REMPLEX 2025

A trial of geoelectrical methods for leak detection and monitoring during waste retrievals from the Magnox Swarf Storage Silo, Sellafield, UK

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Sellafield Ltd

BGS British Geological Survey

MSSS

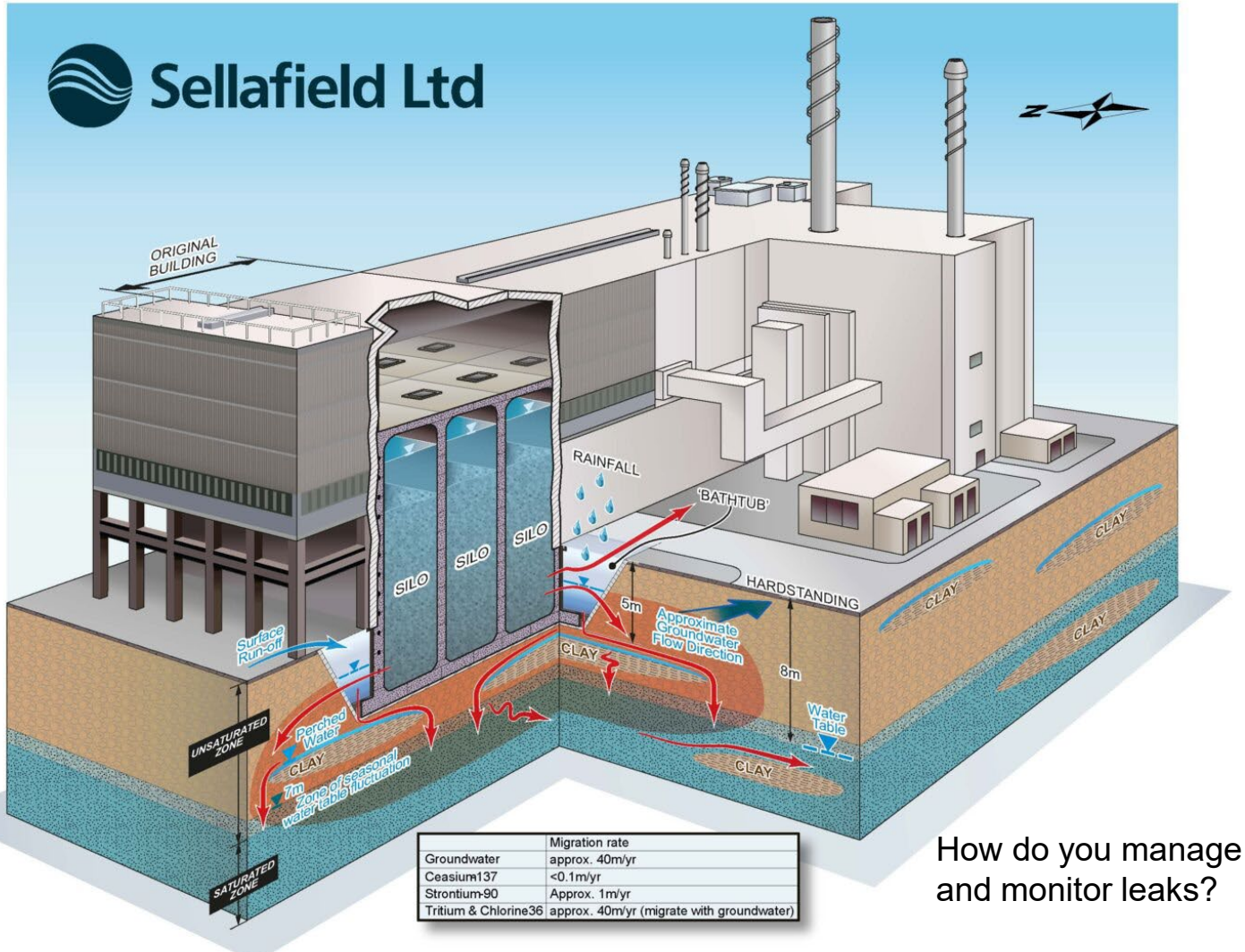
Magnox Swarf Storage Silo

- Located at the Sellafield site, Cumbria, England.
- Originally constructed in the 1960s, to store nuclear waste.
- The building was extended 3 times throughout the 1970s and 1980s as it filled up.
- The building has been leaking radioactive liquor into the ground below MSSS.
- Efforts are ongoing to remediate and decommission the site.

Magnox Swarf Storage Silo

- Contains concrete storage silos which contain water-covered **corroded magnesium alloy** swarf among **other** nuclear waste products
- A leak was first identified in the 1970s, however the leak apparently self sealed, but since 2019 the MSSS has been leaking again.
- Several metallic perforated and blind tubes installed around MSSS to monitor radioactivity.
- No way to fix the leak until all the **waste is removed** (expected to take **several decades**).

https://www.gov.uk/government/case-studies/what-is-the-magnox-swarf-storage-silo



How do you manage and monitor leaks?

Why use geoelectrical methods

Advantages

- Due to radioactivity, drilling further boreholes carries risk and is expensive.
- Geoelectrical methods are non-invasive and (theoretically) spatially sensitive (can observe under the MSSS as well as around it).
- Highly sensitive to fluids of various conductivities (like radioactive liquor).
- Can use pre-existing metallic infrastructure as electrodes.

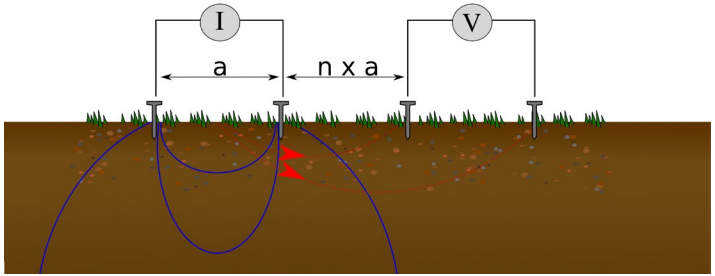
Disadvantages

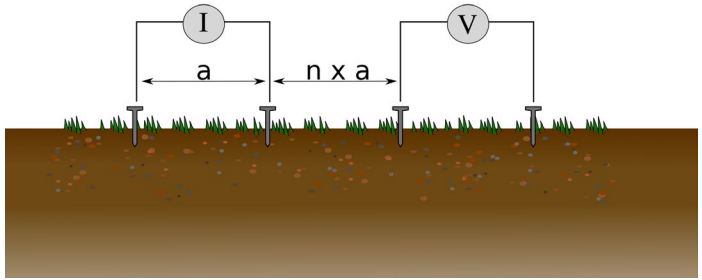
- Subsurface infrastructure is dense and often metallic. Therefore, the site is geophysically noisy (multiple targets are likely to produce geophysical anomalies).
- Geometry is complex, making the problem difficult to process (mesh construction is challenging).
- Indirect information, data can be difficult to interpret.
- Risk of excessive current injecting into the silos (sparking).

A DC resistivity measurement

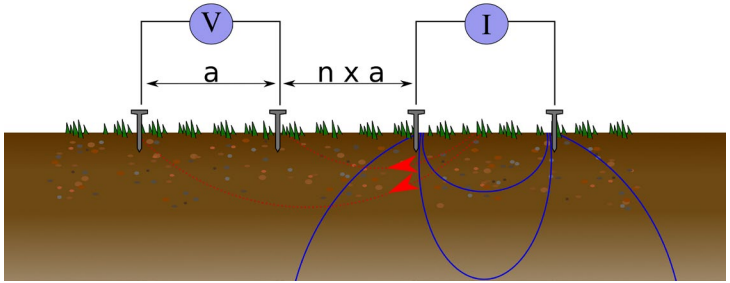
$$R = \frac{\Delta V}{I}$$

Forward configuration

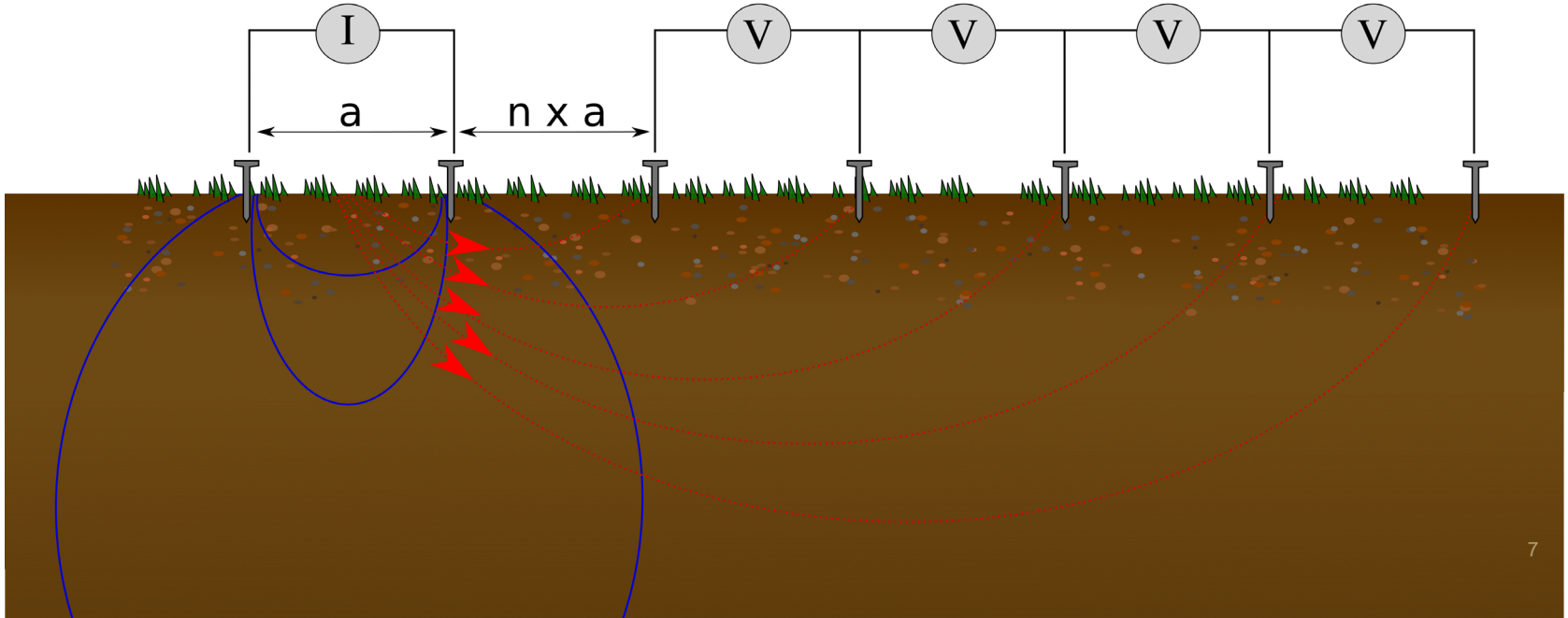




Reciprocal configuration



Multiple DC resistivity measurements



Types of measurement

Mise-à-la-masse (MALM)

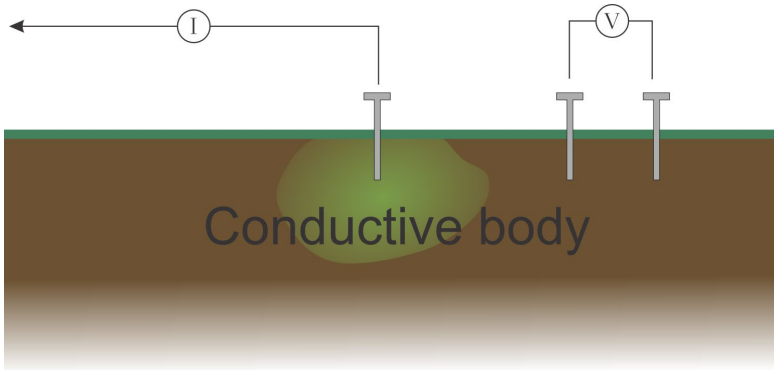
- Loosely translates to the “charged body” method.
- Inject current in the silo and on reference electrode.
- Measure across a potential dipole.
- Used to detect electrically connected (conductive) regions in the subsurface.
- Origins can be traced to ore body exploration. Used for detecting leaks in landfill liners.

Electrical Resistivity Tomography (ERT)

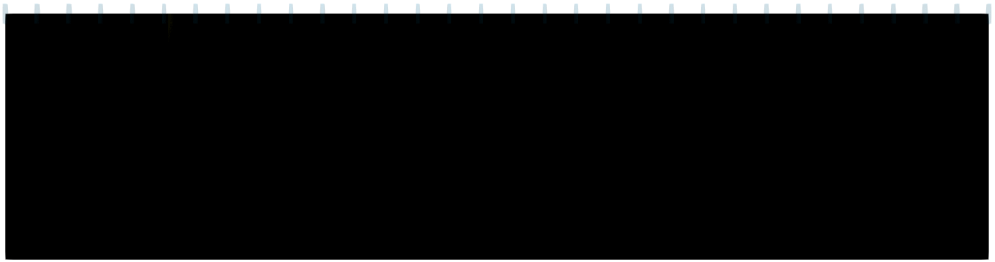
- Also known as electrical resistivity imaging (ERI).
- Measure resistances across 4 electrodes (usually).
- Model a distribution of electrical resistivities, through a process known as inversion or imaging.
- Used for general geophysical imaging of the subsurface. Sensitive to subsurface fluids and lithologies.

Types of measurement

Mise-à-la-masse (MALM)



Electrical Resistivity Tomography (ERT)



Geoelectrical Trials at MSSS

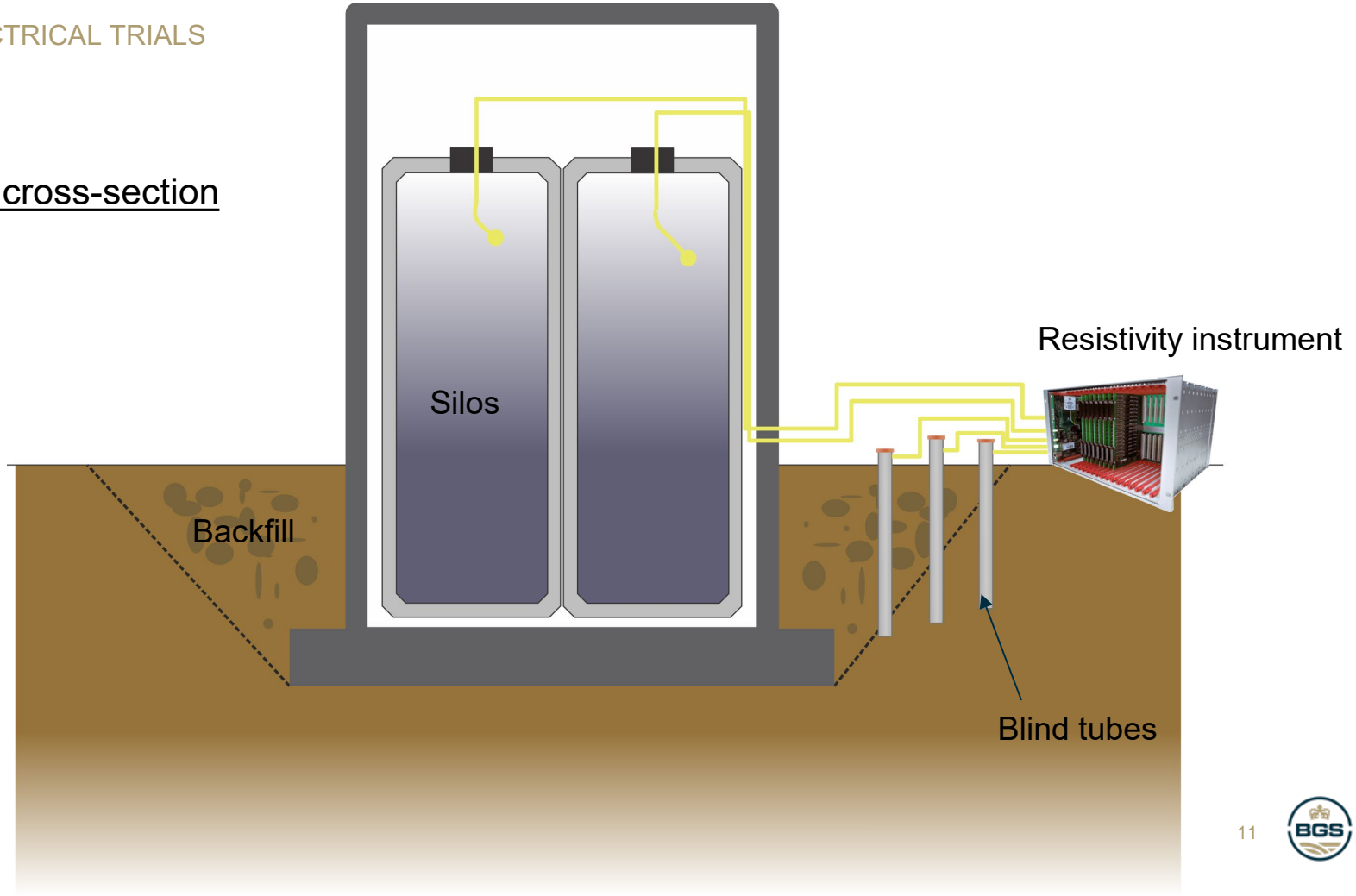
2022

- One instrument (AGI SuperSting)
- 40 electrodes
- Day-time operation
- MALM and ERT data collection
- 4 days data collection
  - Sting: ~22,000 measurements

2025

- Two instruments (AGI SuperSting, BGS PRIME).
- 54 electrodes
- Day- & night-time operation
- MALM and ERT data collection
- 10 days data collection
  - Sting: ~89,000 measurements
  - PRIME: ~181,000 measurements
- Implement standard MALM (forward measurements).

MSSS cross-section



What are the SuperSting and PRIME?

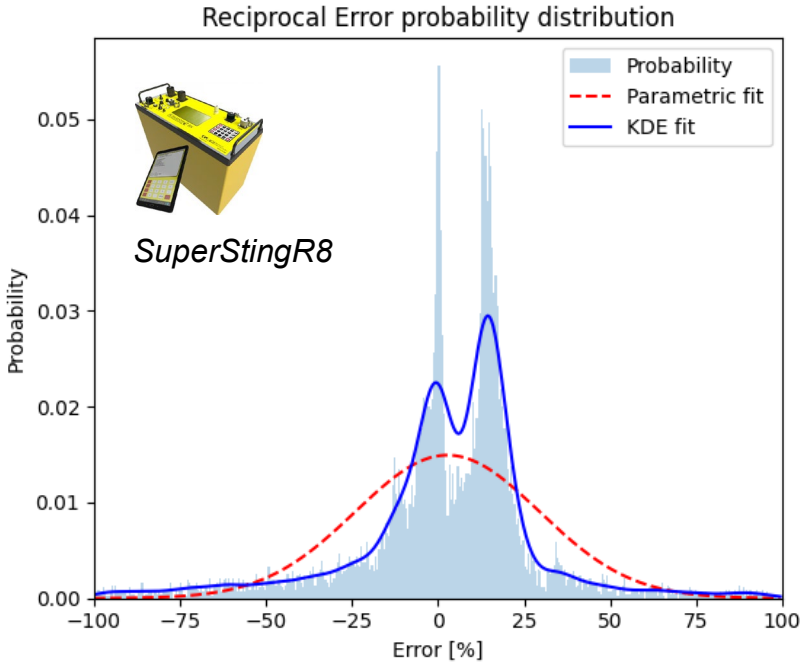
Advanced Geosciences Inc. (AGI) SuperSting R8.

- Measures on up to 8 channels simultaneously.
- Outputs currents of 1- 2000 mA, up to 400 V.
- The output of the Sting was deemed a risk for energising the silos as it may ignite flammable gases contained within. Hence the **electrode connections** were routed through **guard resistors**.
- MALM measurements only made in reciprocal configuration.

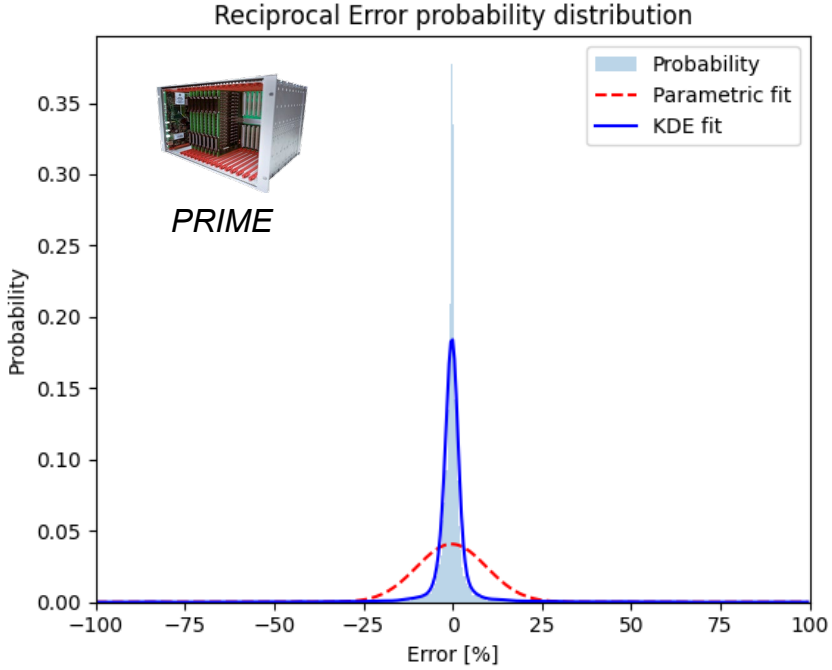
British Geological Survey (BGS). PRoactive Infrastructure Monitoring and Evaluation (PRIME) instrument.

- Measures on up to 7 channels simultaneously.
- Originally designed to be power efficient for autonomous monitoring and hence outputs comparatively small currents (1-100 mA).
- Customised to limit the output voltage to 48 V, which was deemed safe to excite the silos.
- MALM measurements made in forward and reciprocal configurations.

ERT Data quality from recent trial (2025)



Large reciprocal errors and bimodal distribution, not good - shows measurements are inconsistent. Sting measurements are therefore disregarded from 2025.

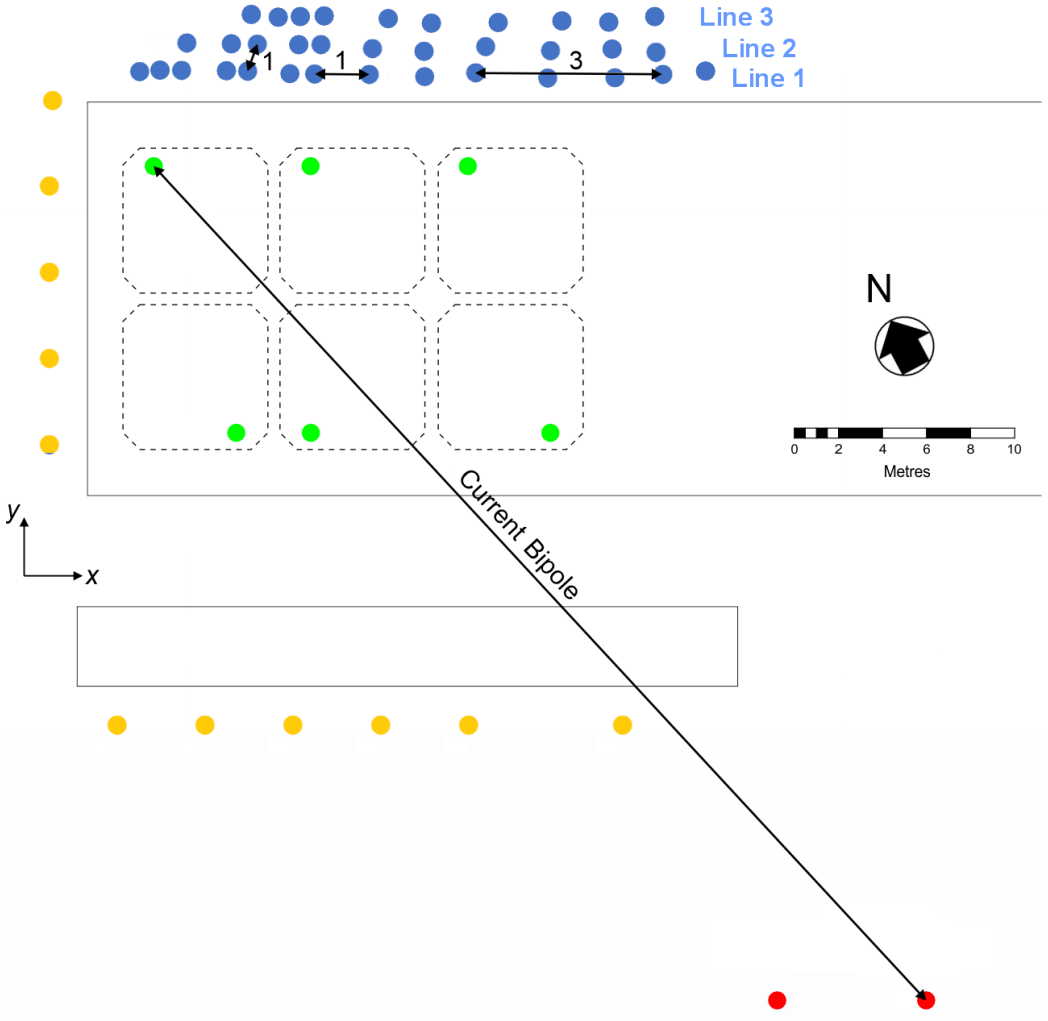


Tight gaussian distribution, demonstrates PRIME has made consistent measurements in the forward and reverse configurations.

MALM measurements

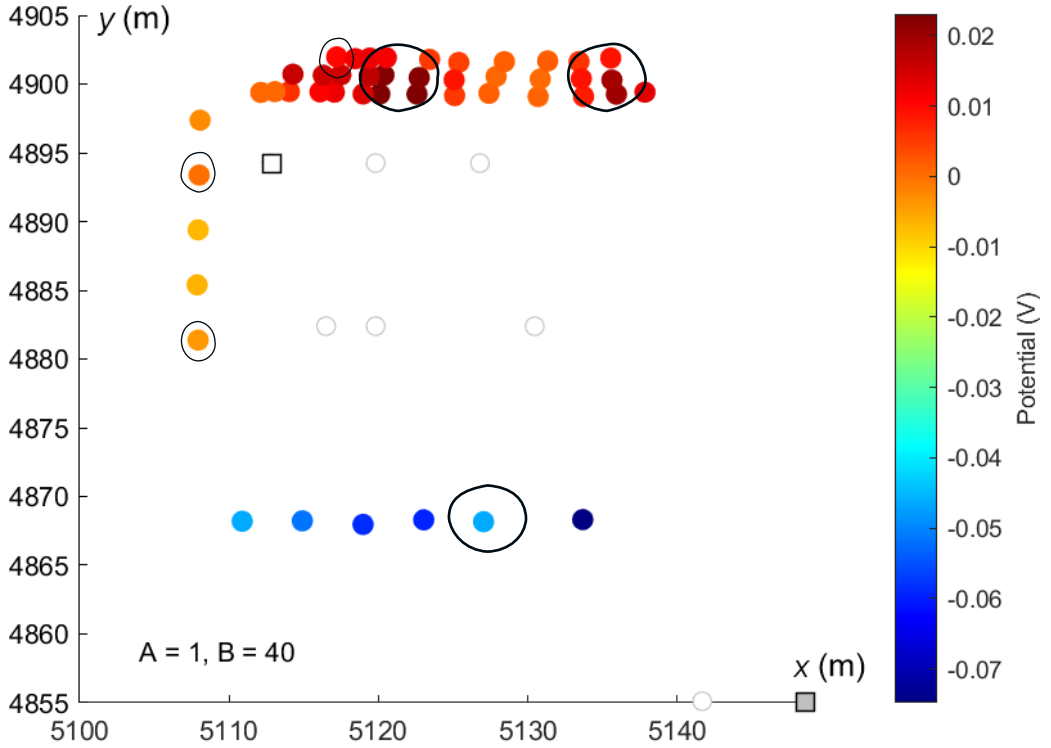
Site Plan

- MALM
- Current injected on electrode in the silo to an external reference electrode.
- Electric potentials measured across pairs of blind tubes.
- Theory: leak should act as a conductive electrical pathway, resulting in a local maximum in the measured potential distribution.

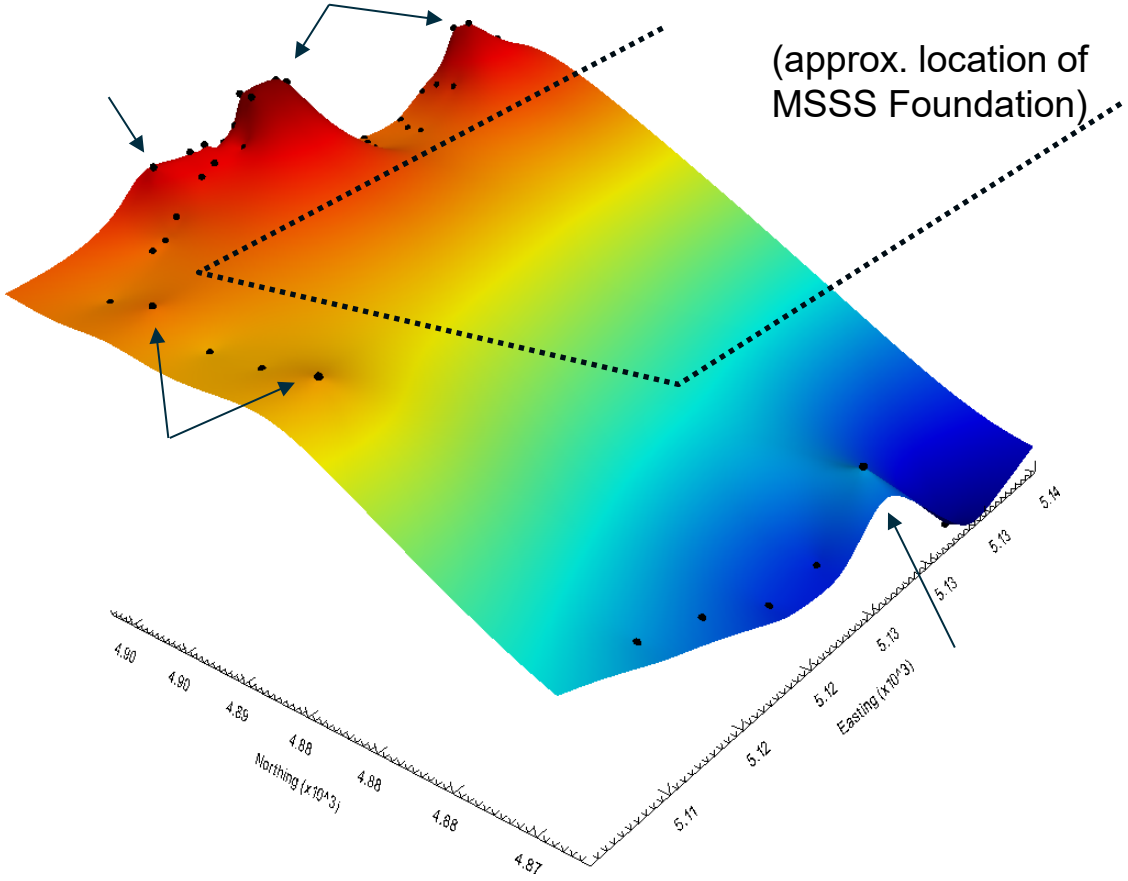


Peaks in the data

- Local maxima may indicate peaks.
- Clearer picture to be had when interpolating the points and displaying as a 3D surface.

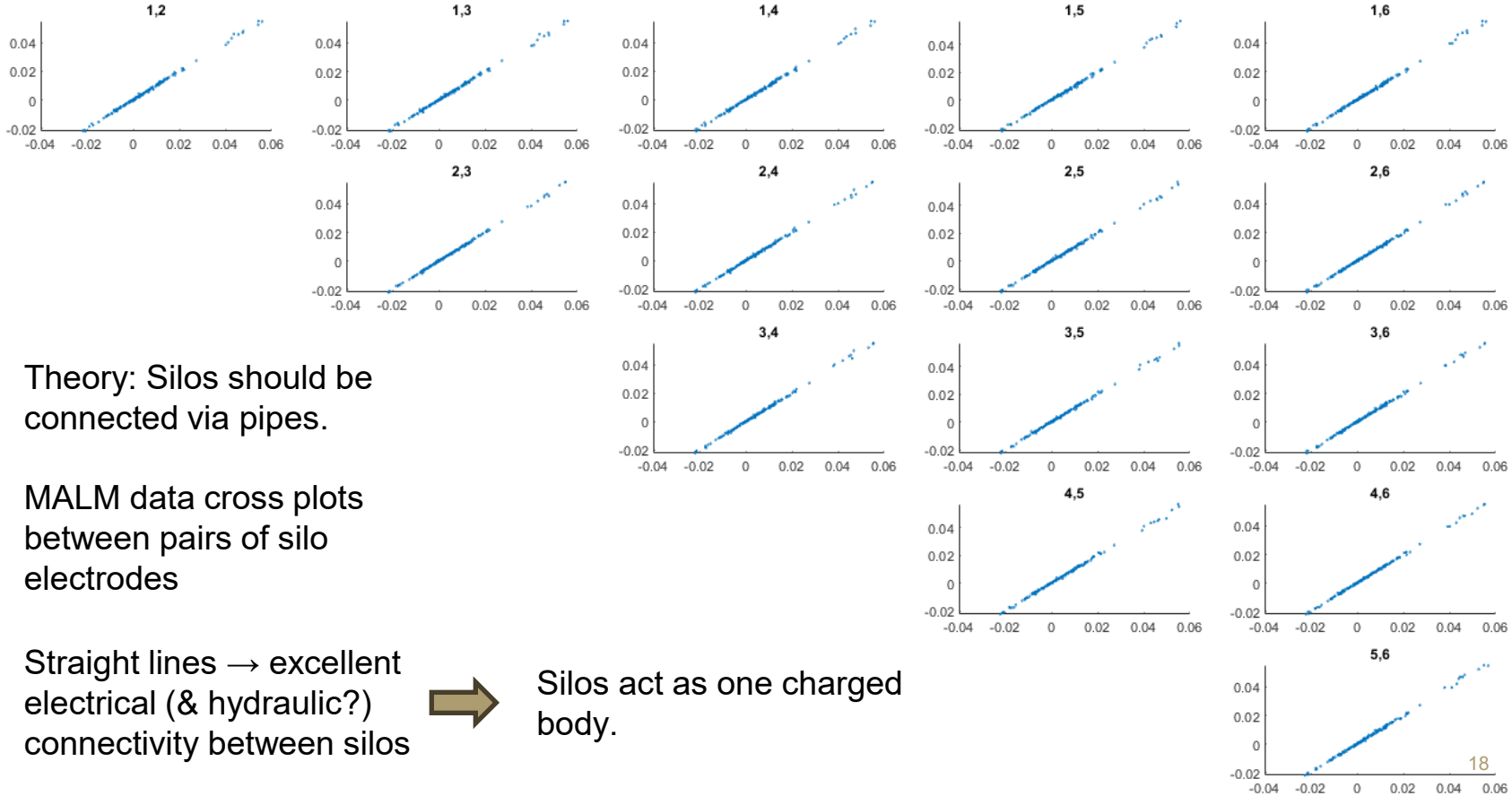


MALM PRIME results - leaks



- Silo electrode positive – current escaping from building → local potential maximum
- Two strong isolated peaks on north side, but evidence for electrical shorting into silos
- Weaker peak on north, no apparent shorting but proximity obscures interpretation
- Two weak peaks on west, possible leaks
- Strong peak on south, indicative of a preferential conductive pathway.

Silo connectivity



Theory: Silos should be connected via pipes.

MALM data cross plots between pairs of silo electrodes

Straight lines → excellent electrical (& hydraulic?) connectivity between silos

Silos act as one charged body.

MALM Summary – data validity

- PRIME MALM measurements were made in standard and reciprocal configurations.
- Proves that current can pass from silo to exterior.
- Evidence of some blind tubes on north side being electrically shorted together and into the silos.
- Peaks occur on the west and south side of MSSS, indicative of leaks.
- Silos are in excellent electrical contact with each other (so electrodes could be moved between silos as retrievals progress)

ERT measurements

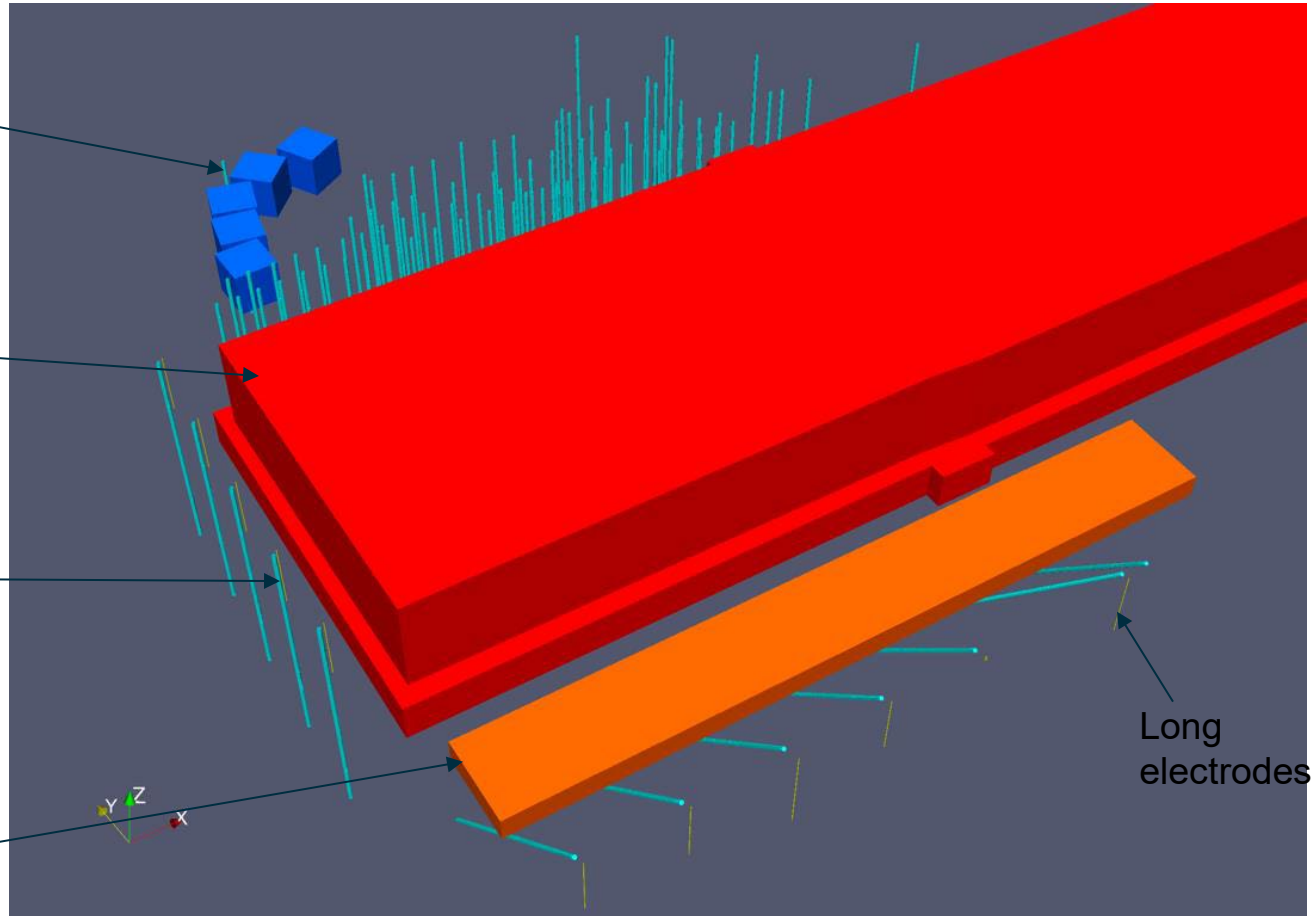
Processing

- DC resistance measurements were processed in E4D (PNNL code).
  - Has capacity for modelling metallic infrastructure (via the IMI module)
  - Massively parallel, efficient for handling large problems.
- We did a “difference” inversion (LaBrecque and Yang, 2001*) between the 2022 and 2025 trial. Effectively the differences measured between a baseline and time step are inverted against a baseline model.
- Data error models based on the reciprocal measurements.
- The finite element mesh was custom developed for this project, to include the building foundations and any metallic infrastructure (like the blind tubes).
- Processing the data proved extremely difficult, and multiple variations to the workflow were required to get reasonable results with acceptable fitting statistics (i.e. $\chi^2 \approx 1.0$).

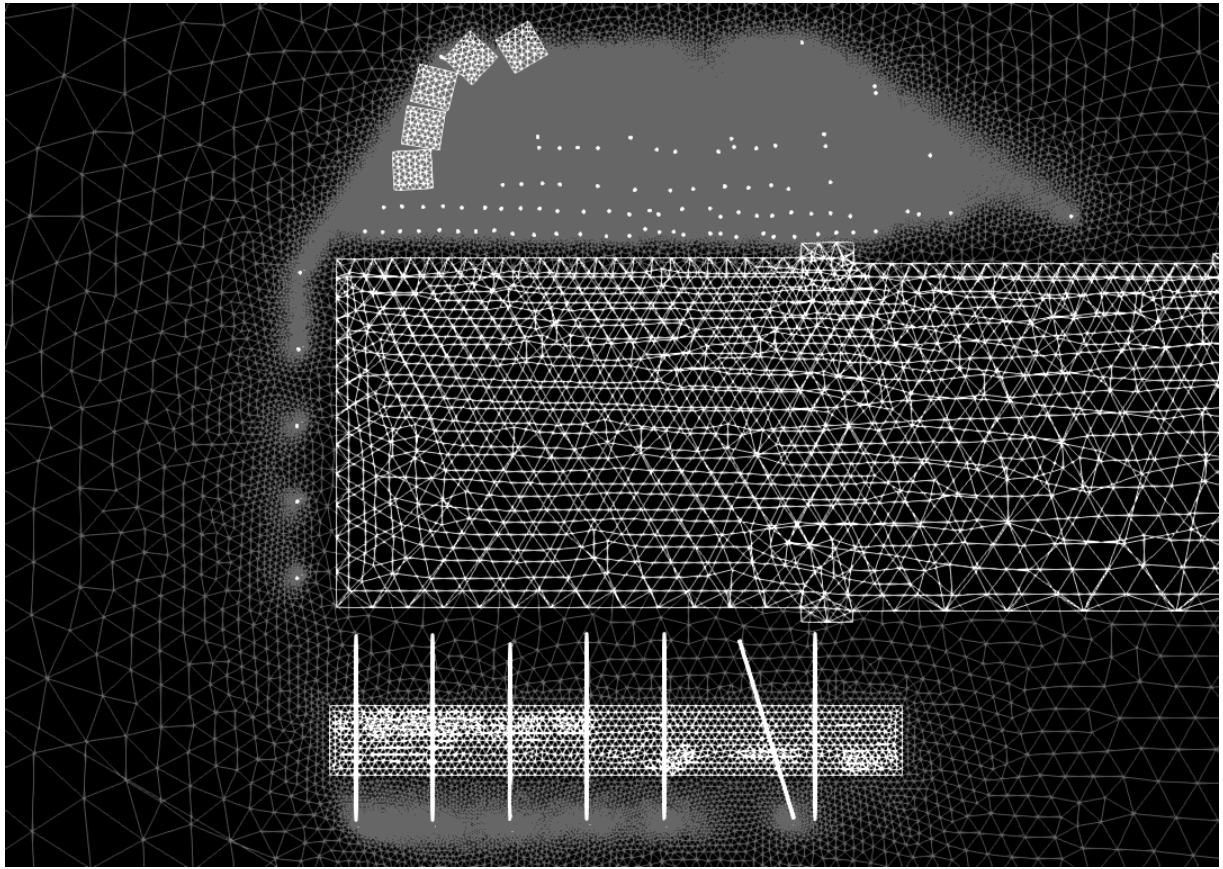
**LaBrecque, D.J. and X. Yang, 2001, Difference Inversion of ERT Data: a Fast Inversion Method for 3-D In Situ Monitoring, Journal of Environmental and Engineering Geophysics, 6(2), 83-89*

ERT inversion mesh

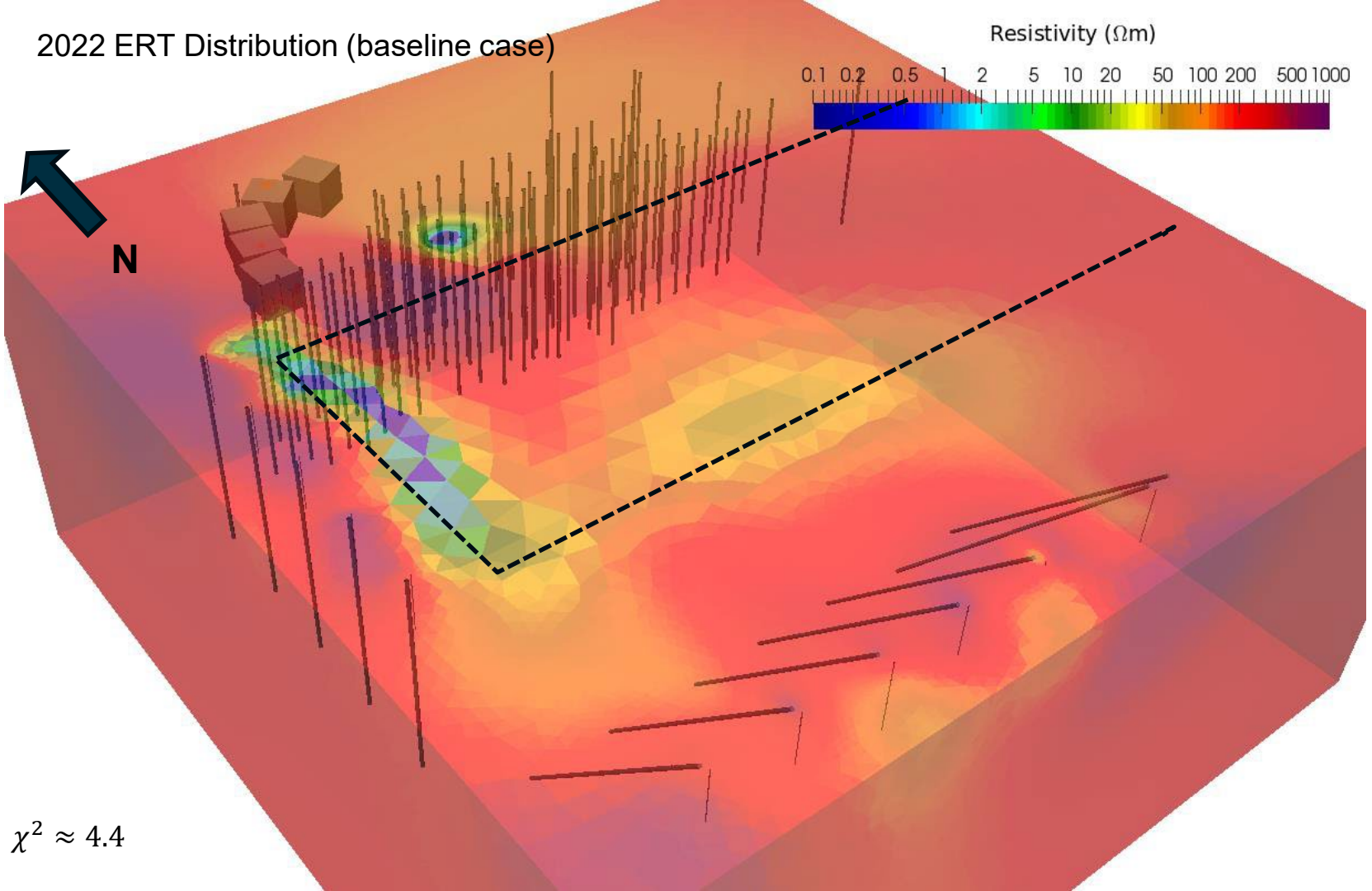
Note: low vertical resolution is to be expected.



ERT inversion mesh

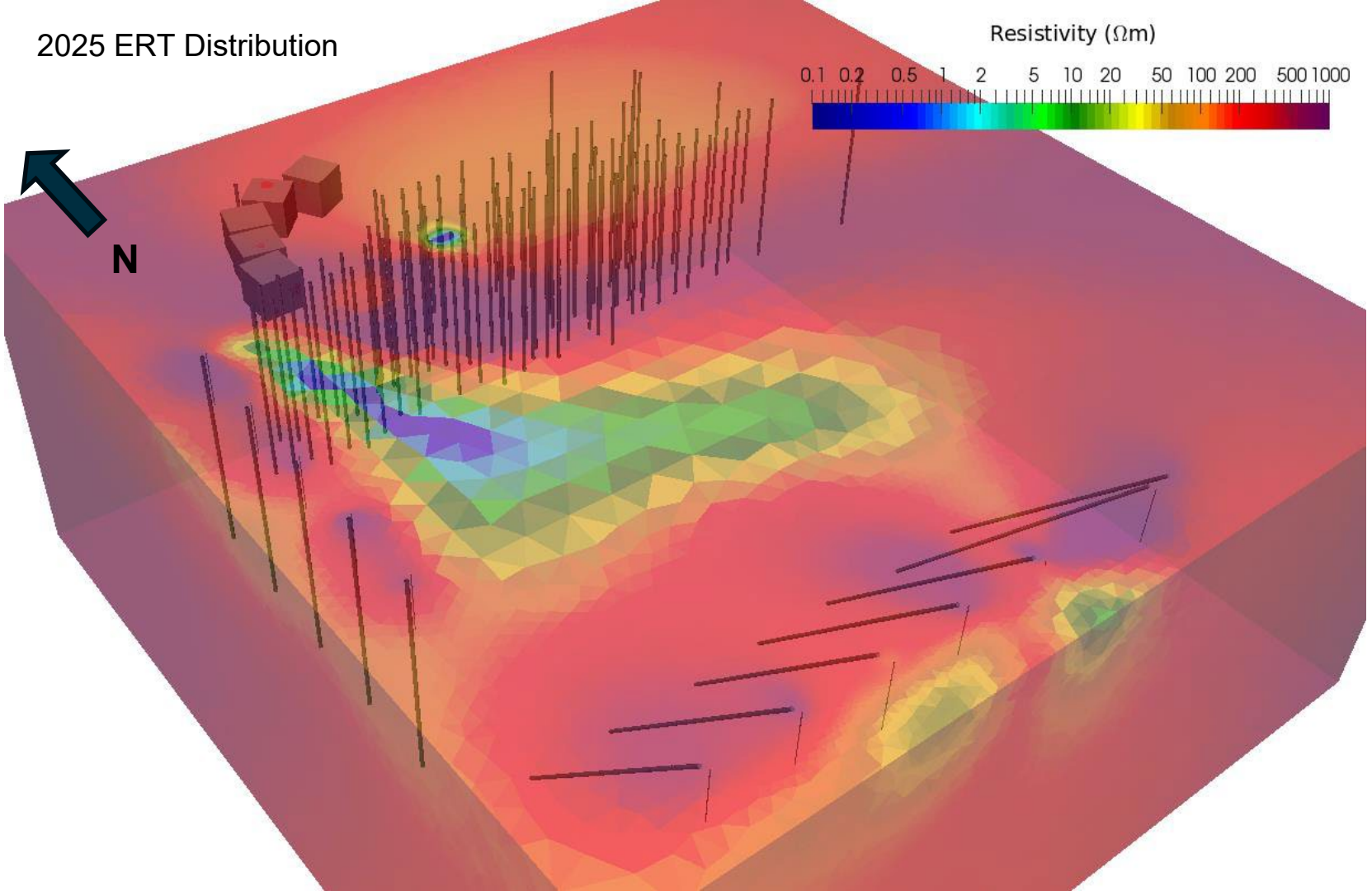


2022 ERT Distribution (baseline case)

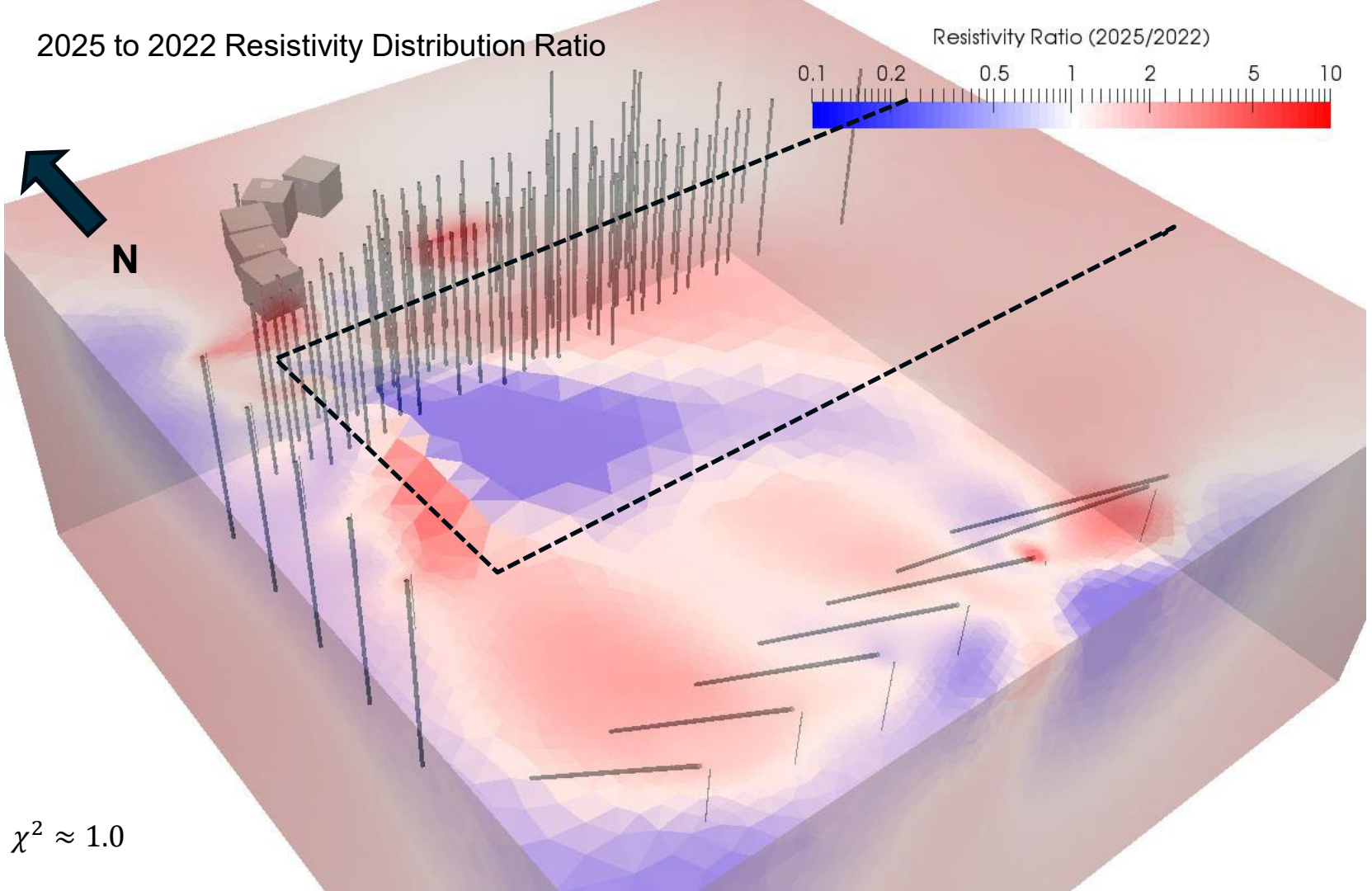


$\chi^2 \approx 4.4$

2025 ERT Distribution



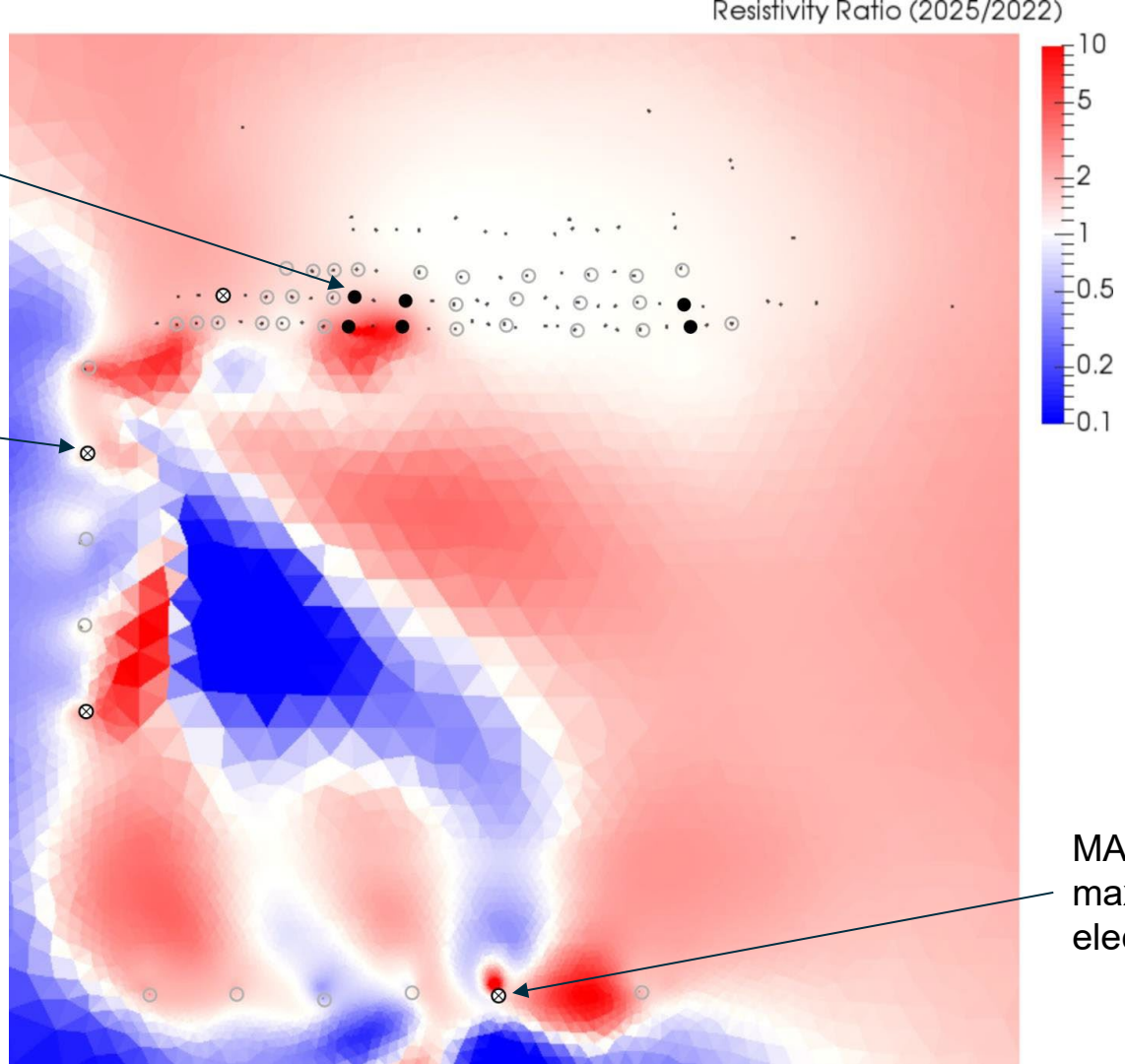
2025 to 2022 Resistivity Distribution Ratio



$\chi^2 \approx 1.0$

MALM maxima electrodes associated with shorting

MALM maxima electrodes



MALM maxima electrodes

ERT Summary

- Presented results have reasonable χ^2 values given the nature of the trial experiment. However, processing these data and subsequent interpretation of the results remains challenging.
- Difference inversion revealed resistivity change anomalies, in vicinity of MALM maxima.
- 2025 Sting data proved unusable (perhaps guard resistors impacted measurements).
- Demonstrated PRIME's sensitivity to subsurface changes. Hence, there is justification for monitoring with PRIME, as well as additional electrodes on the south side of MSSS to improve sensitivity of ERT.

Conclusions

Trial conclusions

- Trial results thus far indicate electrical continuity from between the MSSS silos and exterior foundation.
- Currently working with Sellafield to understand the value of these results how they can help identify any potential leaks.
- BGS recommends a permanent monitoring system and more electrodes (particularly on the southern and western flanks of MSSS). The trial has shown that BGS PRIME technology is well suited to this monitoring task.

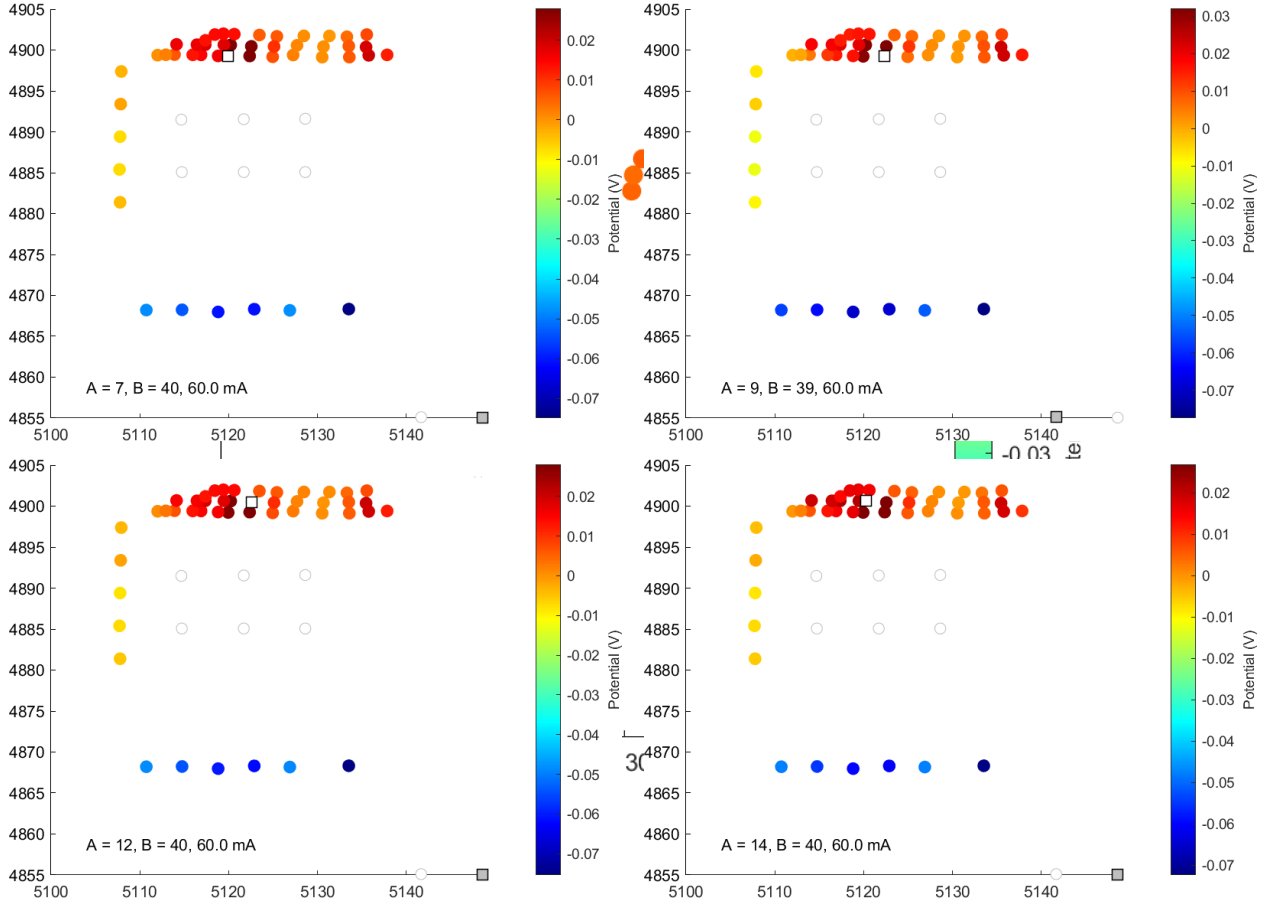
THANK YOU

Any questions?

Acknowledgements:
This work would not have been possible without continued support from Sellafield Ltd. We would also like to thank staff from i3 Decommissioning Partners for their great efforts in delivering the trial on site. Additionally, we thank the National Nuclear Laboratory for their help with understanding the site geometry and any buried infrastructure.

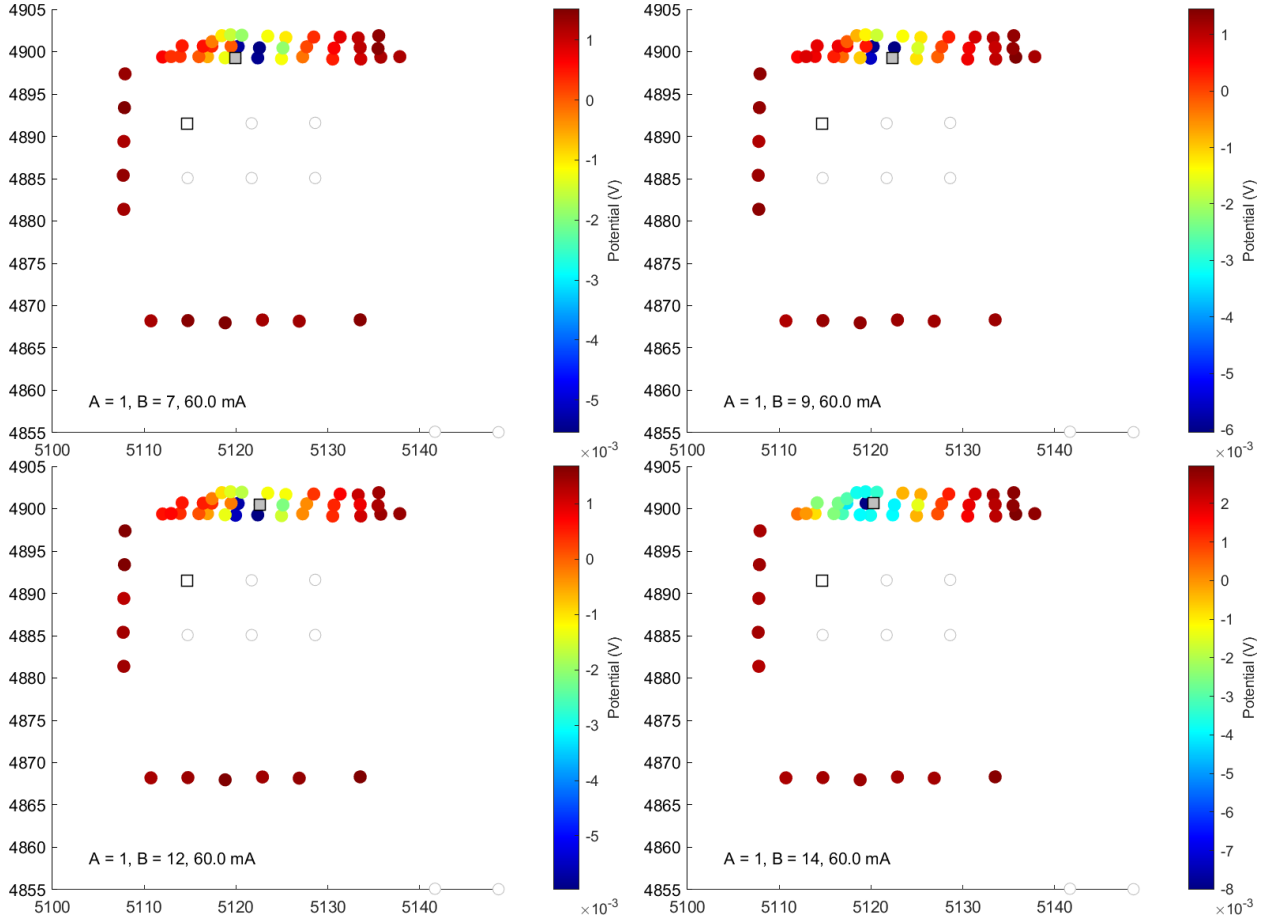

THANK YOU
Appendix

Apparent electrical shorting on perimeter



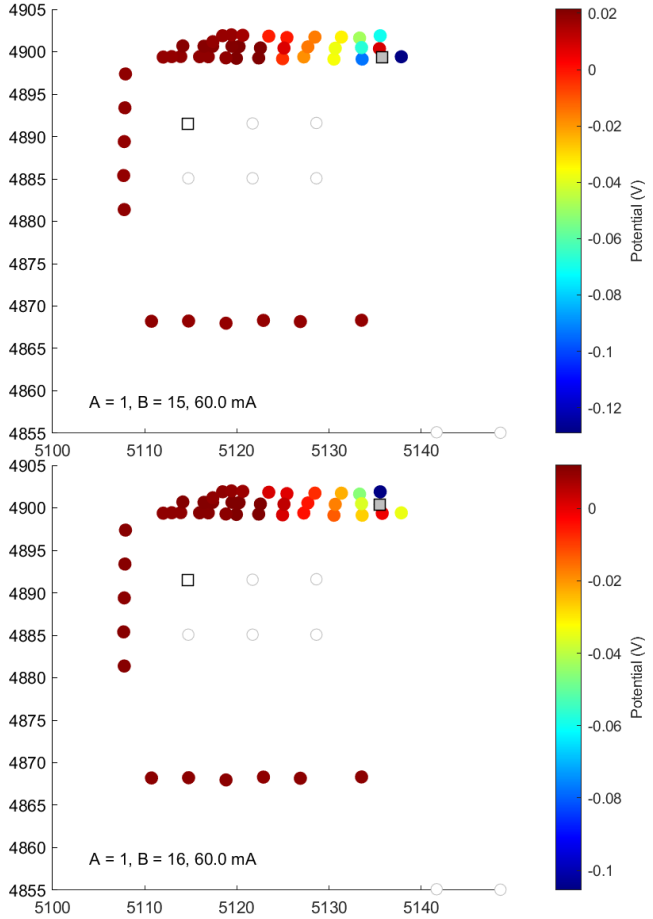
7,9,12 and 14 seem to be electrically connected to the silos (very similar potential distributions if they replace silo electrode)

Apparent electrical shorting on perimeter



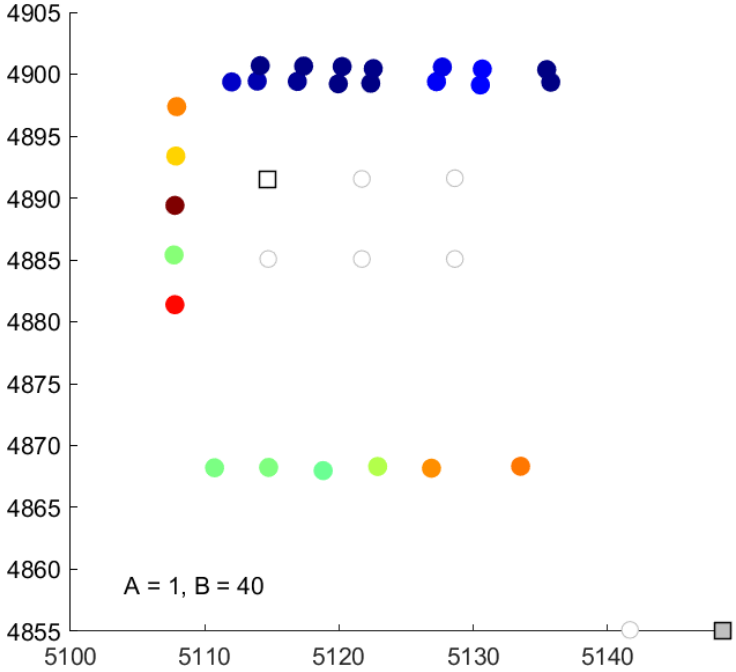
7,9,12 and 14 seem to be shorted together, and into the building/silos (little current seems to be injected into the surrounding ground – very weak potentials)

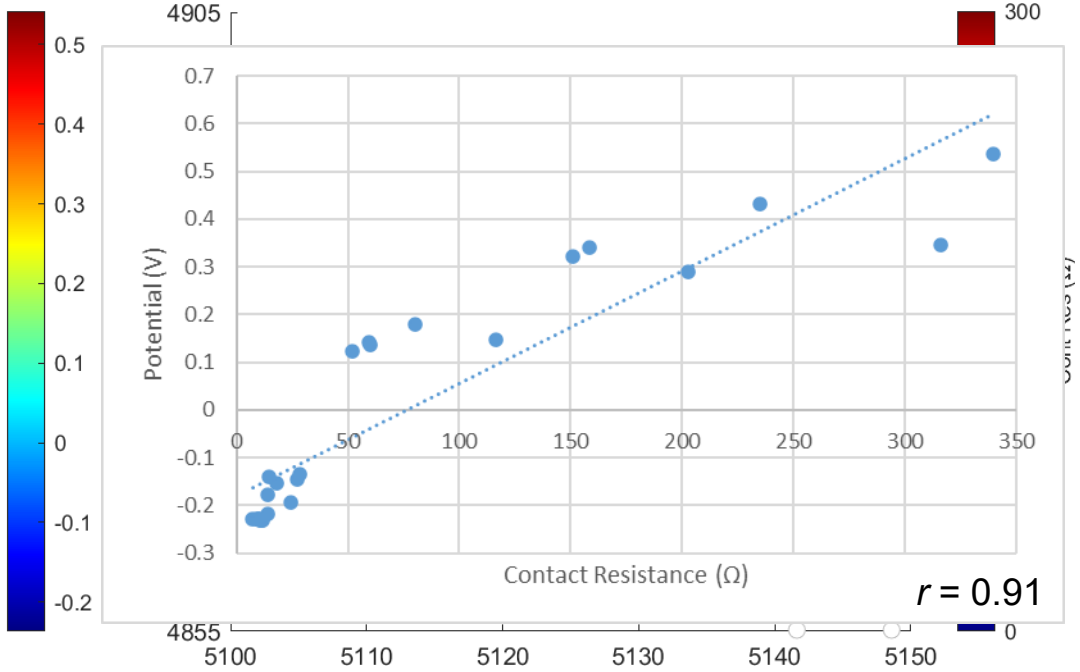
Apparent electrical shorting on perimeter



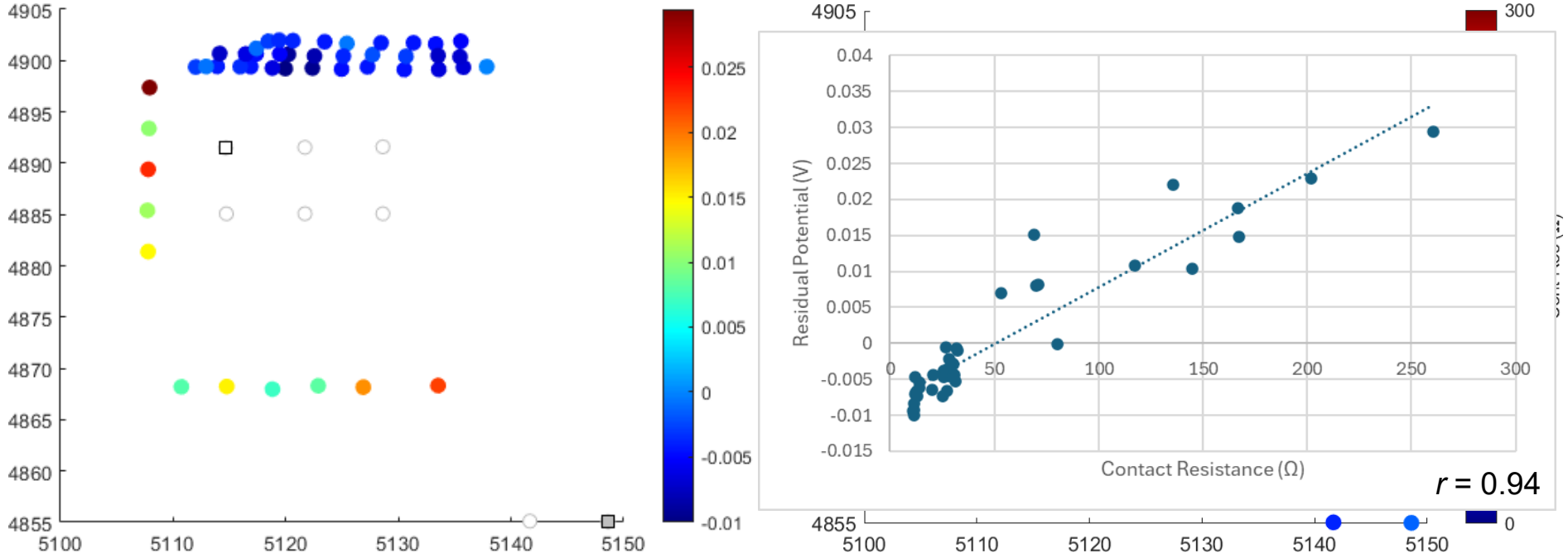
15 and 16 appear to have a low resistivity connection but possibly through the building / silo rather than being in direct contact

2022 Sting MALM – correlation between V and CR



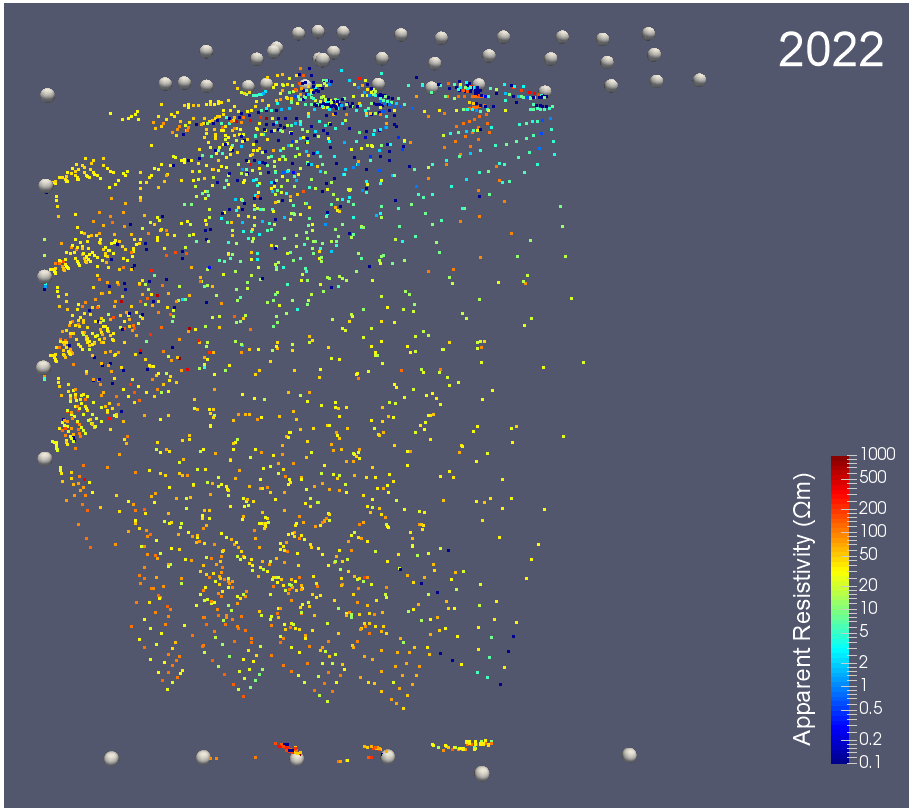


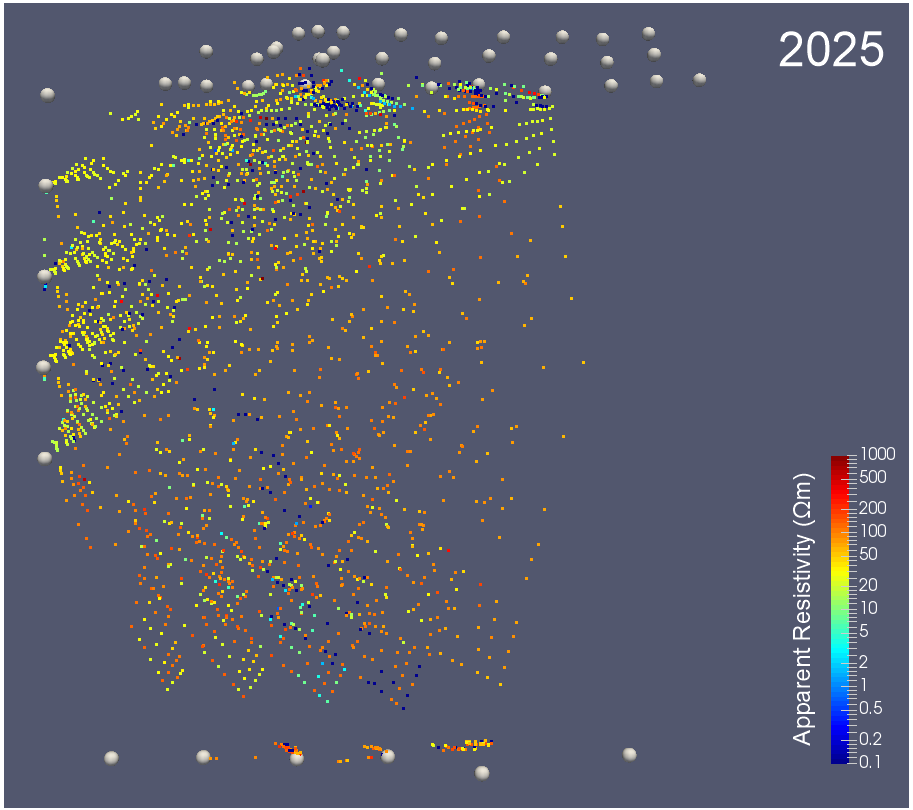
2025 Sting MALM – …a strongly correlated component



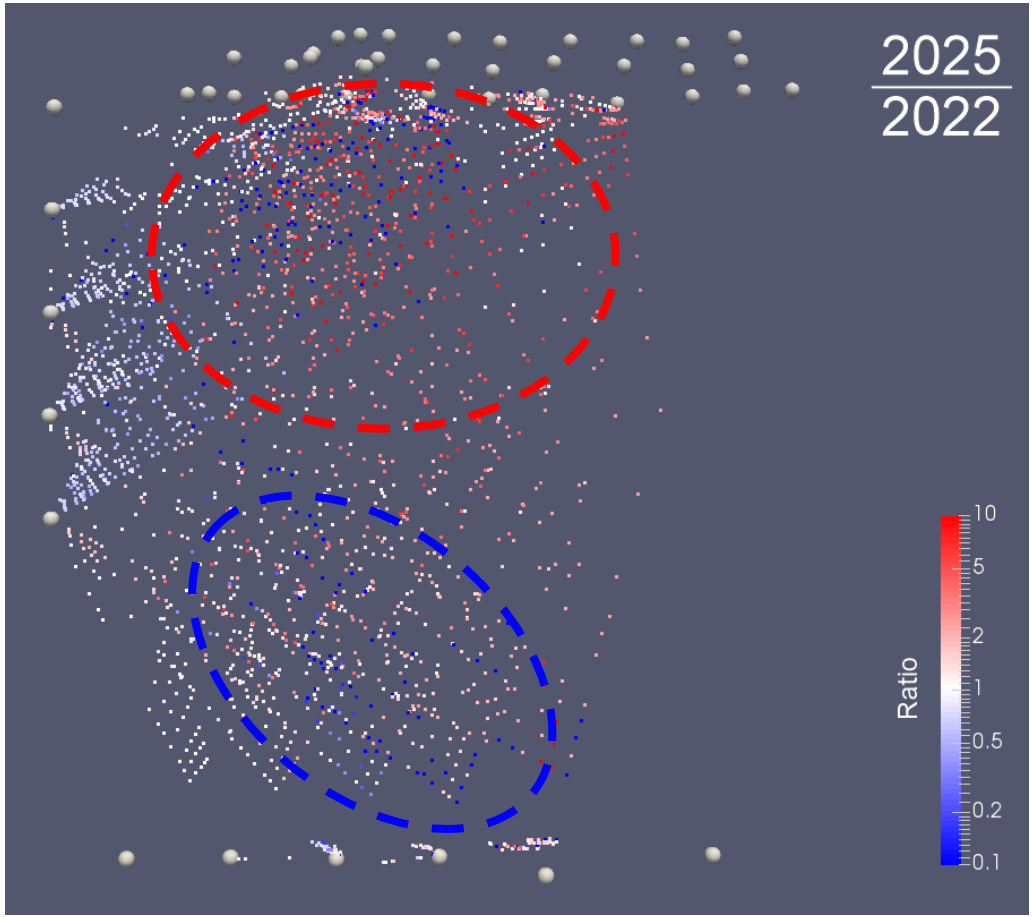
(Sting - PRIME)

ERT data changes



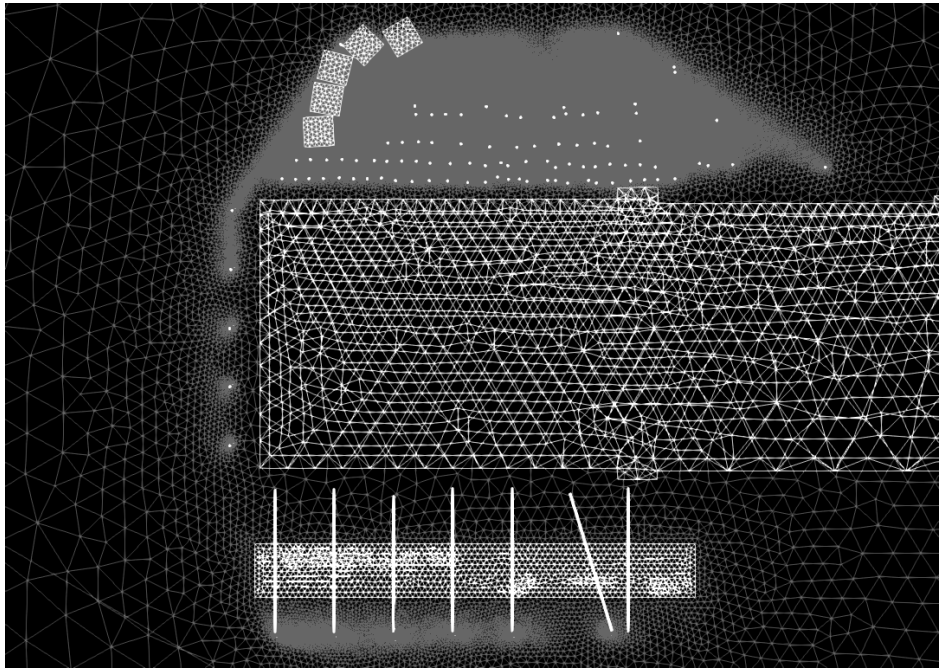


ERT data changes

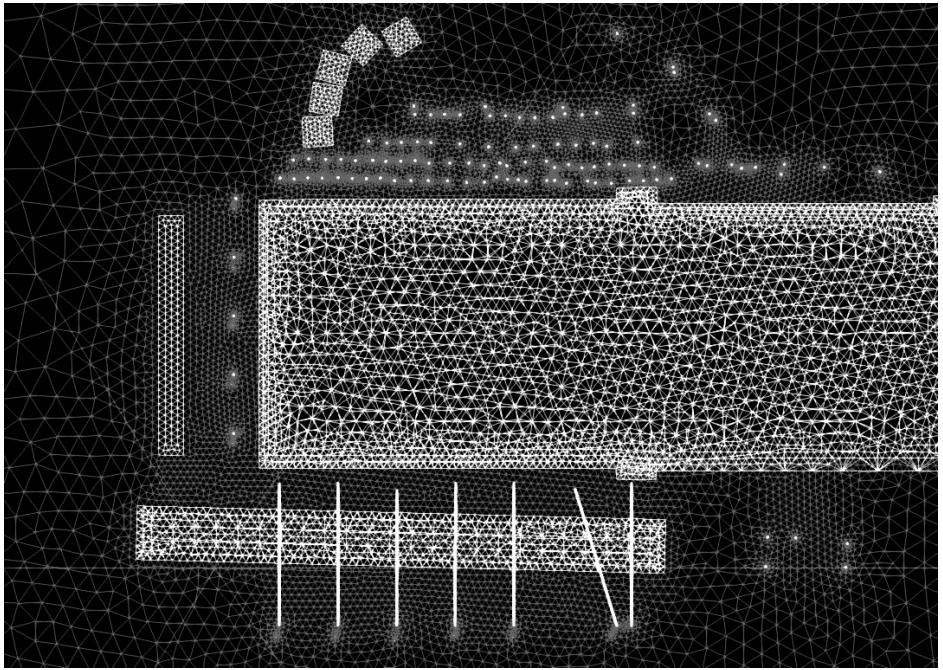


ERT inversion mesh

2022



2025



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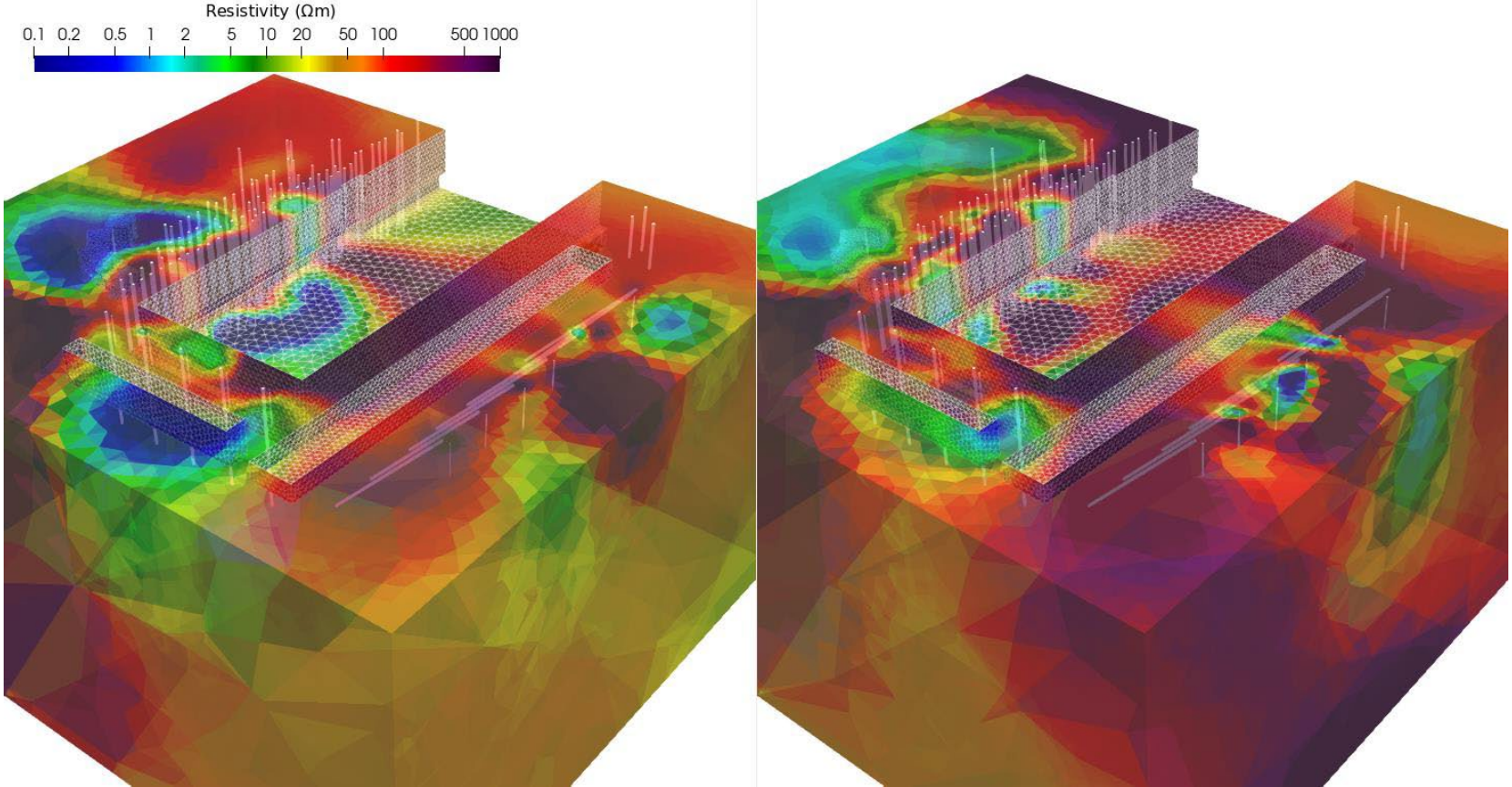

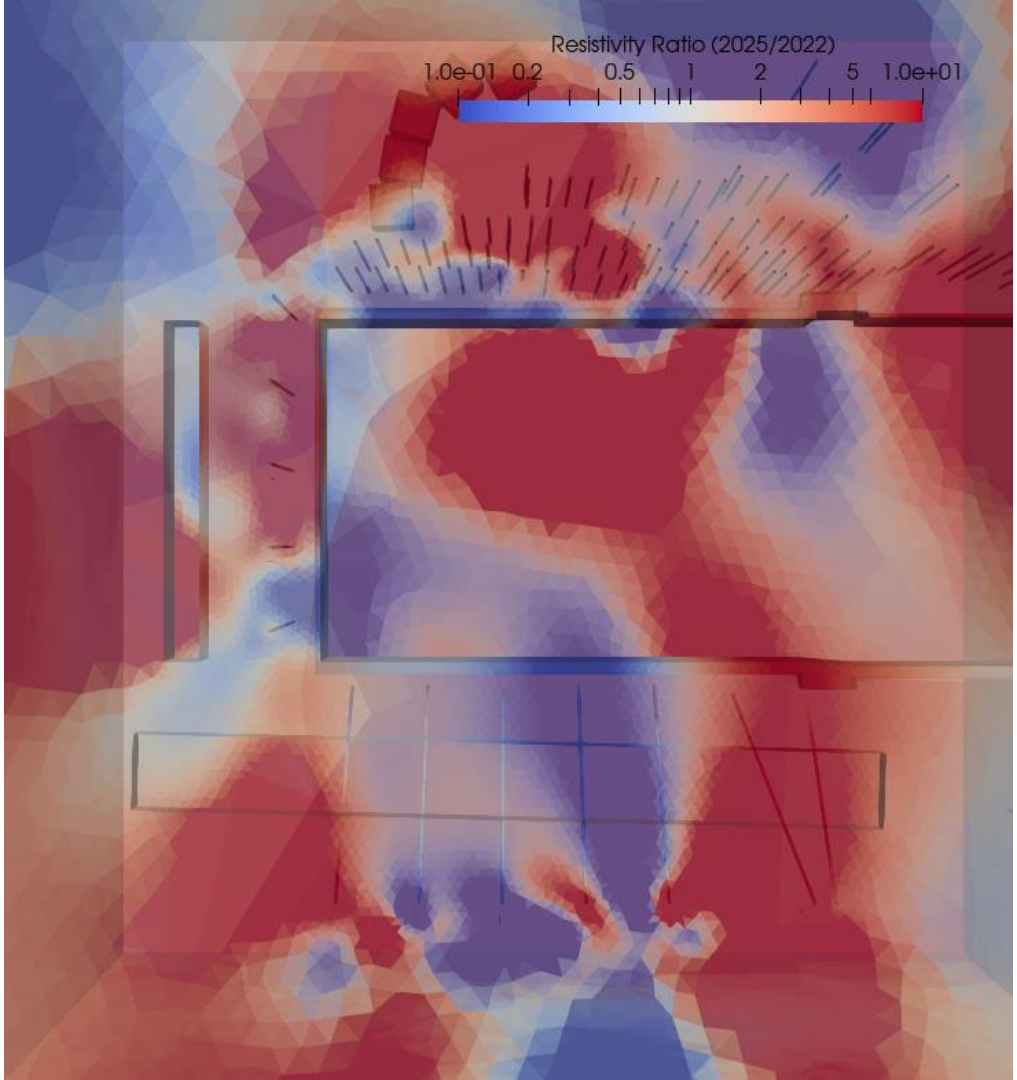
Resistivity Ratio (2025/2022)
1.0e-01 0.2 0.5 1 2 5 1.0e+01