



MAGNETOTELLURIC 3D INVERSION WORKSHOP IV

31 July - 2 August, 2026

Overview of MT3DINV4 workshop

Earth Sciences Department
Memorial University of Newfoundland
31st July – 2nd August, 2026

Alan G. Jones

Mitra Kangazianka

Randy Mackie

(Colin Farquharson)

41 participants (9 cancelled – visa issues)

up to 20 online

Focus on mining-scale issues

MT3DINV4 participants: 41 in person, up to 20 on-line



MT3DINV4 at work

61 presentations

- 34 orals
- 27 posters



LOTS of
discussion
time

MT inversion workshops through the ages...

Forerunner of the MT3DINVs was the MTDIW's – MT Data Interpretation Workshops – in which different groups undertook 2-D inversions of datasets.

These five workshops prompted advances in 2-D inversion

MT-DIW1: Wellington, New Zealand, 24th and 25th August, 1992 (prior to EMIW11)

MT-DIW2: Cambridge, UK, August 5th and 6th, 1994 (prior to EMIW12 in Brest)

MT-DIW3: Tsukuba, Japan, 9th and 10th July, 1996 (prior to EMIW13 in Onuma)

MT-DIW4: Sinaia, Romania, 15th - 16th August, 1998 (prior to EMIW14)

MT-DIW5: Rio de Janeiro, Brazil, 18th - 19th August, 2000 (prior to EMIW15)

MT3DINVs – the modern version

Then in the early-2000s 3-D inversion started exploding everywhere. But some of the same questions exist and are even more amplified about numerical problems and inversion problems (especially uniqueness and resolution)

MT3DINV1: Dublin, Ireland, 12 – 14 March, 2008

MT3DINV2: Dublin, Ireland, 30 March – 1 April, 2011

MT3DINV3: Bari , Italy, 16 – 18 May, 2016

< a long gap... mostly Covid related >

MT3DINV4: St. John's, Newfoundland, 31 July – 2 August, 2026 (prior to EMIW27)

Objective:

To advance understanding and application of 3-D inversion of natural-source EM data through open discussion centred on both the forward problem and the inverse problem.

- Status Quo? (where are we?) – the path we've followed so far
- Quo Vadimus? (where are we going?) – on a path and not changing from it
- Quo Vadamus? (where should we be going?) – change the path!

Over 2 ½ days discussed the near term (<4 years) and medium term (4-10 years) of numerical approaches for forward modelling and inverting ground (MT, Tipper) and airborne (ZTEM, MobileMT, QAMT) natural source EM data

*No point discussion far term >10 years ... Probabilistic inversion possible?
"Prediction is very difficult, especially of the future" – Niels Bohr*

Three tasks:

Task 1: MT3DINV4F – Forward modelling a given shape

Task 2: MT3DINV4S – Inverting responses from a secret model

Task 3: MT3DINV4R – Inverting responses from real data (new for MT3DINV4)

All participants HAD to present work on at least one task to qualify to attend.



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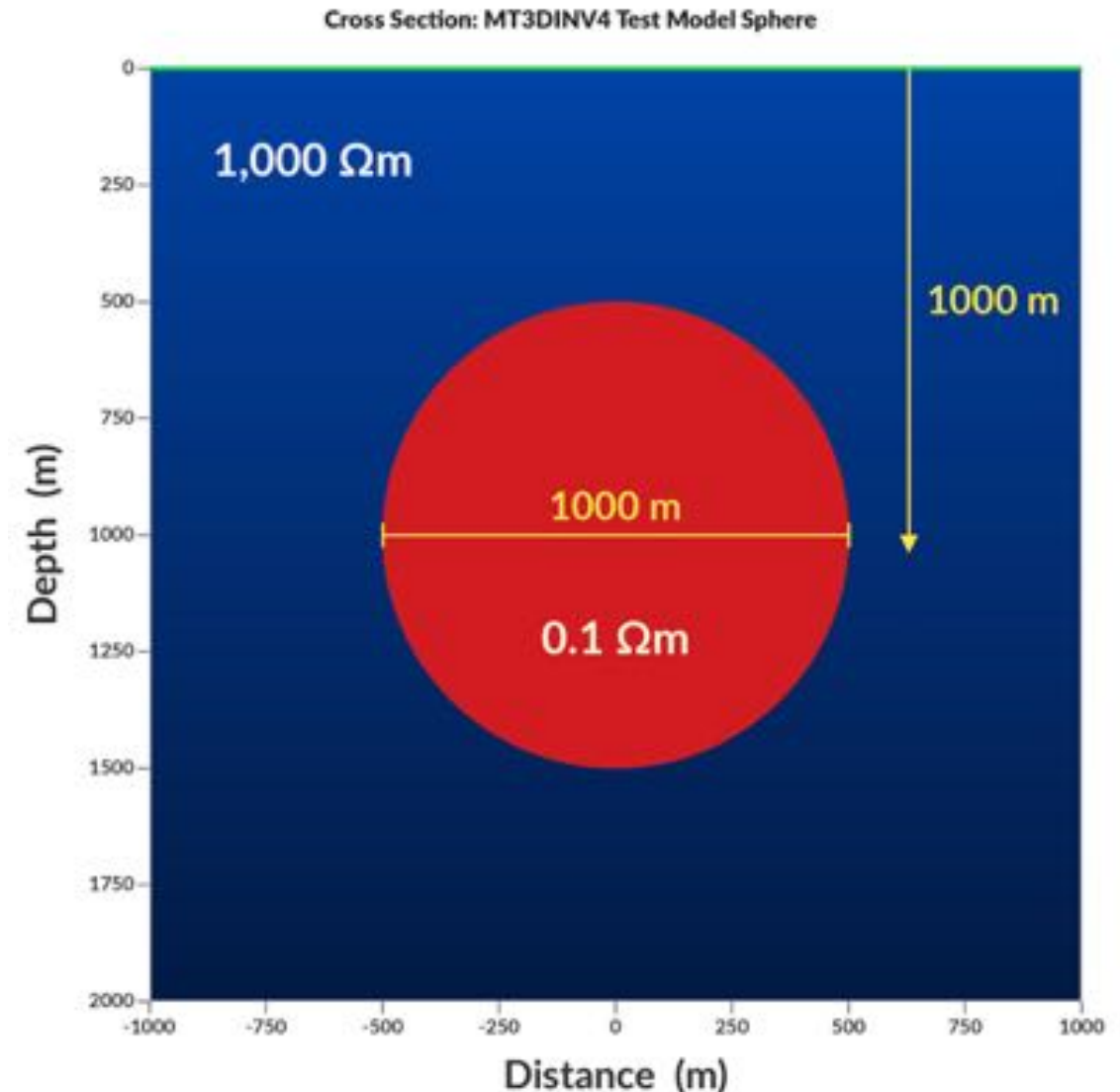
MT3DINV4F Forward Model

Analytical solution from MTSphere code of Marc Vallee

A simple model conceptually, but a very difficult model numerically!

Total of 28 presentations: 16 orals , 12 posters!

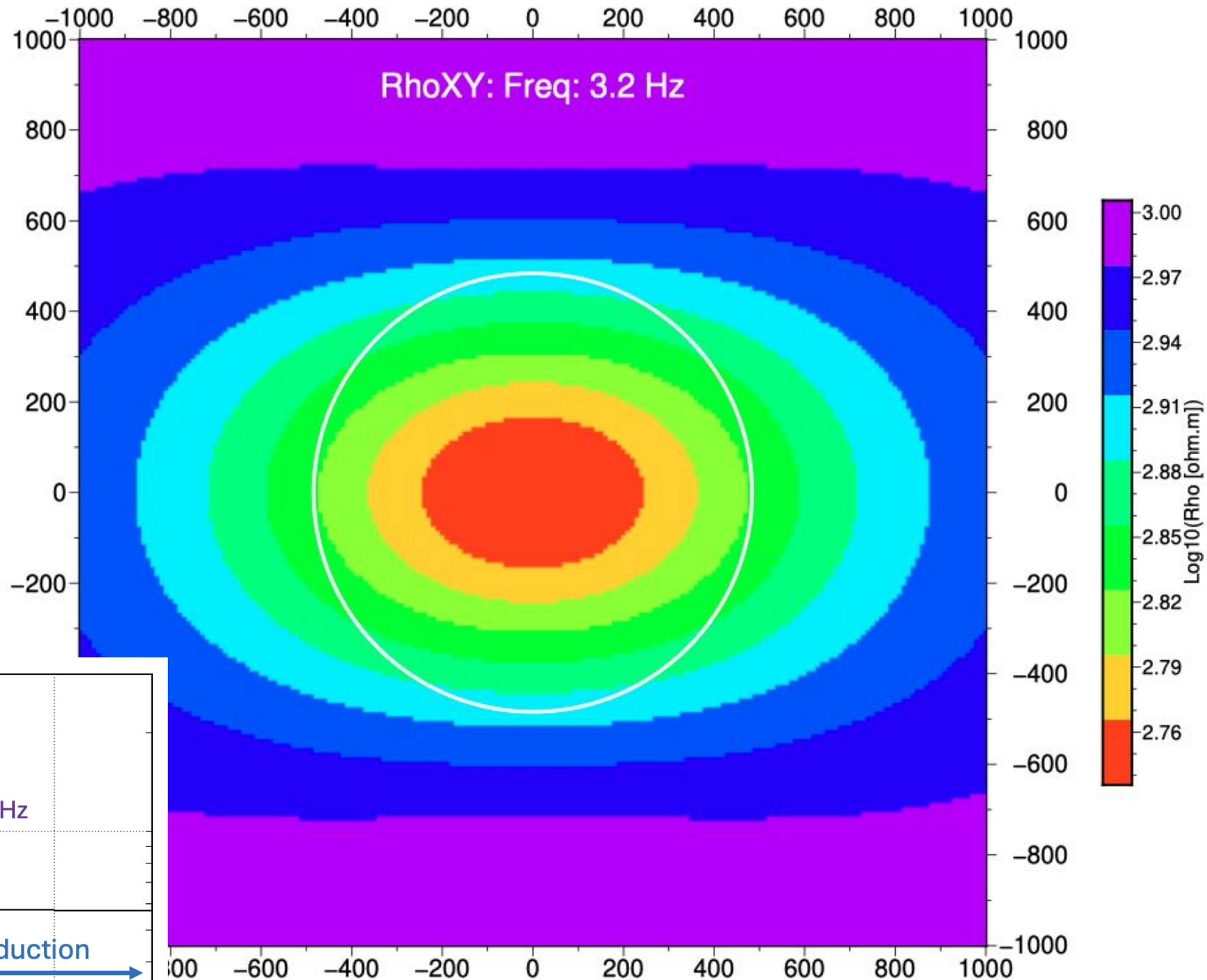
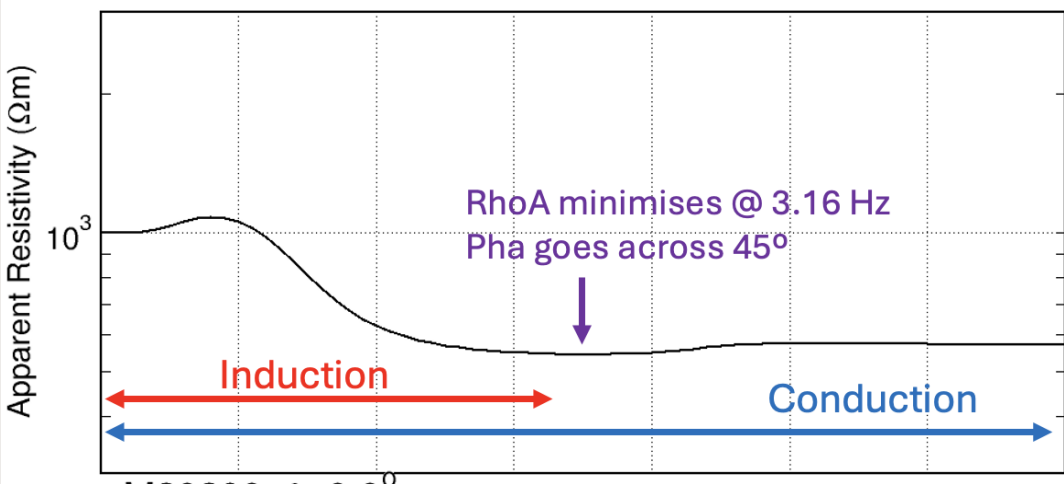
finite element (unstructured tetrahedra, octree hexahedra, high-order bases) · finite difference (staggered, multi-resolution) · integral equation · hybrid space–wavenumber FEM · calibrated coarse-mesh approximation



RhoXY map

Minimum in RhoXY & RhoYX of 544.1 Ωm @ 3.16 Hz in the conduction currents regime

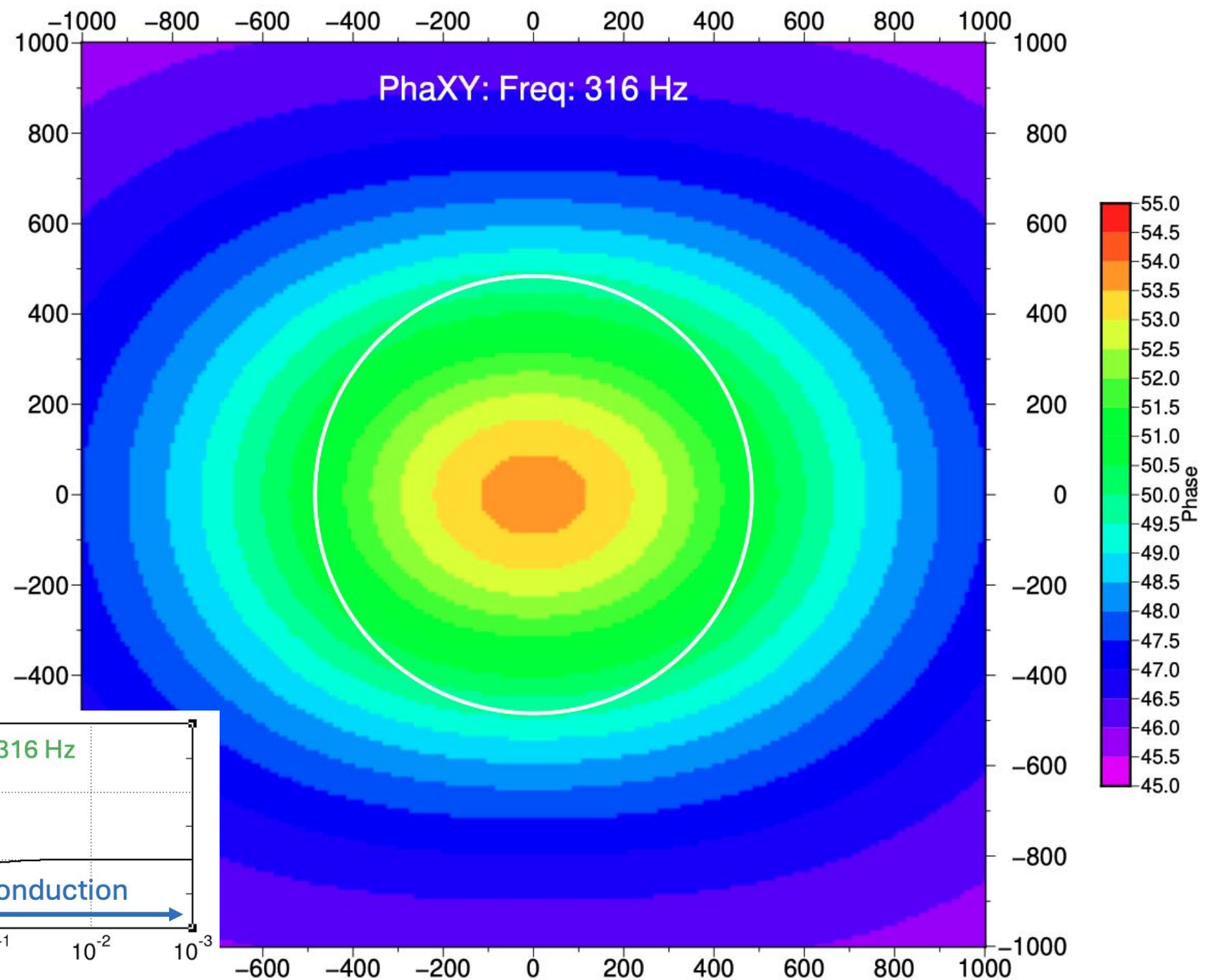
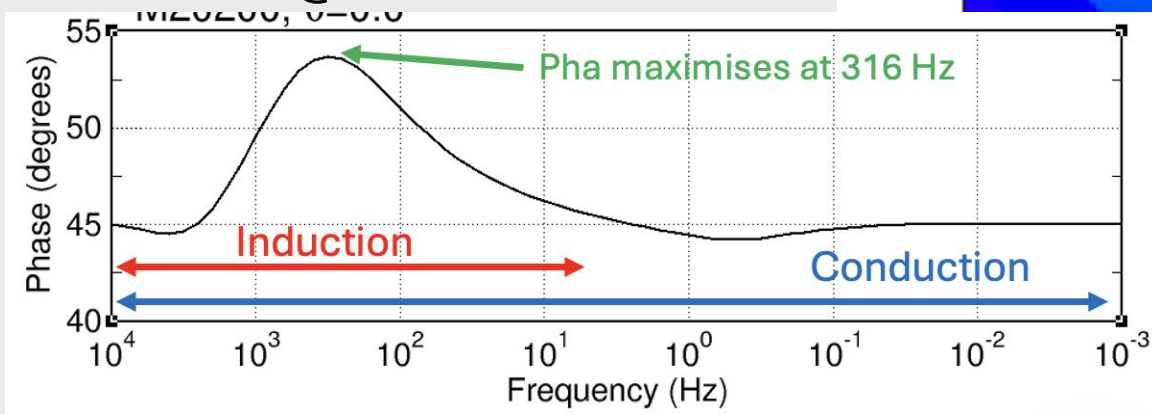
RhoA curve @ central site



Pha max map

Maximum phase response at 316 Hz in the induction currents regime

Pha curve @ central site



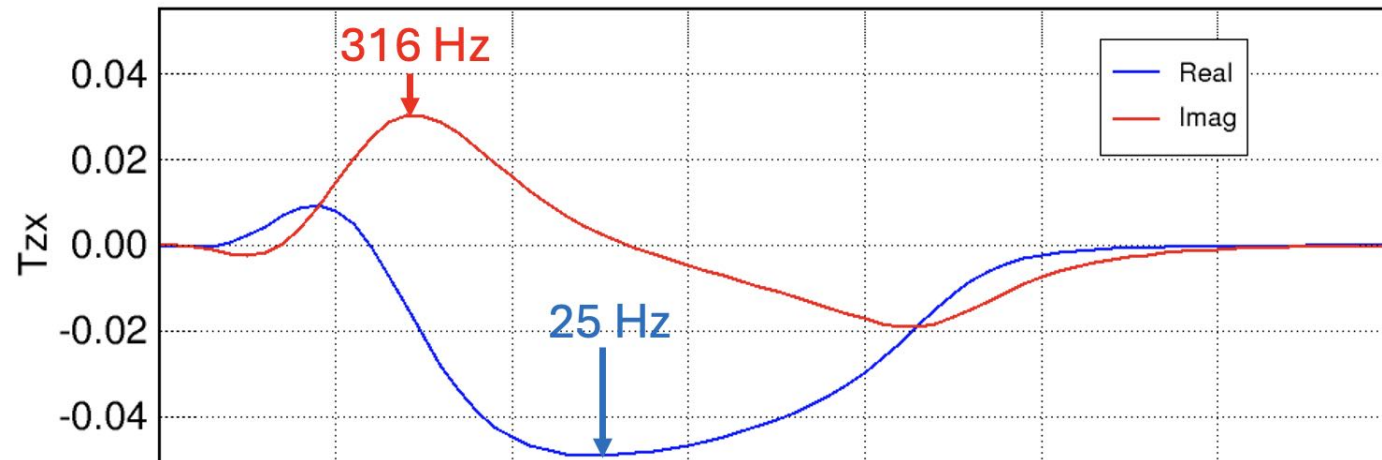
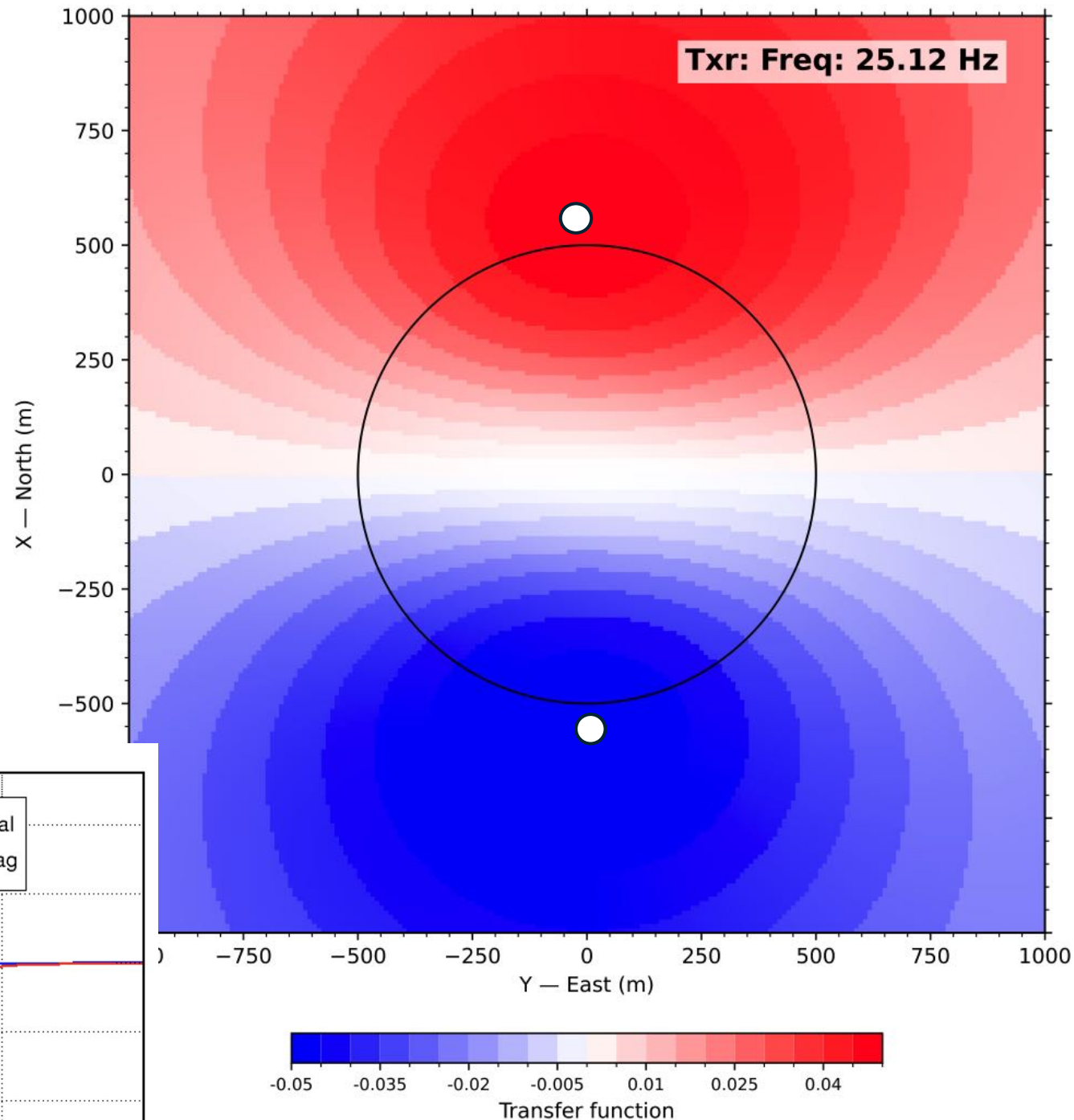
Re(Tx) map

Re(Tx) map at 25 Hz shows lobes to the S and N

Re(Tz) max anomaly 40 m outside the circle @ 0.049

Im(Tz) max anomaly @ 316 Hz – same as PhaMax, which is interesting

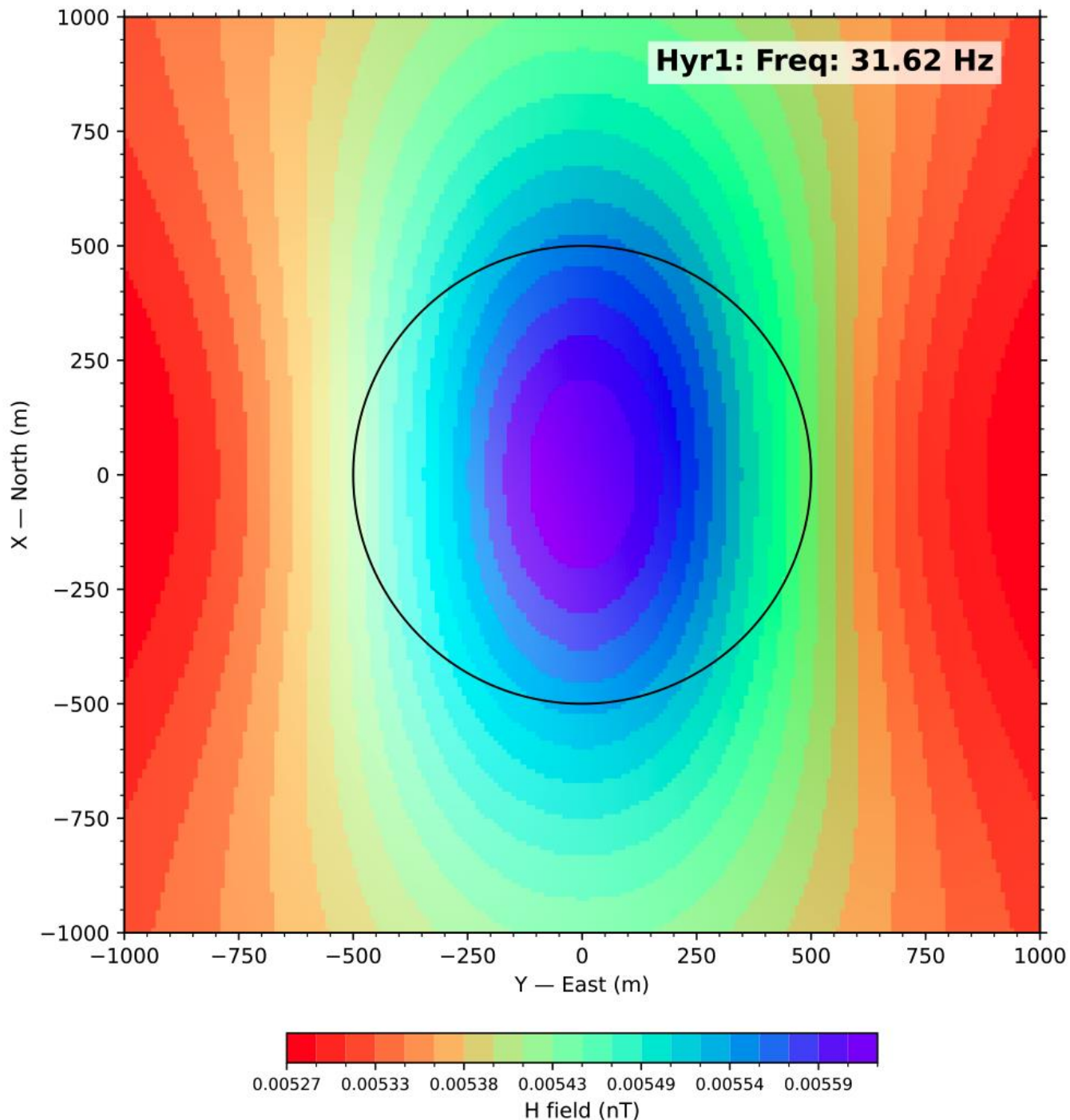
Tippers @ site (-540,0)



Field maps – Re(Hy)

Re(Hy) map at 31.6 Hz
(maximum h-field
response) for a N-S
current source

An amplification of approx.
6%



Field maps – Re(Ex)

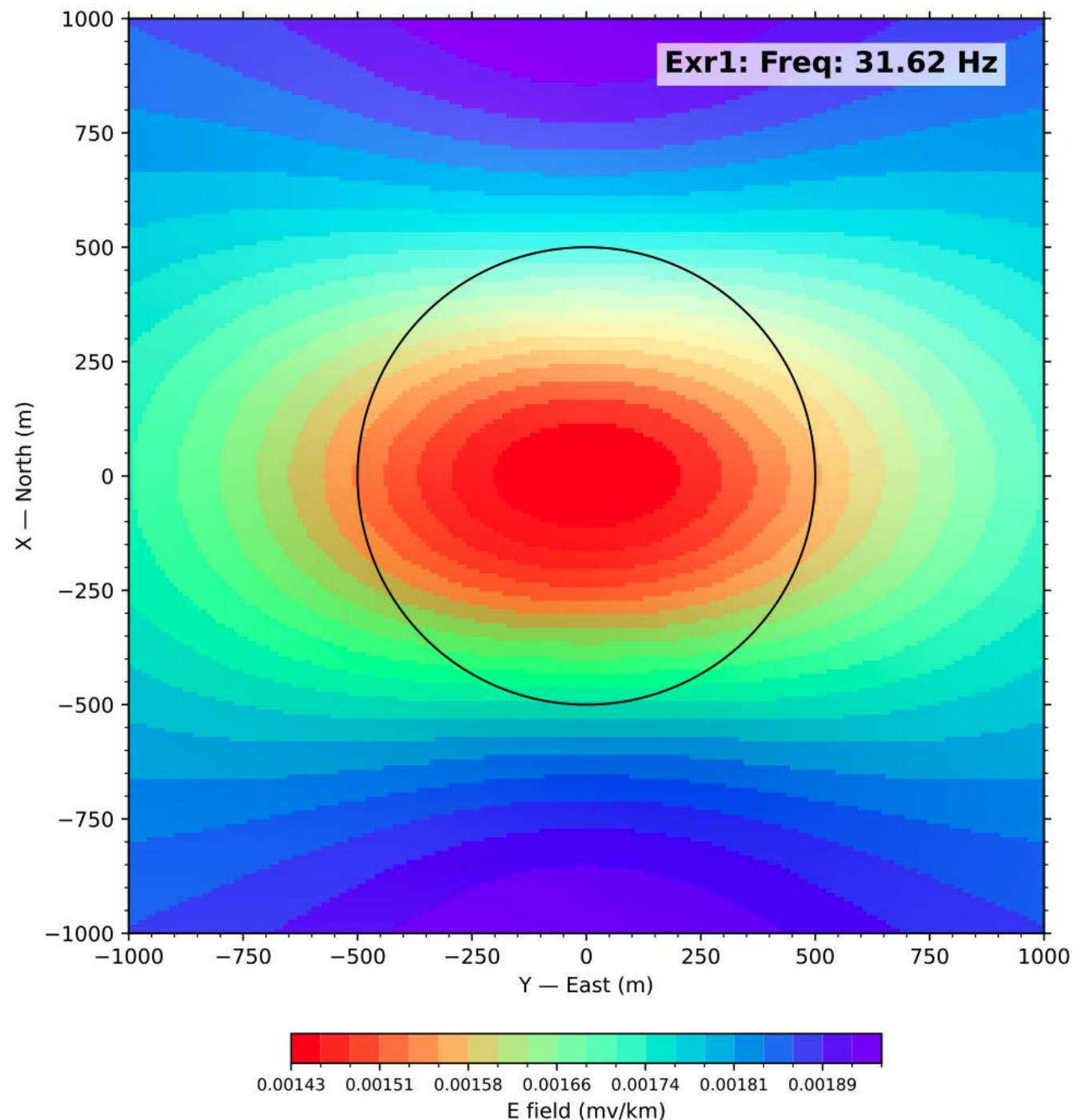
Re(Ex) map at same 31.6 Hz for a N-S current source

A reduction of approx. 36%

➔ Most of the anomalous MT field response (84%) is due to e-field reduction

Scaled $|E_x|/\sqrt{f}$ shows maximum @ 1.5 kHz

Electric and magnetic fields maximise over a decade apart!



● Four things the exercise settled

Points on which independent groups, using unrelated codes, converged

01

Geometry beats brute force

15.1 % → 1.6 %

staircase → boundary-conforming, same cell count (Manara et al.)

How the sphere's boundary is represented dominates the error. Rectilinear meshes sit near 15–18 % (Williamson) and plateau around 3 % however far they are refined (Fry). Effective-medium averaging — harmonic in particular — buys back part of the gap cheaply (Mackie, Li, Stutters), but saturates below ~125 m cells.

02

A tolerance is not an accuracy

1e-7 reported, 25 % wrong

recursively updated residuals overstating convergence (Fry)

Four groups hit this independently. Li: “check the solver before blaming the mesh” — benchmarks need tighter-than-default tolerances. Varilsüha: direct solves are clean where iterative CG is contaminated at high frequency. Mackie: LU on sub-blocks converges where ILU does not.

03

Tippers are the sharp edge

≈ 30 ×

residual amplification in the vertical field (Fry)

Hz is a small difference of large terms, so a tolerance that is safe for impedance is not safe for tipper. Symptoms were consistent: high-frequency roughness and inflated $\text{Im}(T_z)$ (Ansari, Kangazian). Yet peak $\text{Re}(T_{zx}) \approx 0.049$ is $2.5 \times$ the usual 0.02 error floor (Jones) — it carries real signal.

04

Cost is now a design choice

53 s → 13 h

same model, same outputs, comparable accuracy band

Three routes broke the cost curve without losing the answer: GPU-native solvers (Fry, Liu, Varilsüha), formulations that discretise less (integral equation over a 1 km^3 domain, hybrid space–wavenumber FEM), and deliberately coarse meshes calibrated against an analytic response (Deleersnyder — 7 088 cells).

Attributions name the submission in which the point was made most explicitly; in every case at least two independent groups reported the same behaviour.

Twenty-one blind inversions of a Laramide porphyry

The truth, revealed after submission: an 8.2 M-cell model at 25 m, ten distinct resistivities, under real topography. Two unconnected $0.2 \Omega\cdot\text{m}$ mineralised lobes and a conducting fault were the prize.

21

blind inversions
Submitted orally

180

sites, 500 m grid
35 freqs, 25 kHz–10 Hz

0.65 – 3.8

range of final
RMS reported

1 – 10 $\Omega\cdot\text{m}$

best recovered
amplitude vs 0.2 true

WHAT WAS BURIED

- $0.2 \Omega\cdot\text{m}$ eastern lobe — shallow, 930→600 masl
- $0.2 \Omega\cdot\text{m}$ western lobe — 560→200 masl, dips SW, under sediments
- $25 \Omega\cdot\text{m}$ sediments to the west
- $50 \Omega\cdot\text{m}$ NE–SW dyke / fault
- $10 \Omega\cdot\text{m}$ thin layer at the sediment base
- $1\,000 \Omega\cdot\text{m}$ basement to the east

Also distributed, and largely unused: airborne ZTEM and MobileMT (Sattel and cross-product estimates) responses over the same ground. Only one group inverted airborne and ground data jointly (Musila, Cowan & Heagy); one inverted ZTEM on its own (Skibbe & Rochlitz); one tried and was defeated by meshing (Varilsuha).



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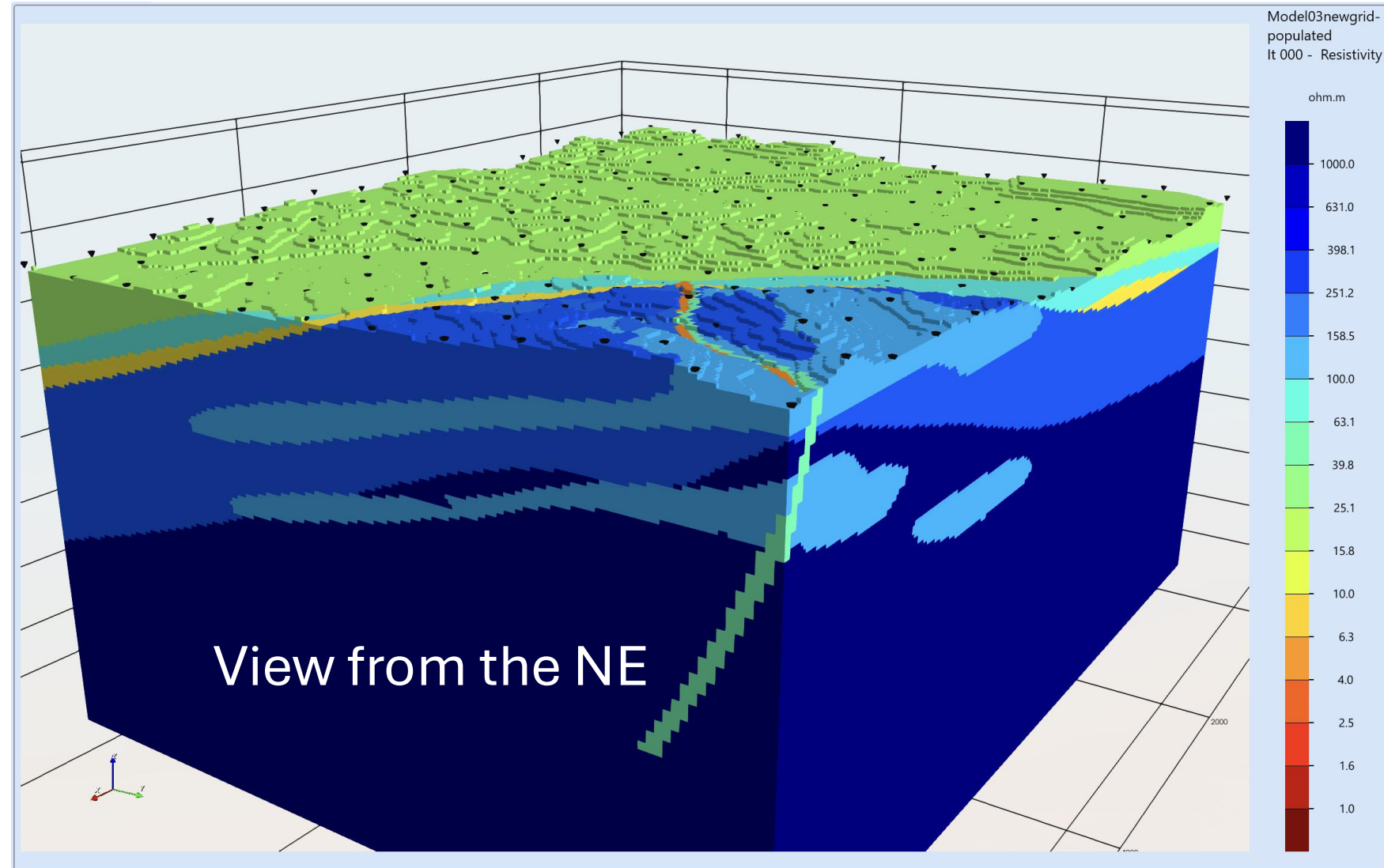
MT3DINV4S Secret Model

A Laramide porphyry
with two concentrations
of conductivity and a
fault

Data: MT+Tipper with
and without noise

ZTEM & MobileMT

21 presentations in
total: 13 orals, 8 posters

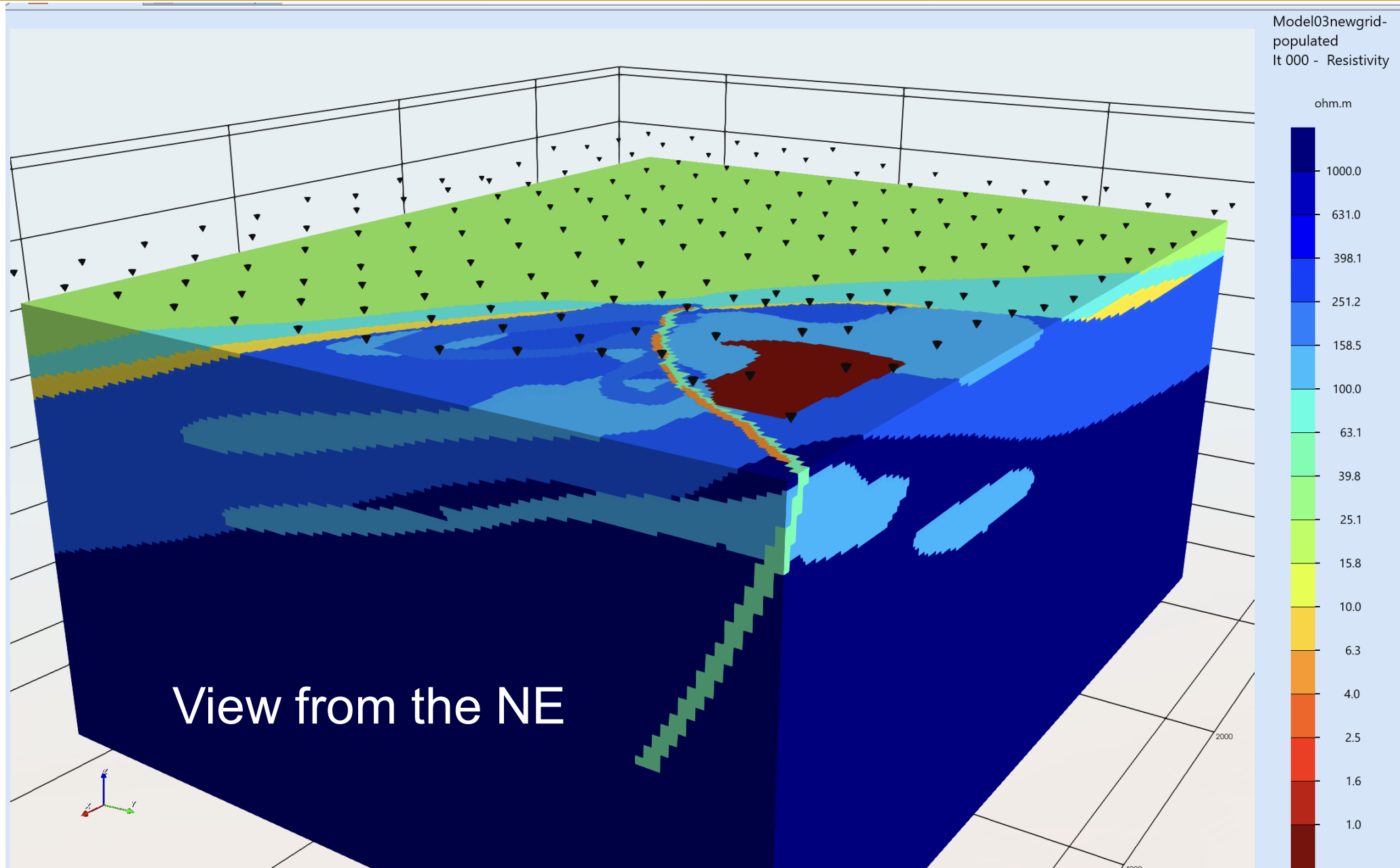


The model – Laramide Porphyry – 950 masl

View from NE

Slice at 950
masl

Shallower 0.2
 Ωm
conductor
first exposed

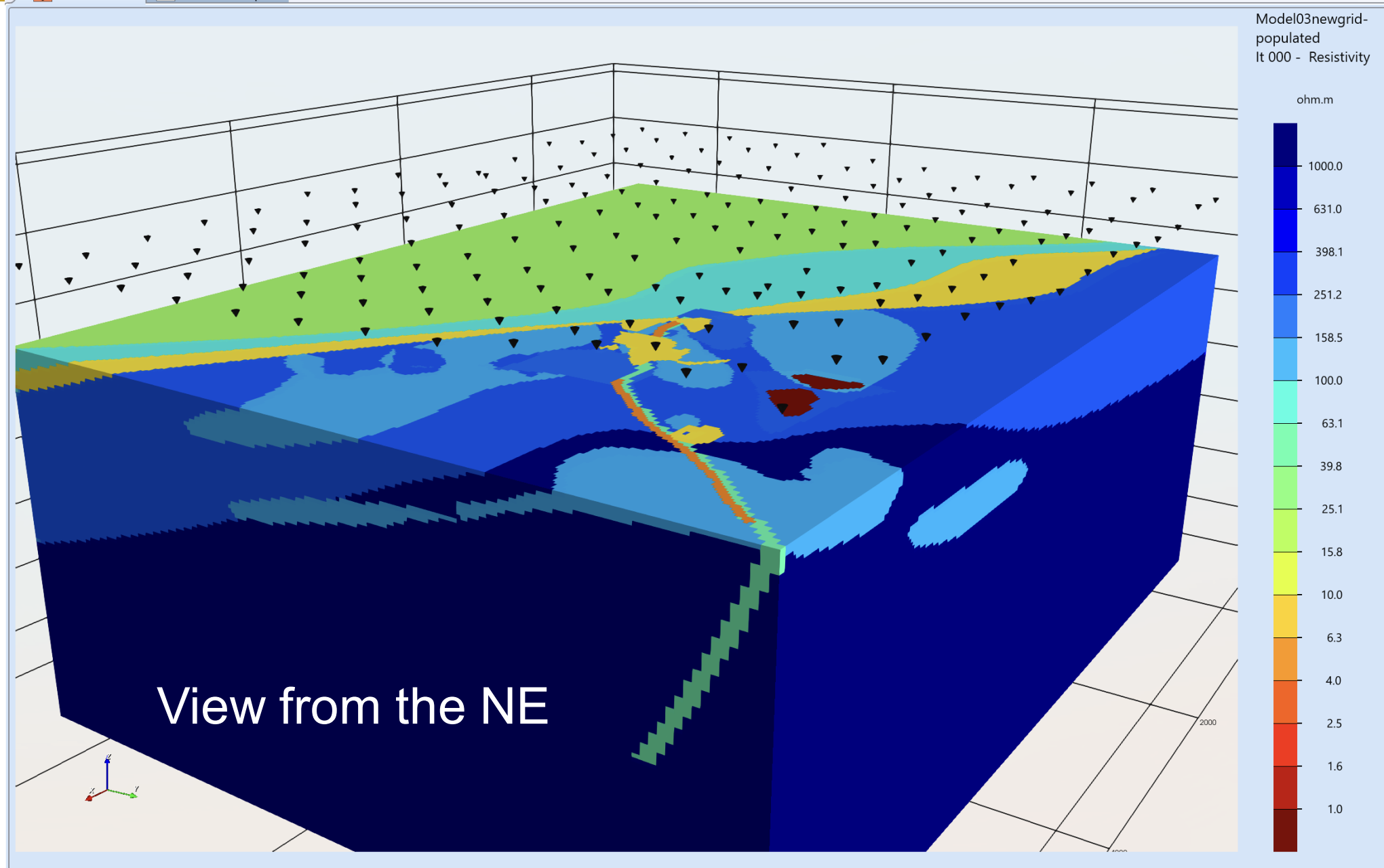


The model – Laramide Porphyry – 600 masl

View from NE

Slice at 600
masl

Base of
shallower 0.2
 Ωm
conductor

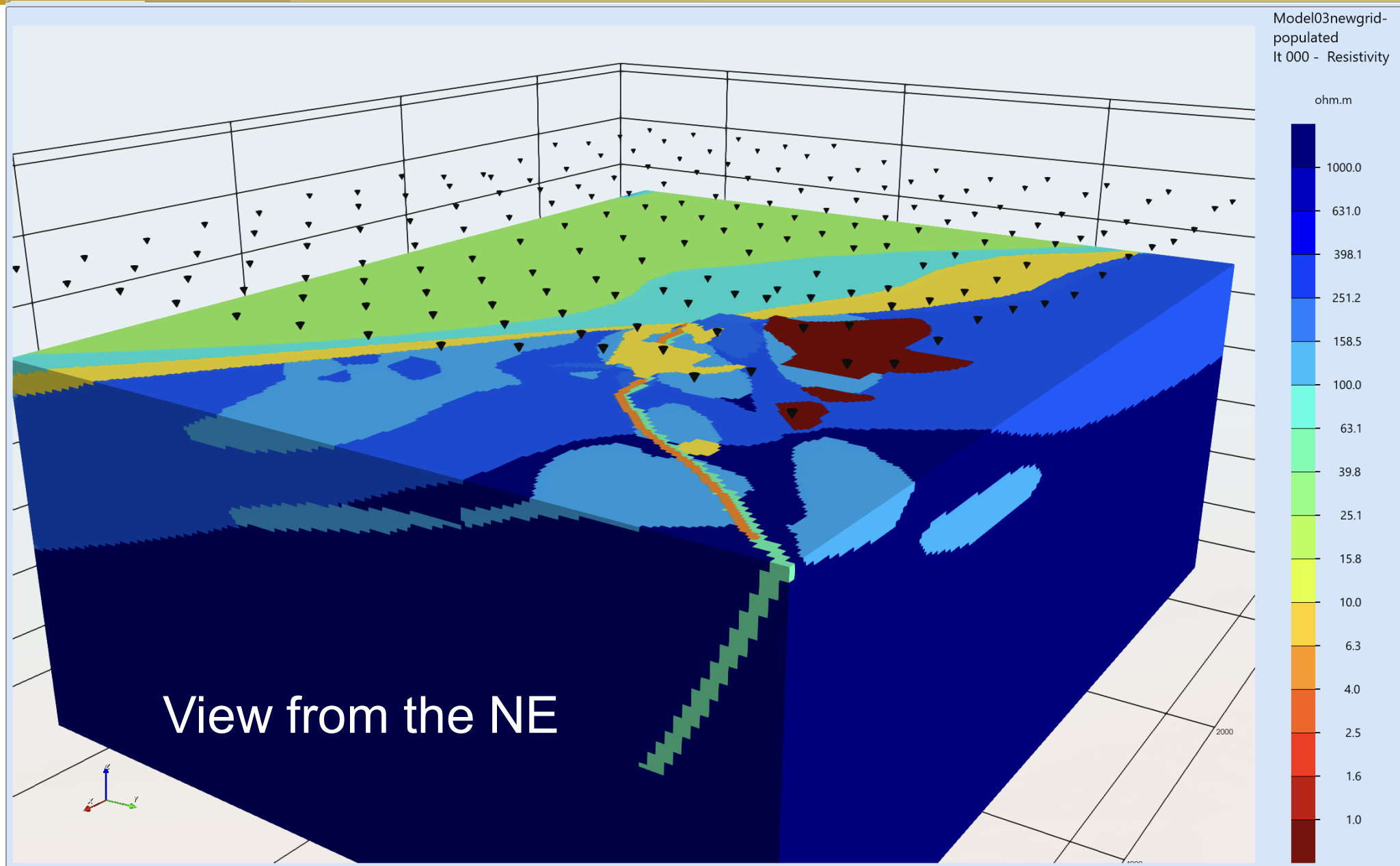


The model – Laramide Porphyry – 550 masl

View from NE

Slice at 550
masl

Deeper 0.2
 Ωm
conductor
first exposed

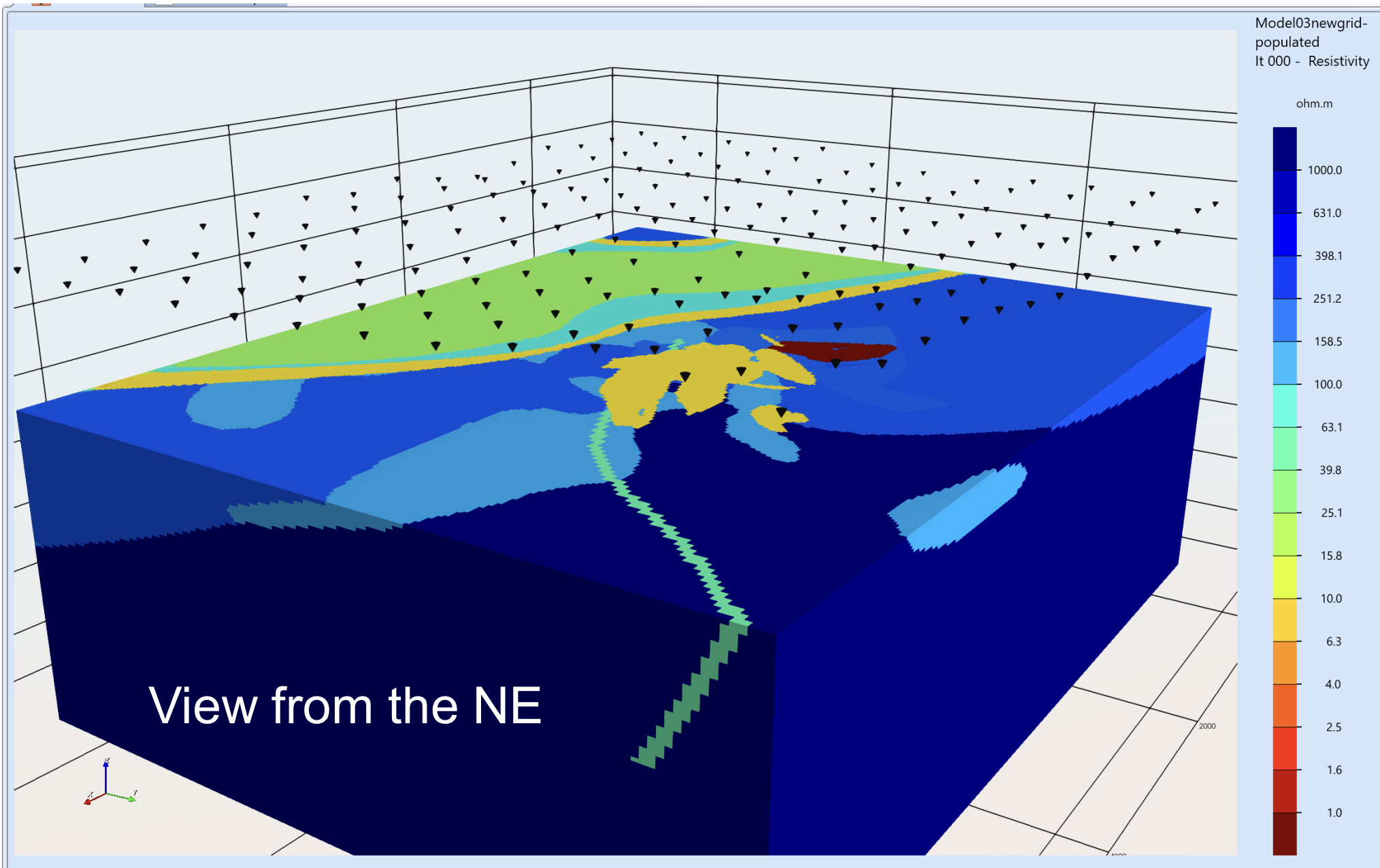


The model – Laramide Porphyry – 200 masl

View from NE

Slice at 550
masl

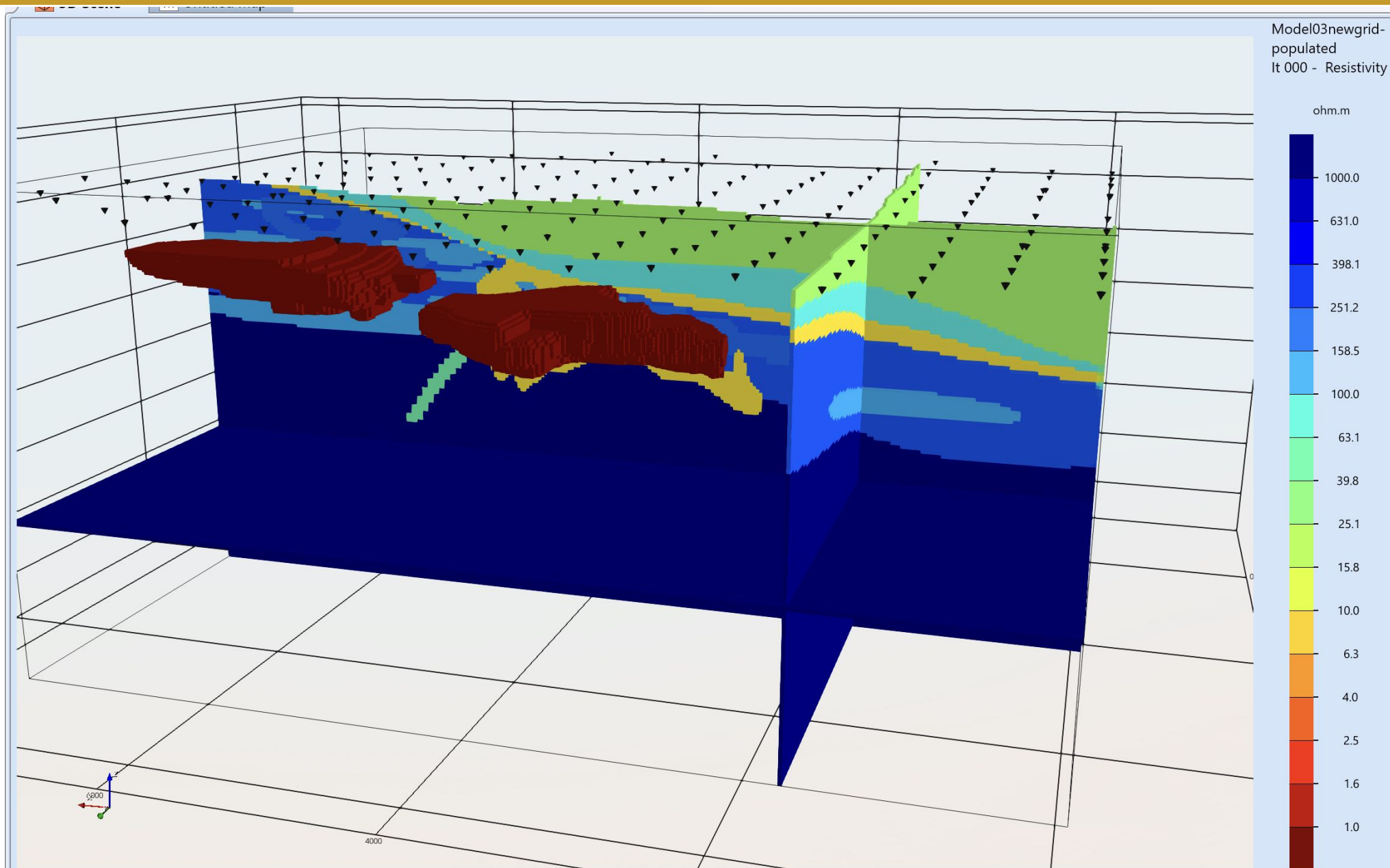
Base of
deeper 0.2
 Ωm
conductor



The model – Laramide Porphyry

The two
conductors

A lot of other
structures as
well



● What the ensemble found

Scored against the revealed model

RECOVERY SCORECARD

Shallow eastern lobe

ALL

Every submission imaged the NE conductor. Position and depth broadly right.

SW–NE resistivity contrast

ALL

Sediments vs basement fell out of the data diagnostics before anyone inverted.

Deeper western lobe

SOME

Found by Jones & Mackie, Ansari, Dong (weakly), Li and Williamson — poorly resolved in all four, and it sits at the edge of the 2 km depth of investigation.

0.2 $\Omega\cdot\text{m}$ amplitude

NONE

Recovered cores run 1–10 $\Omega\cdot\text{m}$; Jones & Mackie reached $< 1 \Omega\cdot\text{m}$. Conductance and position are recoverable, resistivity is not.

50 $\Omega\cdot\text{m}$ dyke / fault

SOME

Impossible to image at this MT site spacing. Only found when using airborne data

● The high-frequency band was compromised on both sides.

Misfit piled up above ~ 1 kHz for nearly everyone. Li quantified it: RMS 3.77 overall, but 0.95 for $f \leq 1$ kHz once high frequencies were down-weighted. Jones concedes the reference responses themselves carry topographic artefacts at sites on ridges and cliff edges. The genuinely informative band was ≤ 1 kHz.

● Noise was not the limiting factor. Practitioner choice was.

Song measured a 0.999 log ρ correlation between clean and noisy inversions; Varilsüha's noisy model held its structure. But Dong handed identical data to three students and got three different models, all at RMS ≈ 1.0 –1.3. Skibbe found the one real casualty: noisy tipper alone would not invert.

● Fitting the data stopped being the discriminator.

Liu ran 171 inversions across background, smoothness and norm, then kept only those that fit — treating agreement across the surviving ensemble as the trustworthy part and disagreement as honest uncertainty. Musila and Cowan ran the same experiment with two practitioners; Song with a matrix of ABIC, OCCAM and L-curve, concluding that none of them removes analyst judgement.

Task 3: Raglan – the task where the data fought back

Zones 2–3 of the Raglan Ni–Cu district, northern Québec, released by Glencore. 164 sites at ~200 m spacing over 3×3 km, no tippers, acquired in 2017 over terrain that is punishing for electric-field acquisition.

11

submissions

90 → 16–25

frequencies retained
after editing

1.31

best final nRMS
(Jones, with distortion)

3

conductors found,
 $\rho < 1 \Omega\cdot\text{m}$

WHAT WAS WRONG WITH IT

- **Daytime acquisition**
112 of 164 sites recorded under 4 hours — the AMT dead band is unusable at those sites
- **Contact impedance**
above 20 k Ω at roughly half the sites
- **Coil mismatch**
Geometrics G100K at high frequency against Phoenix MTC-50H at low — a corrected dataset had to be issued
- **Galvanic distortion**
severe, worst in the SW; usually one element of C dominates

Editing was measurable, not cosmetic: Jones scored every site with a Quality Factor against a 7 % / 2° error floor. Correcting and editing moved the mean from 1.47 to 1.25, the median from 1.30 to 1.12 and the standard deviation from 0.61 to 0.48 — the dataset became consistent with the errors people were about to assume for it.



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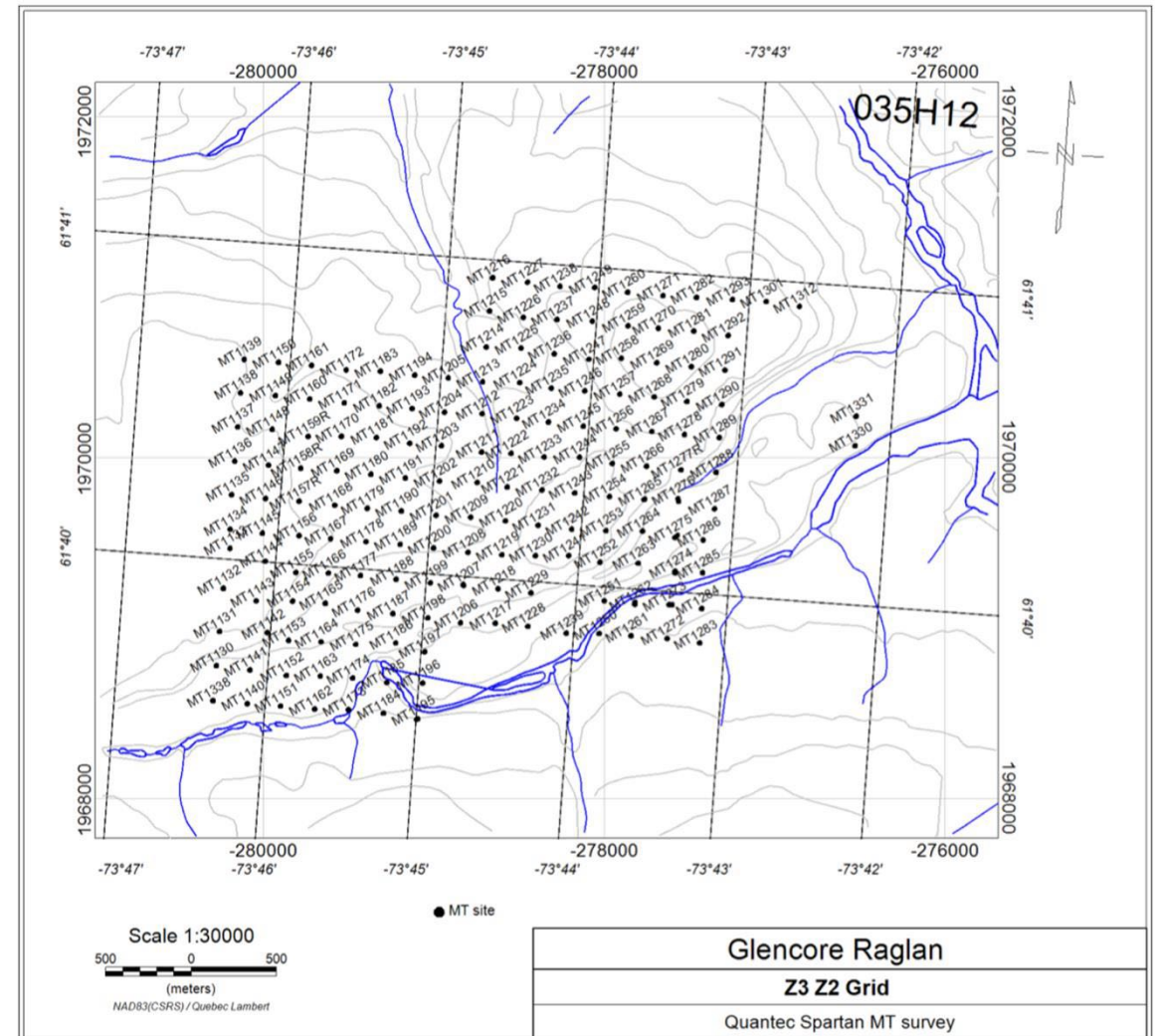
MT3DINV4R Real Data

Real data from Raglan mining district
in northern Quebec

11 presentations, 5 orals, 6 posters

RAGLAN MINE
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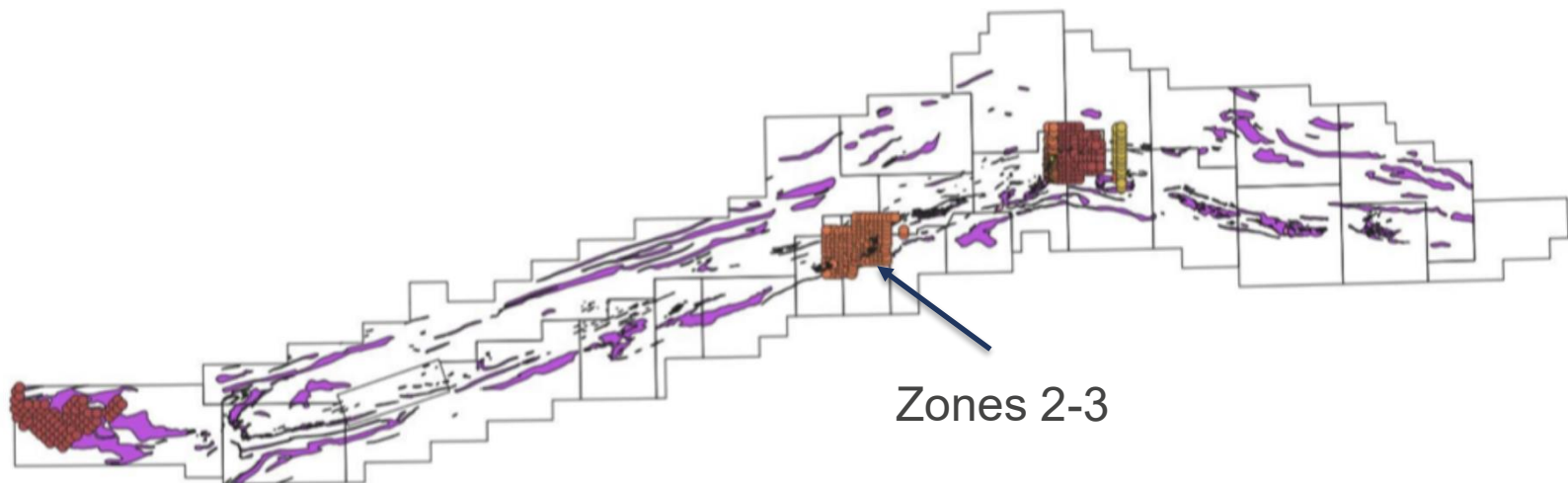
Many thanks to Raglan
Mine for permission to
use these data



MT3DINV4R – Raglan location

The real data come from Zones 2-3 in the Raglan mining district in northern Quebec

A plan map of the mining district shows the ultramafic belts in purple



MT3DINV4R – Field conditions

Really tough terrain
for especially e-field
acquisition

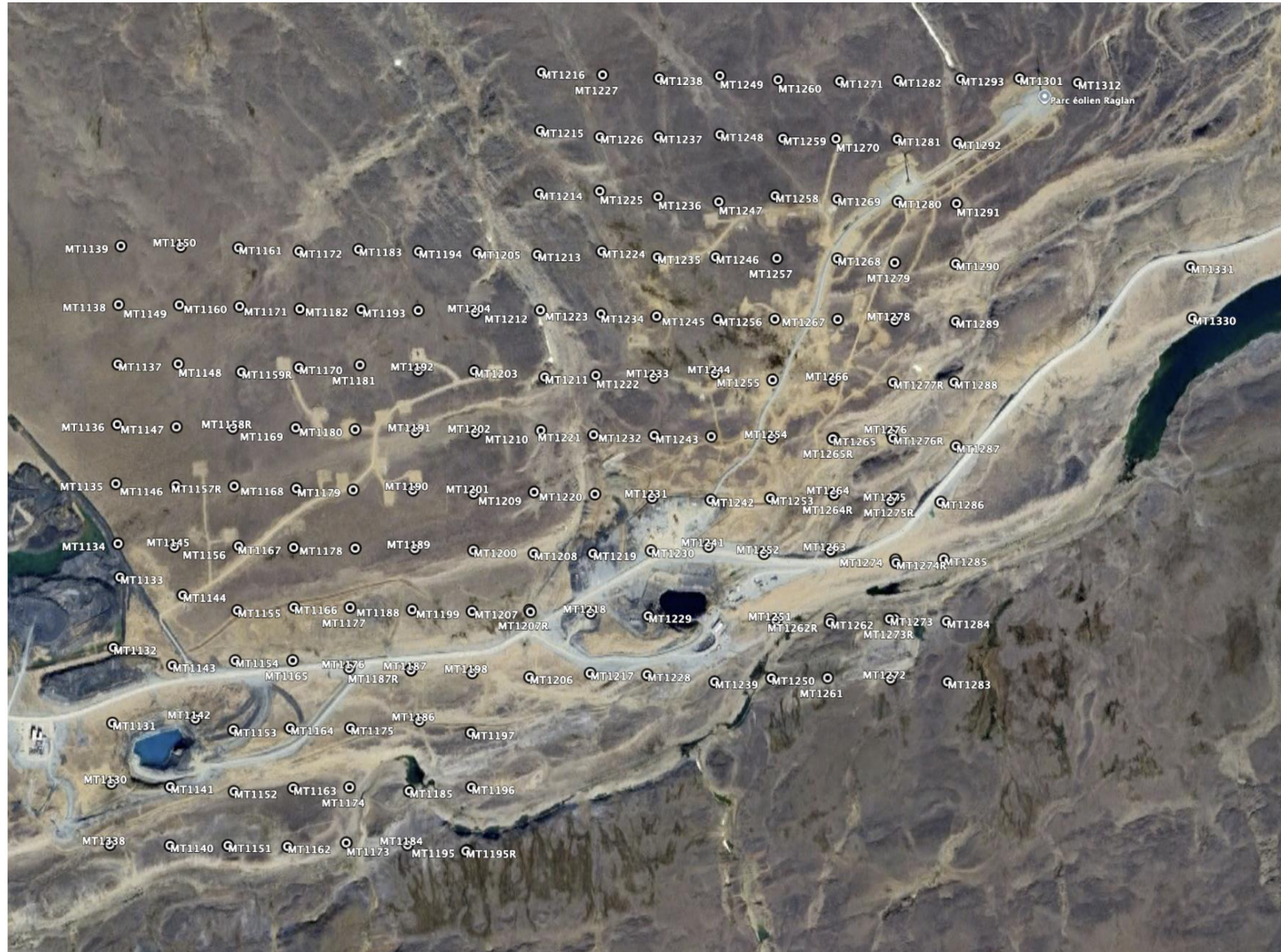


MT3DINV4R – Site locations

MT data (no Tippers)
from a total of 164
locations.

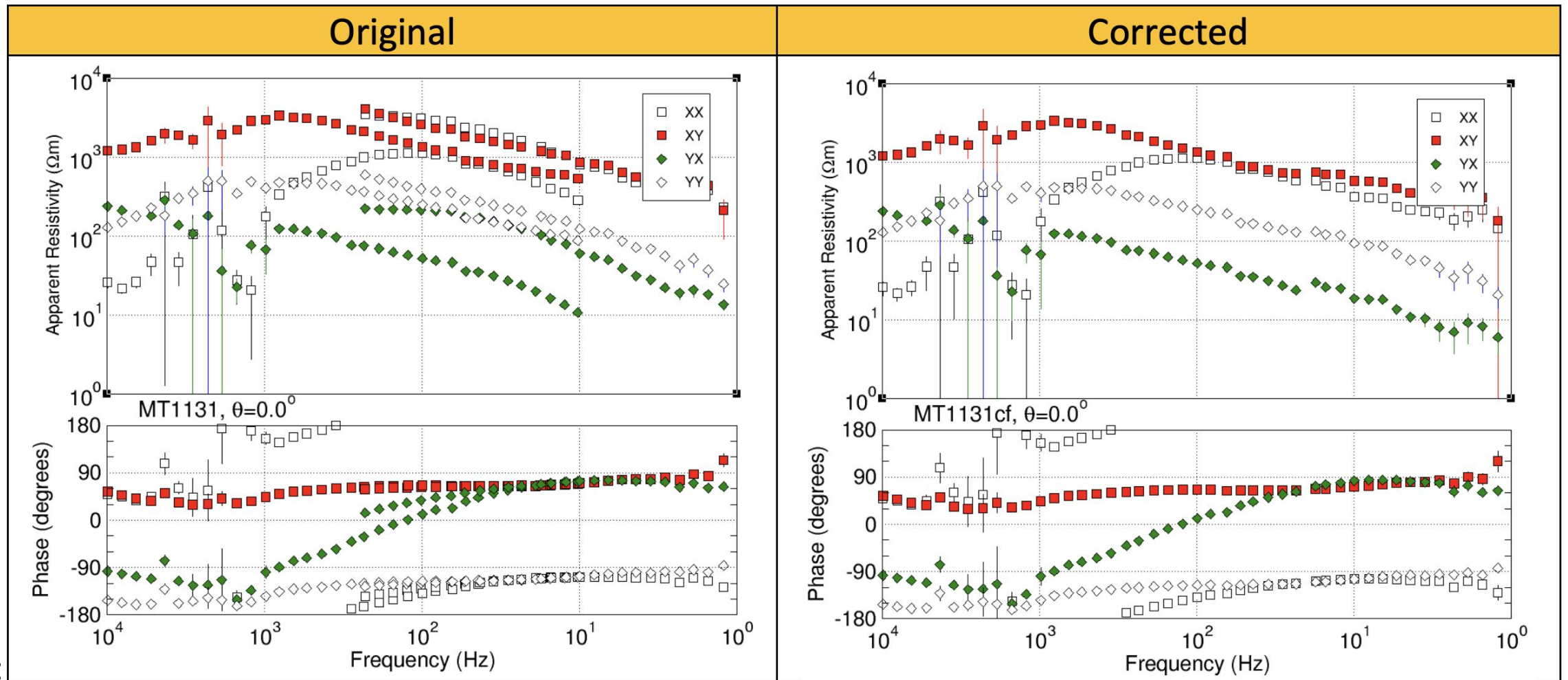
14 sites repeated (“R”),
so total of 178 EDI files
available.

Original Quantec
processing
downloadable from the
Province of Quebec's
Examine web site



MT3DINV4R – Real data – Corrected

Additional data made available are those that have been corrected for the mismatch between the high frequency response estimates (made with Geometrics G100K coils) and the low frequency response estimates (made with Phoenix MTC-50H coils)



MT3DINV4R – Quantec data model cf. MTGS

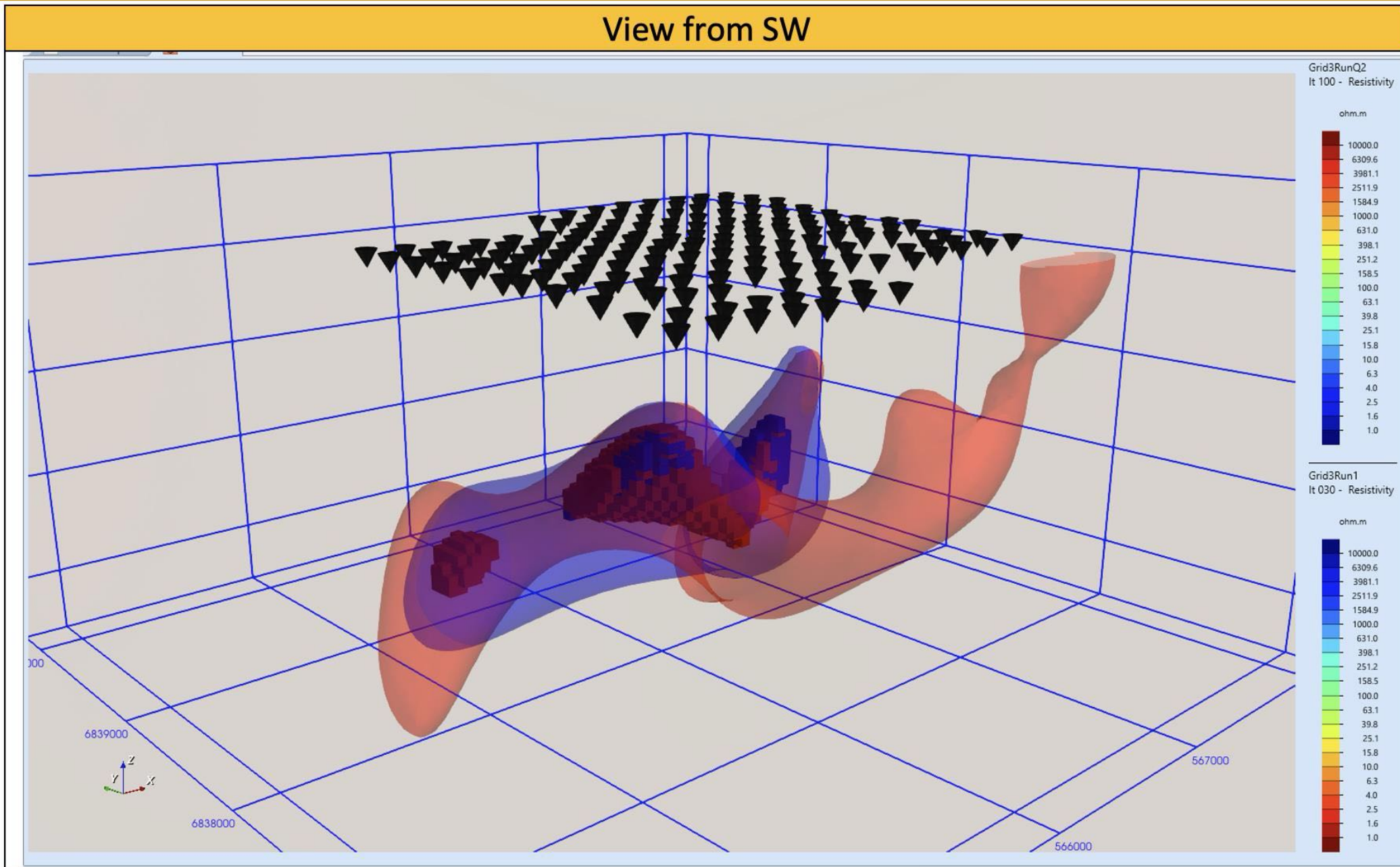
Comparison

MTGS data
model:

Dark red is $\rho < 1 \Omega\text{m}$ and
light red = $3 \Omega\text{m}$ for the

Quantec data
model:

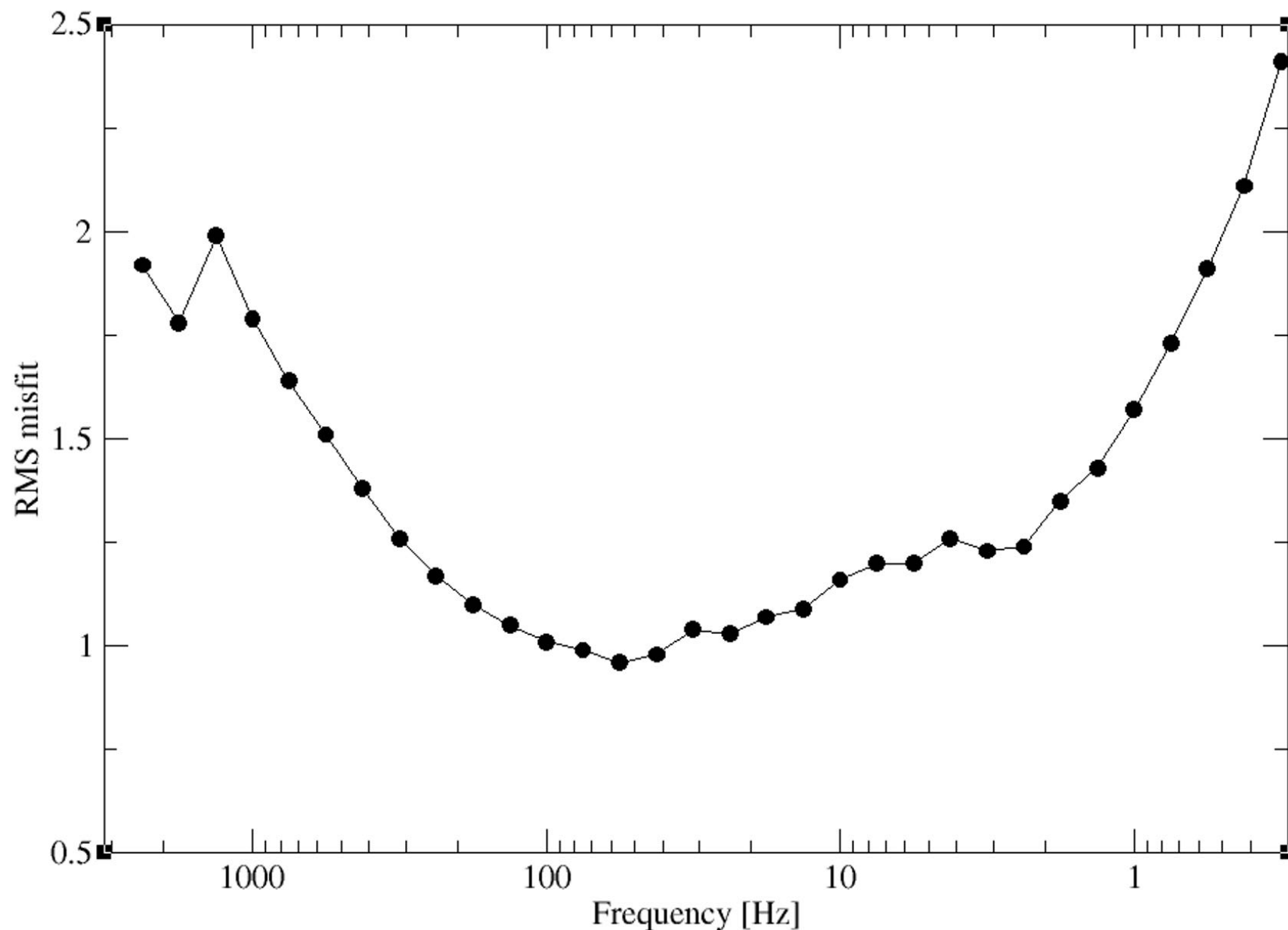
$\rho < 1 \Omega\text{m}$
and light blue = $3 \Omega\text{m}$



MT3DINV4R – Misfits over frequency

Misfits averaged over frequency for all sites most of the misfits are highest and lowest frequencies

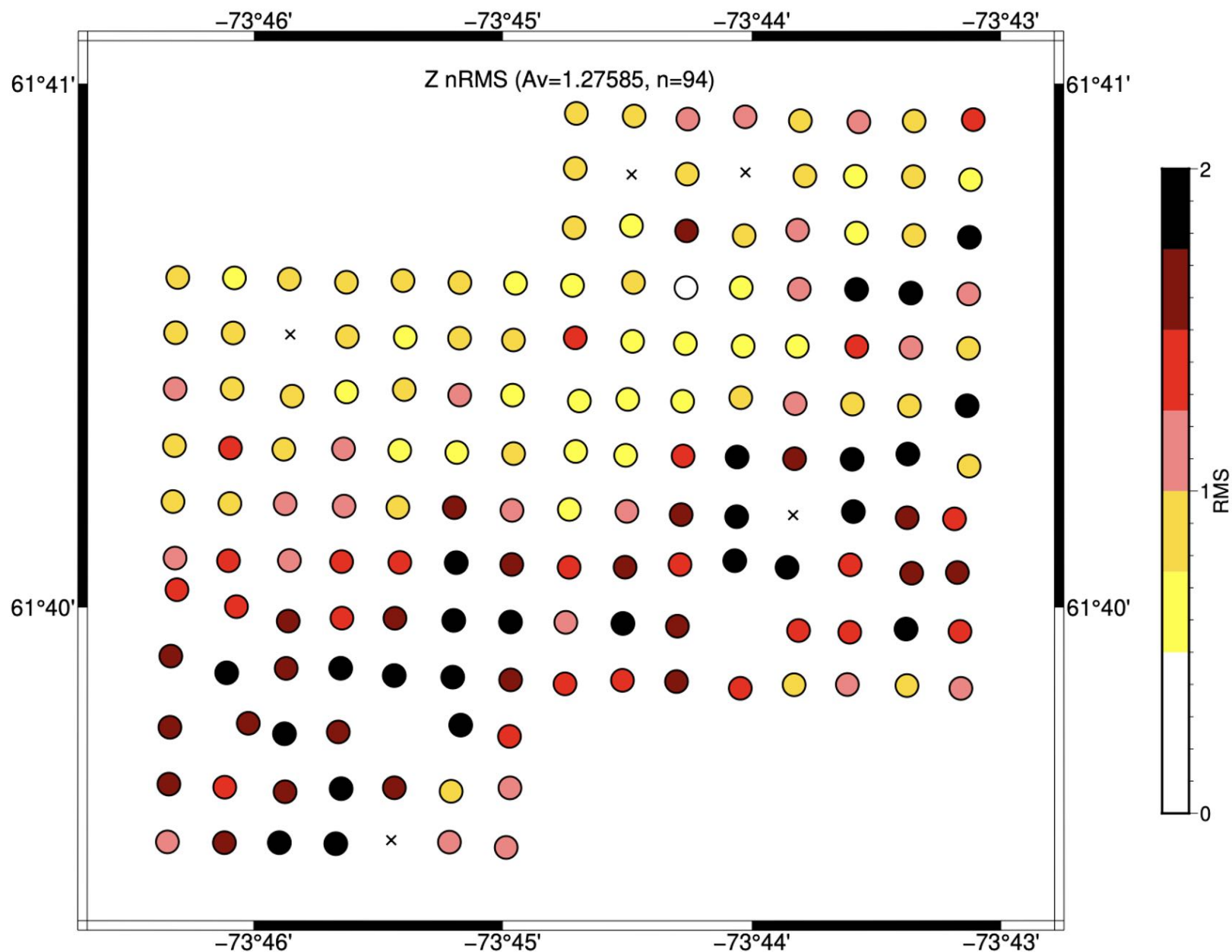
➔ The topmost and lowermost parts are likely more poorly resolved than the middle parts



MT3DINV4R – Misfit map

Misfit map over all frequencies at each site shows most of the misfits are at sites in the SE

→ These sites had higher noise and more distortion



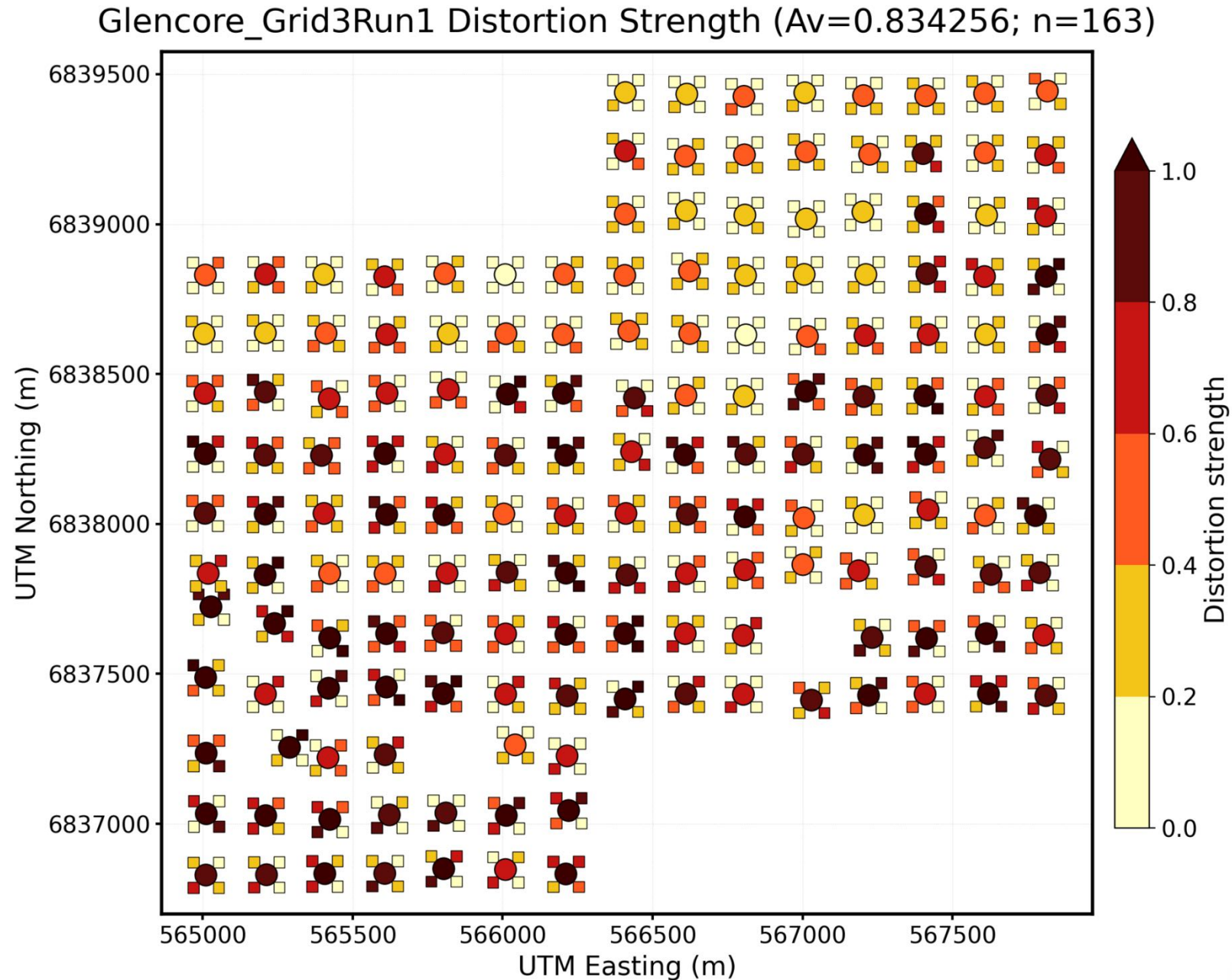
MT3DINV4R – Distortion

The distortion map shows a huge amount of distortion at many sites, particularly those in the SW.

Note that in most cases it is one element of the C matrix that is large

Small squares show the 4 elements of the C distortion matrix

Centre circle is the distortion strength, given by $Ssq(\underline{C} - \underline{I})$



● What real data changed

Measured against Tasks 1 and 2, where the data were perfect by construction

01

Nobody reached RMS 1

1.31 · 2.7 · 3.69 · 7.97

final misfits, Jones · Smirnov · Montiel · Lu

In Task 2 almost every submission landed near unity. Here the best result took five runs, three grids, iterative muting and solved-for distortion to reach 1.31. The gap between those two numbers is the entire difference between synthetic and field data, and it is worth stating plainly rather than explaining away.

03

Distortion and robust norms did the heavy lifting

220 → 2.7

Smirnov's ModEM run, once Huber-loss IRLS was applied

L2 on data that partly cannot be fit does not converge to anything useful. Smirnov's robust reweighting and Jones's solved-for C are two answers to the same problem. Where the treatments differ, the models differ: MR3DMod with distortion returns a 10 $\Omega\cdot\text{m}$ background, ModEM without it returns 500 $\Omega\cdot\text{m}$.

02

The real work was deciding what to throw away

90 → 16

frequencies retained by Lu; Montiel kept 20, Smirnov 19

Every group independently discarded most of the band and some of the sites. Jones muted by Quality Factor and by per-point RMS; Lu deleted ten EDIs and de-spiked site by site; Smirnov dropped to 142 sites. Editing was not preparation for the inversion — it was the largest single determinant of the result.

04

The target survived all of it

3 conductors

found independently by Jones and by Montiel Alvarez

Three compact bodies below 1 $\Omega\cdot\text{m}$: one central-western, one north-central and elongated NE–SW, and a smaller one SE of centre. They sit between sea level and ~600 m below it, roughly 600–1200 m below surface, and they recur across all four of Jones's models and across the independent Quantec processing.

Geophysics is art of approximation.

Here are some quotes from this workshop

- “I don’t care how much time my inversion takes”
- “Inversion mesh can/should be different than forward mesh”
- “How accurate forward/inversion is good enough?”
- “Nobody other than Naser can use ModEM”
- “ We should plot RMS map at each frequency”
- “I used 5000 core hours for task 2”
- “I ran deterministic inversion for 21 days”
- “It’s a workshop, you can show weird stuff”
- “How do you regularise?, bring larger structures' first”

● What to do next

Six things the presenters themselves proposed

01

Invert the airborne data

ZTEM, MobileMT and QAMT went almost untouched — an independent test of the models we already have.

Li · Skibbe · Musila & Cowan · Vanlsüha

02

Report uncertainty, not one model

Ensembles or stochastic sampling in place of a single preferred result.

Mishra · Liu · Song · Musila & Cowan

03

Standardise what a submission states

Validated error per band, tipper separately, sign and coordinate conventions declared.

Fry · Li · Kangazian · Song

04

Study the error floors

Floors ran 0.5 % to 10 %, and shaped the models more than the choice of code did.

Jones · Montiel Alvarez · Musila & Cowan

05

Settle topography meshing

Conforming meshes, finer top layers, no stations on cell edges or cliff faces.

Jones · Dong · Ansari · Manara · Skibbe

06

Push joint inversion

MT with CSEM, gravity and magnetics — affordable now that forward cost has collapsed.

Fry · Smirnov · Musila & Cowan · Skibbe

Underneath all six: one model and one number is not a result.

Publication:

There will be a publication coming from this workshop, as we did after MT3DINV1+MT3DINV2 (Miensopust et al., 2013)

Deadline for submission of responses and models is end-October
- *other contributions welcome*

Geophysical Journal International



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Magnetotelluric 3-D inversion—a review of two successful workshops on forward and inversion code testing and comparison

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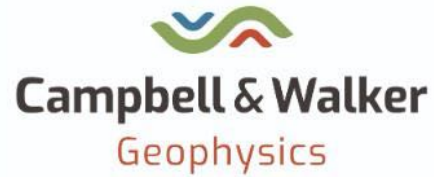


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