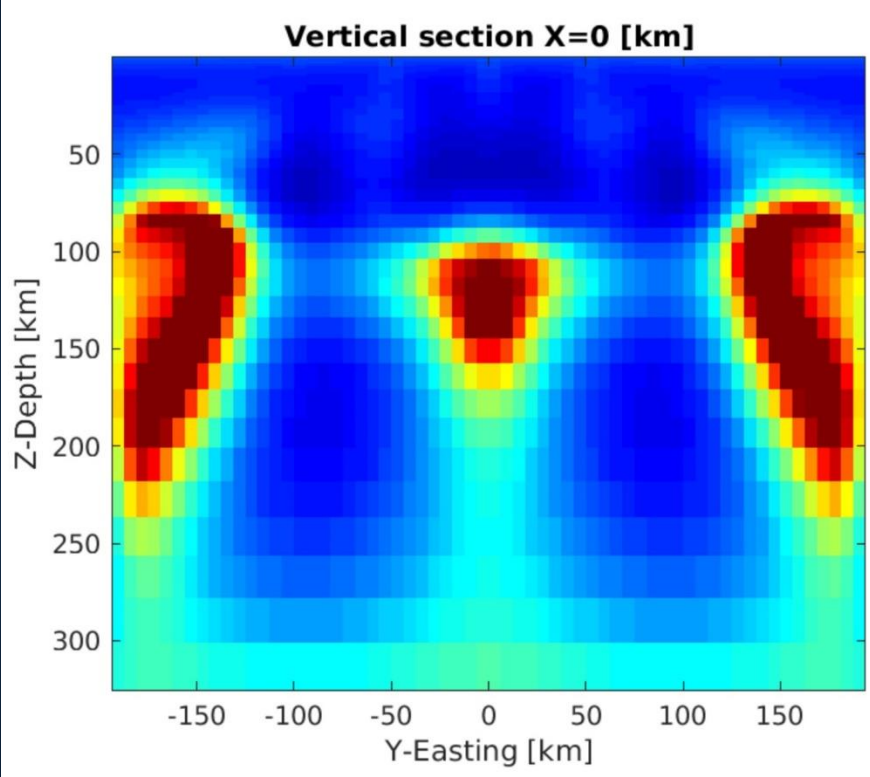
Anisotropy study

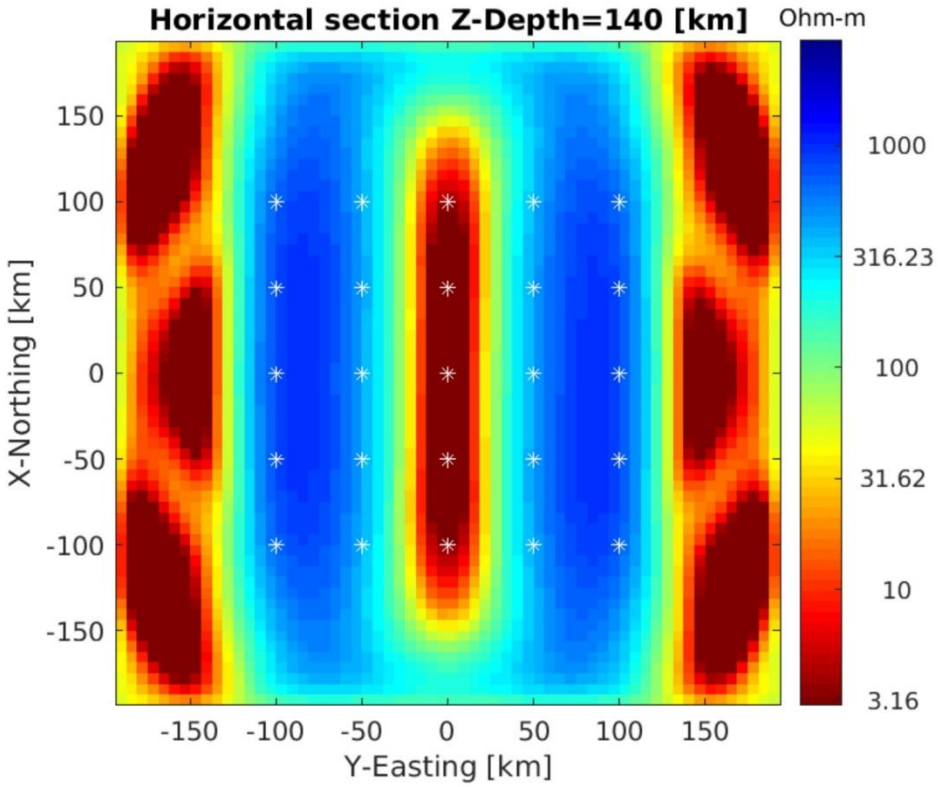
- Our inversion code is not capable of producing models with anisotropic conductivities.
- Several researchers noticed the presence of anisotropy in the upper mantle in the Western Superior Province
- Difference between X- and Y- directed resistivities would manifest itself in different values of the observed MT apparent resistivities and phases of different observed MT impedance components.

True anisotropic model




Zxx; X=50000, Y=50000
Zxy; X=50000, Y=50000
log10(Rho$_a$ [Ohm-m])
log10(Period [sec])
Phase (deg)
obs.
pred.
Zyx
Zyy

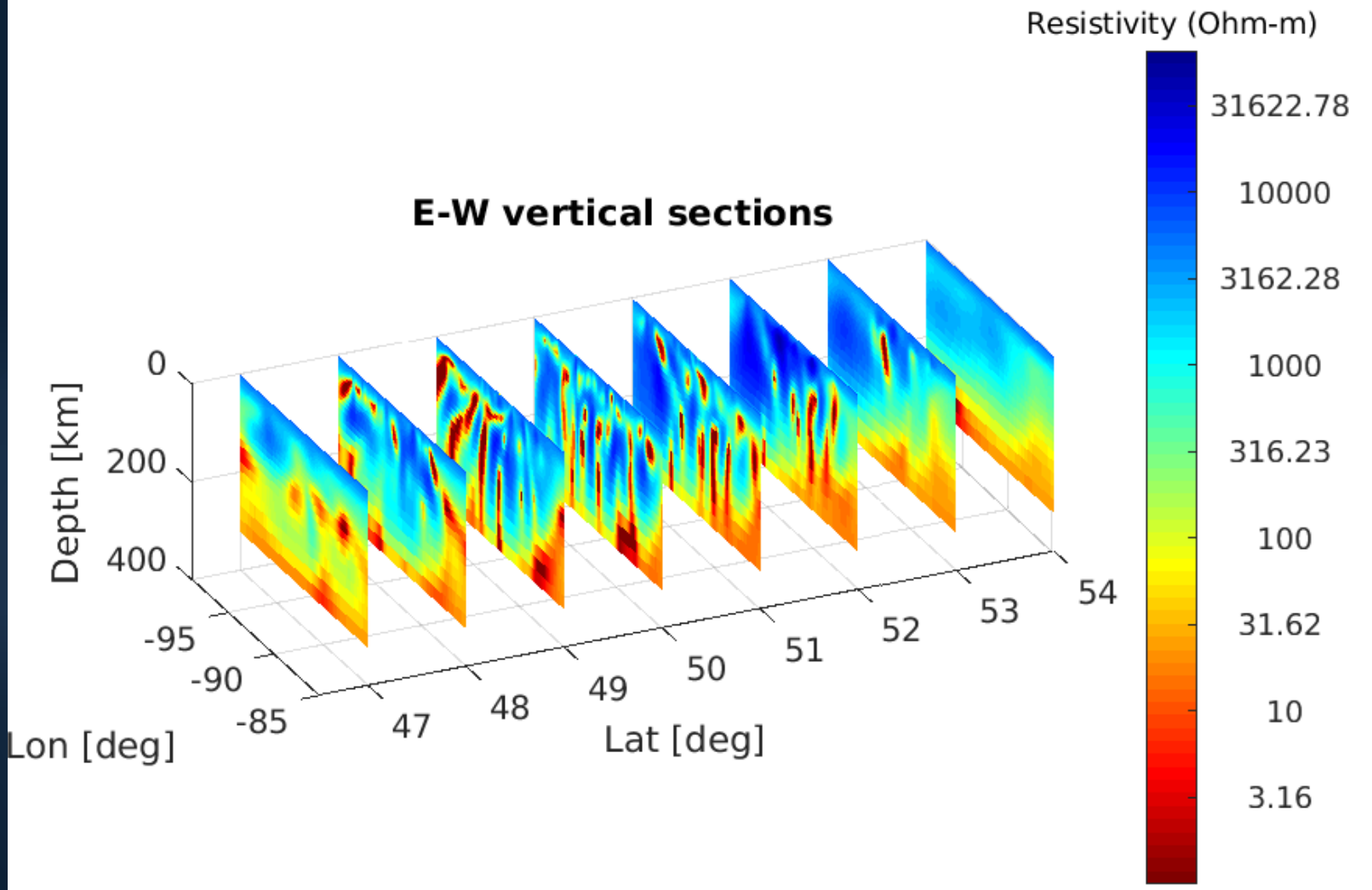

Vertical section X=0 [km]
Z-Depth [km]
50
100
150
200
250
300
-150
-100
-50
0
50
100
150
Y-Easting [km]


Horizontal section Z-Depth=140 [km]
Ohm-m
X-Northing [km]
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
Y-Easting [km]
1000
316.23
100
31.62
10
3.16

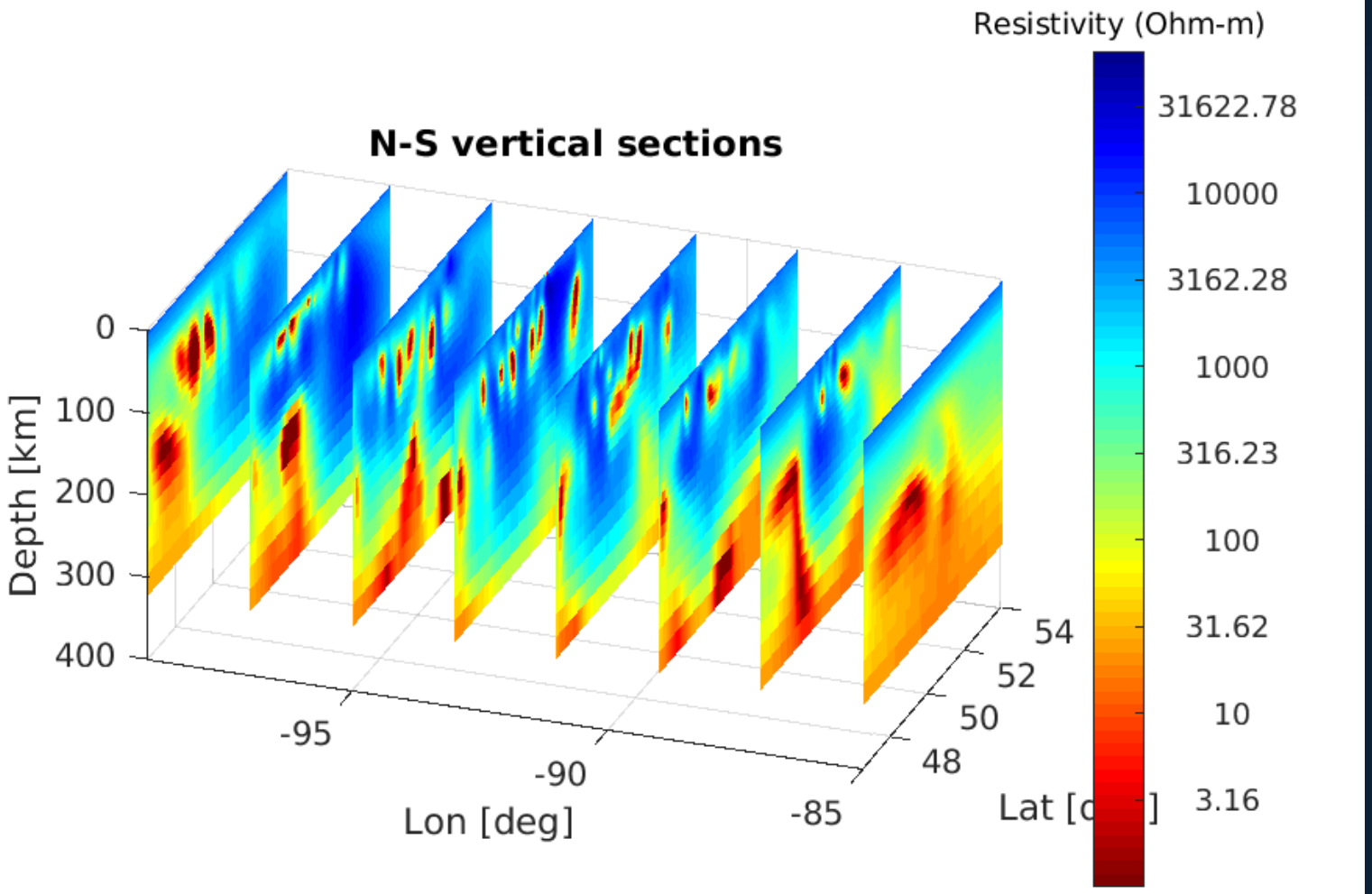
Inversion parameters

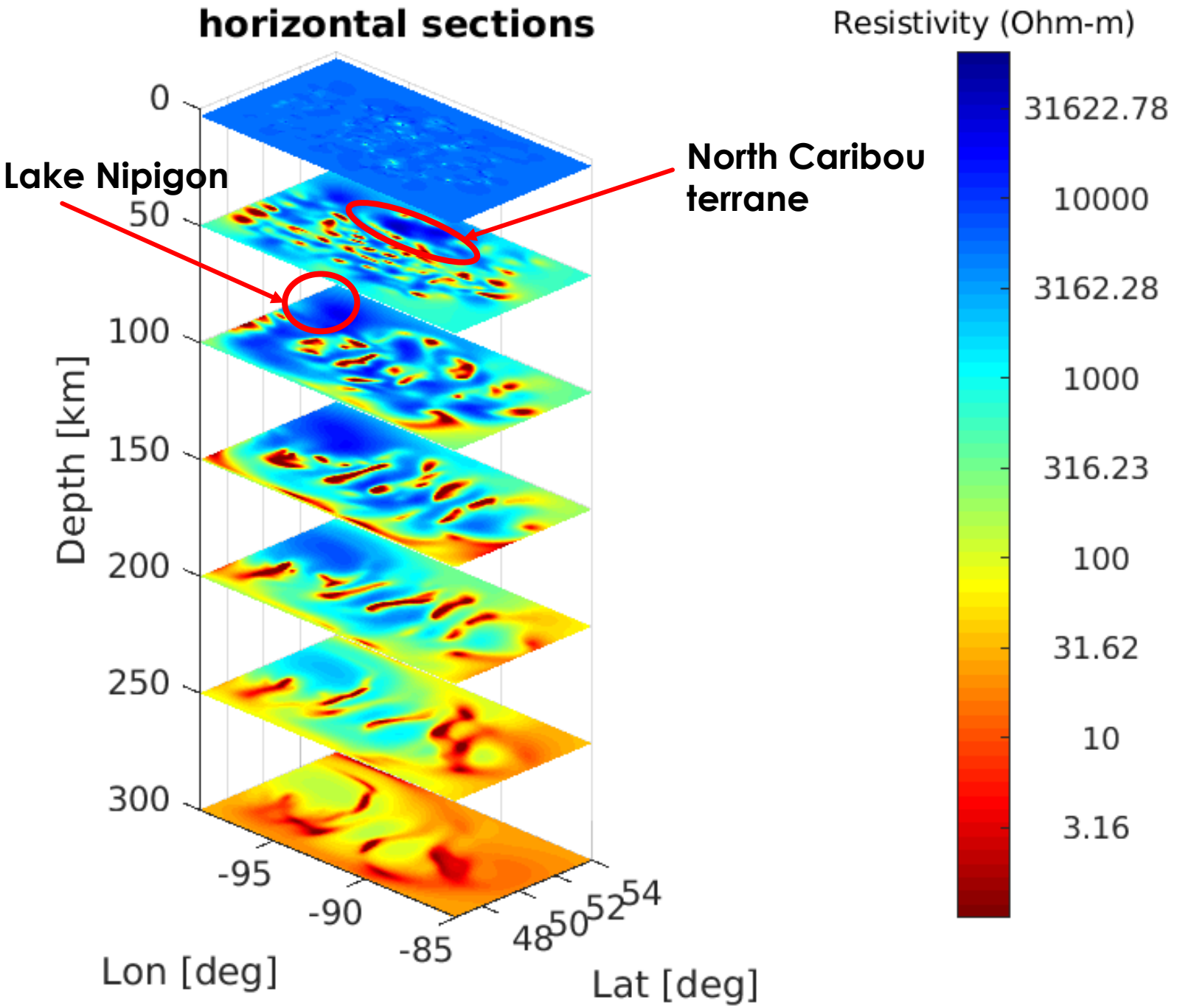
- Inversion domain: 880 x 1120 km (NS-WE)
- Horizontal cell size: 6.5 x 6.5 km
- Vertical cells: 40 layers increasing logarithmically from 630 m to 31.5 km
- Total number of cells: 941,120
- Misfit: 3.41 (iteration #51)

Vertical slices

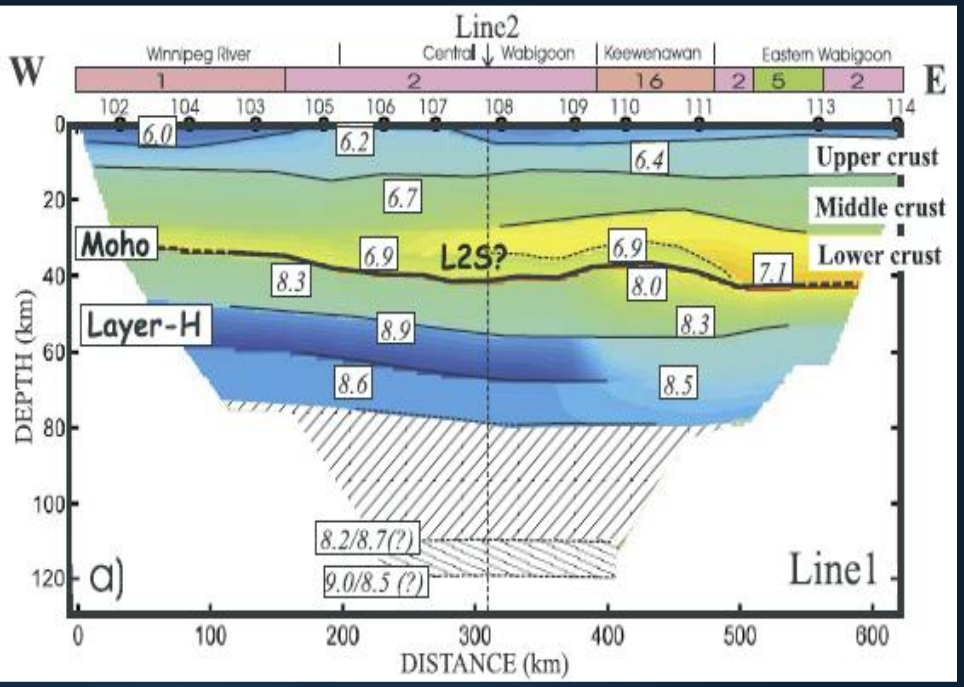


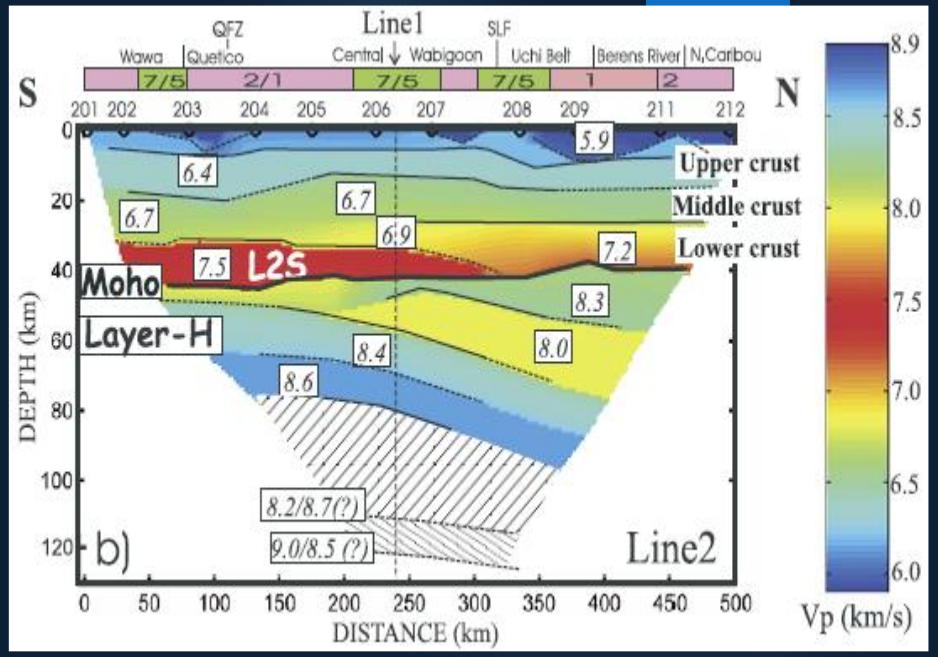
Vertical slices 2

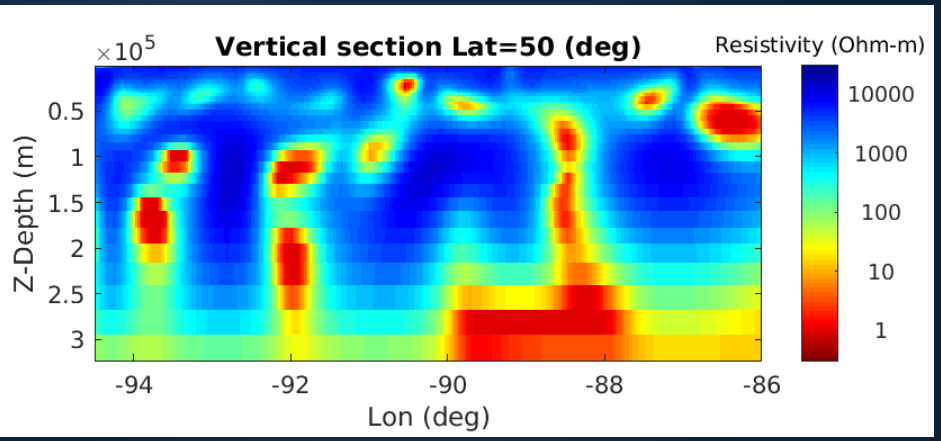


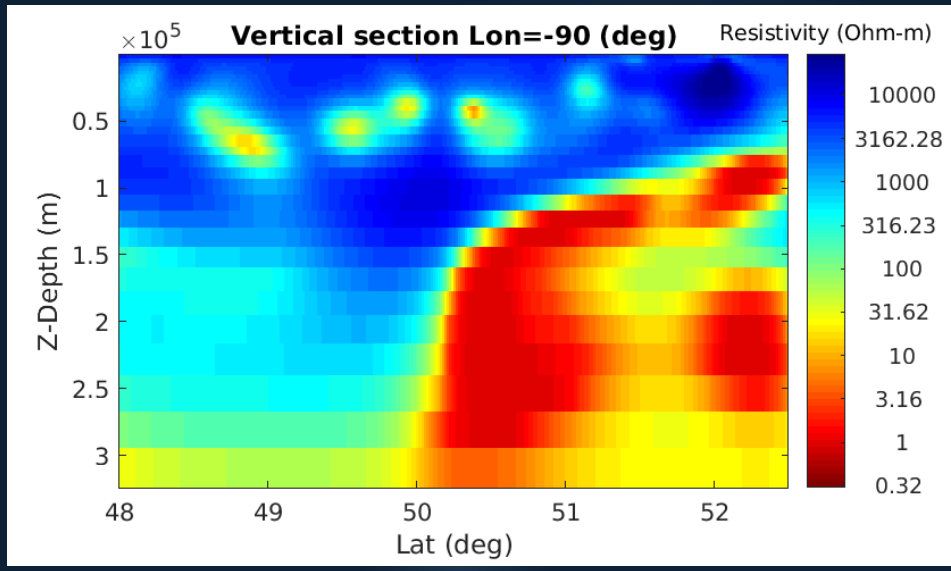

horizontal sections
Lake Nipigon
North Caribou terrane
Resistivity (Ohm-m)
31622.78
10000
3162.28
1000
316.23
100
31.62
10
3.16
Depth [km]
0
50
100
150
200
250
300
-95
-90
-85
Lon [deg]
48
50
52
54
Lat [deg]

(Musacchio et al, 2004)







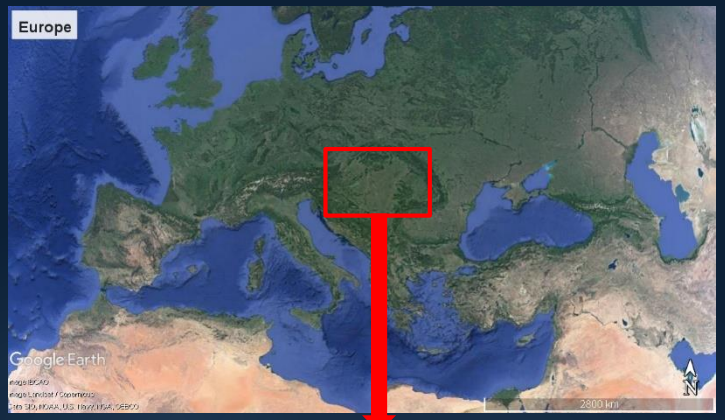


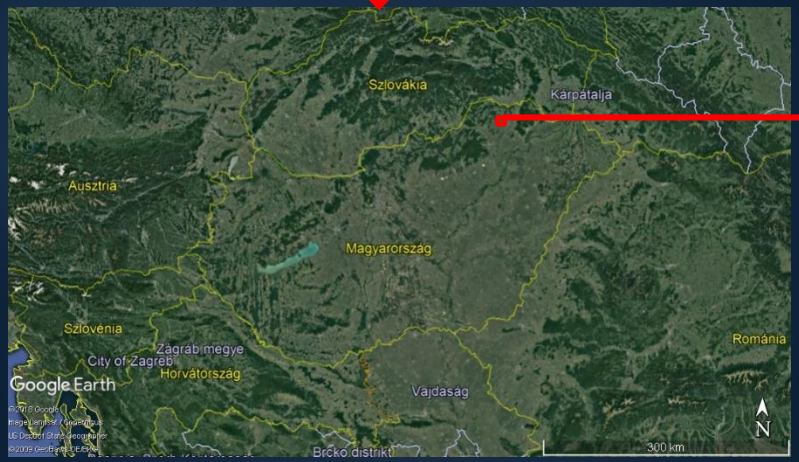
Conclusion

- 3D inversion of 159 MT data were performed using RGN method
- Several resistivity-conductivity anomalies were identified
- Similarities with earlier geophysical models
- Because of the sharp contrast, the regularization parameter can be refined in the future
- The electrical anisortopy can be also challenging to find appropriate minima in data misfit

Case study 2
Irota, Cserehát, North Eastern Hungary

Station map


Europe
Google Earth
2800 km
N


Szlovákia
Kárpátalja
Ausztria
Magyarország
Szlovénia
Zágráb megye
City of Zagreb
Horvátország
Vajdaság
Románia
Google Earth
300 km
N


340600
340400
340200
340000
339800
339600
339400
339200
339000
338800
786200
786400
786600
786800
787000
787200
787400
787600
787800
788000

Geological setting

- Neogene rocks

  sedimentary hiatus (devonian, carboniferous–miocene)

- Paleozoic rocks

  Outcrop in Szendrő mountain

  Hundreds of kms lateral moving

  Greenschist facies dynamo-thermal metamorphism (Cretateous)

Data preparation

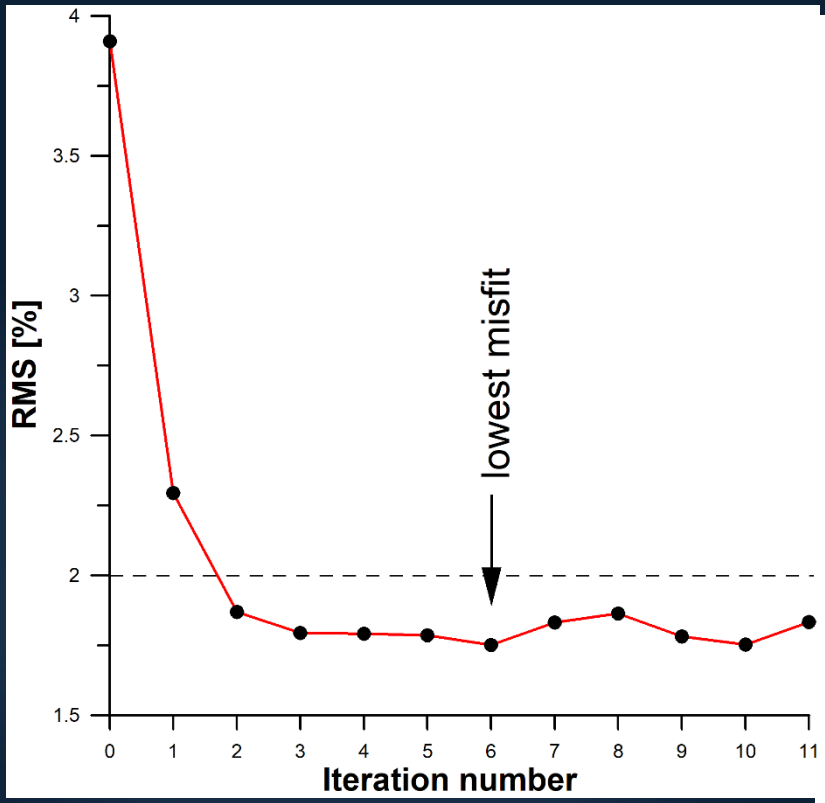
- originally 24 MT stations
- Getting rid of 1 station (23 stations!)
- Frequency domain (0.1–100 Hz)
- At least six values in each decade
- Inverting full impedance tensor
- Number of total data values: 1514 (~23*19*4)

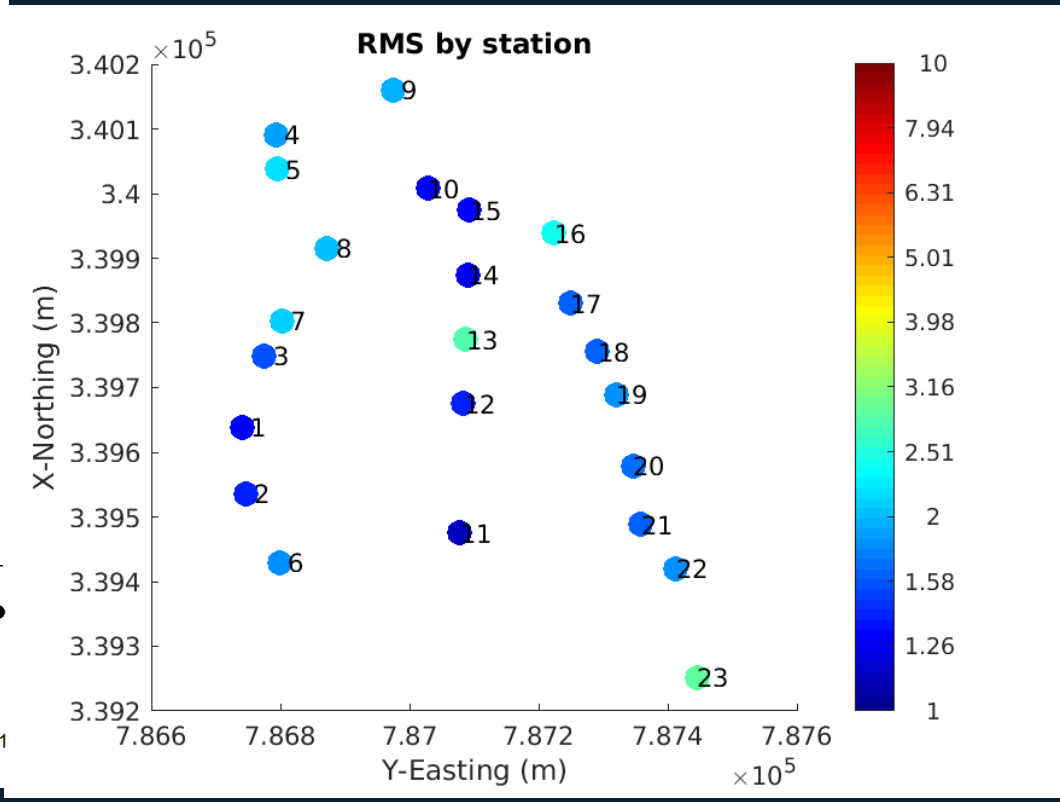
Input parameters

- Horizontal cell sizes (25*25 m)
- 84x76 cells horizontally (X*Y); 2.1x1.9 km area
- Vertical cell sizes: logarithmically increasing with depth
- 36 cells from the surface to 7090 m
- Total number of cells: 84*76*36=229824
- Average resistivity halfspace: ~15 ohmm
- Static shift: real distortion matrix

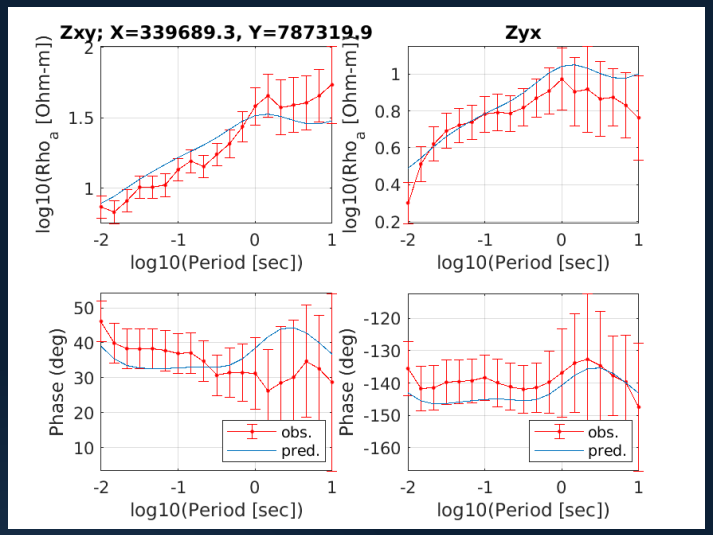
Other inversions

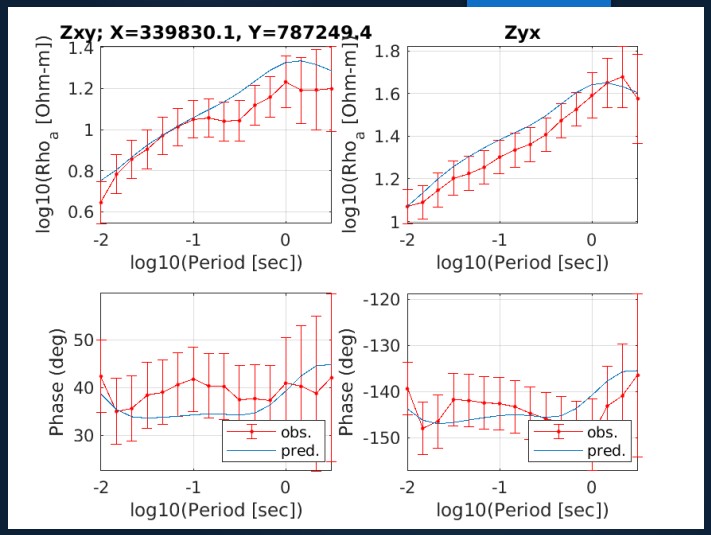
- Initial model: 1D layered, half space with larger resistivity values
- no shift, coarser cell sizes

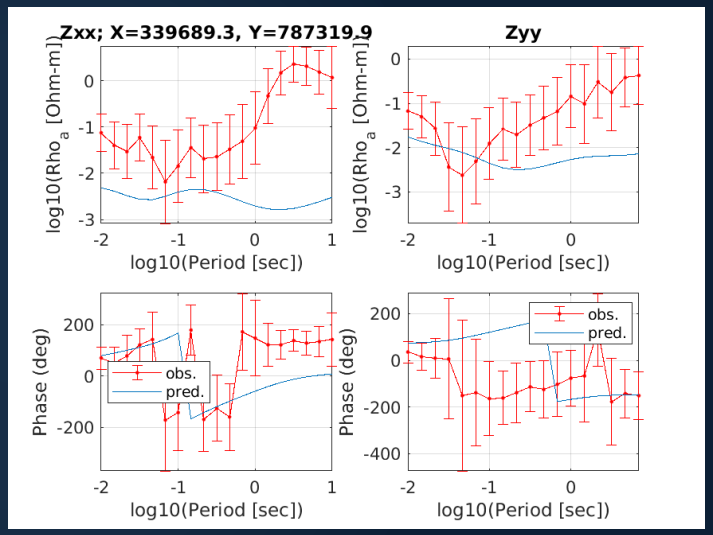

RMS [%]
Iteration number
lowest misfit
4
3.5
3
2.5
2
1.5
0
1
2
3
4
5
6
7
8
9
10
11

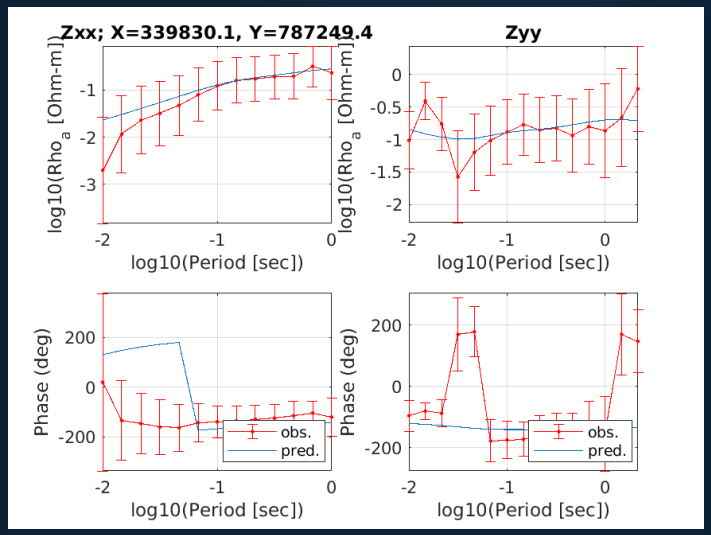

RMS by station
X-Northing (m)
Y-Easting (m)
×10^5
3.402
3.401
3.4
3.399
3.398
3.397
3.396
3.395
3.394
3.393
3.392
7.866
7.868
7.87
7.872
7.874
7.876
9
4
5
10
15
16
8
14
17
7
13
18
3
19
12
1
20
2
21
11
6
22
23
10
7.94
6.31
5.01
3.98
3.16
2.51
2
1.58
1.26
1

Observed, predicted data

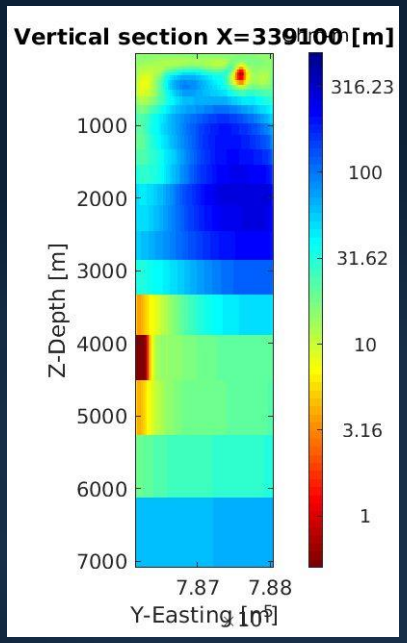


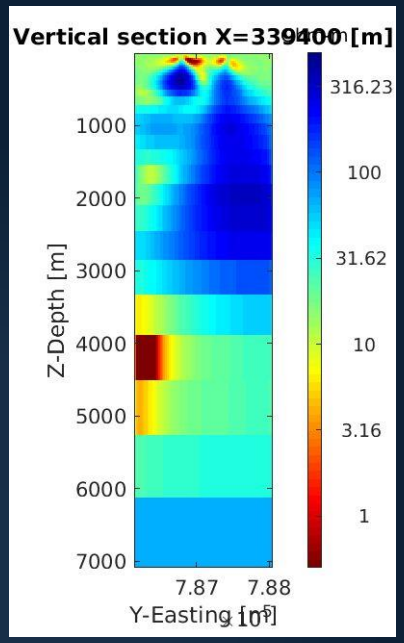


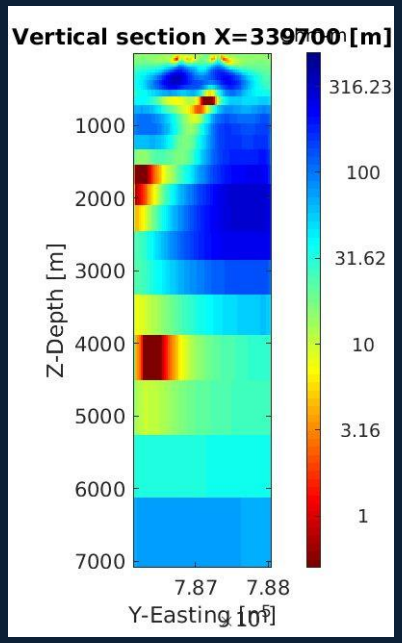


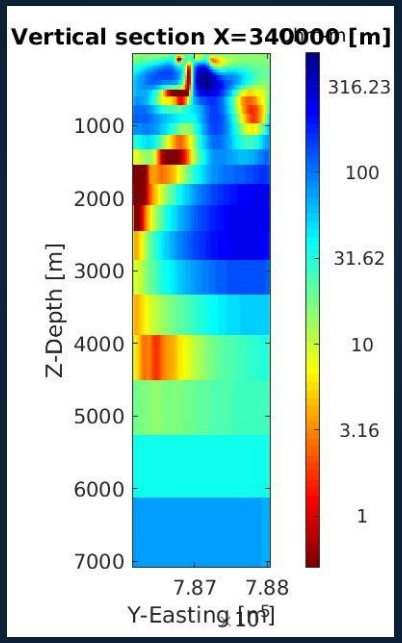


Vertical slices

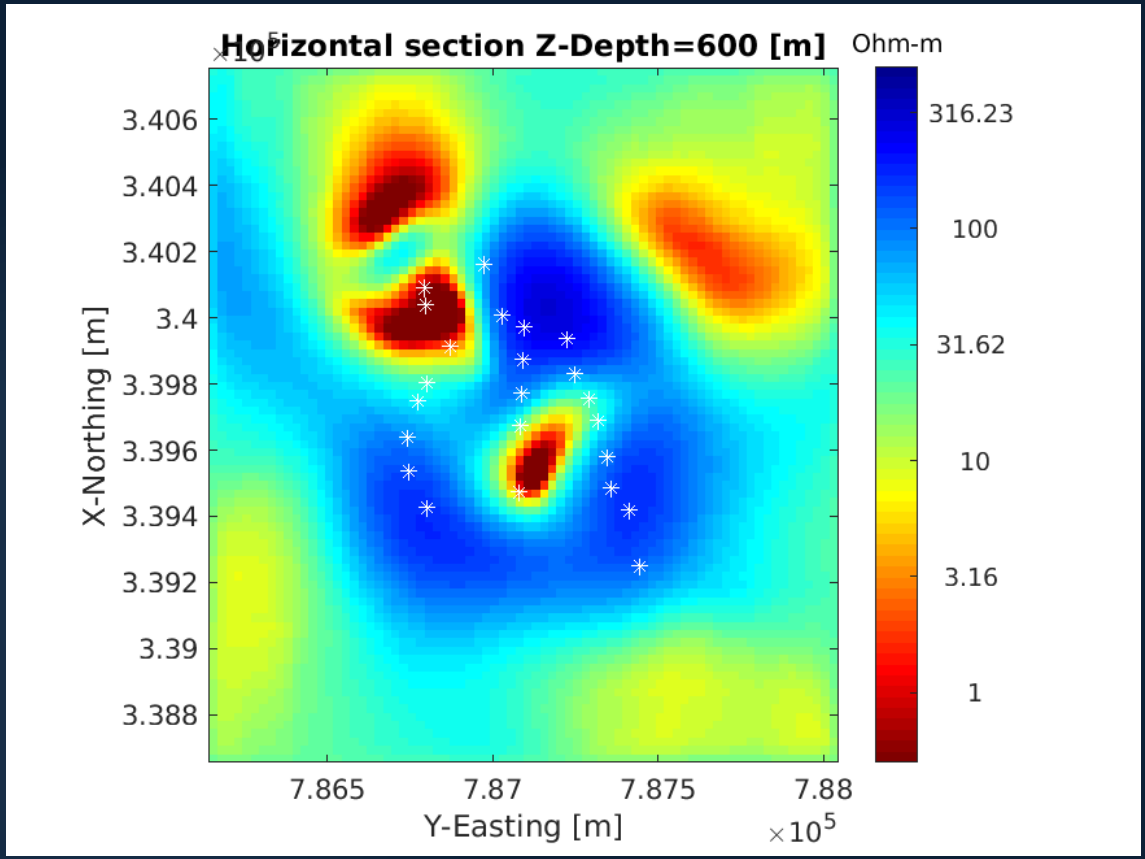








Horizontal slices (200-600 m depth)



Conclusion

- The application of RGN method for the 3D inversion of MT data
- The inverted model shows two low resistivity anomalies, which can be interpreted in the framework of local geological setting
- The extension of inversion domain in depth (Z) can result better fit of low frequency domain
- Extension of inversion domain horizontally as well

Acknowledgement

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- András Madarasi
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- Earth Scope project