



UNIVERSITÀ DEGLI STUDI
DI MILANO
DIPARTIMENTO DI SCIENZE
DELLA TERRA "ARDITO DESIO"



BIBLIOTECA
DI SCIENZE
DELLA TERRA
"A. DESIO"



Aperitivi scientifici coi piedi per Terra!

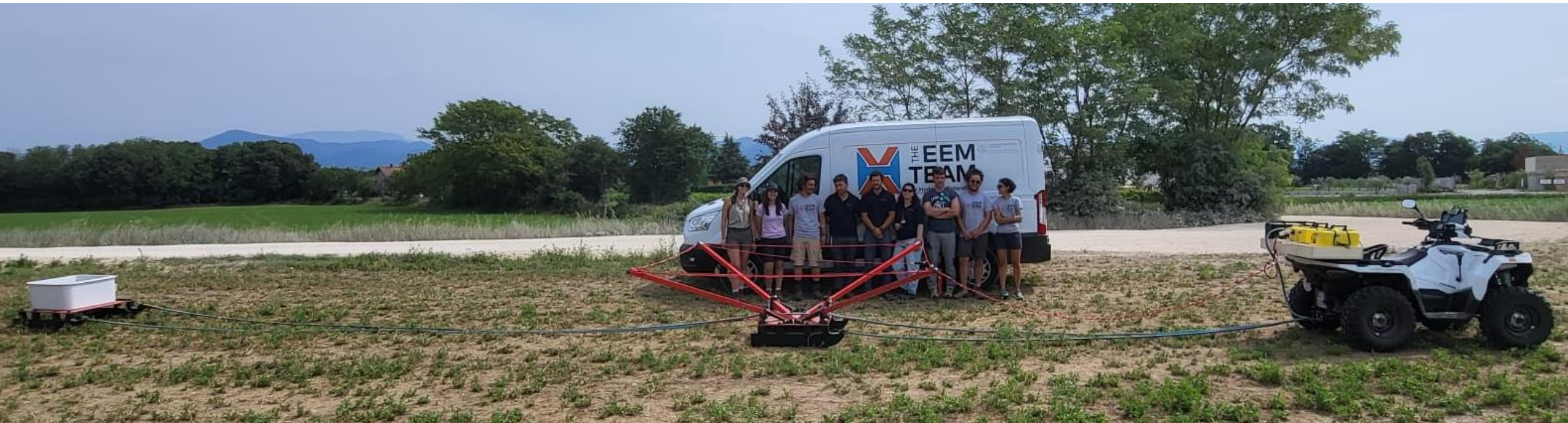
Esplorare il sottosuolo volando.



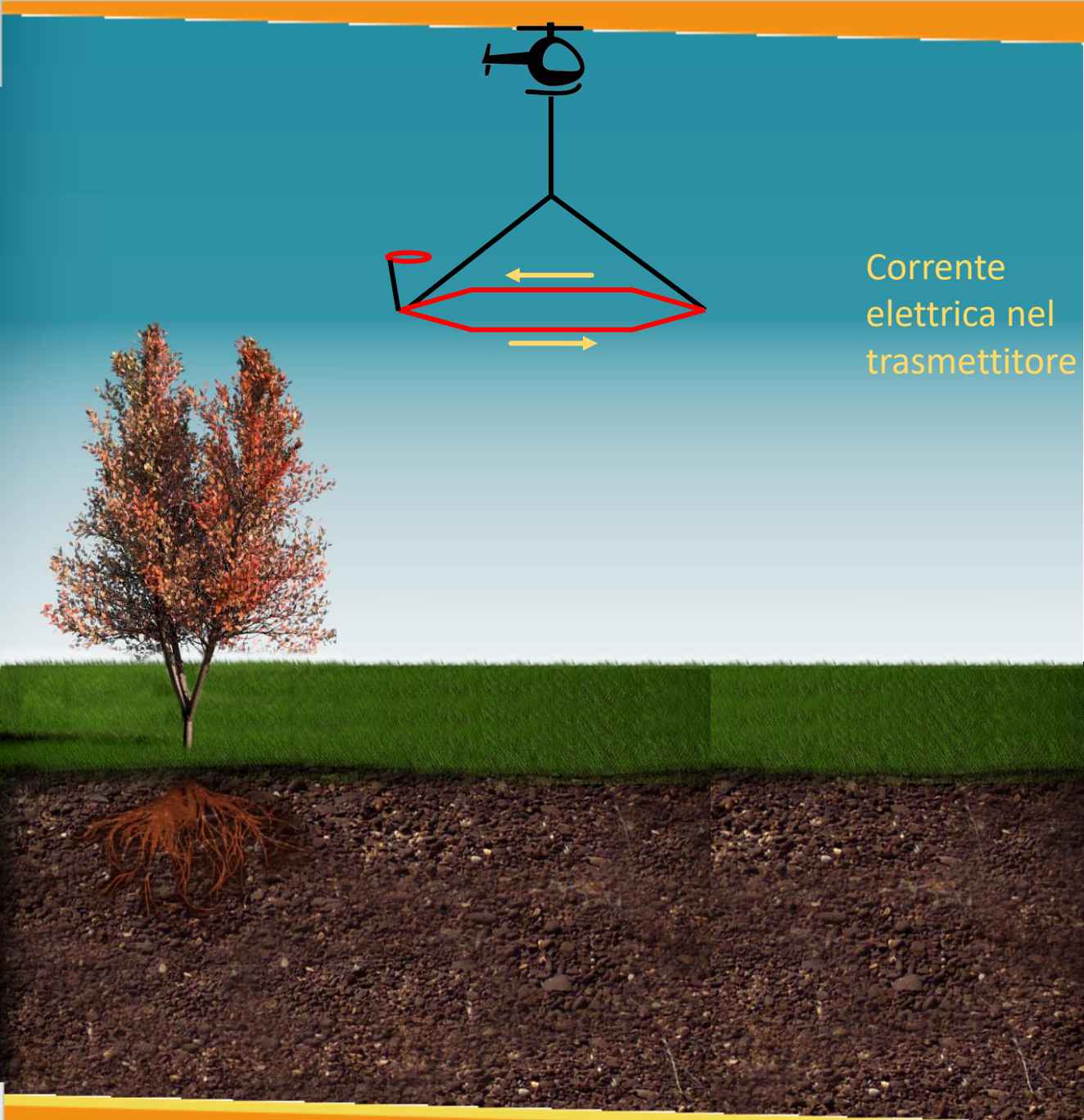
**Gianluca
Fiandaca**

Ringraziamenti

- PhDs: Alessandro Signora, Alice Lucchelli, Francesco Dauti, Stefano Galli, Daniel Ciraula, Lukas Römhild
- PostDocs: Nicole Sullivan, Arcangela Bollino, Jian Chen
- Bachelor/Master graduates & trainees: Silvia Spagna, Mattia Lonardi, Barkha Burkhey, Giulia Tezzon, Giulia Airoidi, Alessia Barbagallo, Valeria Fedeli, Federico Fasolato, Andrea Miglierina etc
- Technician: Chiara Compostella.

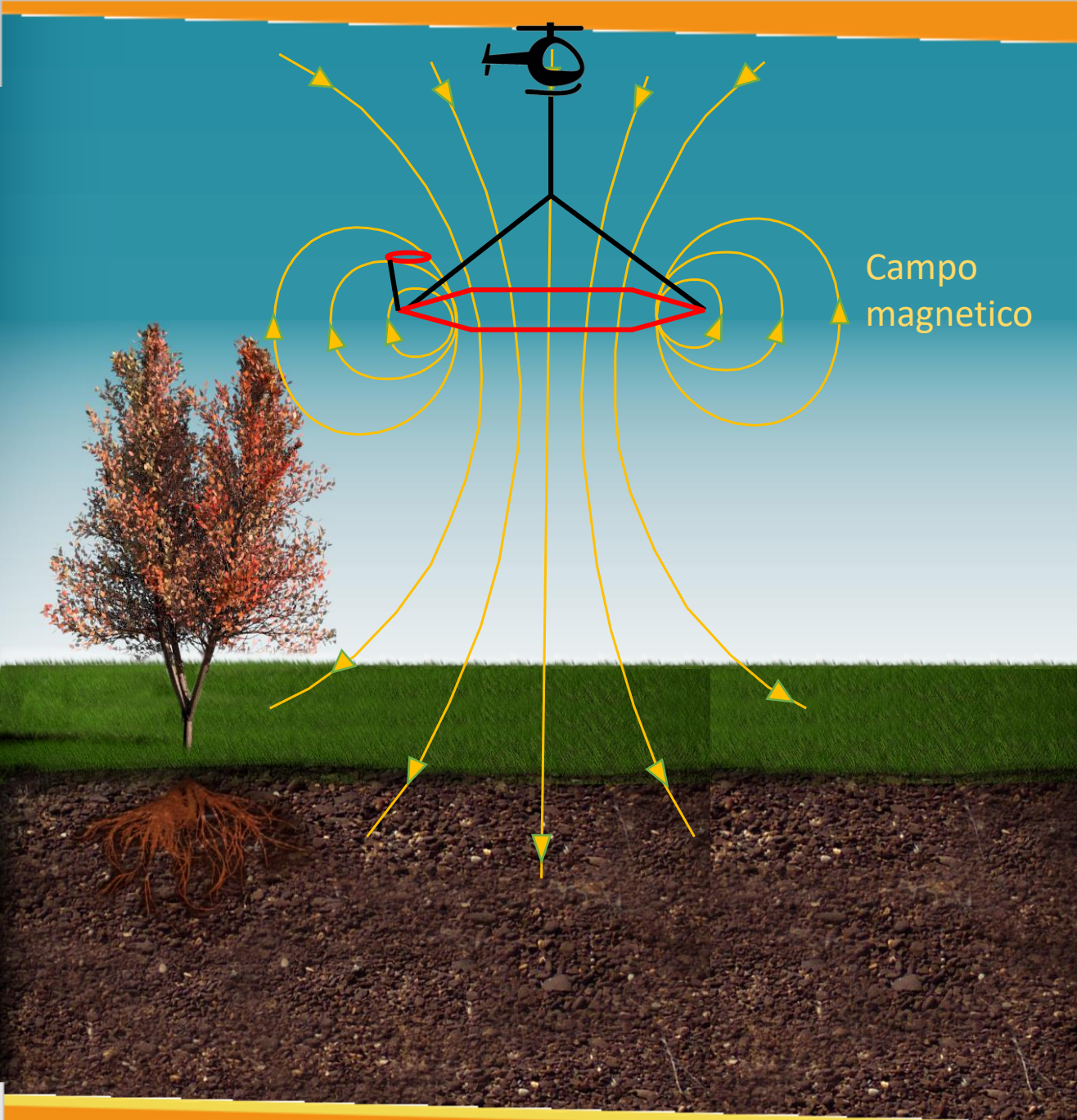


II METODO AEM



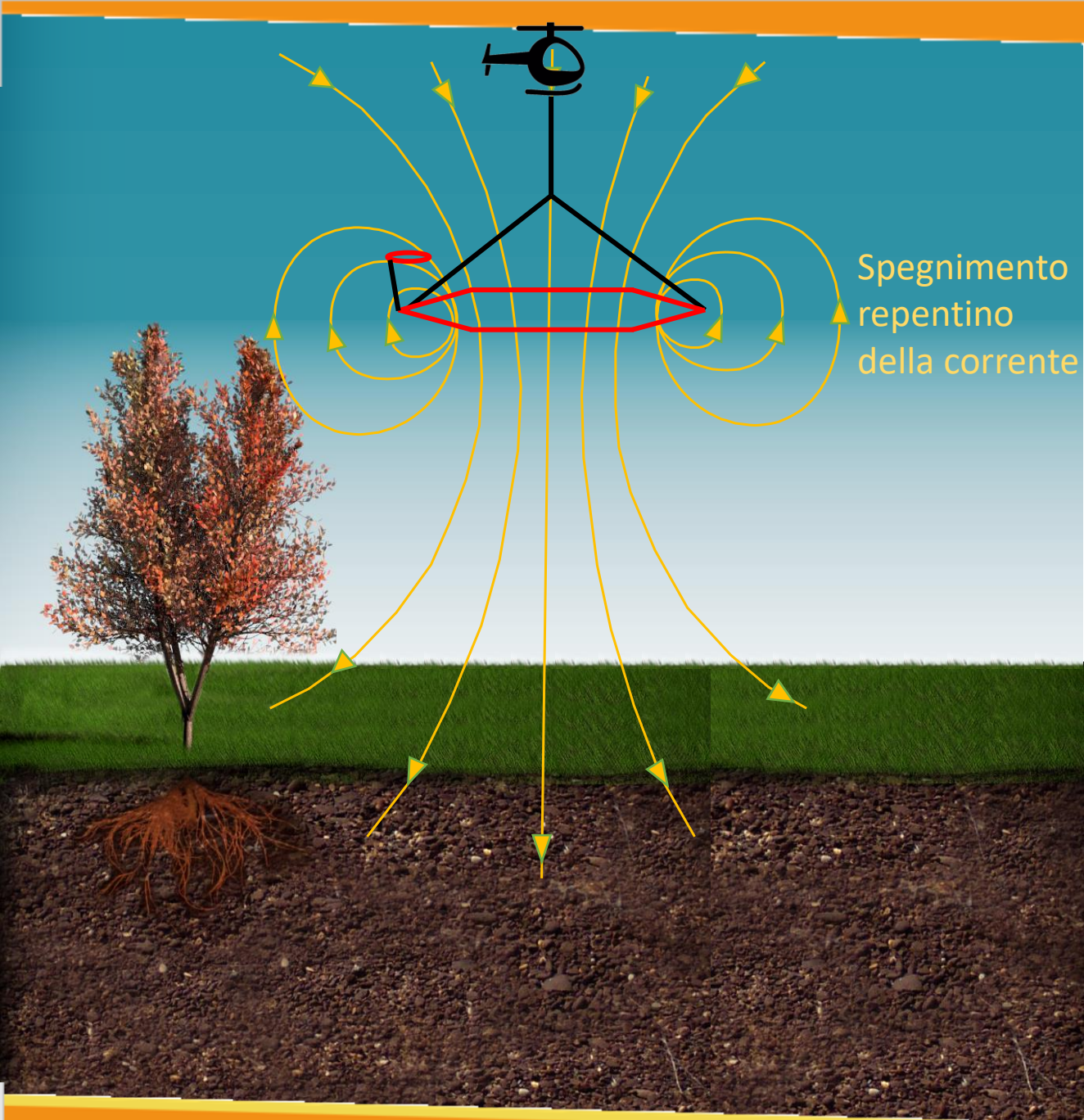
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II METODO AEM




Esplorare il sottosuolo volando.

II METODO AEM



Esplorare il sottosuolo volando.

II METODO AEM



Corrente elettrica nel sottosuolo generata dallo spegnimento del campo magnetico

1 μ s

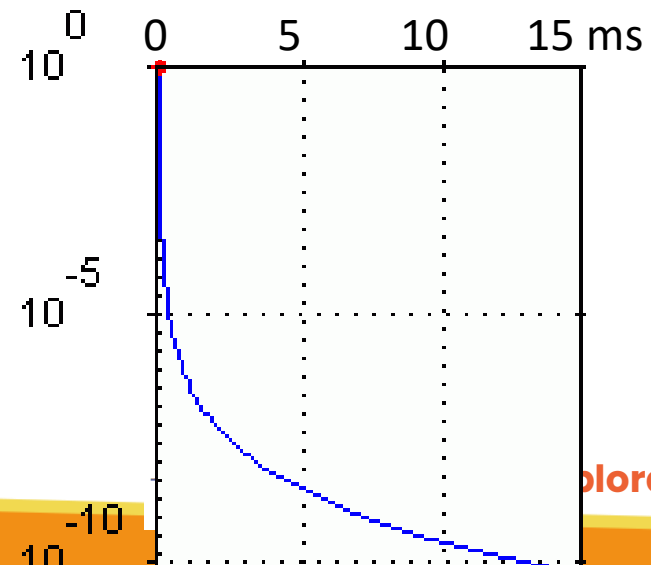
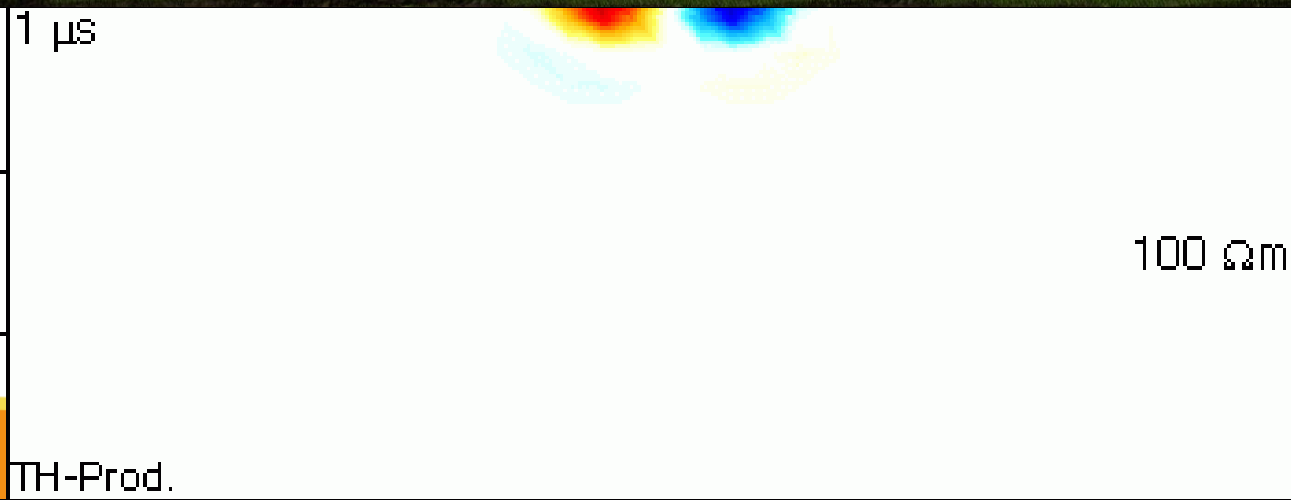
100 Ω m

Esplorare il sottosuolo volando.

II METODO AEM

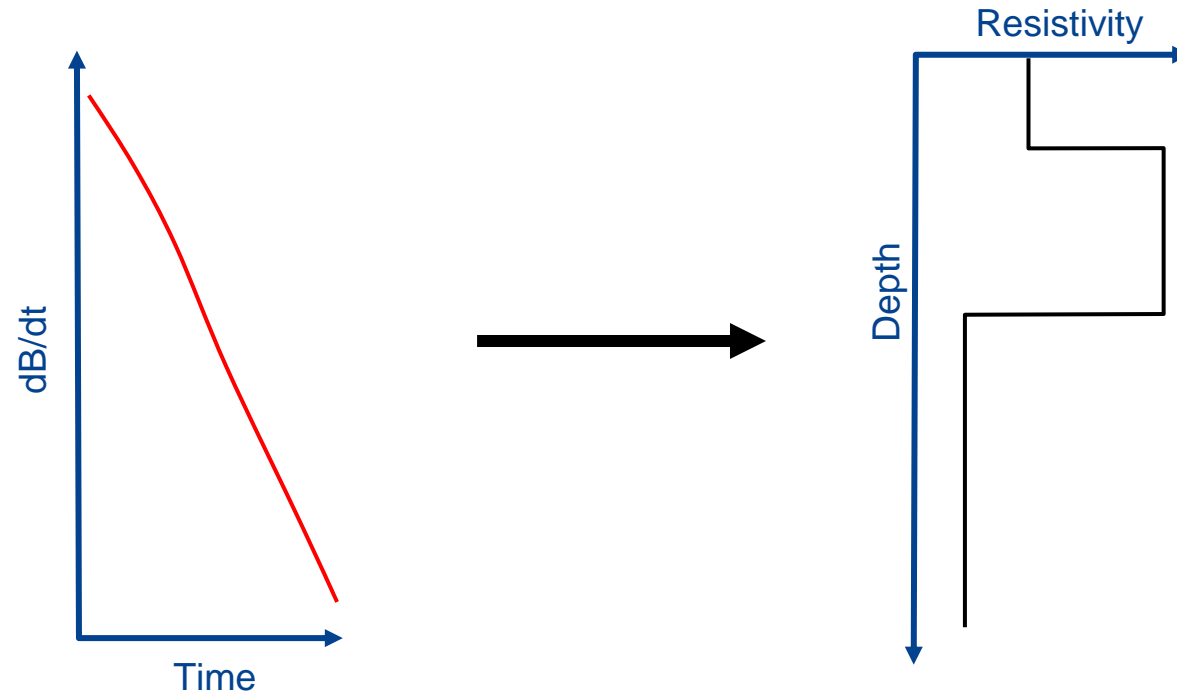
Corrente elettrica nel sottosuolo generata dallo spegnimento del campo magnetico

Segnale magnetico nel ricevitore generato dalla corrente elettrica nel terreno



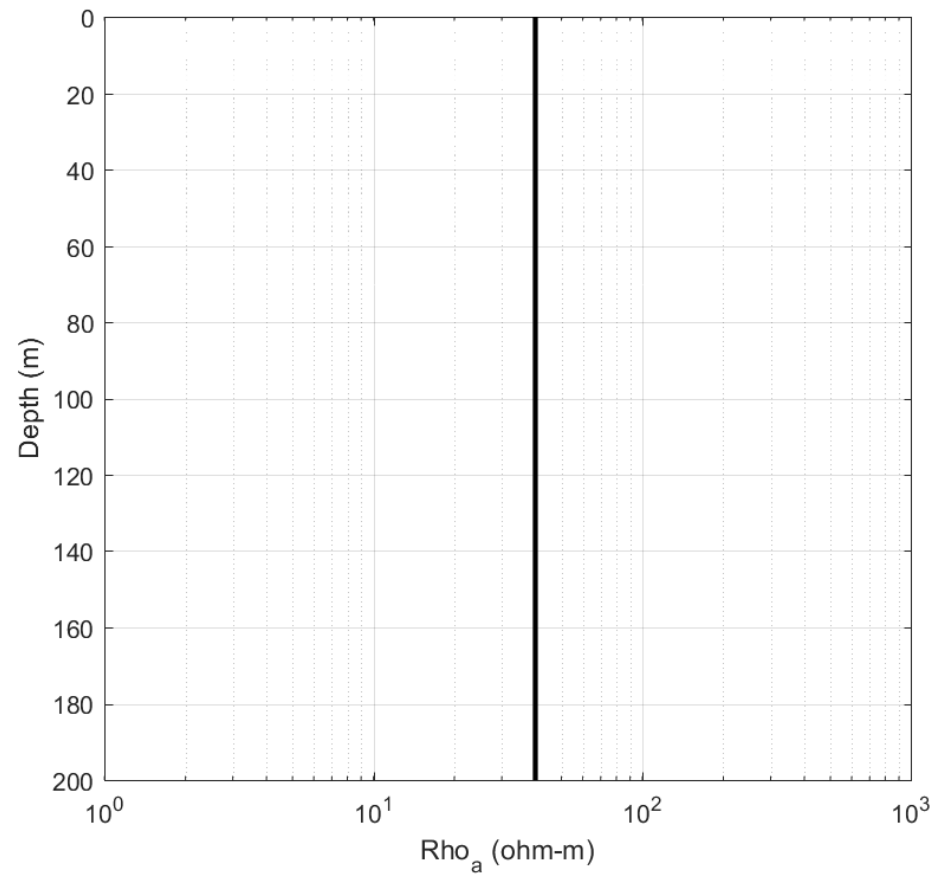
Esplorare il sottosuolo volando.

Inversione dei dati

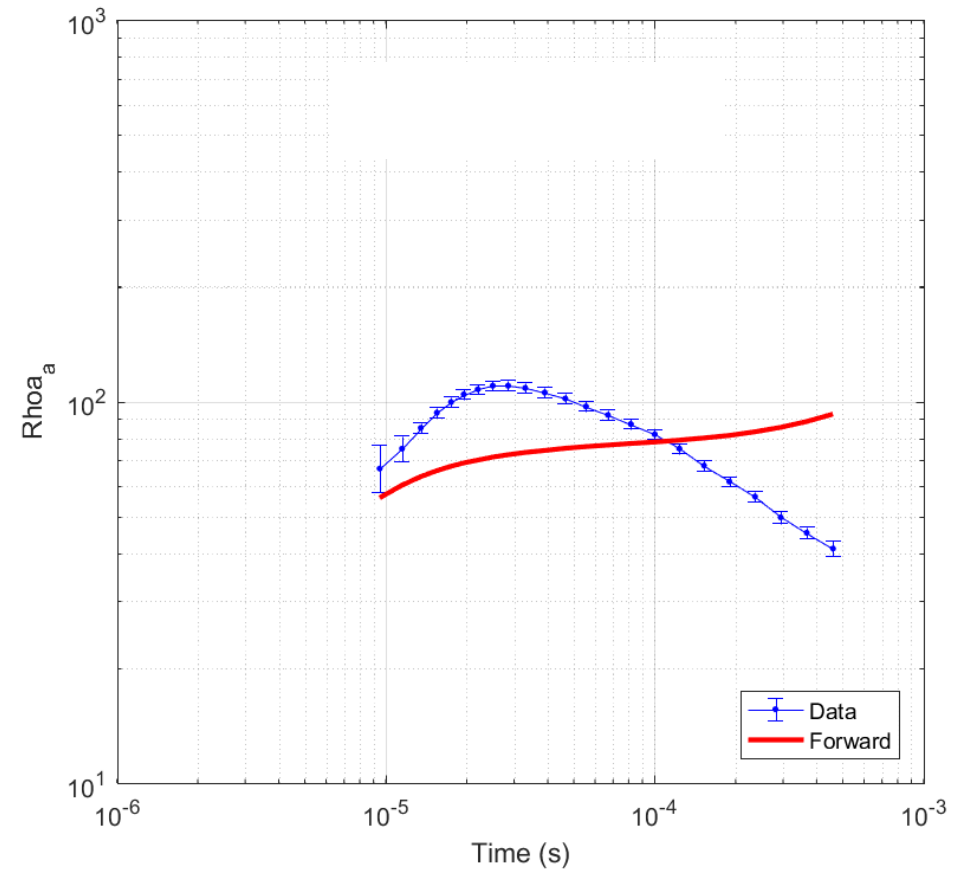


Un esempio...

- Inversione TEM



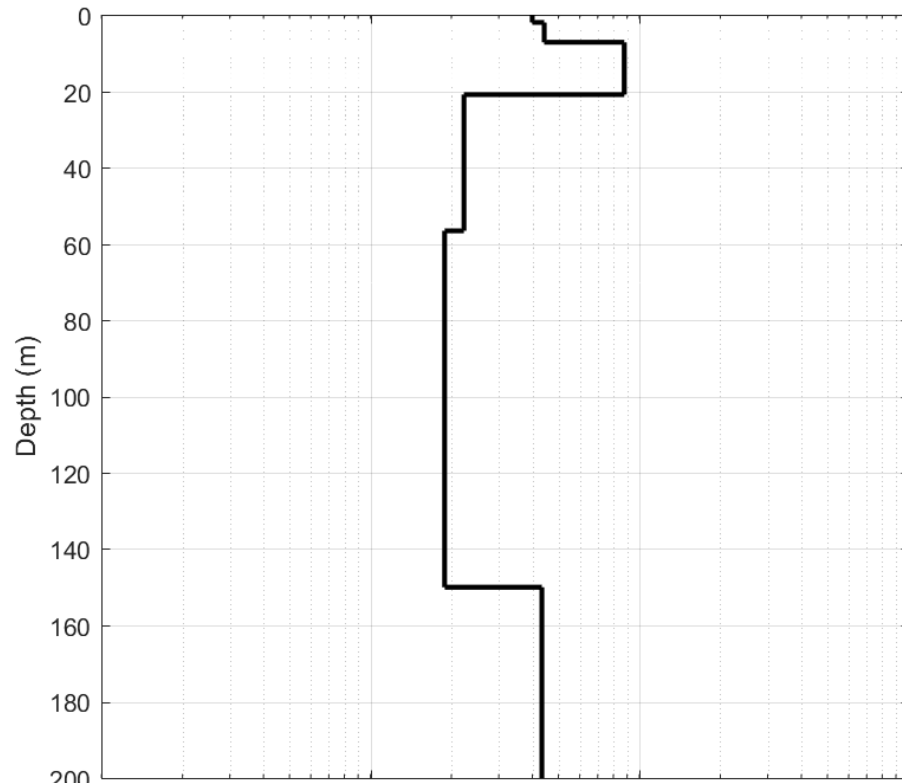
$$Q = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{\sigma_i^2} \right)^{\frac{1}{2}}$$



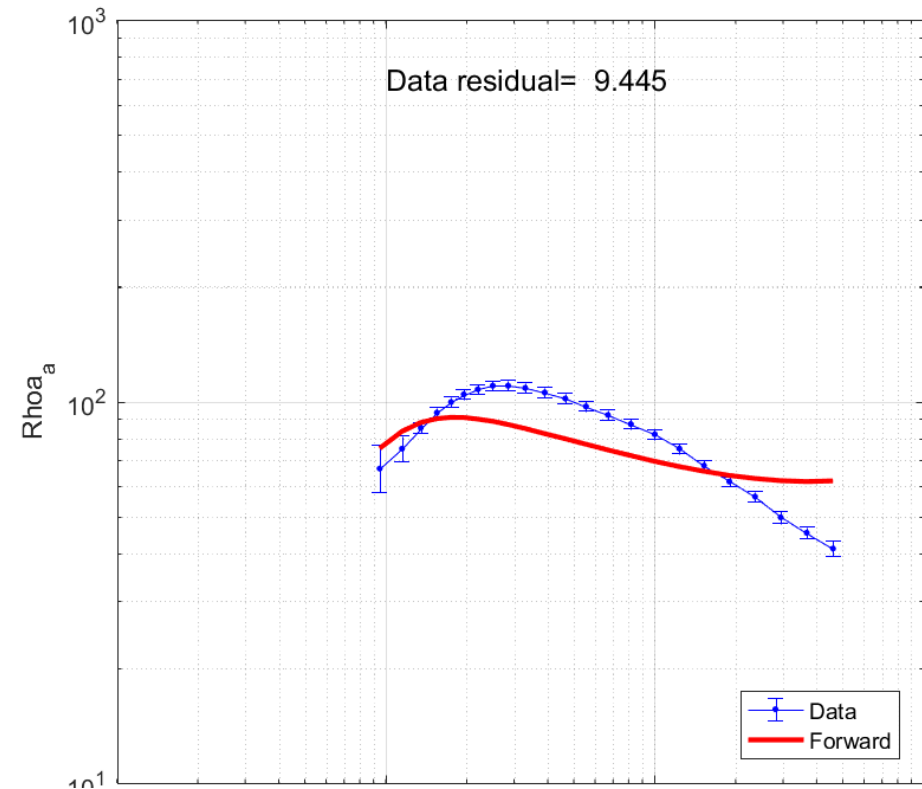
Modello iniziale

Un esempio...

- Inversione TEM



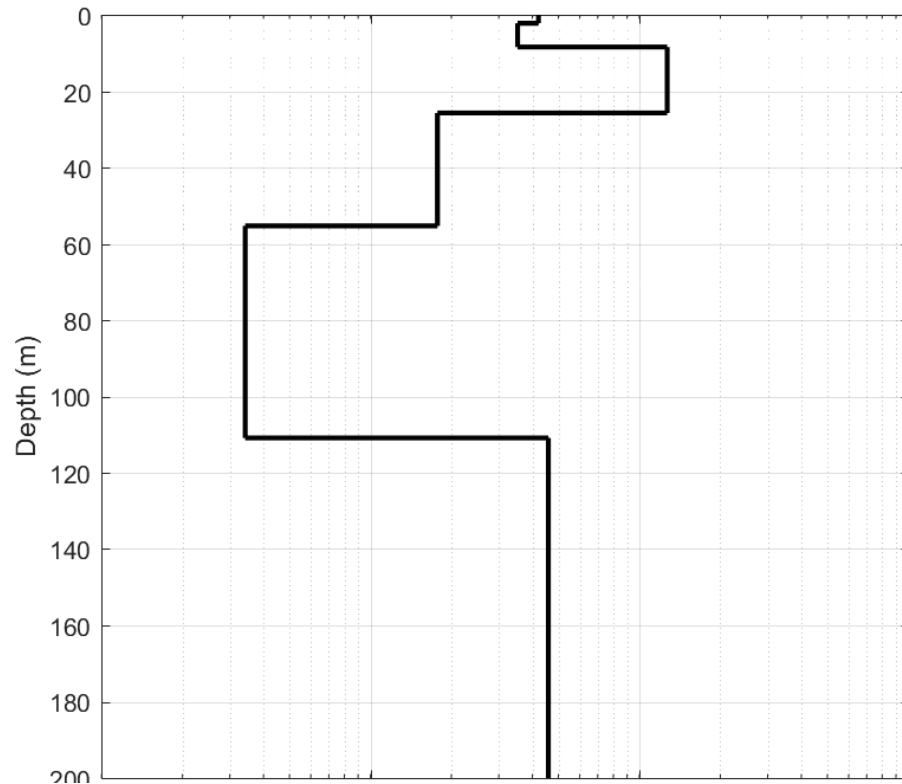
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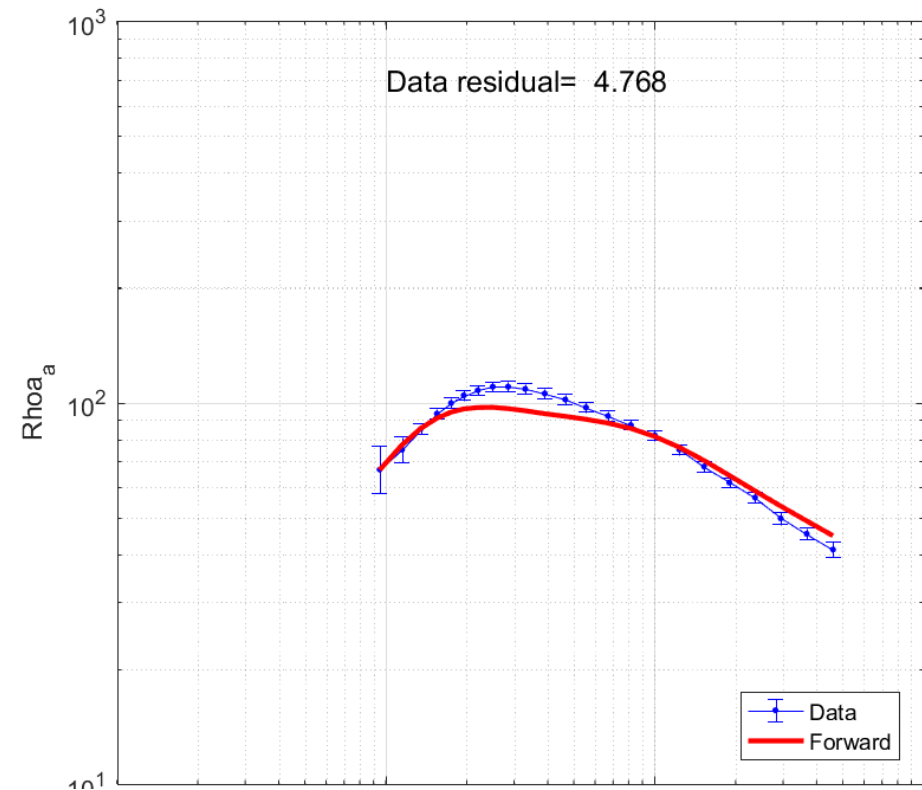
Iterazione 1

Un esempio...

- Inversione TEM



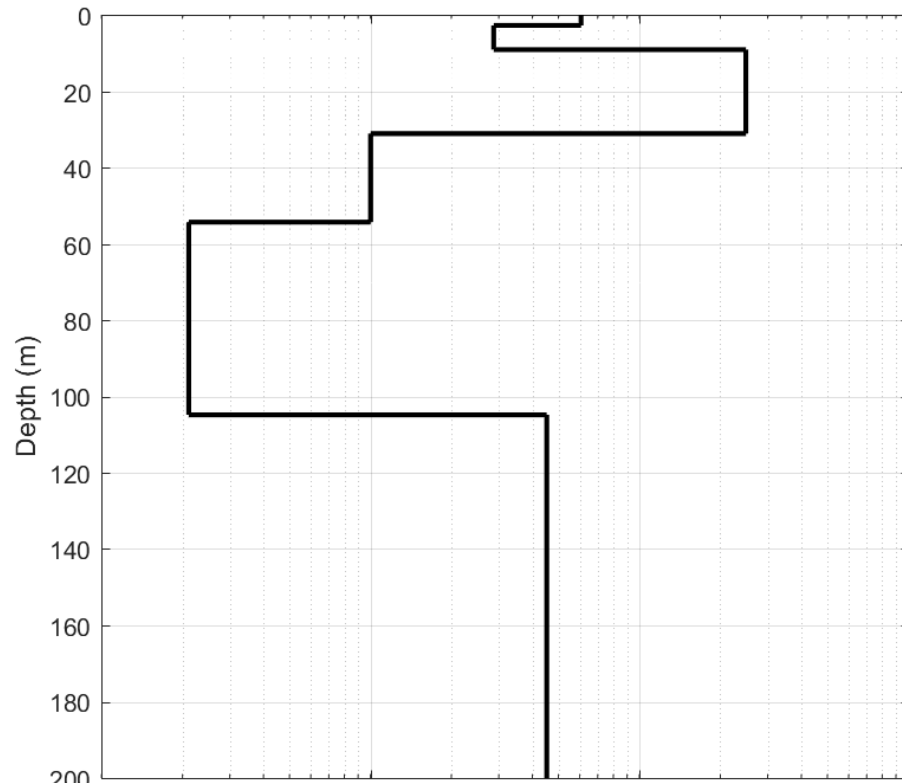
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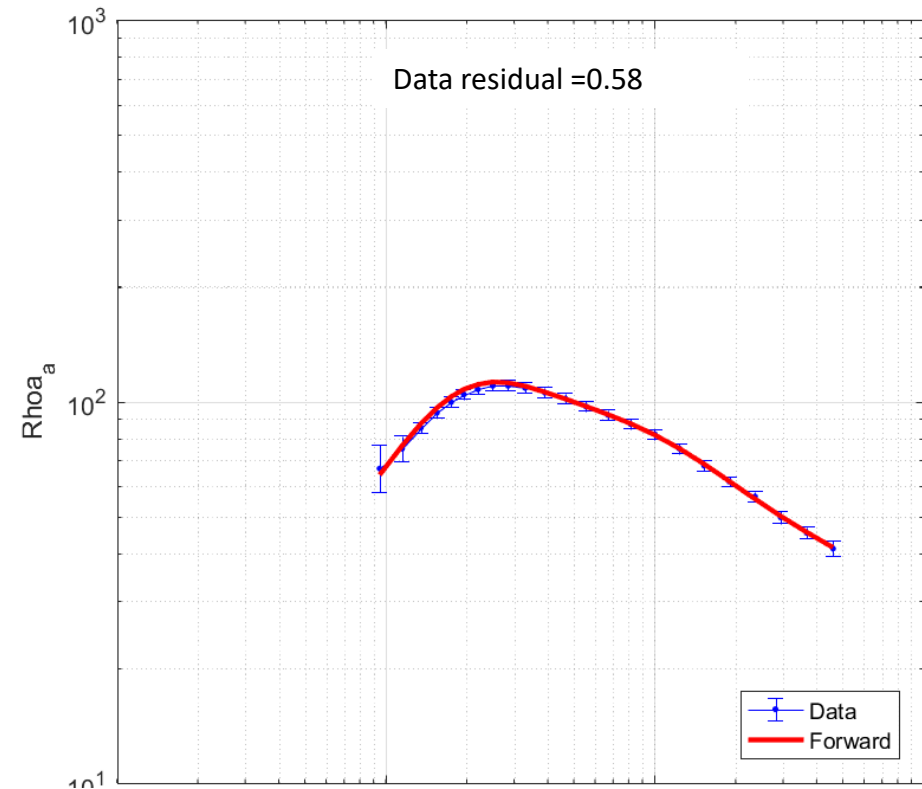
Iterazione 6

Un esempio...

- Inversione TEM

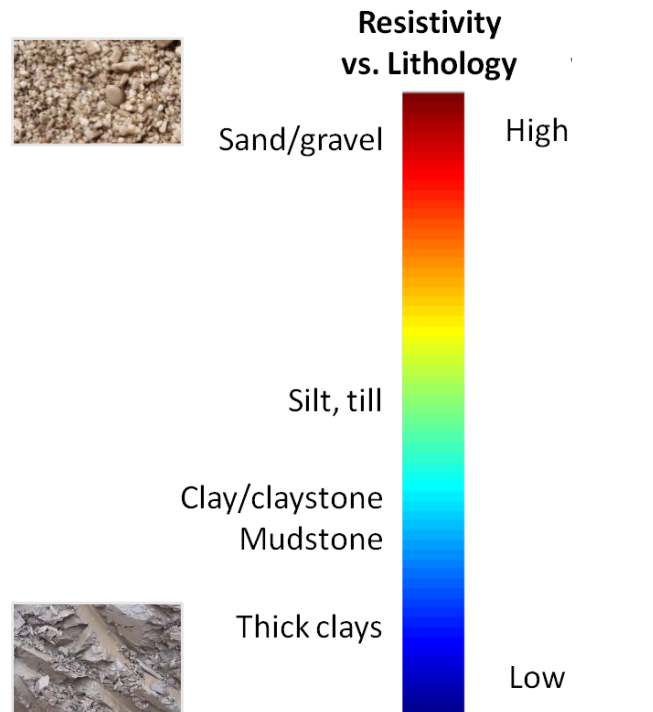


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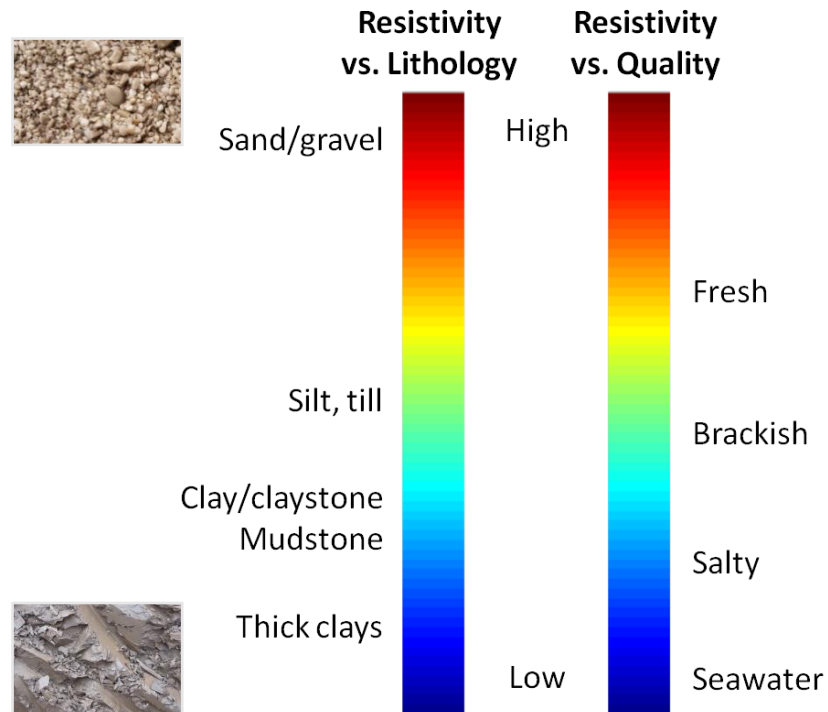


Iterazione 9

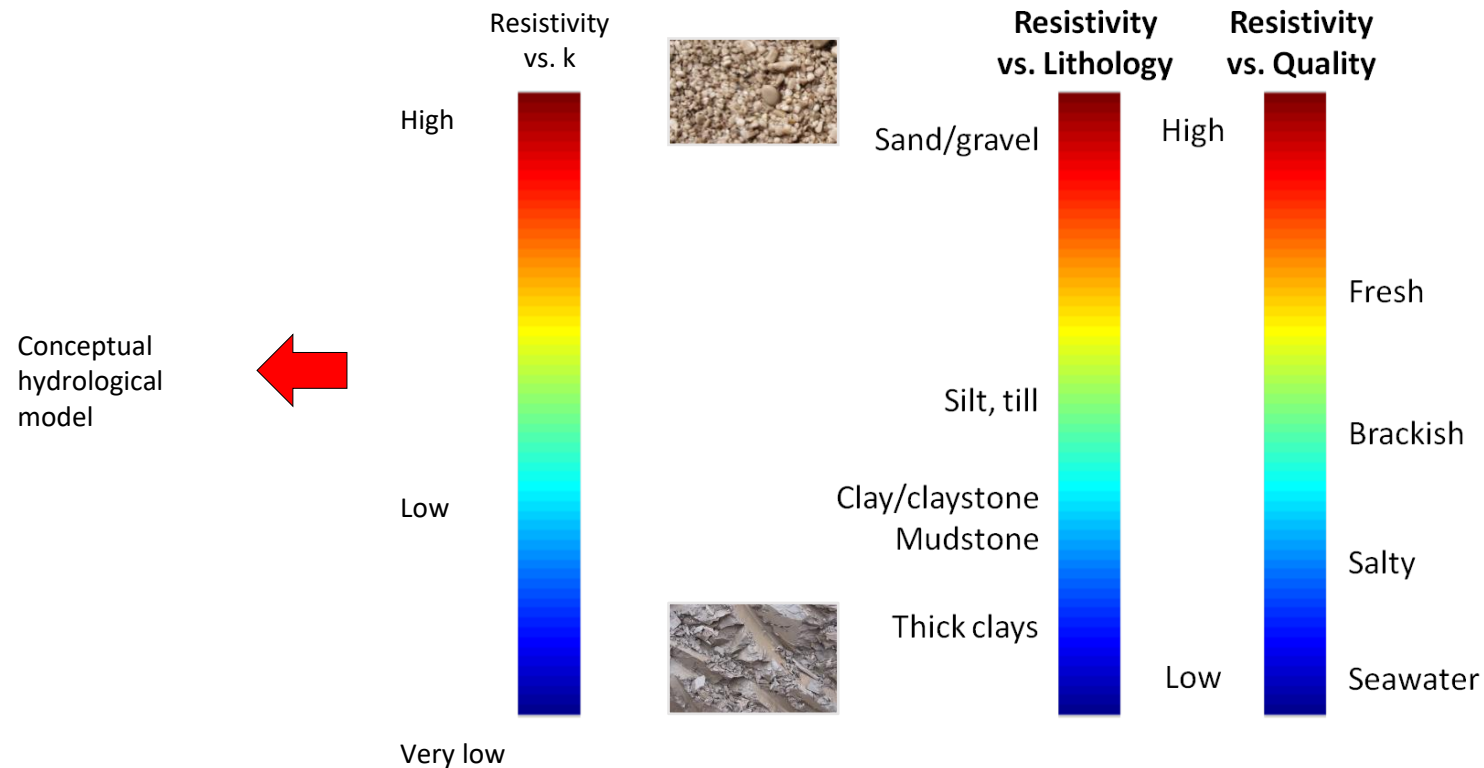
Resistività – litologia – Idrogeologia



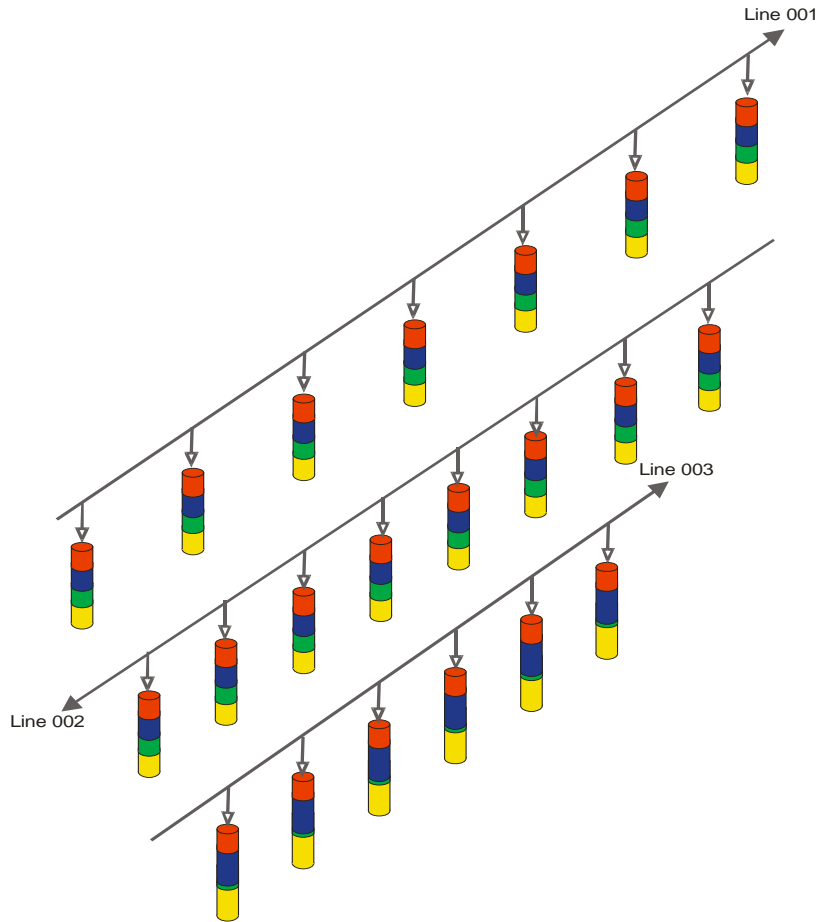
Resistività – litologia – Idrogeologia



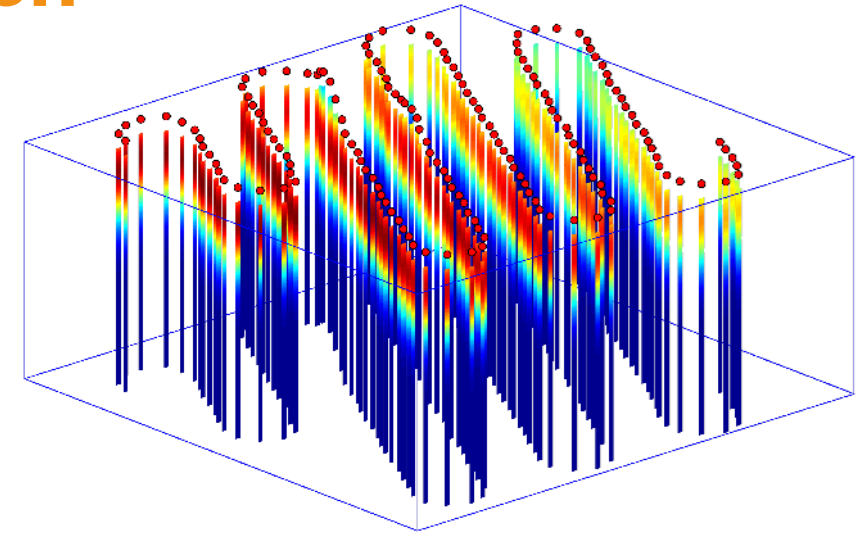
Resistività – litologia – Idrogeologia



1D Laterally Constrained Inversion

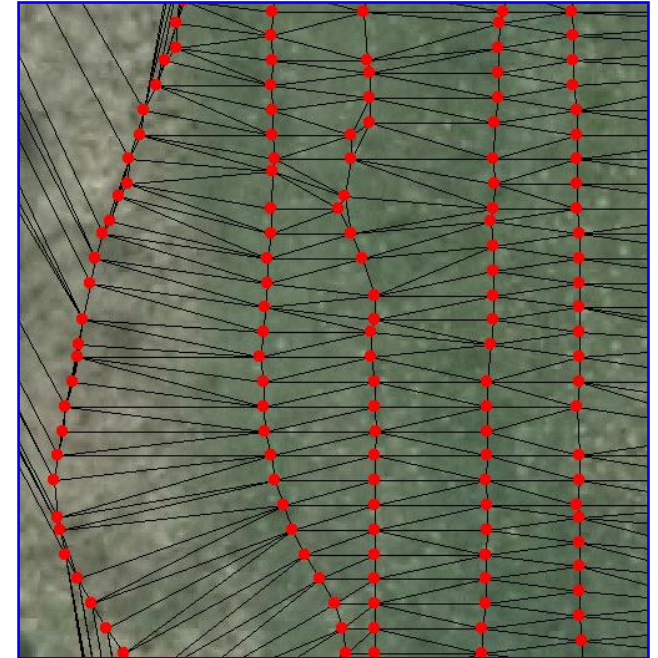
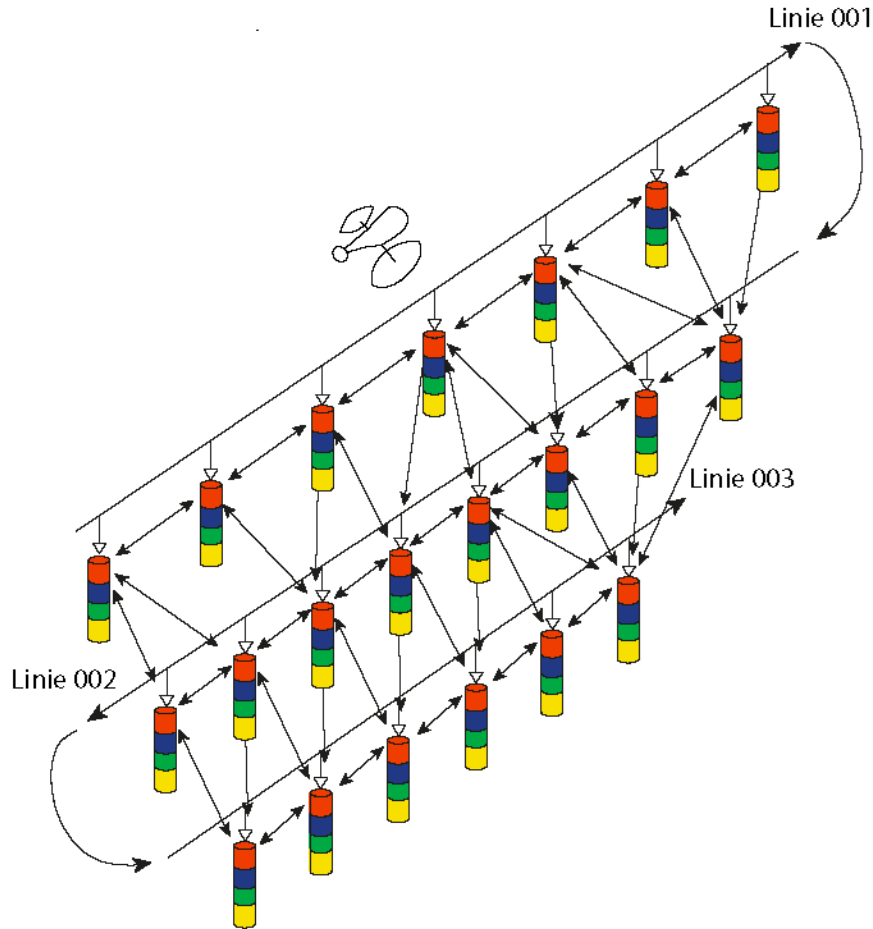


- Spazio dei modelli 3D
- Localmente modelli/sondaggi TEM 1D
- Laterally Constrained Inversion (LCI)
- Inversione non lineare LSQ



1D Spatially Constrained Inversion

- Spazio dei modelli 3D
- Localmente modelli/sondaggi TEM 1D
- Spatially Constrained Inversion (SCI)
- Inversione non lineare LSQ



IL METODO AEM – Punti di forza e debolezza

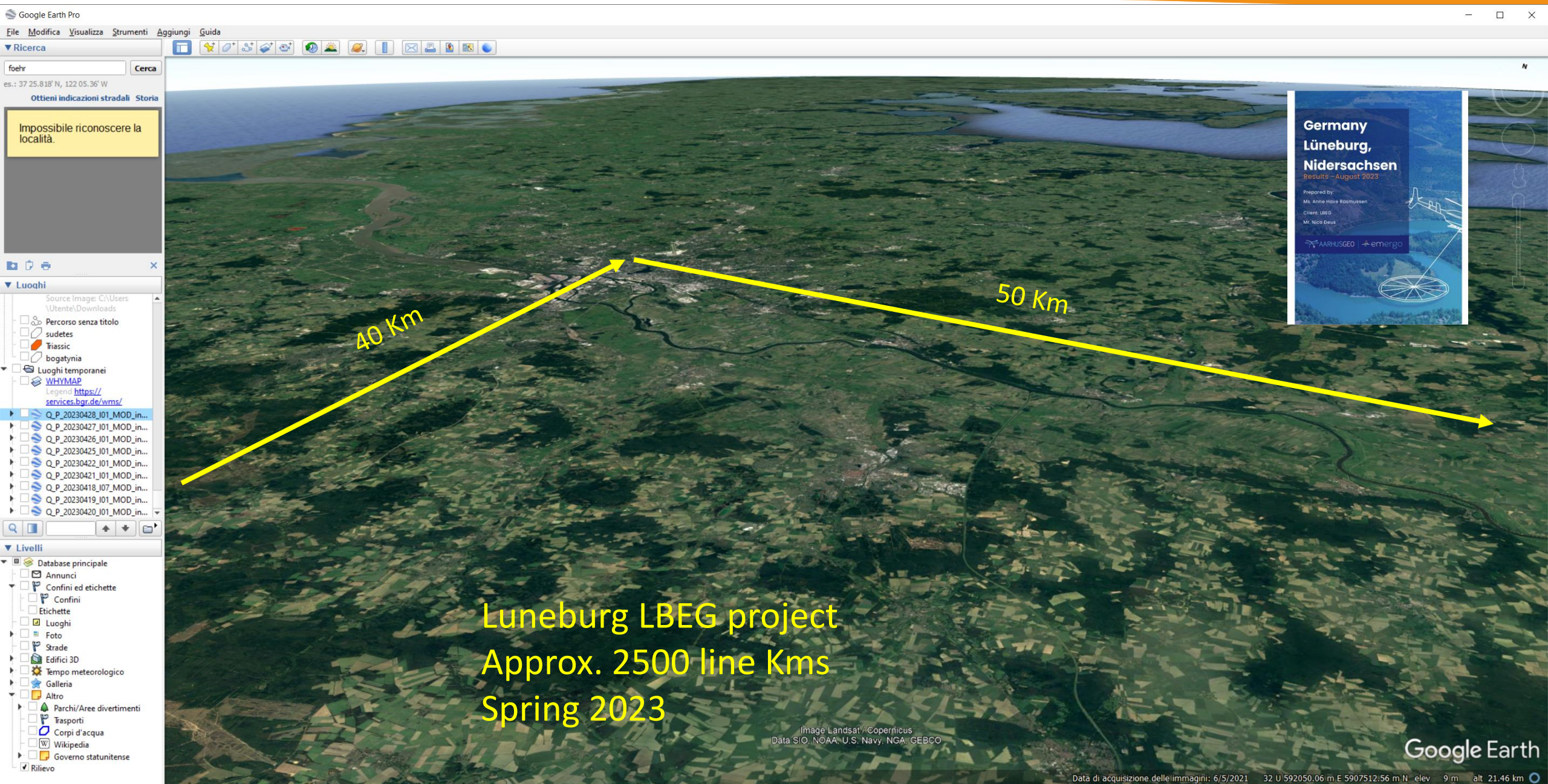
- + **Produttività impareggiabile**
- + **Particolarmente sensibile ai sedimenti con bassa resistività (ad esempio argille)**
- + **Grande profondità di indagine**
- **Concettualmente avanzato**
 - Necessita una modellazione accurata
- **Sensibile al coupling con strutture metalliche**
 - Necessita un processing accurato
- **Relazione tra resistività e litologia non-univoca**
 - Poca sensibilità alle alte resistività

IL METODO AEM – Punti di forza e debolezza

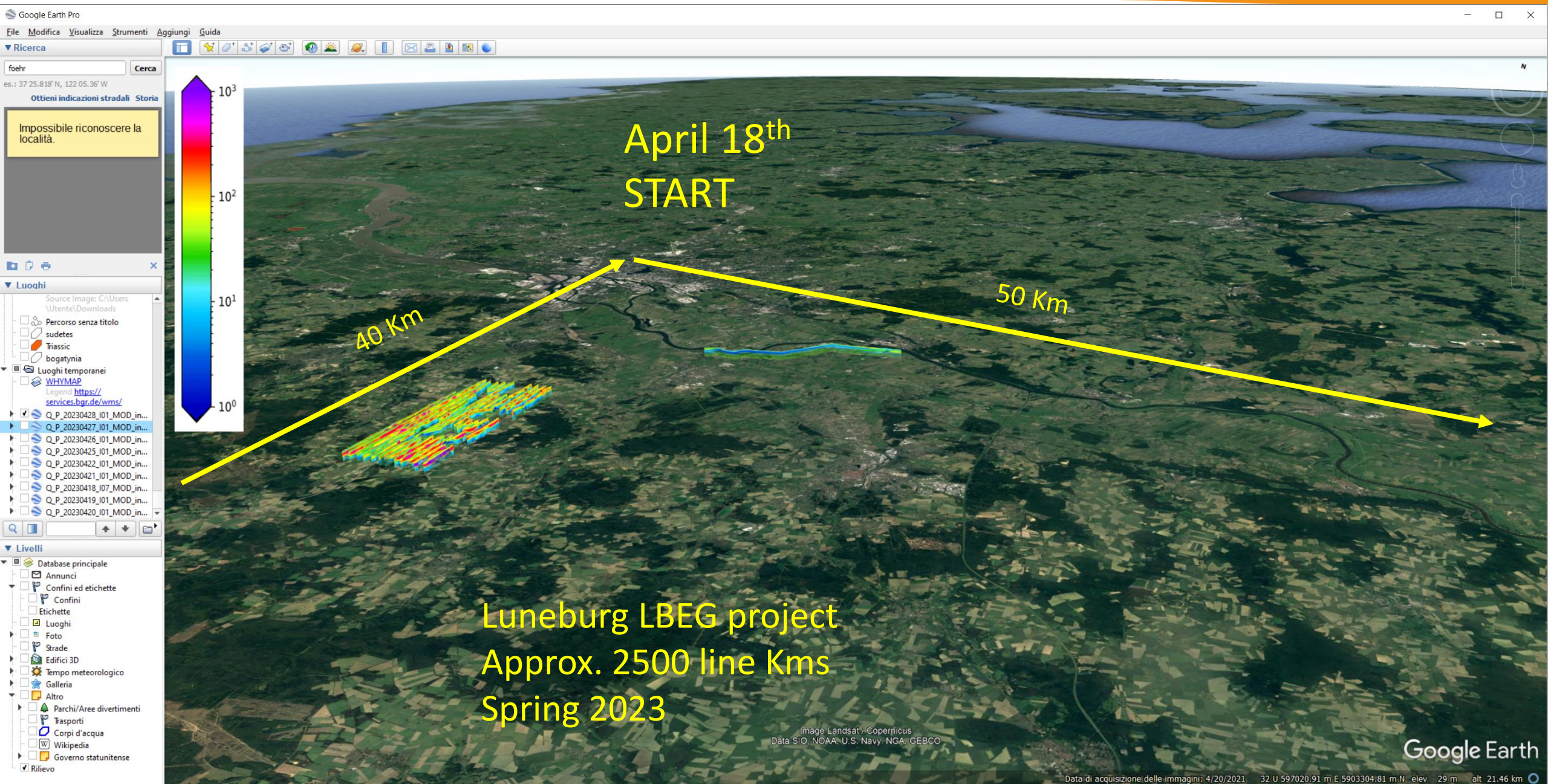
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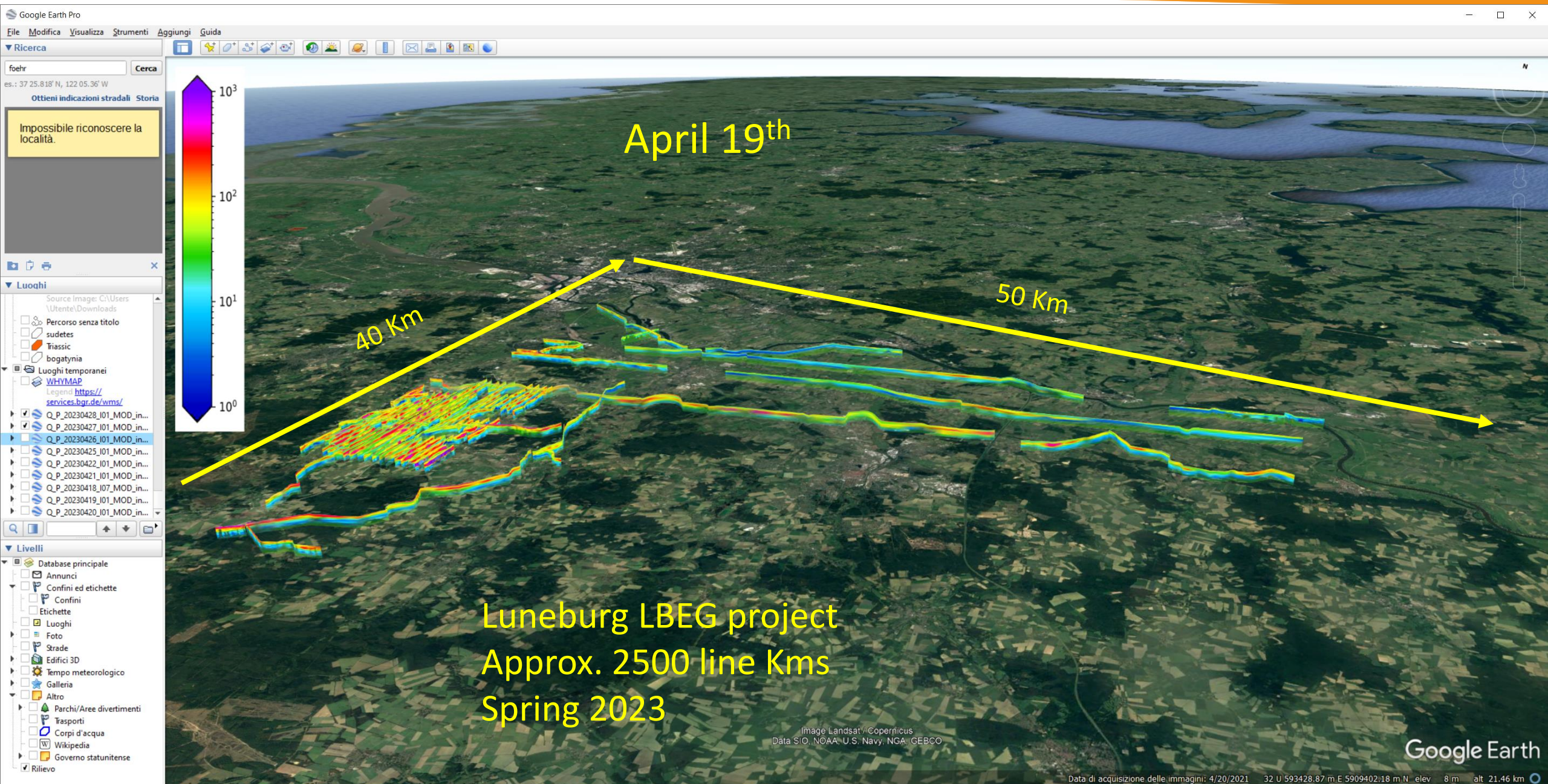
IL METODO AEM – Punti di forza e debolezza

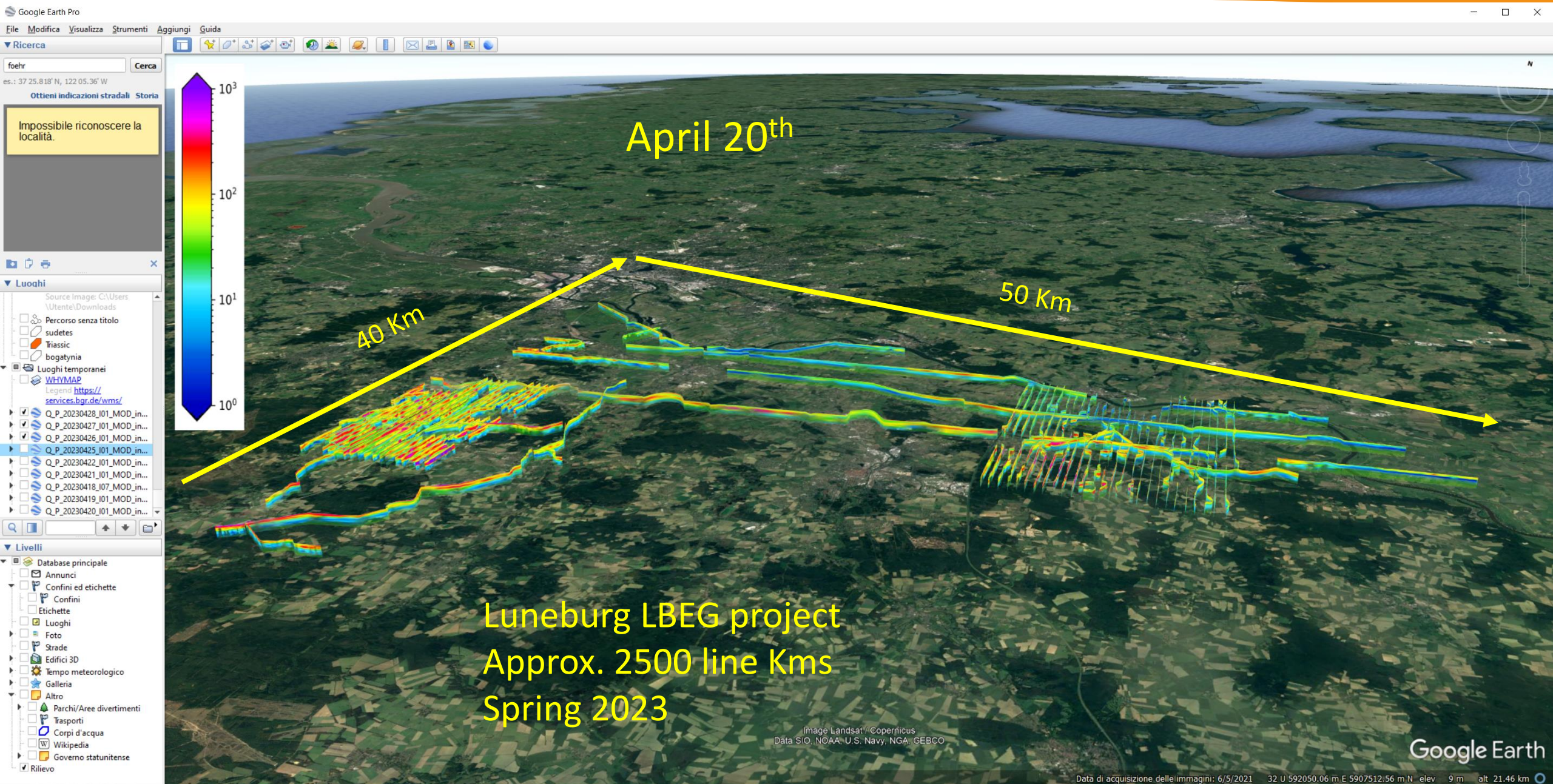
- + Produttività impareggiabile**
 - + Particolarmente sensibile ai sedimenti con bassa resistività (ad esempio argille)**
 - + Grande profondità di indagine**
-
- 300 km/giorno (lineari)**
 - Risoluzione da 5 a 400 m di profondità**

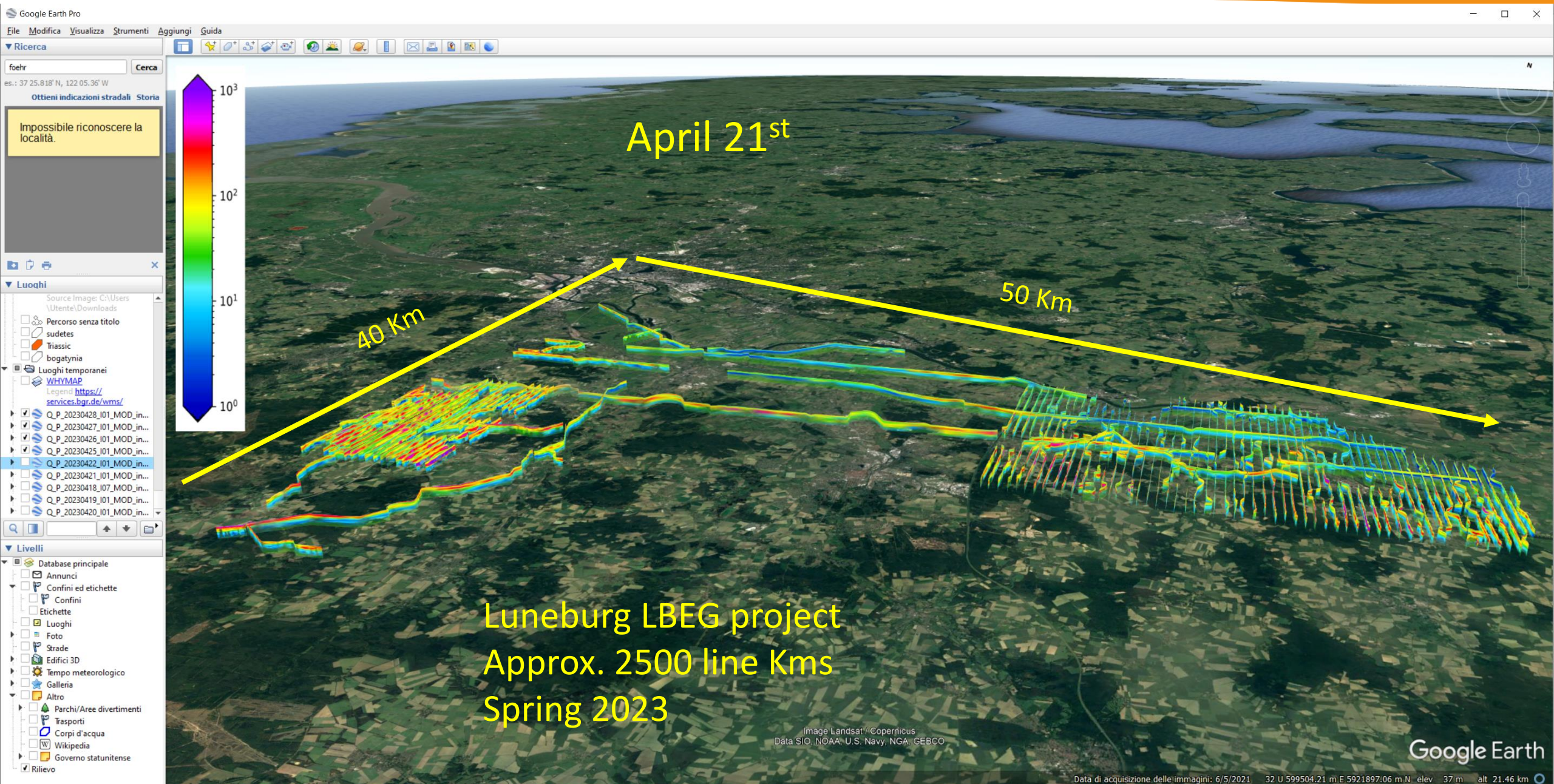


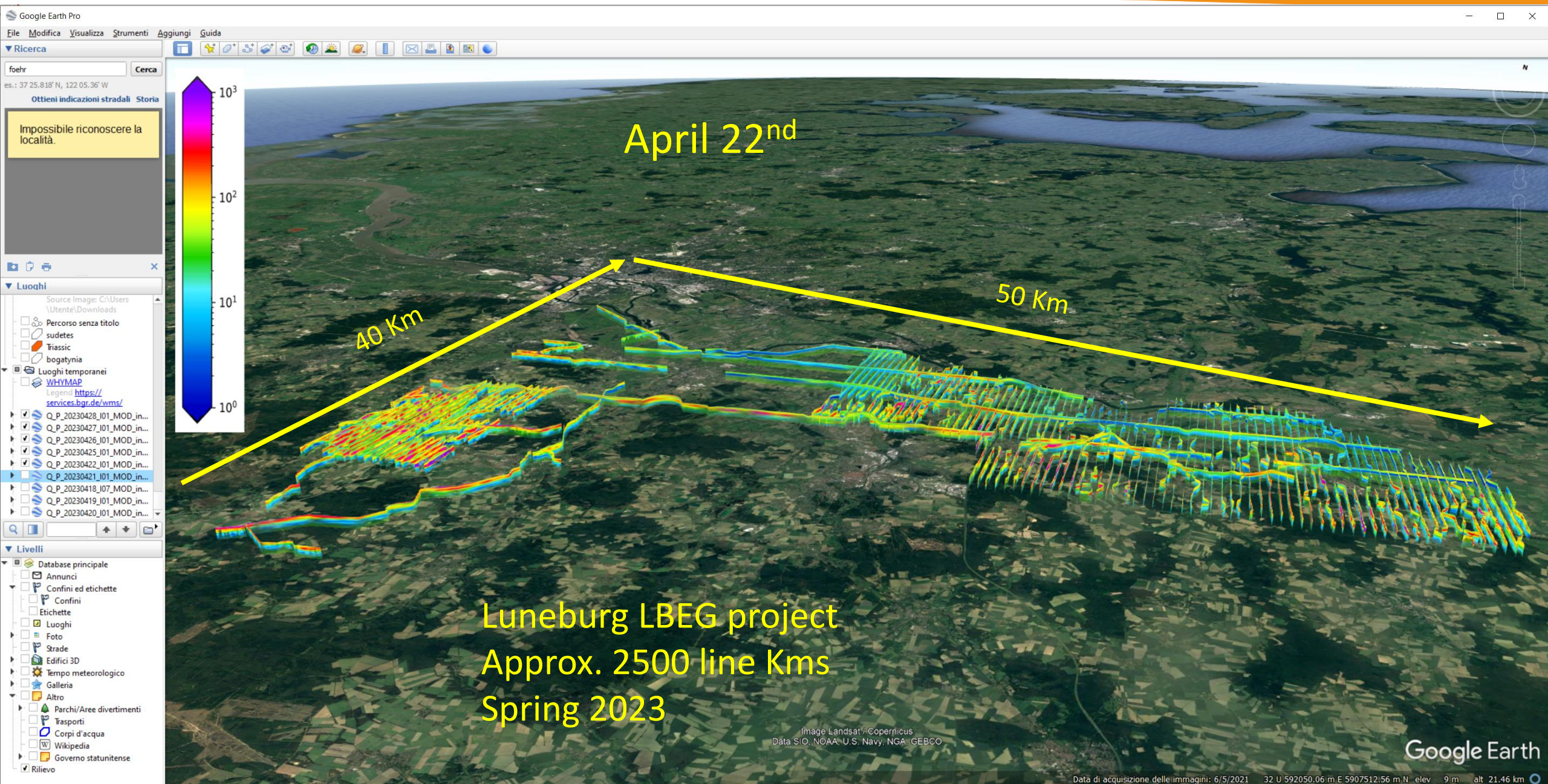
Lüneburg LBEG project
Approx. 2500 line Kms
Spring 2023

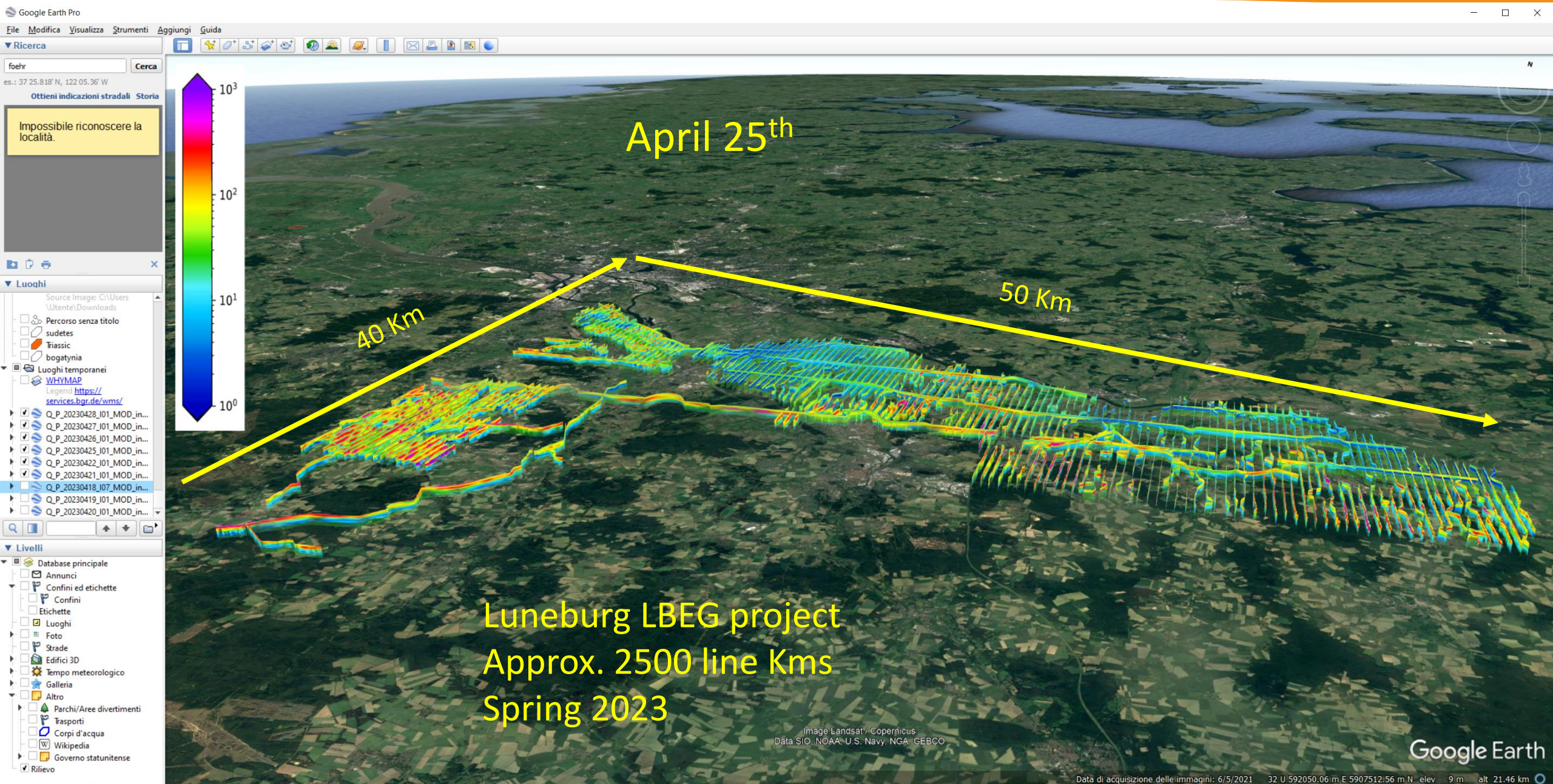


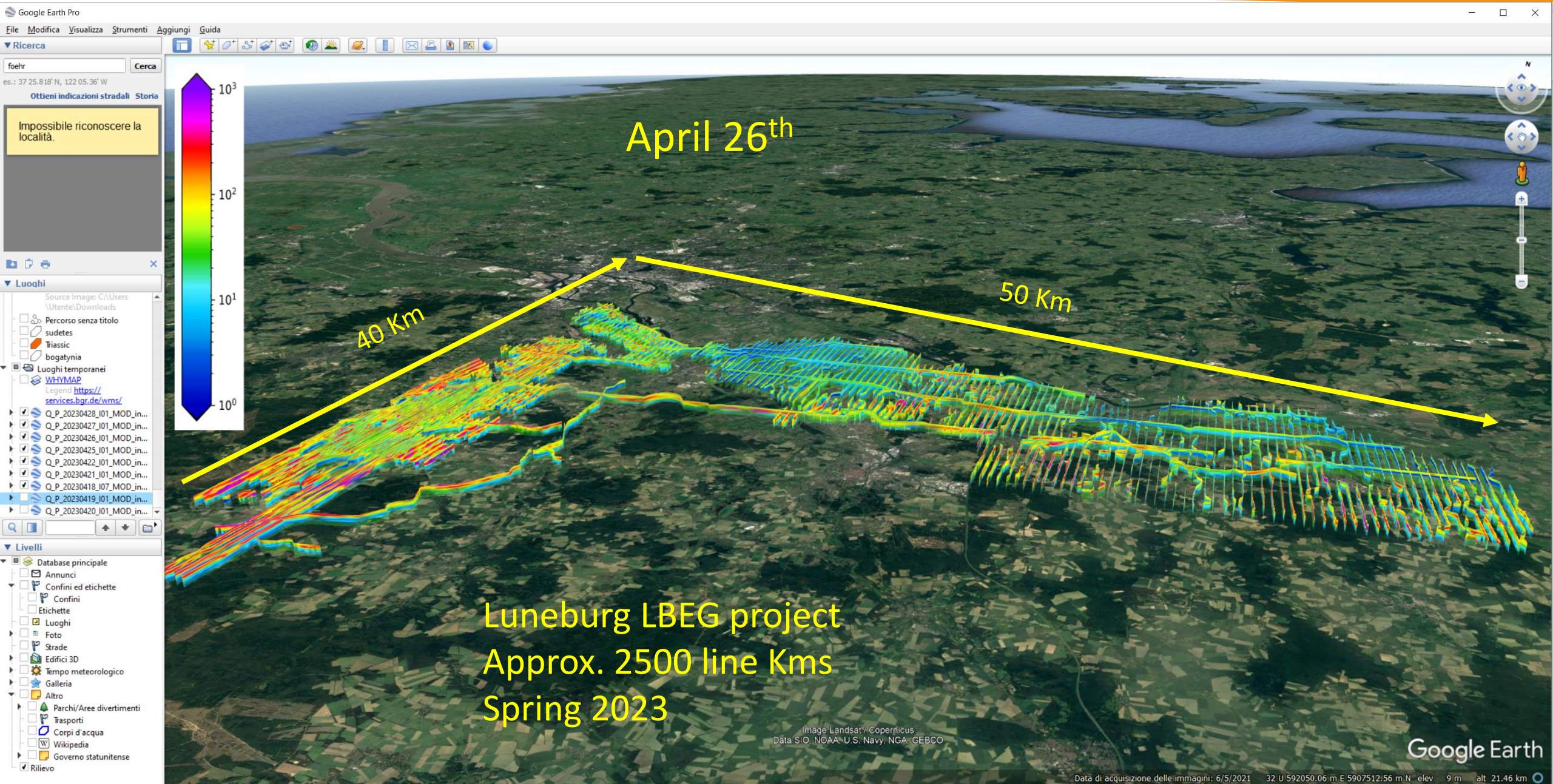


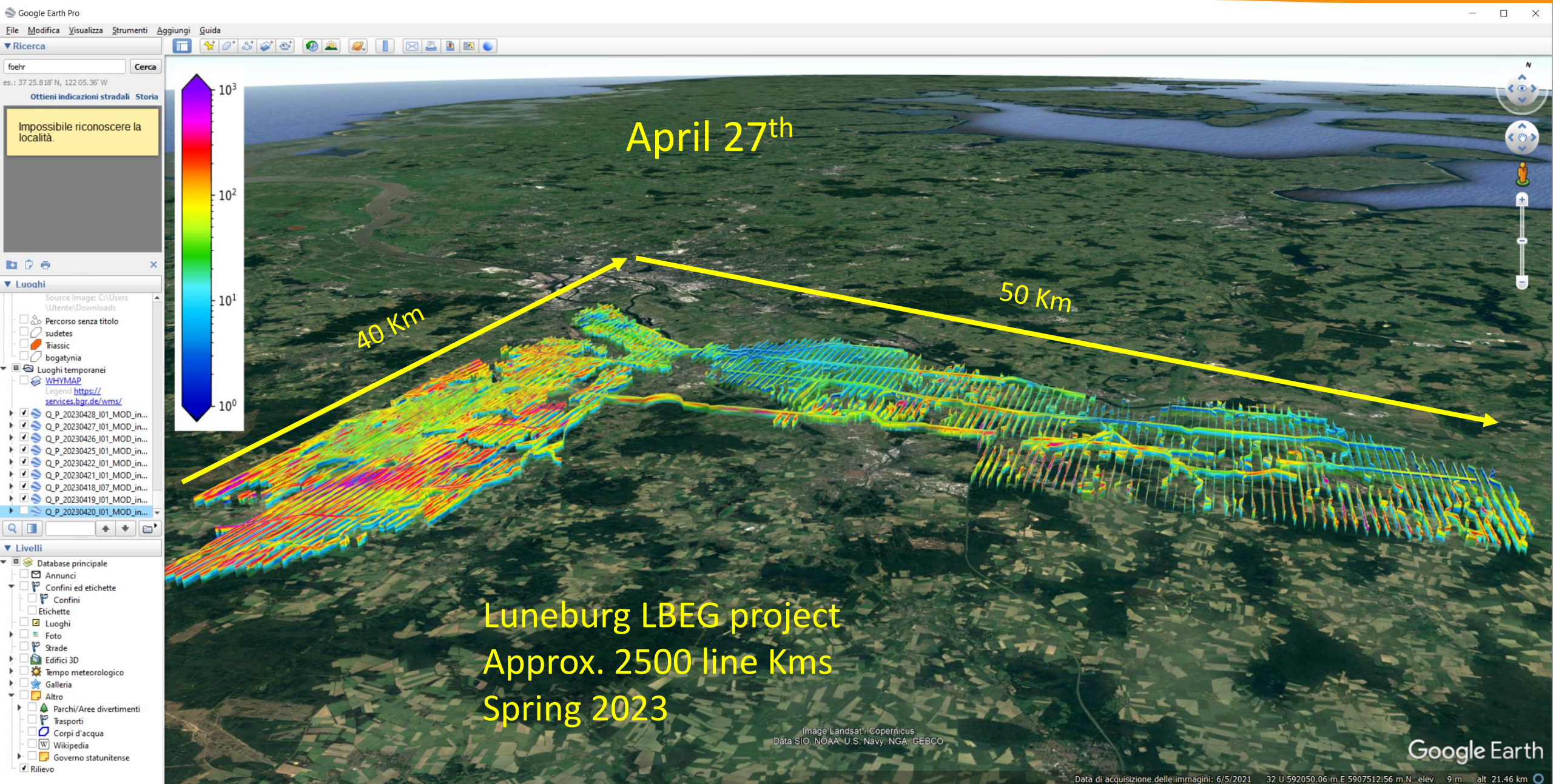


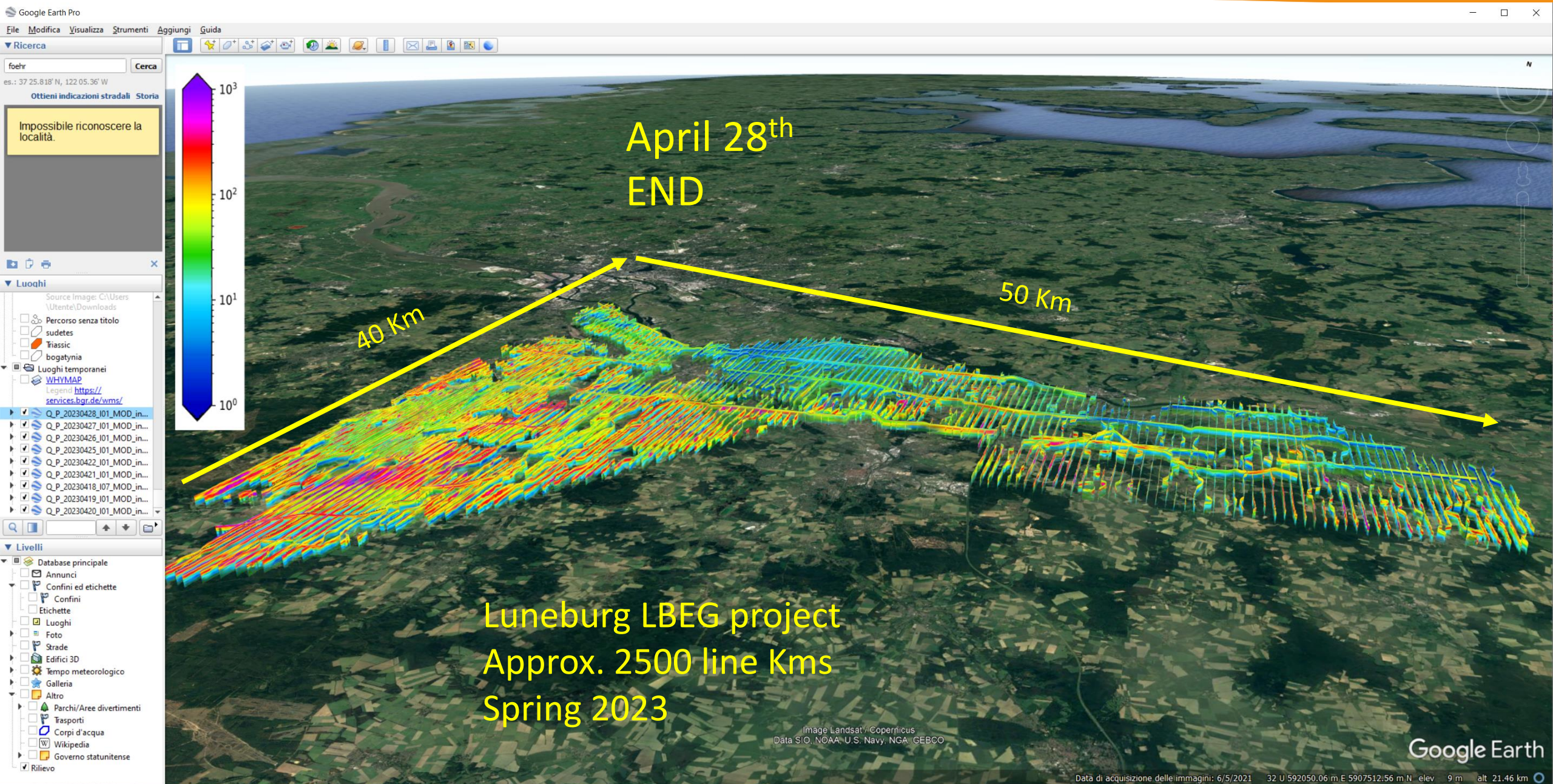










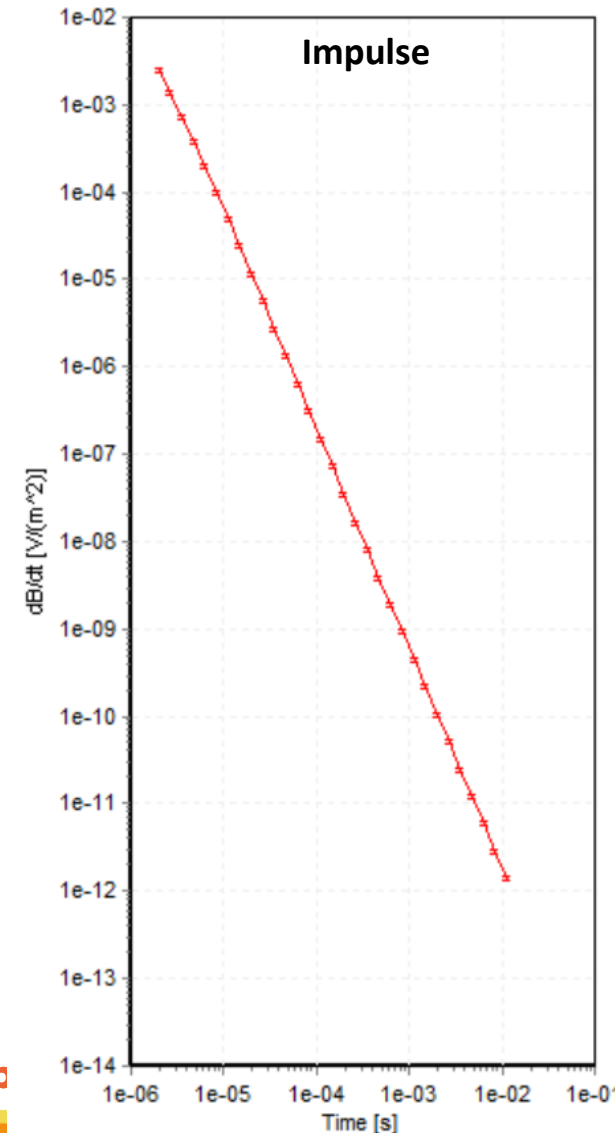


IL METODO AEM – Punti di forza e debolezza

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SEGNALE MISURATO

- **Ai late times decade come $t^{-5/2}$**
- **Il livello del segnale scende di 5 decadi in 2 decadi di tempo**
- **Accuratezza necessaria per la mappatura di acquiferi:**
 - 3-5%
- **Necessità di**
 - Sistemi accurati & descrizione del sistema
 - Software di modellazione accurati
 - Dati riproducibili – sito di calibrazione e riferimento



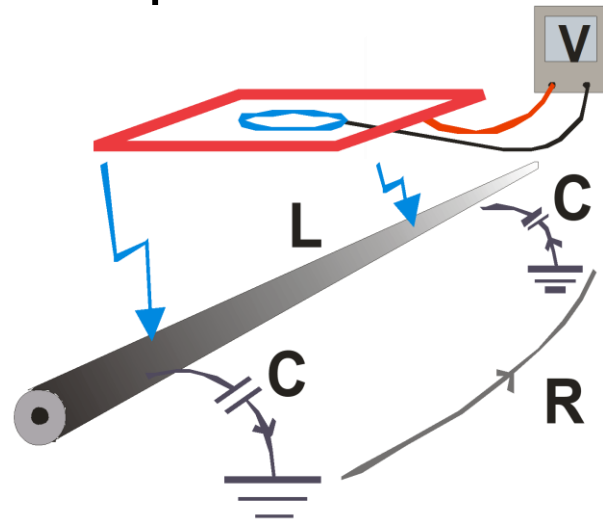
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Coupling

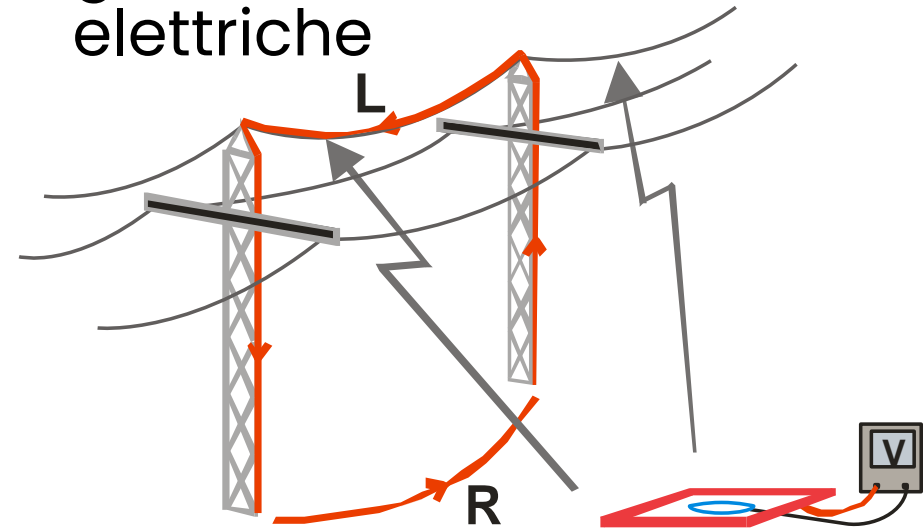
- **Capacitivo – Circuiti RLC**

- Conduttori isolate, cavi telefonici, cavi elettrici sepolti



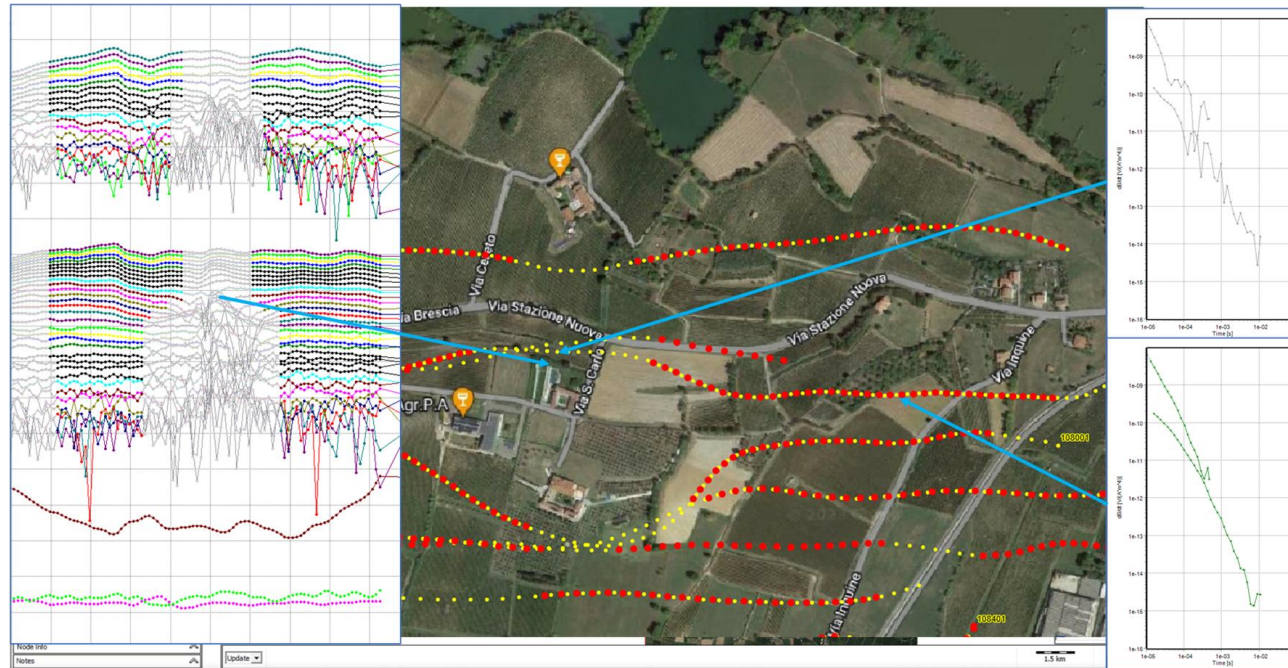
- **Galvanico – Circuiti RL**

- Conduttori messi a terra, guard rails, recinzioni, line elettriche



Necessità di un processing accurato

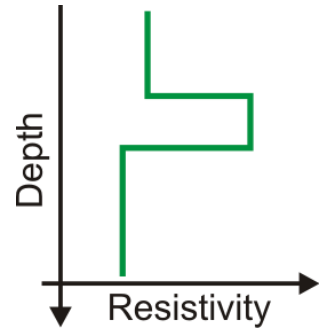
- Niente volo su aree urbane
- In ogni caso, alta copertura anche in aree altamente urbanizzate come la pianura padana



IL METODO AEM – Punti di forza e debolezza

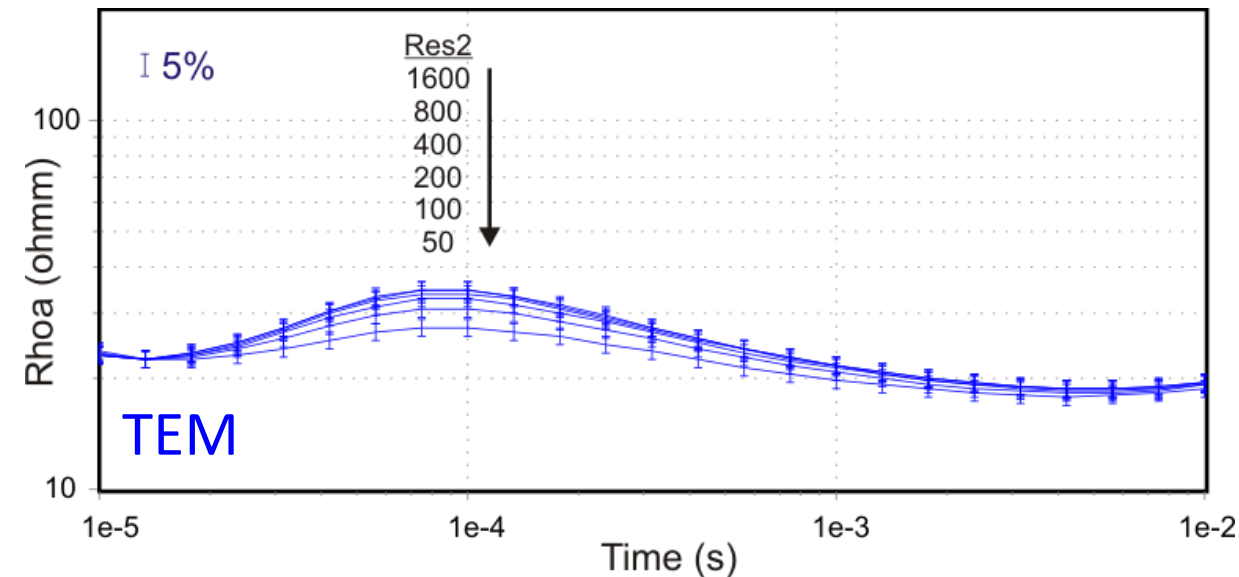
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Equivalenze



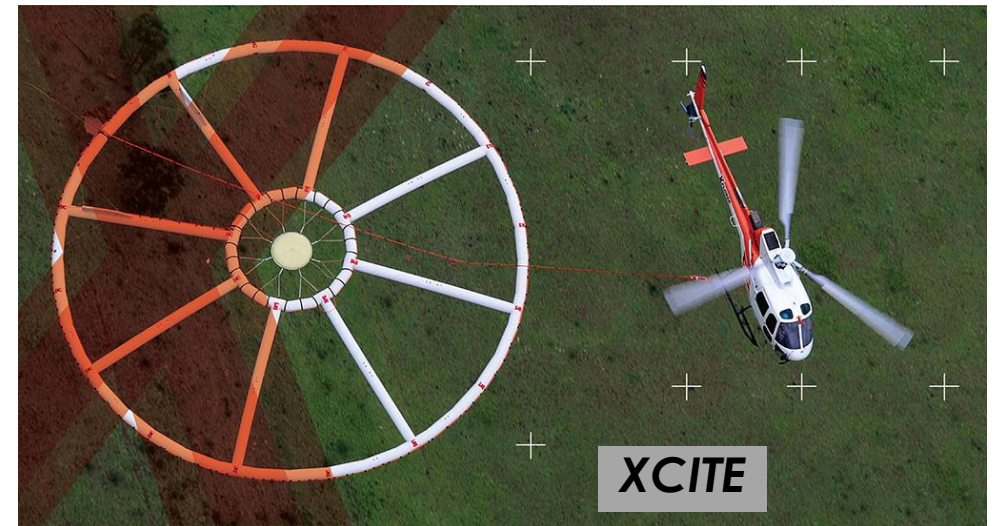
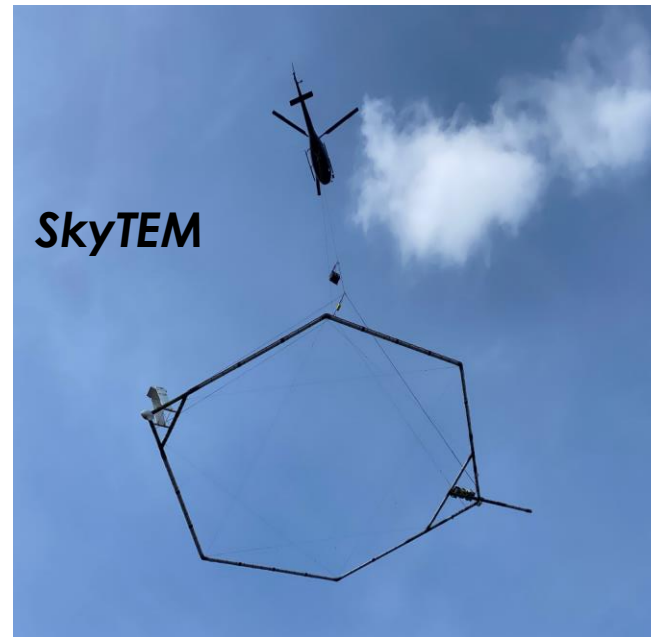
- **La resistività nel secondo strato cambia**
Modello:

Resesitivity (Ωm)	Thickness (m)
20	15
1600, 800, 400, 200, 100, 50	25
15	inf



Esplorare il sottosuolo volando.

Sistemi Airborne Time-Domain

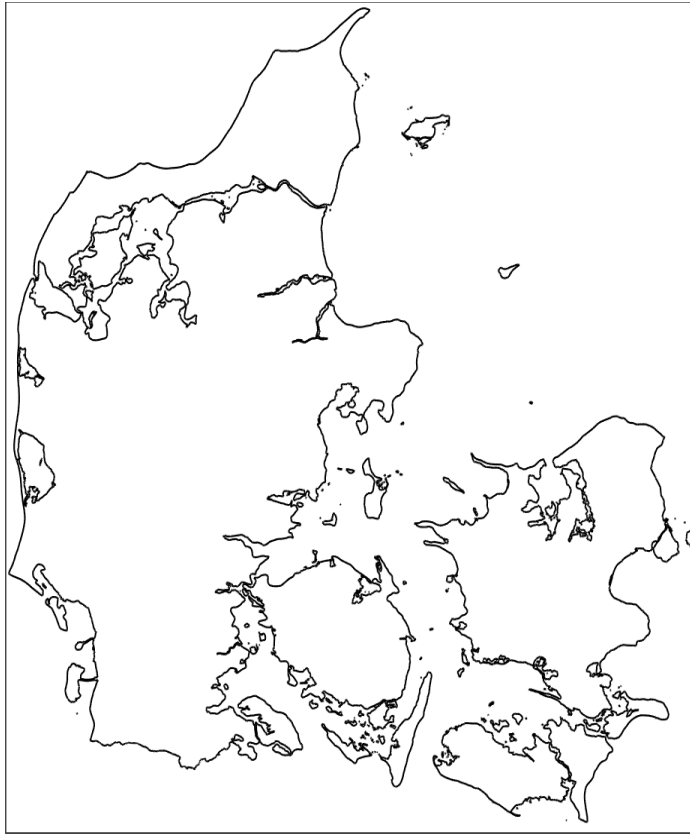


Sistemi Airborne Frequency-Domain



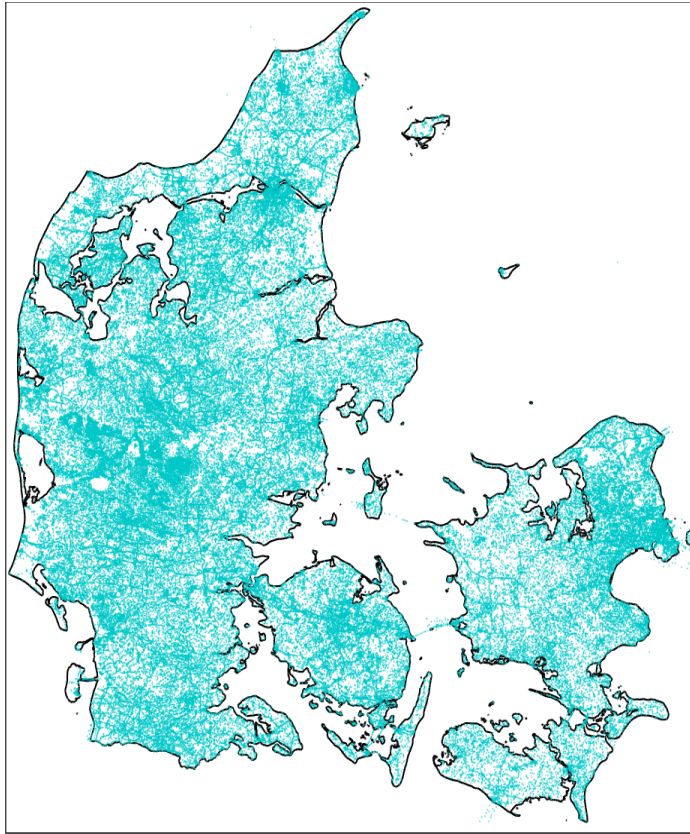
Data COVERAGE

Jupiter, il database dei pozzi danese



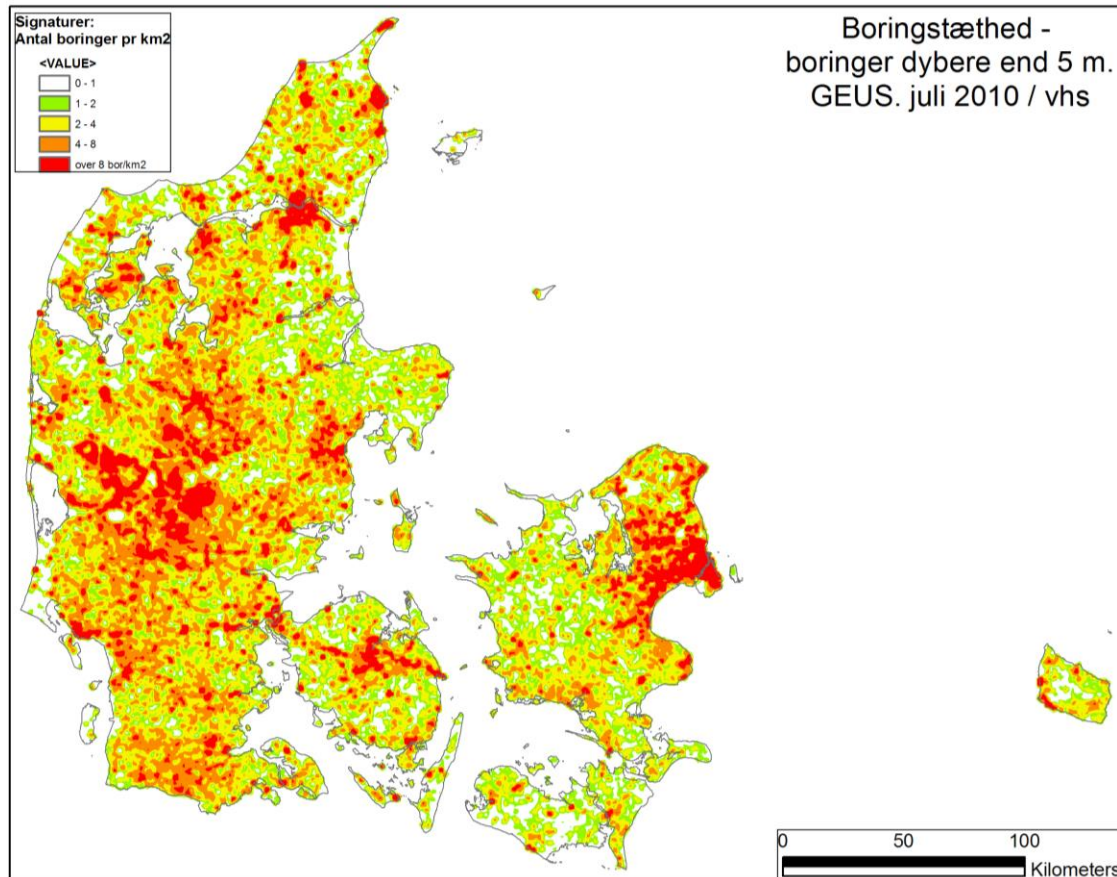
Data COVERAGE

Jupiter, il database dei pozzi danese



Data COVERAGE

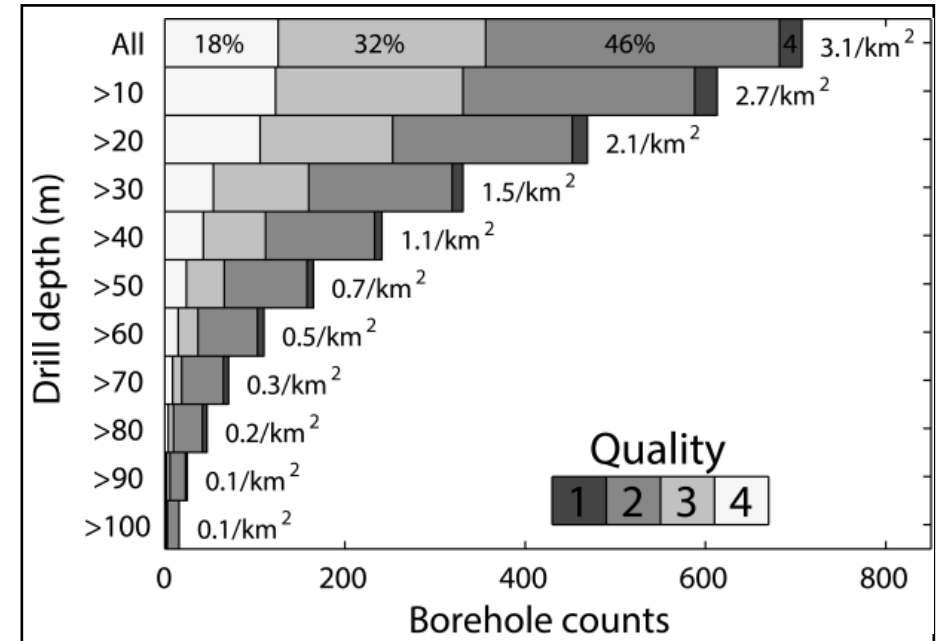
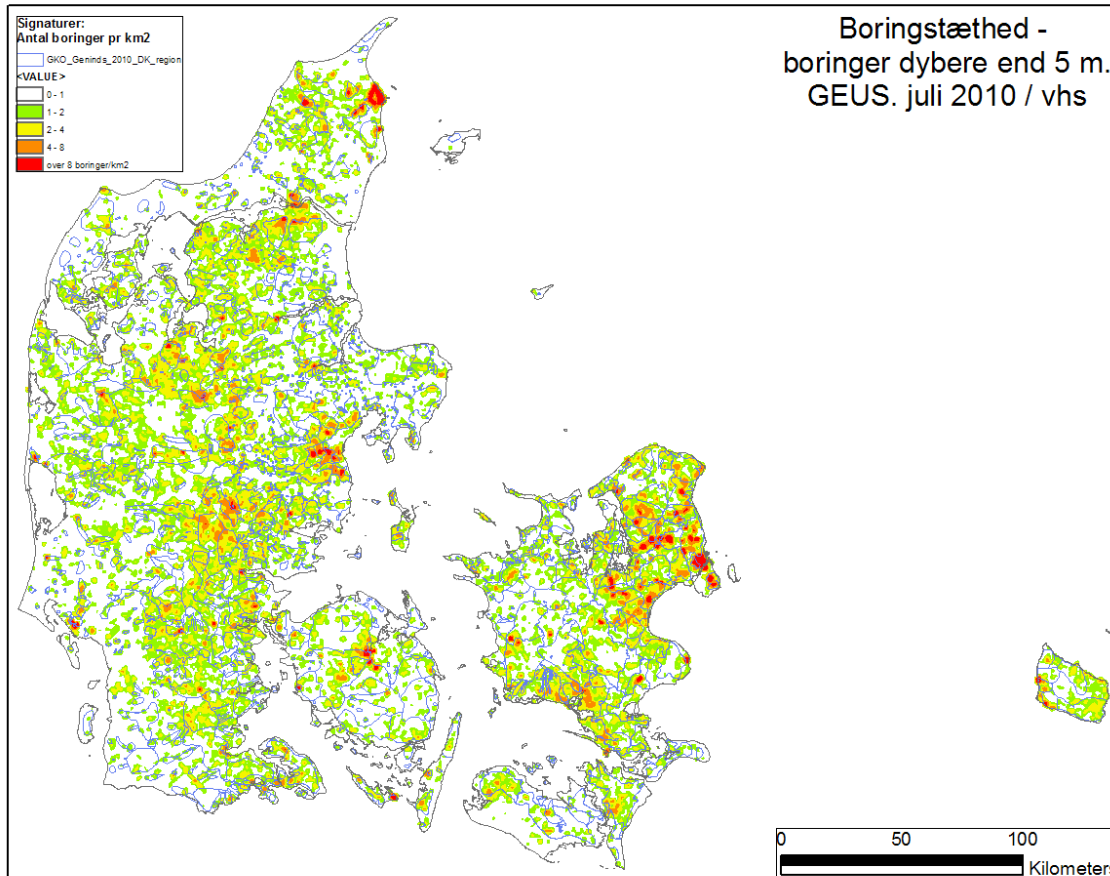
Jupiter, il database dei pozzi danese



- Pozzi in
Danimarca più
profondi di 5 m
~ 4,1 pozzi/km²
(Jupiter Dec. 2009)

Data COVERAGE

Jupiter, il database dei pozzi danese

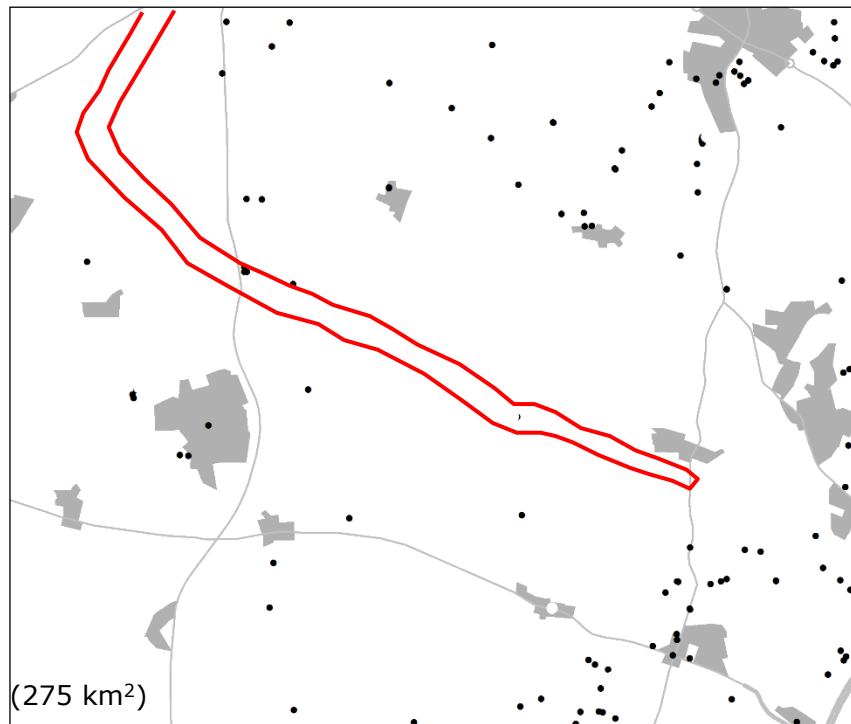


Foged et al., 2014, *Hydrology and Earth System Sciences*, vol 18, 4349-4362

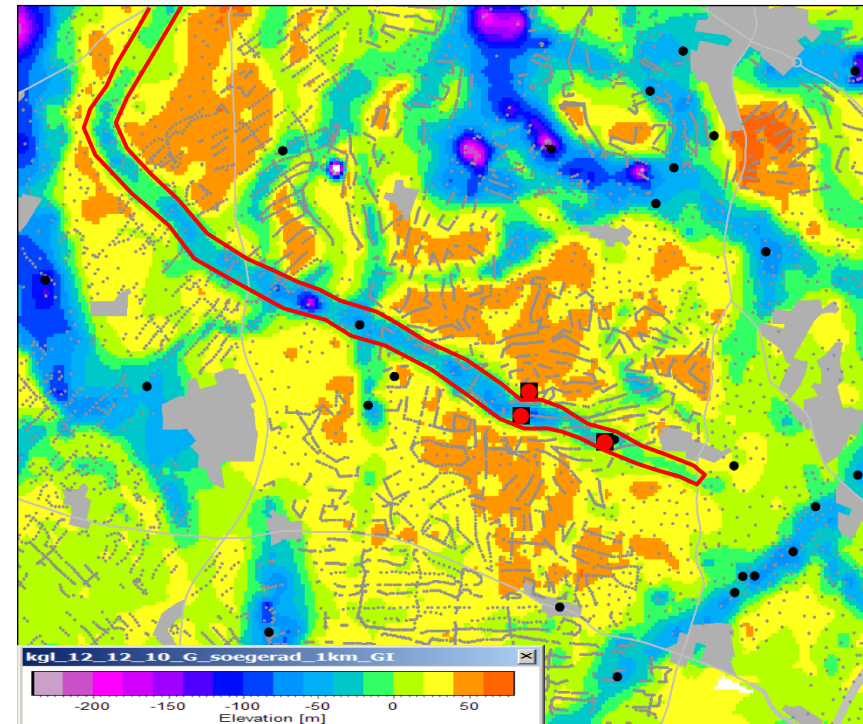
Data COVERAGE

Jupiter, il database dei pozzi danese

Anche una densità di pozzi buona non è in grado di individuare un Sistema complesso di valli sepolte



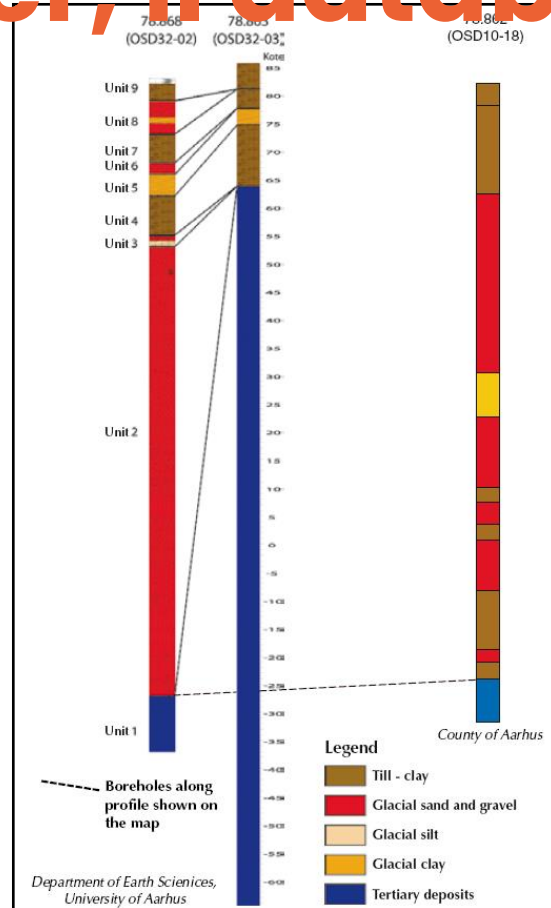
Vecchi pozzi più profondi di 50 m



Livello del buon conduttore profondo (argille) basato sui soindaggi TEM (black)

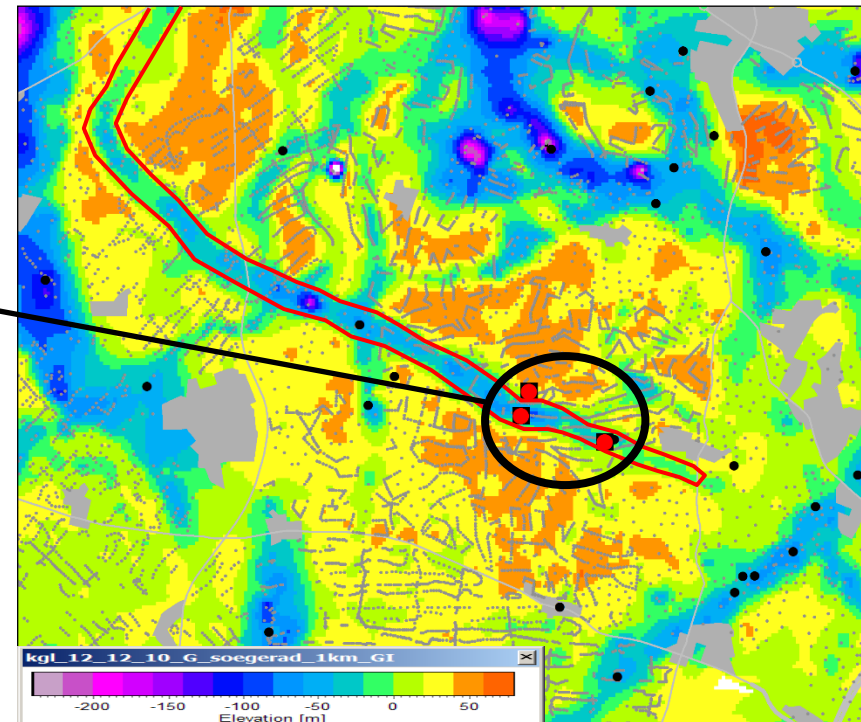
Data COVERAGE

Jupiter, il database dei pozzi danese



I due pozzi perforati nelle valli sepolte rivelano spessi (fino a 80 m) acquiferi sabbiosi (in rosso). Le valli sepolte sono larghe circa $\sim 0,5$ km

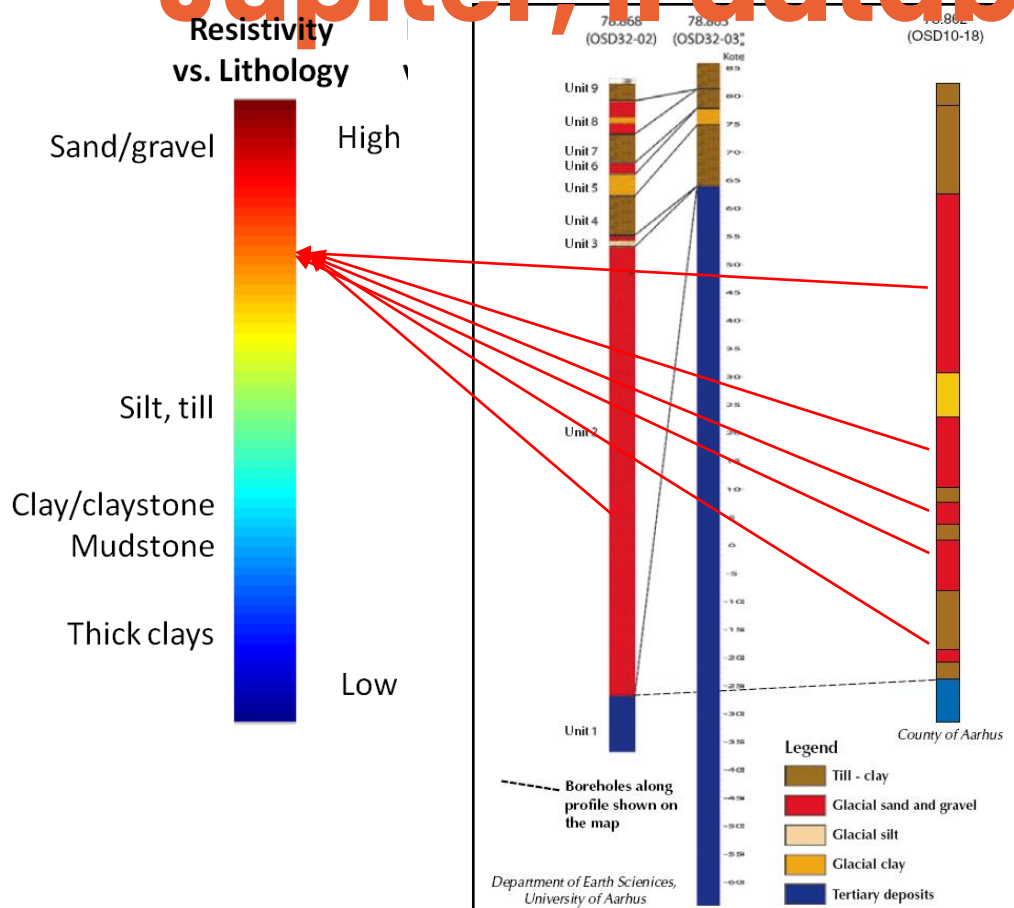
L'interpretazione geofisica è seguita da una campagna di perforazioni



Livello del buon conduttore profondo (argille) basato sui sondaggi TEM (black)

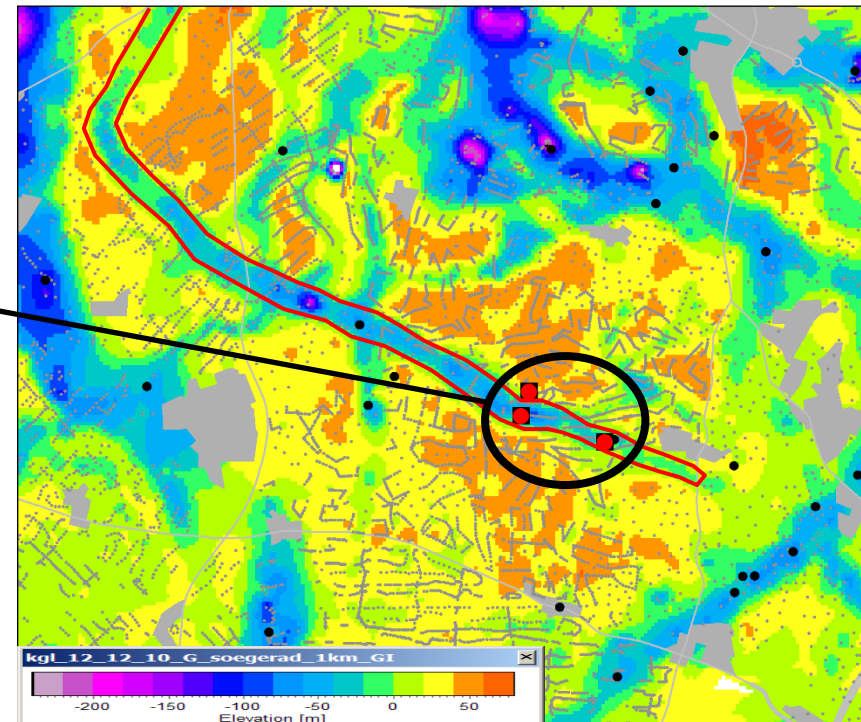
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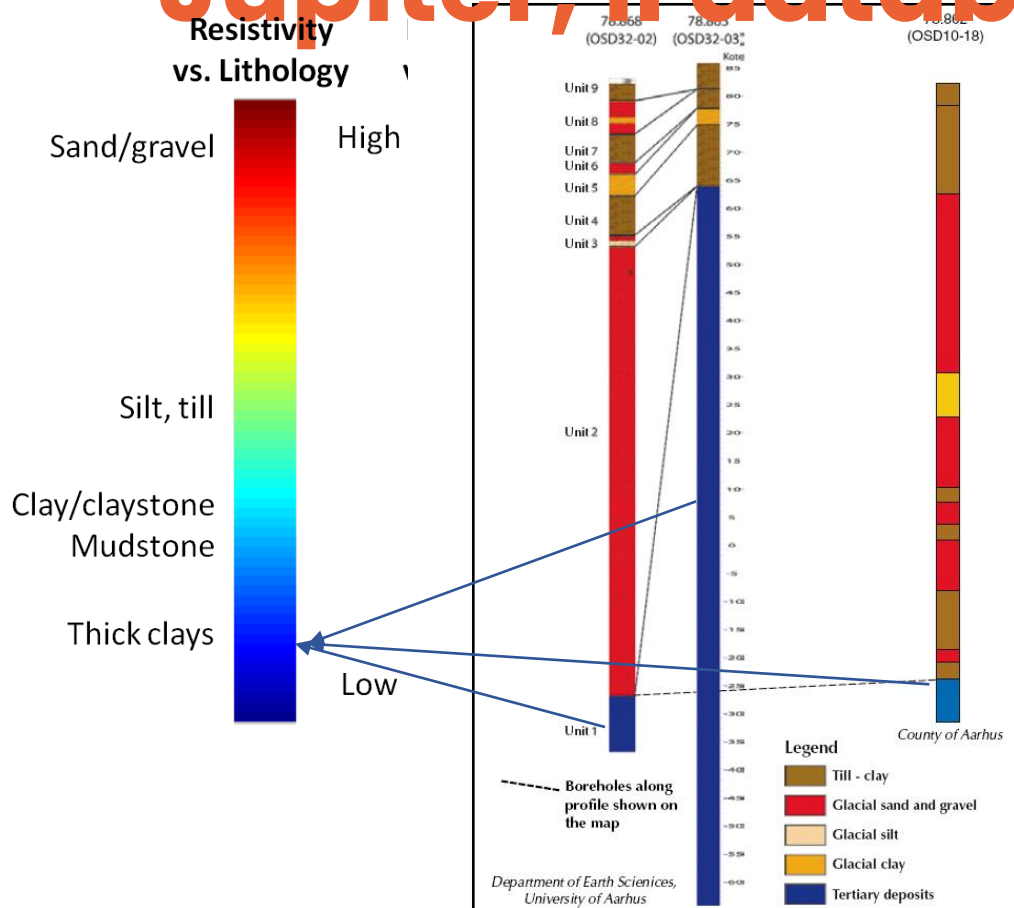
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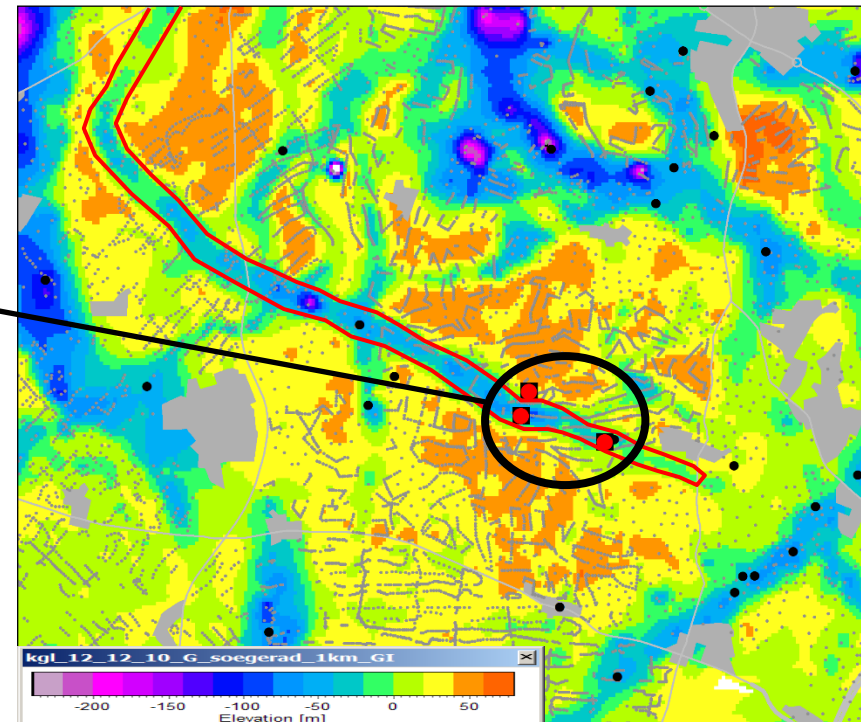
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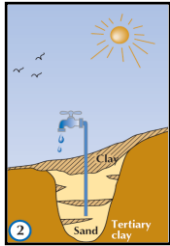


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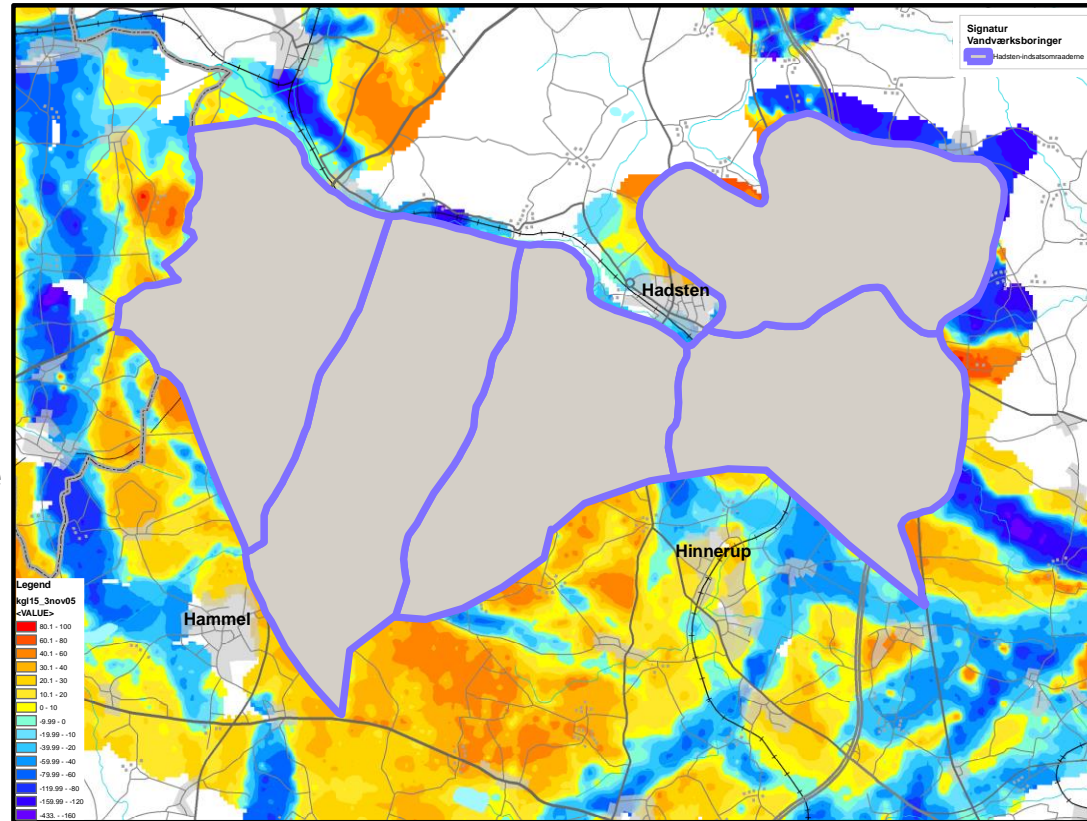


Esplorare il sottosuolo volando.

La scala delle strutture?

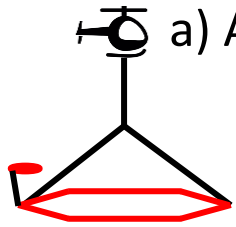


Aree di indagine
troppo piccole
non danno la
visione
d'insieme
(profondità delle
argille)



Metodi elettromagnetici ed elettrici

Method	a)	b)	c)	d)	e)	f)	g)
Depth of Investigation (m)	~300-400	~50-250	~250-500	~6	~120	~50	~30-100



a) Airborne EM

ERT & IP

TEM

EM31-8

System towed
by ATV

tTEM

System towed
by ATV

Loupe TEM

System on
backpacks

FloaTEM

towed by
boat

b)

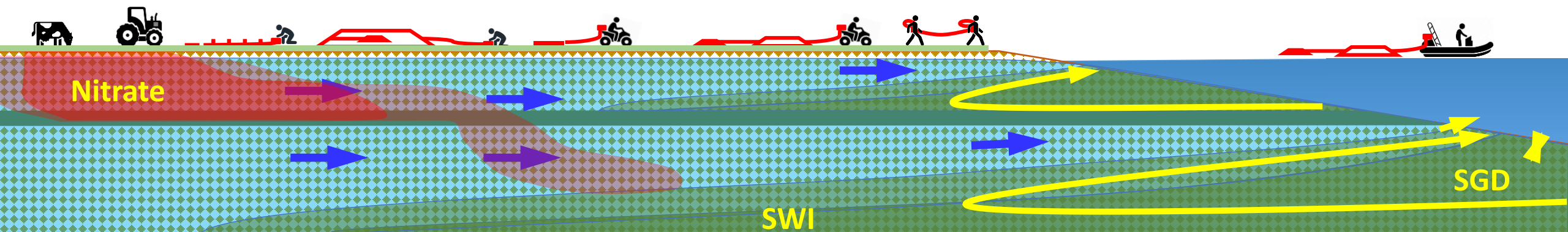
c)

d)

e)

f)

g)



Acquisizione in continuo anche ground-based e waterborne!

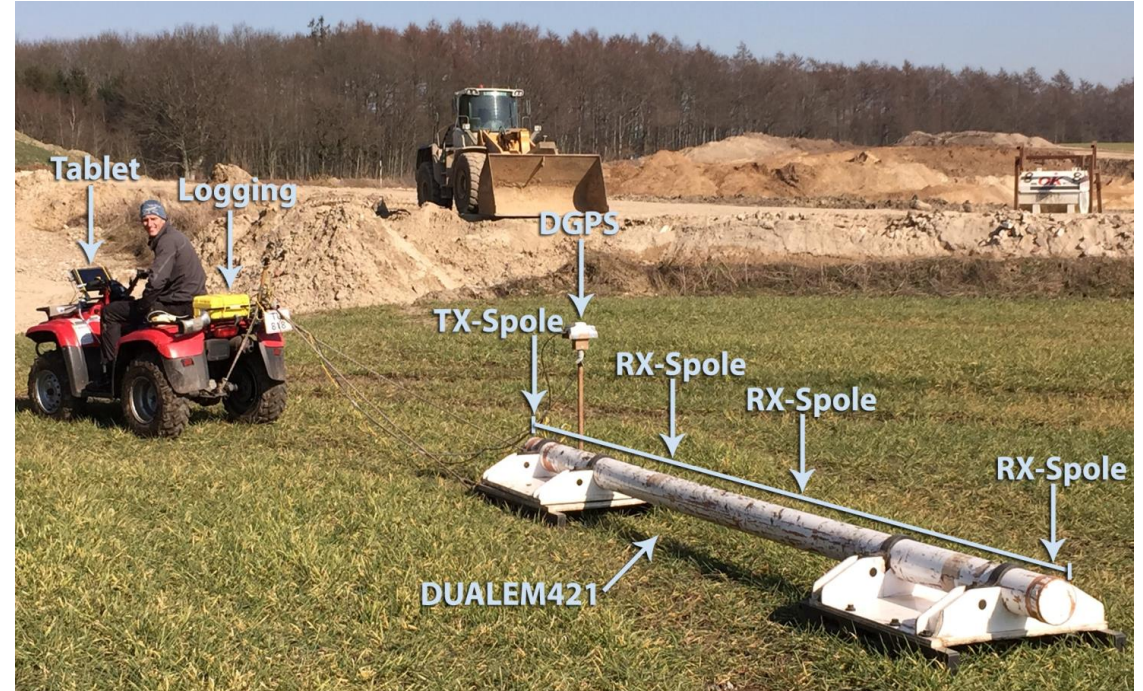


Esplorare il sottosuolo volando.

EM in acquisizione continua: ground-based & waterborne

Ground-based

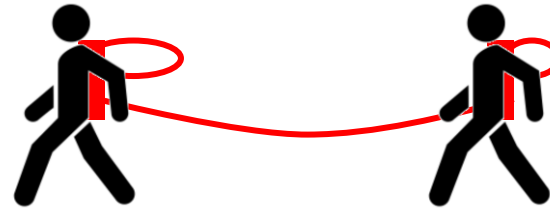
- Conduttivimetro
 - Strumento trainato da all terrain vehicle
 - Fino a 5/8 m di profondità
 - 15/20 km/h in acquisizione continua



EM in acquisizione continua: ground-based & waterborne

Ground-based

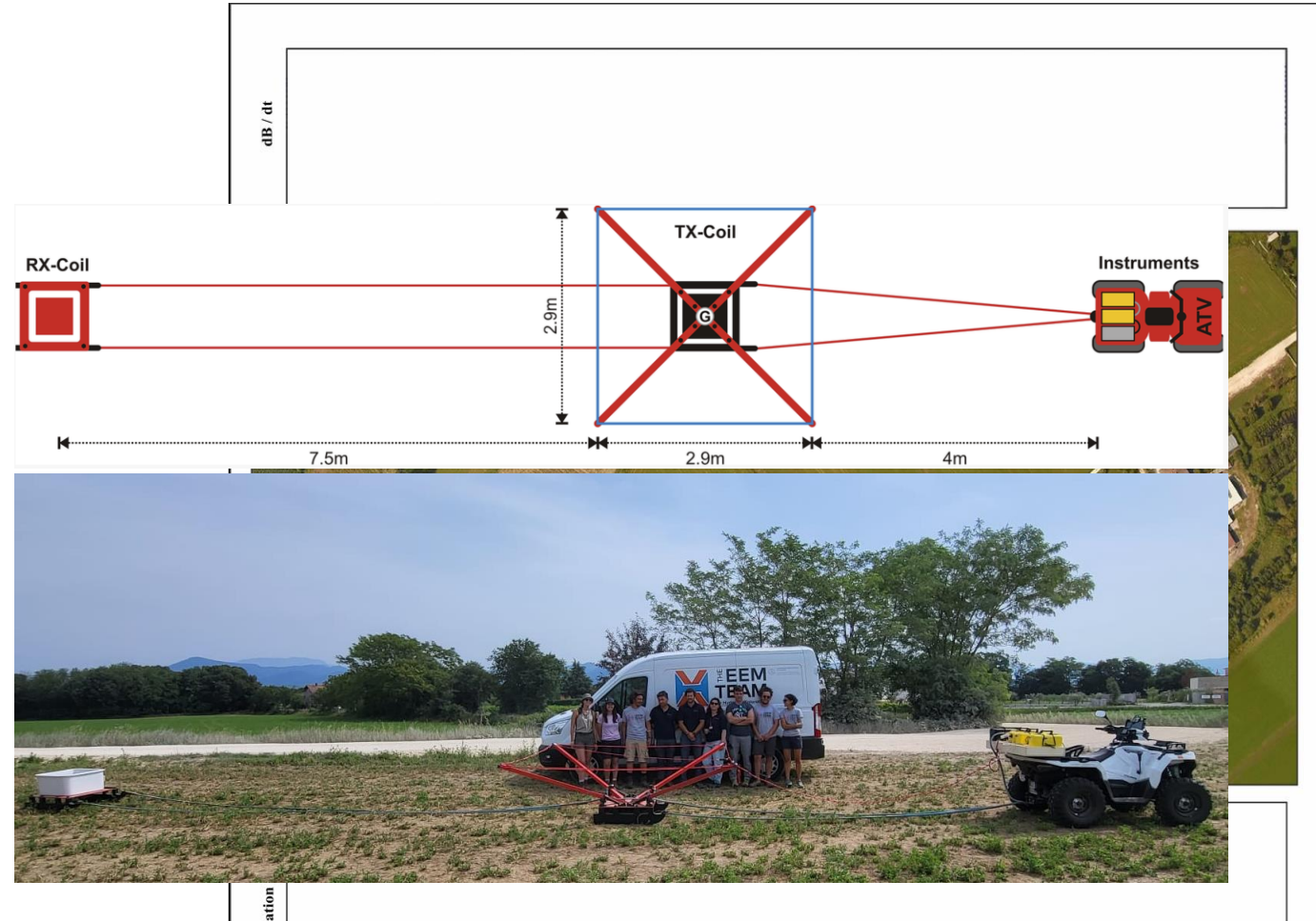
- **Conduttivimetro**
 - Strumento trainato da all terrain vehicle
 - Fino a 5/8 m di profondità
 - 15/20 km/h in acquisizione continua
- **Loupe**
 - Strumento montato su zaini
 - Fino a 30/40 m di profondità
 - 2/3 km/h in acquisizione continua



EM in acquisizione continua: ground-based & waterborne

Ground-based

- Conduttivimetro
 - Strumento trainato da all terrain vehicle
 - Fino a 5/8 m di profondità
 - 15/20 km/h in acquisizione continua
- Loupe
 - Strumento montato su zaini
 - Fino a 30/40 m di profondità
 - 2/3 km/h in acquisizione continua
- tTEM (towed Transient EM)
 - Strumento trainato da all terrain vehicle
 - Fino a 100/150 m di profondità
 - 15/20 km/h in acquisizione continua



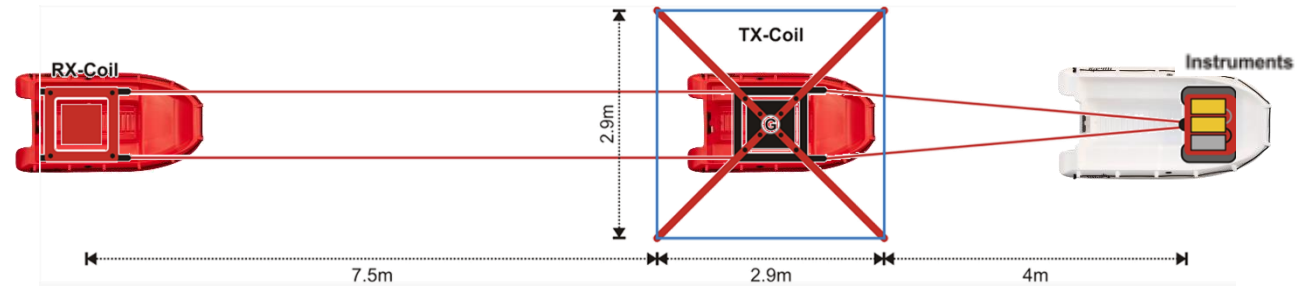
EM in acquisizione continua: ground-based & waterborne

Ground-based

- **Conduktivimetro**
 - Strumento trainato da all terrain vehicle
 - Fino a 5/8 m di profondità
 - 15/20 km/h in acquisizione continua
- **Loupe**
 - Strumento montato su zaini
 - Fino a 30/40 m di profondità
 - 2/3 km/h in acquisizione continua
- **tTEM (towed Transient EM)**
 - Strumento trainato da all terrain vehicle
 - Fino a 100/150 m di profondità
 - 15/20 km/h in acquisizione continua

Waterborne

- **FloaTEM (Floating Transient EM)**
 - Strumento trainato da barche
 - Fino a 80/120 m di profondità
 - 7/10 km/h in acquisizione continua



L'esempio della danimarca: mappatura delle disponibilità idriche

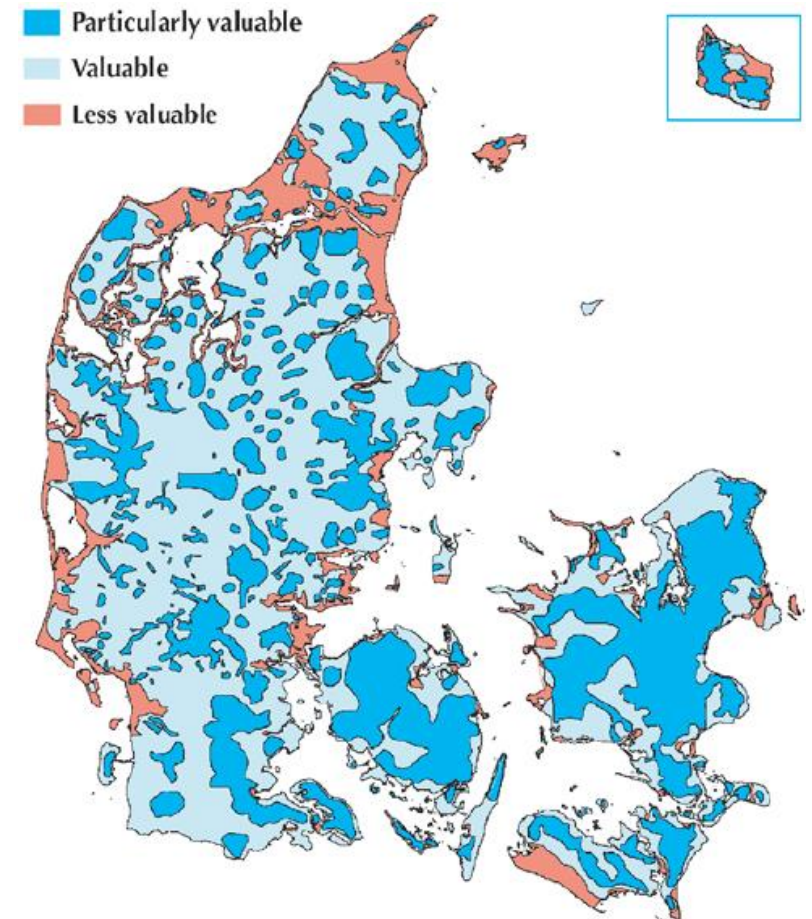


Danish Groundwater Mapping and Geodata Management

THE DANISH LAW OF GROUNDWATER PROTECTION (1998)

- Drinking water must be naturally clean and untreated groundwater
- Categorized recharge areas
 - Recharges area of major value (40%)
 - Recharges area
 - Recharges area of limited value
- Dense groundwater mapping (40%)
 - Resource today and future
 - Vulnerability towards pollution
- Funding
 - Taxes on groundwater withdrawals
 - € 0,07 pr. m3 ~ € 15 mil per year
- Time perspective
 - Mapping finished in 2015, total cost approx. € 250 mil

*see Thomsen, R. & Sondergaard, V (Tech. Ed.) & Klee, P. (Ed.), 2013. Greater water security with groundwater - Groundwater mapping and sustainable groundwater management. The Rethink Water network and Danish Water Forum white papers, Copenhagen. Available at www.rethinkwater.dk



Mappa di classificazione delle acque sotterranee che mostra la suddivisione della Danimarca in aree di estrazione delle acque sotterranee di particolare valore, valore e meno valore nel 2001

Esplorare il sottosuolo volando.

2. Methods and tools for mapping and hydrogeological modelling

Airborne data sampling can now generate a detailed 3D-picture of subsurface structures. But just as 3D brain scans require detailed analysis by experts, so airborne geophysics needs analysis and interpretation of data by professionals, in order to fully understand the geology

VERNER SONDERGAARD
Research Geophysicist
GEUS GEOLOGICAL SURVEYS
OF DENMARK AND GREENLAND

The Danish government's decision to protect and secure Denmark's groundwater for future generations has led to new innovative methods and tools that today constitute a proven setup for conducting groundwater mapping on a large scale. Developments include new geophysical mapping methods, a unique geophysical database, world-class data processing tools and innovative 3D geological modelling software. The advanced methods and tools are all scientifically and internationally documented and are continuously being improved through different tests and the establishment of new boreholes.

Mapping using two data sources

In most parts of the world groundwater mapping is based only on one data source: drilling information. However, low borehole density means that this strategy often leaves many uncertainties in the models. In Denmark, and a few other countries, geophysical measurements are used in conjunction with drilling to map aquifers. Intensive, large-scale use of geophysical methods, particularly airborne electromagnetic surveys in an integrated workflow together with drilling, makes mapping results more accurate and reliable.

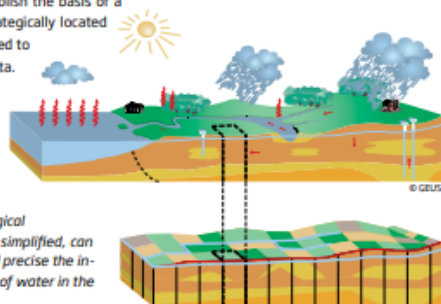
Borehole data contributes significantly when mapping overall geology, but inevitably the density is low and most boreholes are quite shallow. Spatially dense geophysical measurements can be used to establish the basis of a hydrogeological model. Strategically located boreholes may then be drilled to confirm the geophysical data.

They provide critical information for translating interpretations of the geophysical data into a geological model. Used together, the two datasets multiply their respective descriptive and modelling capabilities.

Two methods – the electrical and the electromagnetic methods – are particularly useful among the geophysical methods since there are strong correlations between both the measured resistivity and the lithology of the subsurface, and between the resistivity values and water salinity. Thus, airborne mapping with electromagnetic methods provides detailed area-covering input for a geological model of the subsurface, at basin scale. The data density obtained over large areas using airborne surveys is many times greater than can be achieved with ground-based surveys, and magnitudes larger than that of drilling surveys.

Transient electromagnetic measurement

The SkyTEM system, developed in Denmark, is recognized as one of the best airborne transient electromagnetic measurement systems in the world, and the only system developed specifically to meet the high data quality requirements of hydrological mapping. Airborne survey methods produce data sets with a high lateral density. Typically, a survey is flown with parallel lines at a distance of 100-500 metres (one metre equals 40 inches), depending on the target



Groundwater model A hydrogeological model is a simplified description of a real geological system. Creating a perfect replica of the geology is impossible using only geological and geophysical surveys and drilling, because a geological system is extremely complicated. But creating a groundwater model, though simplified, can support decision making in groundwater management. The more detailed and precise the input data is, the more realistic and useful the calculations of flow and storage of water in the underground system will be. (Courtesy: GEUS).

It is our experience that the acquisition of dense, accurate geophysical data, that is followed by rigorous processing procedures, adds valuable information to the existing knowledge of the hydrogeology and towards better management of the resources

ANDREA VIEZZOLI
Director
AARHUS GEOPHYSICS

and the complexity of the geology. The in-line sounding distance is typically 20-40 metres with a depth of investigation around 300 metres below the surface. The standard output is therefore a 3D description of the subsurface, from the surface to a depth of 300 metres, based on hundreds of data points per square kilometre. Alongside the development of the SkyTEM system a dedicated data processing, inversion and visualisation system has been built, called the Aarhus Workbench.

Other geophysical methods

In order to improve the models, the airborne measurements are often supplemented by other measures, such as seismic measures to supply detailed structural information not obtained by the airborne methods, or the magnetic resonance sounding (MRS). Magnetic resonance sounding measures water content directly, and can distinguish salty groundwater from heavy clay, for example.

Other important mapping methods

Geophysical data is typically supplemented by other data. This includes new boreholes, pumping tests, groundwater head mapping, water mapping and soil chemistry mapping. New boreholes are drilled in areas where precise knowledge about the geological structure of the groundwater system is lacking. Pumping test analyses give valuable information about the hydrogeological structure of the system. Systematic mapping of the groundwater head is used to determine flow patterns and the interaction between multiple aquifer systems and

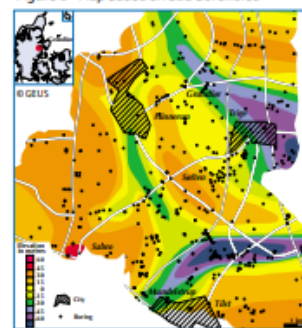
surface water systems. Groundwater chemistry mapping based on water samples from multiple boreholes provides information that can help with groundwater protection and may help shed light on the subsurface structure, thus helping with the interpretation of data from other sources.

Modelling

Geological, hydrogeological and hydrological as well as groundwater chemistry models are needed to identify groundwater protection areas, optimum well locations, sustainable water extraction levels and so on. These models are developed by combining airborne measurements, ground-based geophysical measurements and data from boreholes using a 3D modelling tool. This requires a multitude of skills and the experienced geological modeller combines an understanding of geophysical data, a knowledge of geological development processes and history, and a practical understanding of the nature of rock and soil. To facilitate model building, new geological modelling software has been developed, called GeoScene3D.

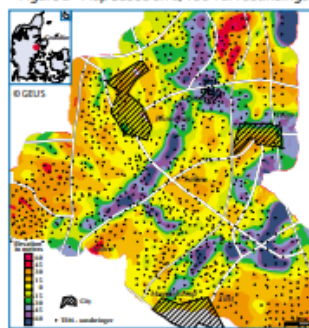
A consistent, documented and traceable path leads from the first well drillings and airborne survey and groundwater chemistry data, through the processing and analysis, to the final model. It is crucial that the entire workflow, from collection of the electromagnetic measurement data to generation of the groundwater model, is carried out to the highest technical level and with the highest possible degree of accuracy, transparency and documentation.

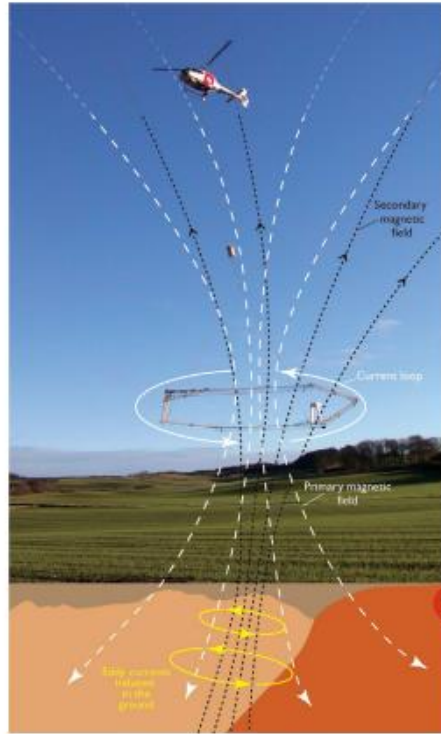
Figure 1 - Map based on 518 boreholes



Accuracy of mapping This diagram shows our understanding of the aquifer structures before and after geophysical mapping based on airborne transient electromagnetic measurement in an area of Denmark. The survey revealed completely unknown aquifers in the area. Figure 1 shows our understanding of the aquifers based solely on well drilling. The dark blue areas are thick aquifers; red colours show areas with no aquifer or a thin aquifer. Figure 2 shows the same area after geophysical mapping by ground based TEM. The revised interpretation shows substantial differences in aquifer location, which have subsequently been verified by new boreholes. (Courtesy: GEUS).

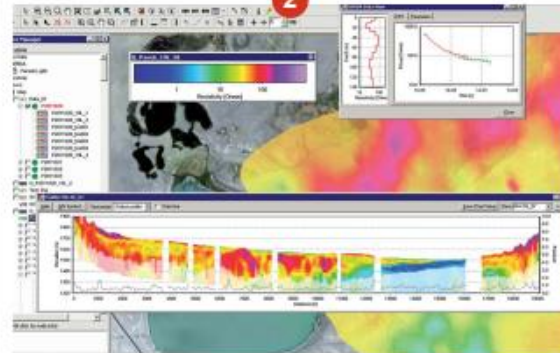
Figure 2 - Map based on 1,400 TEM soundings



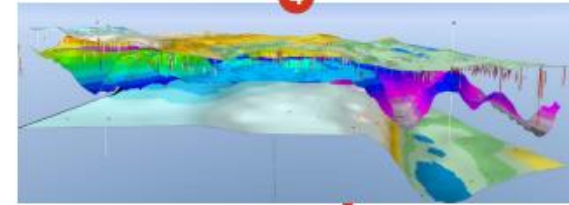
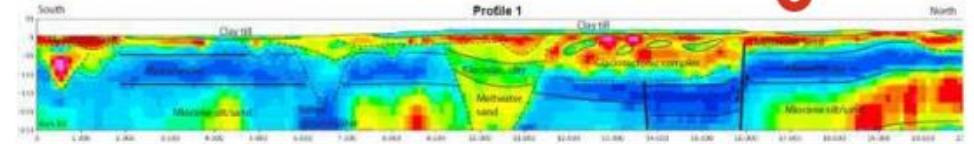


Step 1 The SkyTEM airborne survey system has proved to be an invaluable aid in the large-scale mapping of groundwater resources in Denmark, and other countries, through the detailed mapping of the subsurface resistivity. The system transmits an electromagnetic signal towards the ground, and translates the signal it receives back into a resistivity model. (Courtesy: Aarhus University, HydroGeophysics Group and GEUS).

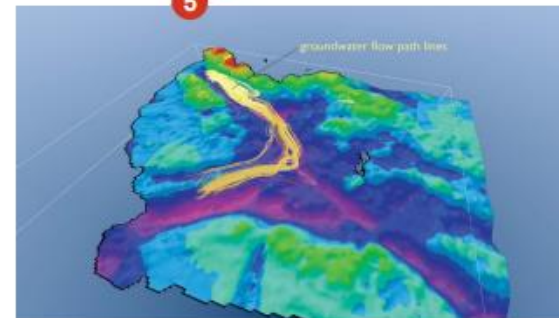
Step 2 The Aarhus Workbench software allows geophysicists to turn the SkyTEM raw data into accurate, transparent and well-documented 3D resistivity models of the subsurface, which are the geophysical basis for the groundwater mapping programme. The software is unique, as it was developed specifically for the hydrogeological application of airborne geophysical data. It incorporates tools for applying data processing and modelling protocols to ensure the results meet the quality required in groundwater mapping. (Courtesy: Aarhus Geophysics).



Step 3 When the geophysical data has been processed, and interpreted, specific structures in the subsurface can be identified. The task is to identify different layers and structures based on differences in electrical conductivity. Knowledge about the electrical properties of different sediments is crucial to distinguishing the various geophysical structures. This step relies heavily on information from boreholes in the area. Once the structures have been identified, geological modelling can be carried out, using the GeoScene3D tool. (Courtesy: GEUS).

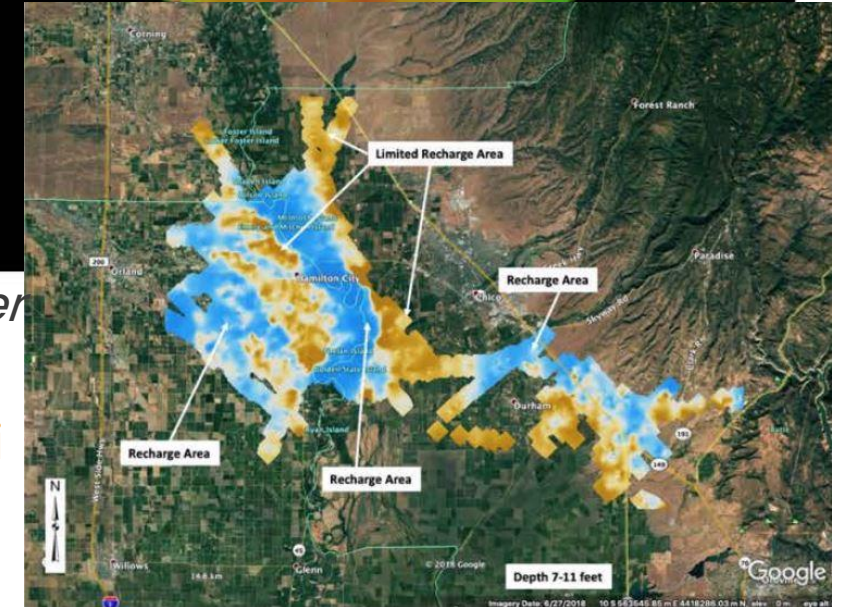
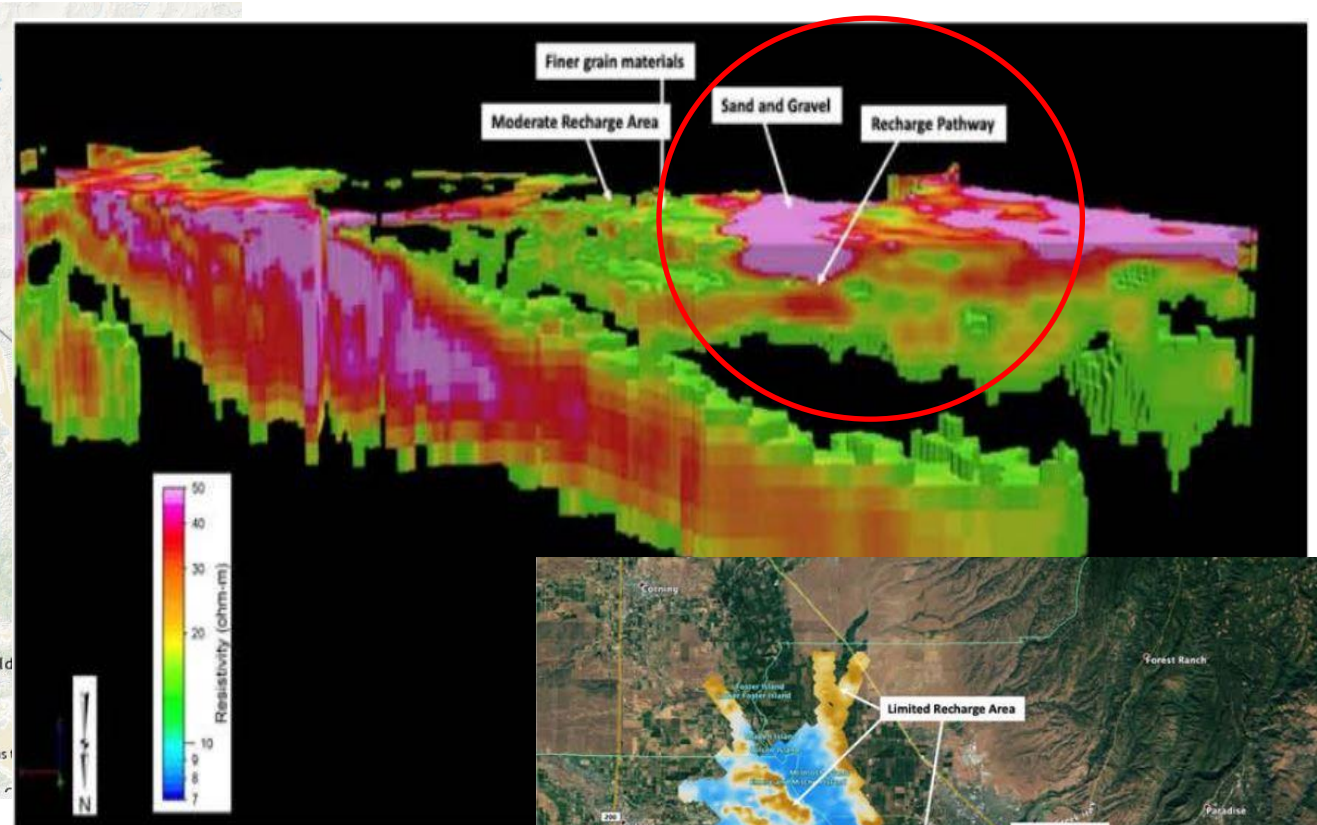
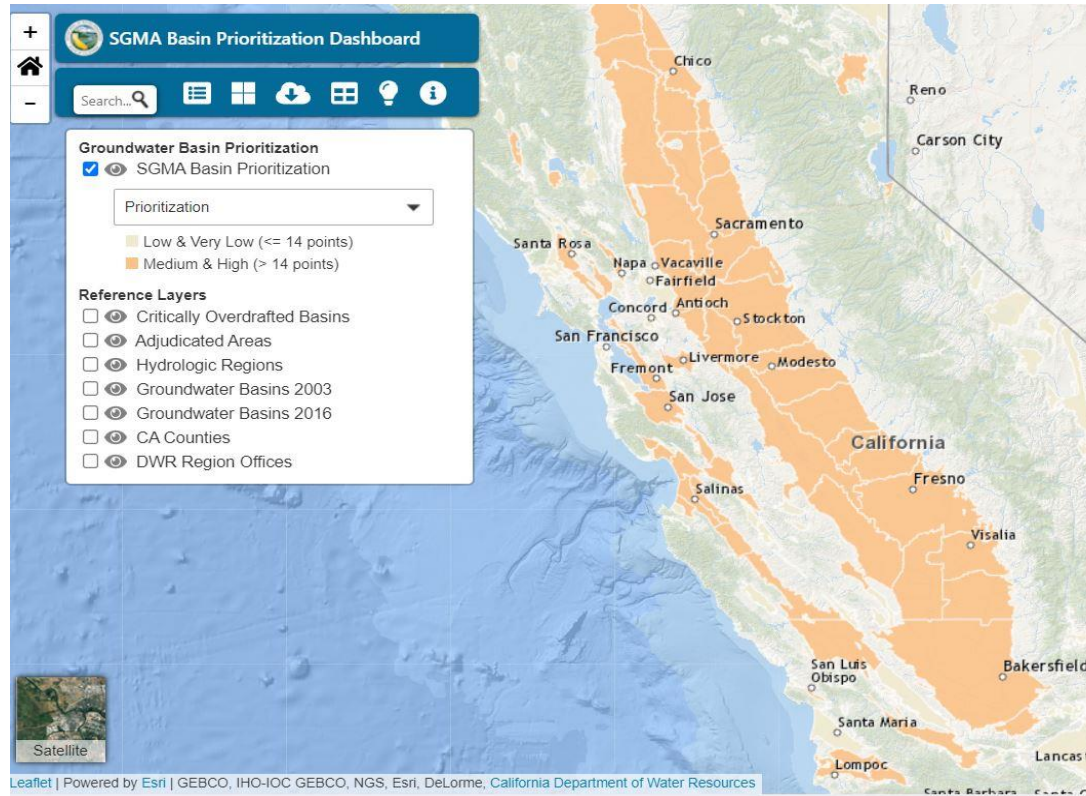


Step 4 In GeoScene3D both airborne and borehole data is collated in a 3D environment. The geologist, in collaboration with the hydrogeologist and hydrochemist, can now develop a geological model for the area being studied. The result is a model that can be used in groundwater flow calculations by applying hydrological modelling software, such as MikeShe, Modflow or FeFlow. (Courtesy: I-GIS).



Step 5 A groundwater model reveals how groundwater flow is determined by geological structures. All the necessary details for the groundwater model are exported directly from GeoScene3D into the hydrological modelling software. Calculations of groundwater flow path lines, to mention one example, are completely dependent on the quality of the input from the geological model especially when it comes to more complex subsurface geological structures. An example would be the incised valleys shown in the example here. (Courtesy: GEUS).

L'esempio della California (Central valley)



Lo Stato della California ha promulgato il *Sustainable Groundwater Management Act*, che richiede alle agenzie locali nei bacini idrici sotterranei ad alta e media priorità di sviluppare e attuare piani di sostenibilità delle acque sotterranee

L'esempio della California (Central valley)



Proposition 68 Funded Project
California Department of Water Resources
Sustainable Groundwater Management Program



CONDUCT AIRBORNE ELECTROMAGNETIC SURVEYS

Airborne Electromagnetic (AEM) surveys will be conducted in California's High and Medium Priority Groundwater Basins, including areas with disadvantaged communities (DACs). The project will generate coarse-grid subsurface maps that will provide fundamental information about aquifer structures that supports the development and implementation of groundwater sustainability plans (GSPs). The coarse-grid AEM data may serve as the basis for the collection of fine-grid AEM data by local stakeholders in the future.

What is Proposition 68?

The California Drought, Water, Parks, Climate, Coastal Protection and Outdoor for all Fund (Senate Bill 5, Proposition 68) authorized \$4 billion in general obligation bonds for state and local parks, environmental protection and restoration projects, water infrastructure projects, and flood protection projects. The AEM survey will utilize \$12 million on data, tools, and analysis efforts for drought and groundwater investments to achieve regional sustainability in support of the Sustainable Groundwater Management Act (SGMA).

How Does This Project Support SGMA?

This project will provide state and federal agencies, groundwater sustainability agencies, related stakeholders, and the public with basin-specific and cross-basin geophysical data, tools, and analysis aligned to the technical requirements of the groundwater sustainability plan (GSP) regulations and SGMA. The resulting information will provide a standardized statewide dataset that supports the

What is the Value of this Information?

The AEM data will provide supporting information about subsurface hydrogeologic characteristics of aquifer systems in groundwater basins. AEM data support the development and refinement of groundwater models, improve the potential for the successful development and implementation of GSPs, and reduce uncertainty in identifying locations for groundwater recharge projects. The collection of AEM data supports multi-benefit projects and has been successfully implemented in basins in California through a recent pilot project. The AEM surveys will benefit DACs by providing data to enhance understanding and management of their basins.

What is New?

In 2020, DWR plans to award a contract to collect AEM data throughout California's High and Medium Priority Groundwater Basins. The AEM data will be collected in a grid or set of parallel lines with the survey lines oriented to collect data in areas with known data gaps, adjacent to critical water



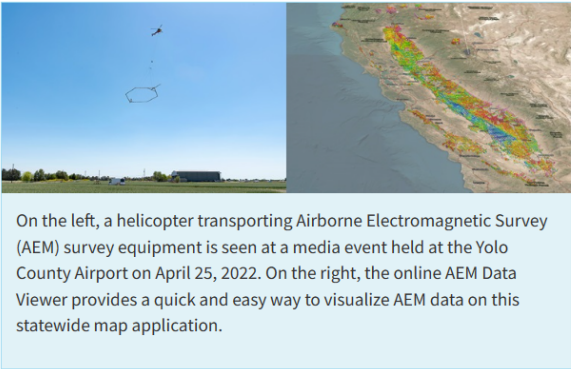
Esplorare il sottosuolo volando.

Home | News | DWR Updates

DWR’s Innovative Underground Aquifer Mapping Project Reaches Major Milestone in Central Valley

DWR’s Innovative Underground Aquifer Mapping Project Reaches Major Milestone Available for Entire Central Valley

Published: February 06, 2023



On the left, a helicopter transporting Airborne Electromagnetic Survey (AEM) survey equipment is seen at a media event held at the Yolo County Airport on April 25, 2022. On the right, the online AEM Data Viewer provides a quick and easy way to visualize AEM data on this statewide map application.

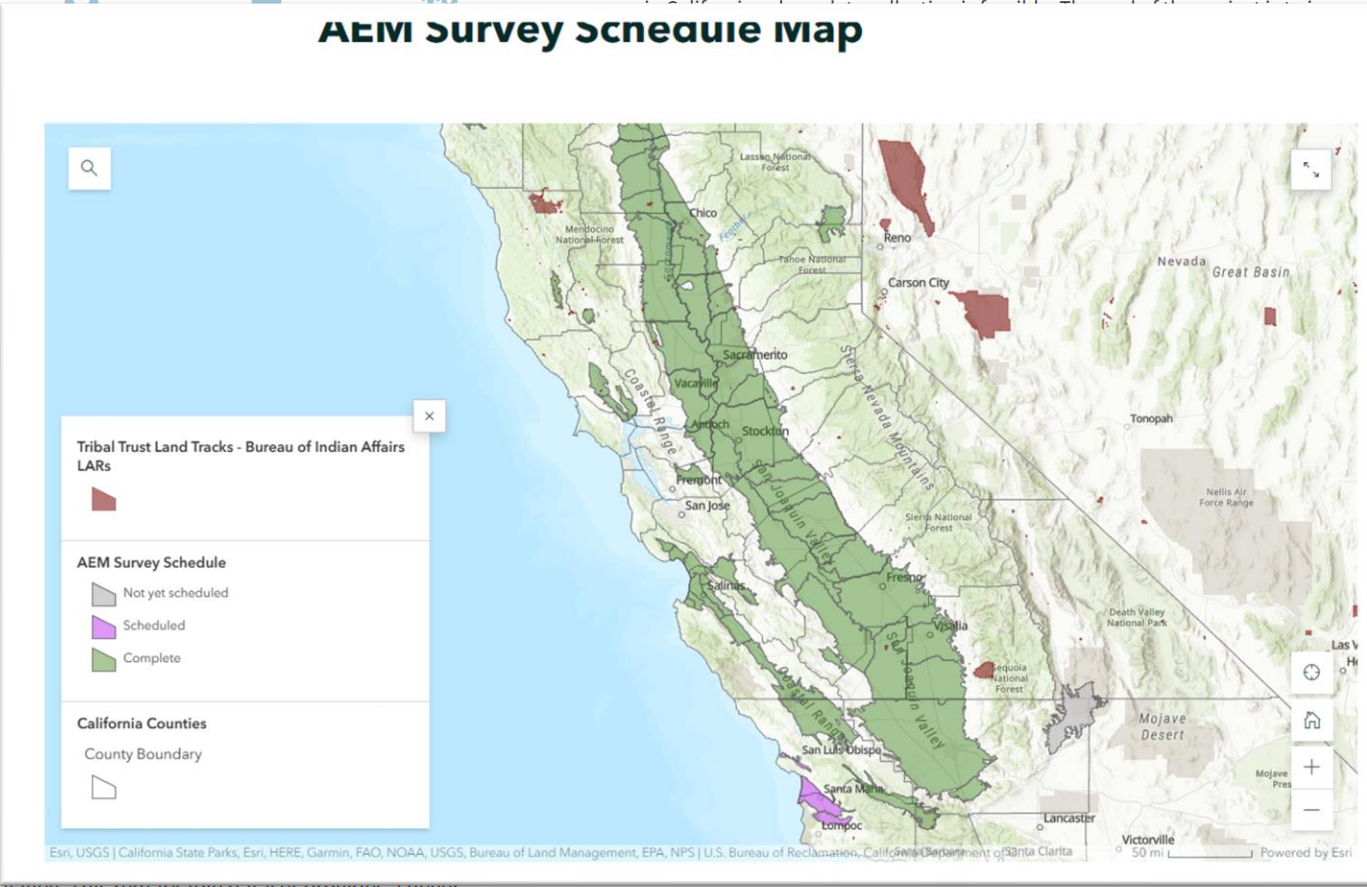
The Department of Water Resources (DWR) has now made the AEM data available for the entire Central Valley. Over 11 years of data collection, this helps us understand the subsurface and the Sacramento-San Joaquin River Delta. This remarkable dataset provides a never-before-seen continuous view of the structure below the earth’s surface in one of the most groundwater-dependent areas of the world.

The State is fast-tracking investments in the latest technology, like AEM, to ensure we are prepared for the weather extremes that are playing out in the new climate reality. AEM data is vital in providing local agencies and the State with a better understanding of the complex underground aquifer systems in California. This data is invaluable for identifying the most suitable locations to implement [groundwater recharge projects](#) that can capture water from extreme rain events like we have just seen, and store that water for use during dry periods.

“As California adapts to a new normal of climate extremes, we recognize that local groundwater sustainability agencies are going to have to adjust their groundwater sustainability plans over time to incorporate effects of extended dry periods and intense rain events,” said Paul Gosselin, Deputy Director of DWR’s Sustainable Groundwater Management Office. “DWR provides technical support to local agencies, including this vital AEM data, to help them reach their sustainability goals.”

DWR’s Statewide AEM Surveys

As a part of the Statewide AEM Survey Project, DWR is collecting AEM data in all [high- and medium-priority groundwater basins](#)



The AEM data is made publicly accessible and can be viewed on DWR’s [AEM Data Viewer](#). This online, GIS-based tool displays AEM data in a three-dimensional space and allows the user to interact with the data by zooming and viewing the data from various angles. The tool can be accessed on a computer or mobile phone and does not require data to be downloaded or the use of specialized software. AEM data, and supporting data like newly digitized well lithology logs and geophysical logs (e-logs), can also be accessed on the [California Natural Resources Agency Open Data Platform](#).

Upcoming Surveys

DWRs AEM surveys began in summer 2021 and surveys have already been conducted throughout the Central Valley, Salinas Valley, Monterrey Bay Area, North San Francisco Bay Area, and Northern California. The surveys are planned to continue through 2023 and into 2024 with data being collected in the San Luis Obispo and Santa Barbara County Areas, Southern California, and the Salton Sea Area. The survey schedule is available online at [AEM Survey Schedule](#).

The surveys are funded by voter-approved Proposition 68, Senate Bill 5, and from the State’s general fund. More information can be found in the [AEM Proposition 68 Fact Sheet](#).

the understanding of large-scale aquifer structure and implementation of the Sustainable Groundwater Management Act (SGMA) of groundwater aquifer structures and refine hydrogeologic conceptual models targeted surveys may be beneficial to fill knowledge gaps for water resource projects, and other projects that support groundwater sustainability. To gather this data themselves, and they can will help them reach their sustainability goals. Implementing to reach sustainability, and an example, as seen in Governor Gavin Newsom’s “[California Future](#),” which was released last year, provides for groundwater recharge when rain events occur. Agencies find the best places to put project implementation efficient and effective. Getting input on areas of interest prior to implementation supports a wide range of groundwater and geologic data, and technical experts from across the U.S. The TAC ensures that the project is implemented based on practitioner needs.

Il Tender olandese

Tender.Ned

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Amministrazioni aggiudicatrici

Personale

 Accedi / Registrati

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26 marzo 2024 - Bando di gara - orientamento generale, disposizione standard


La fornitura di servizi elettromagnetici aerei nei Paesi Bassi

Organizzazione olandese per la ricerca scientifica applicata TNO

Ci sono ancora 3 giorni per iscriversi

 Registrati digitalmente

 Per rimanere informato

 Condividi su LinkedIn



Esplorare il sottosuolo volando.

Il Tender olandese

Dettagli

Quadro giuridico
Legge sugli appalti del 2012

Tipo di incarico
Servizi

Procedura
Pubblico

Parole chiave
Indagine elettromagnetica aerea (AEM), aerotrasportata, elettromagnetismo, acque sotterranee saline, mappatura degli strati di argilla

Assegnazione principale (codice CPV)
71351500-8 Servizi di analisi del suolo

Luogo di esecuzione (codice NUTS)
PAESI BASSI (NL)

Programma

Inizio incarico
4 giugno 2024

Completamento dell'incarico
19 dicembre 2025

Data di chiusura
22 aprile 2024, 12:30

Pubblicazioni correlate



26 marzo 2024
[Annuncio di un incarico - linee guida generali, disposizione standard](#)



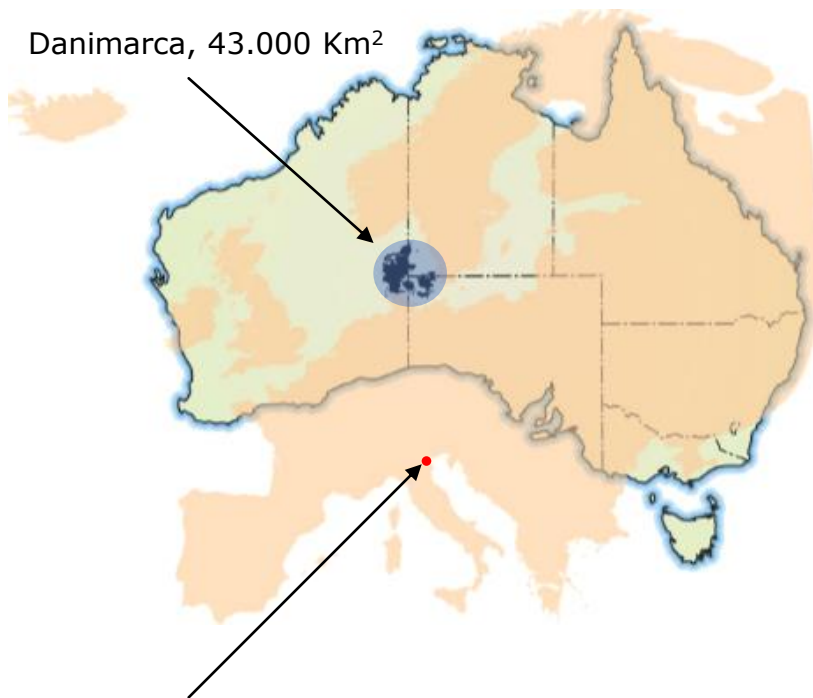
13 febbraio 2024
[Annuncio di un incarico - linee guida generali, disposizione standard](#)



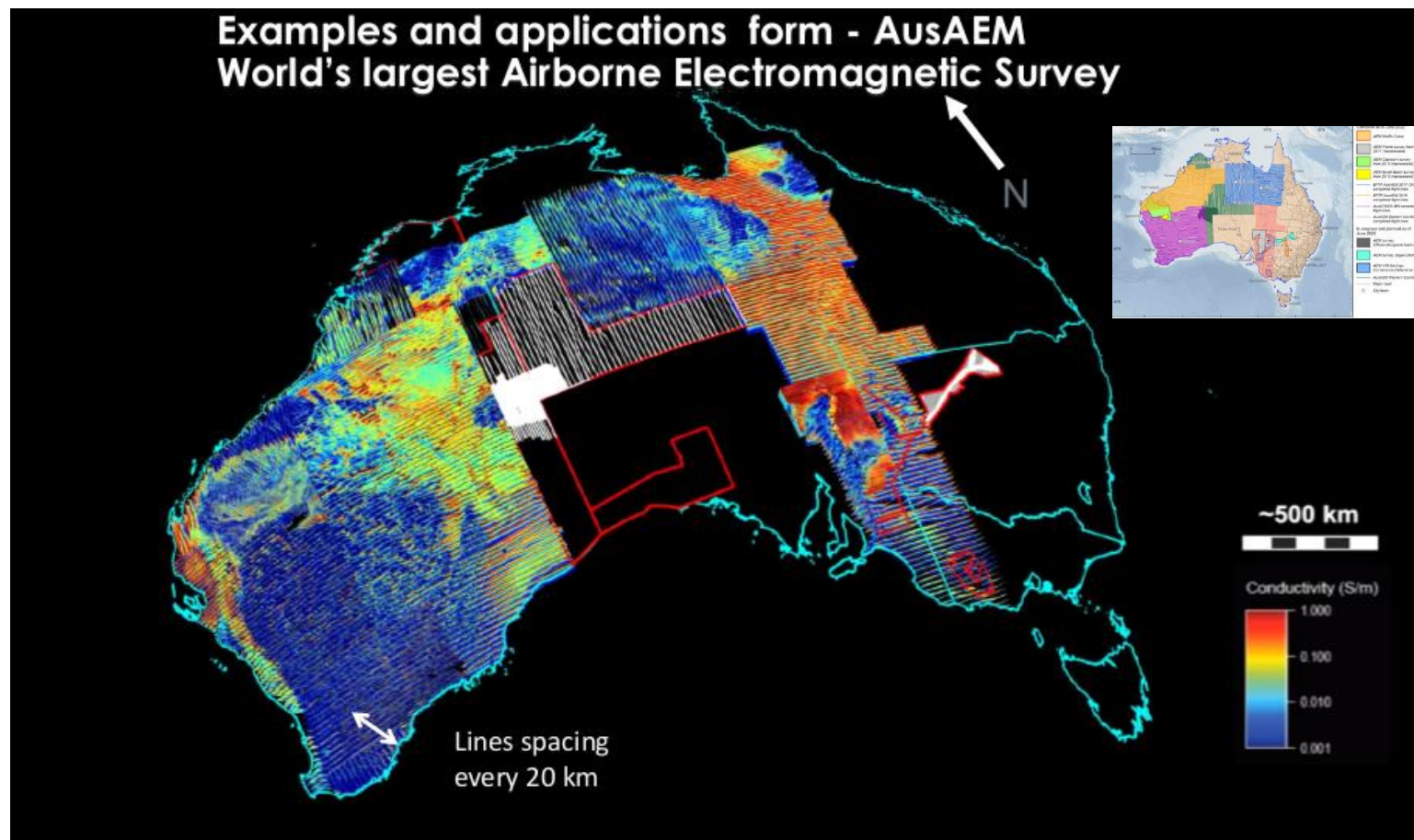
Esplorare il sottosuolo volando.

L'esempio del governo australiano

Danimarca, 43.000 Km²



Bacino Po, mappabili circa 35.000 Km²



Mappato circa il 70% del continente (5.331.900 Km²)

AEM per esplorazione mineraria

SEMACRET:

- **Sustainable exploration for orthomagmatic (critical) raw materials in the EU: Charting the road to the green energy transition**
- **Progetto Horizon Europe**

IPRaMa:

- **Induced Polarization for Raw Materials**
- **Progetto PON 1061**

AEM per esplorazione mineraria



PROJECT ▾

NEWS & EVENTS

PUBLICATIONS

WEBINARS & WORKSHOPS

PARTNERS

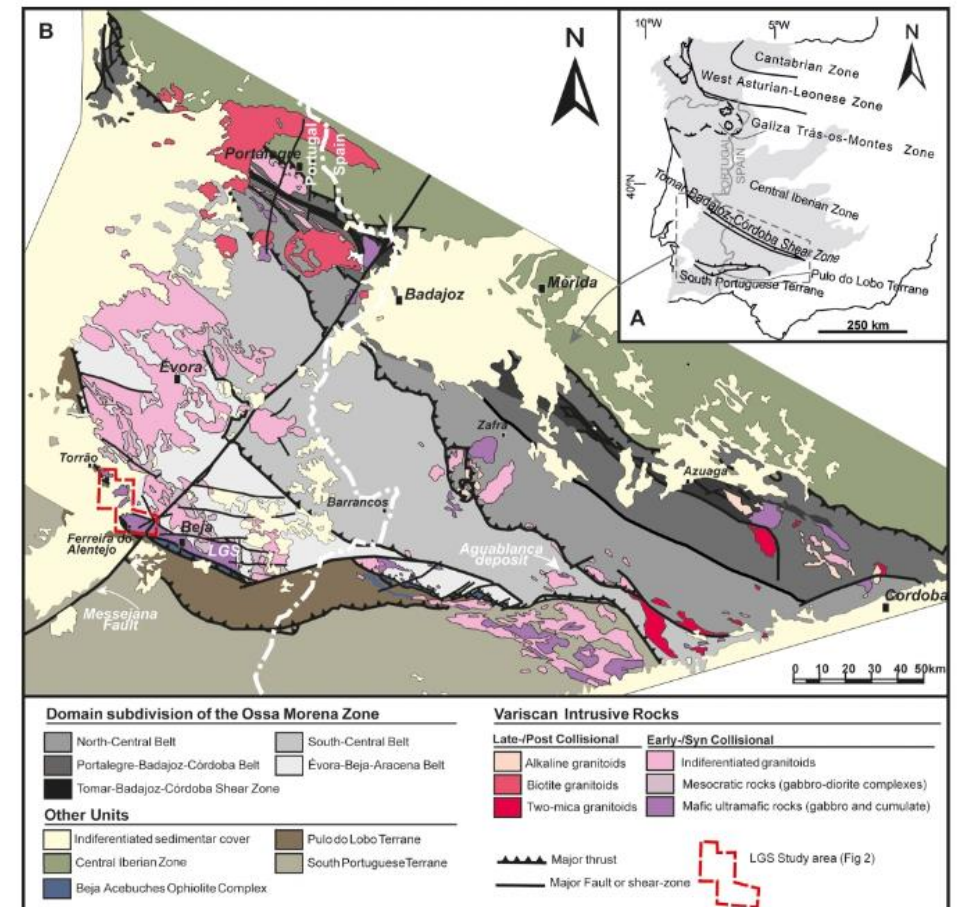
CONTACTS ▾

SEMCRET PROJECT

Reference Sites

1 DE JUNE DE 2022

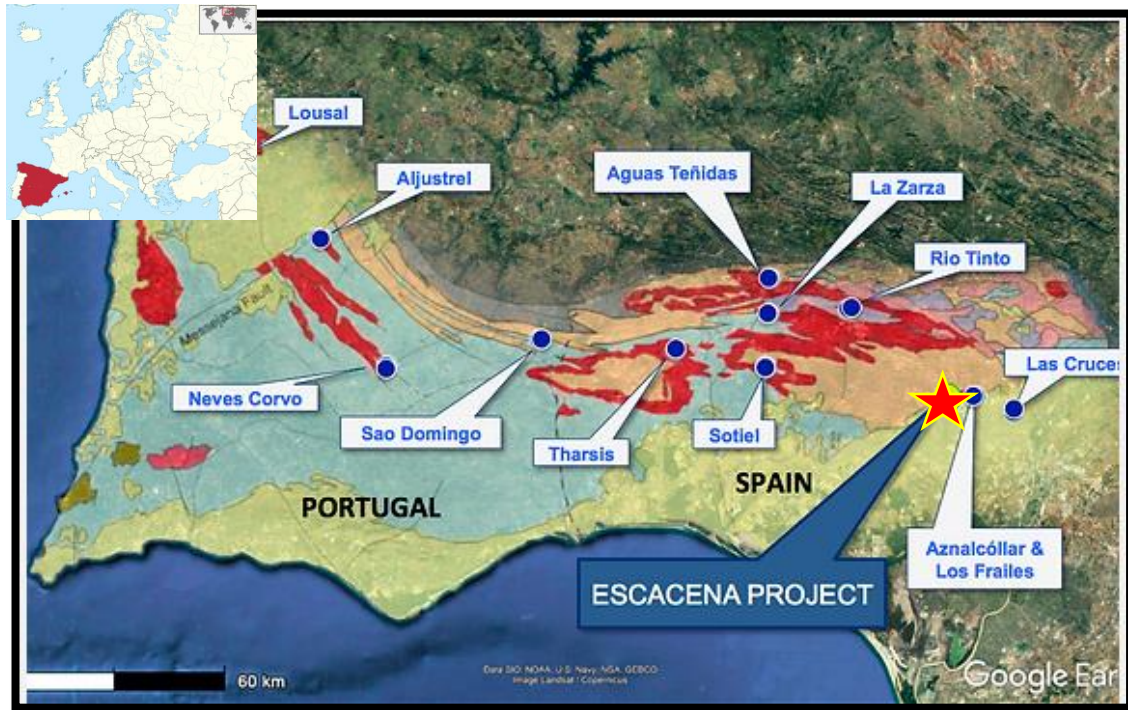
under-exploration of the complex is that the area is intensely used by agriculture, requiring carefully designed geophysical and geochemical exploration methods.



Location of Aguablanca deposit (Spain) and Beja intrusion (Portugal) in the Ossa Morena Zone of the

Variscan belt Jesus et al 2020

AEM per esplorazione mineraria



From PanGlobal.it



Location:

- Andalusia, Spain



Geological Context:

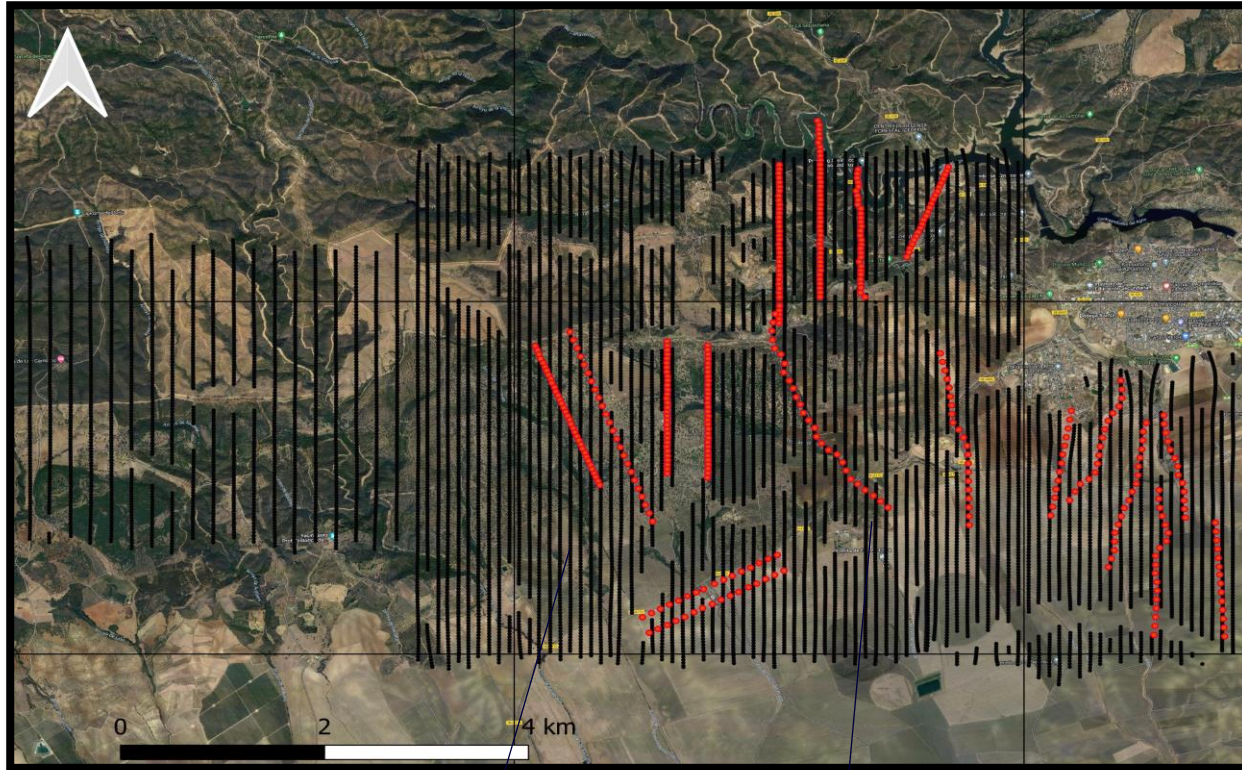
- Veriscan Iberian Pyrite Belt



Target:

- VMS, Disseminates

AEM per esplorazione mineraria



Airborne EM

Ground IP

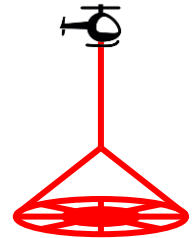
Ground DCIP

- Geometrical Configuration: Dipole-Dipole
- Electrode Distance: 100m
- Stacking: 50



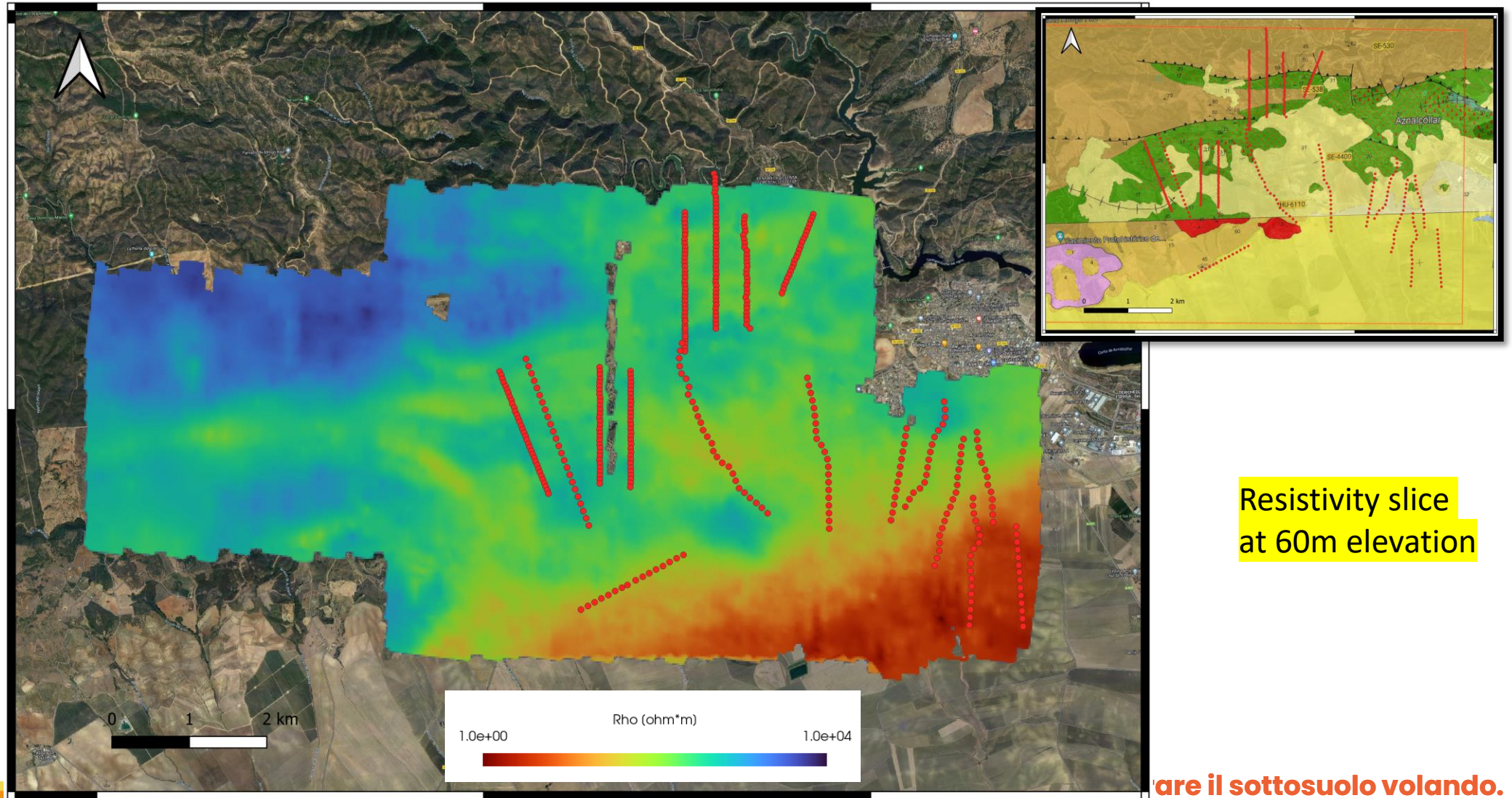
Airborne EM:

- System: NRG - Xcite
- Base Frequency: 25 Hz
- Dipole Moment: 300000 NIA



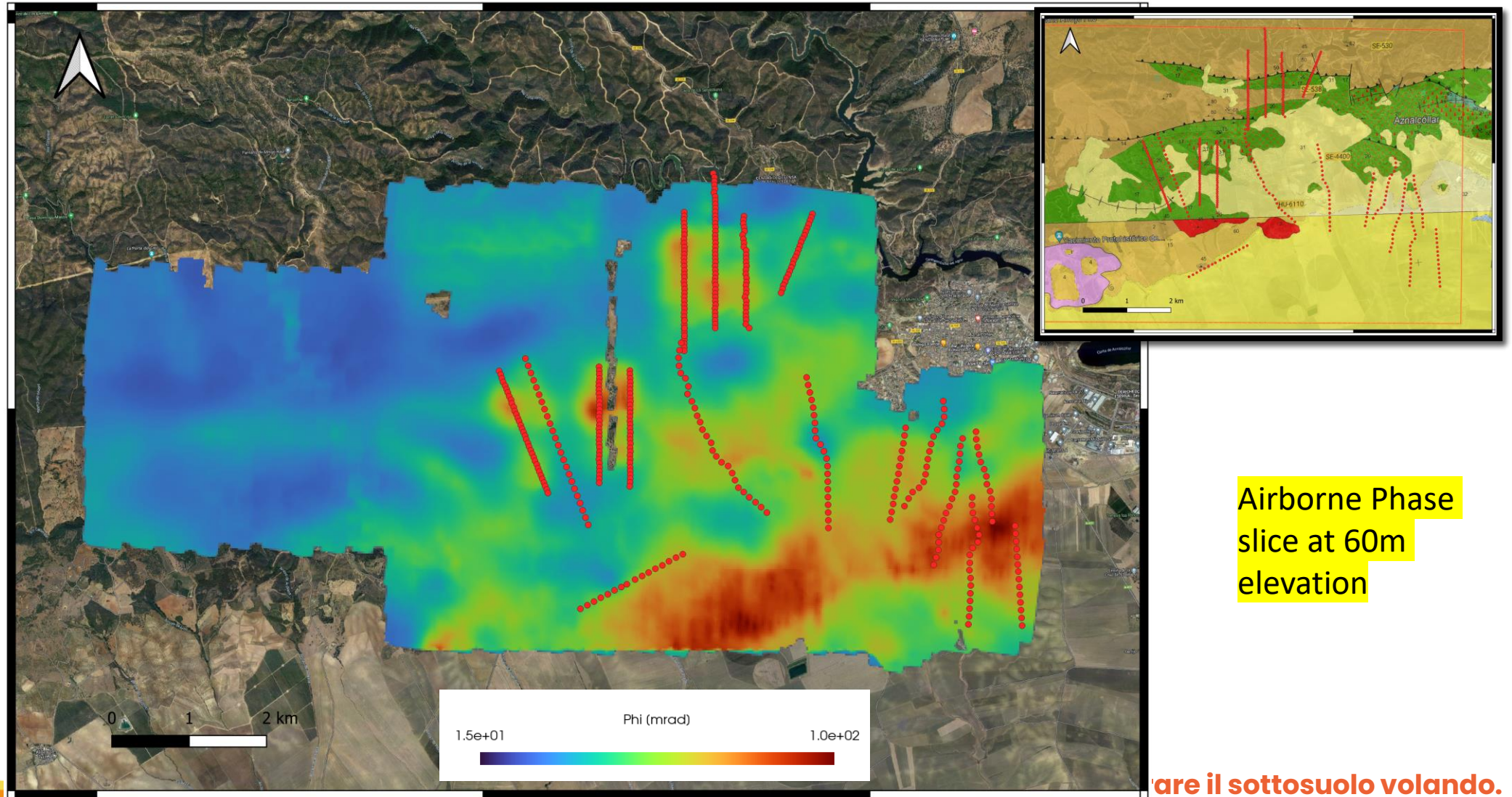
AEM per esplorazione mineraria

- Indipent
inversions



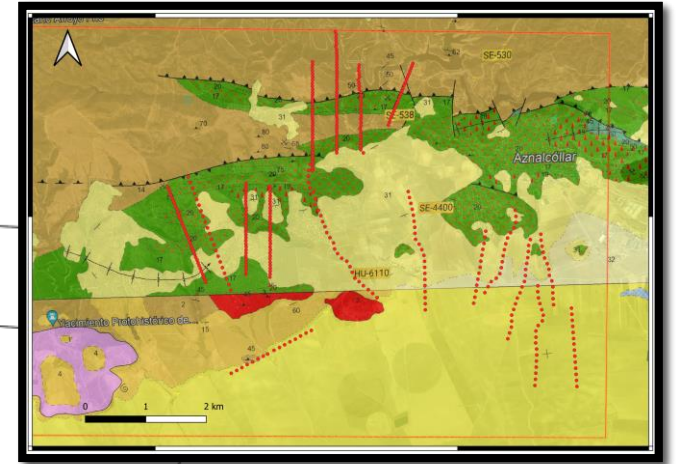
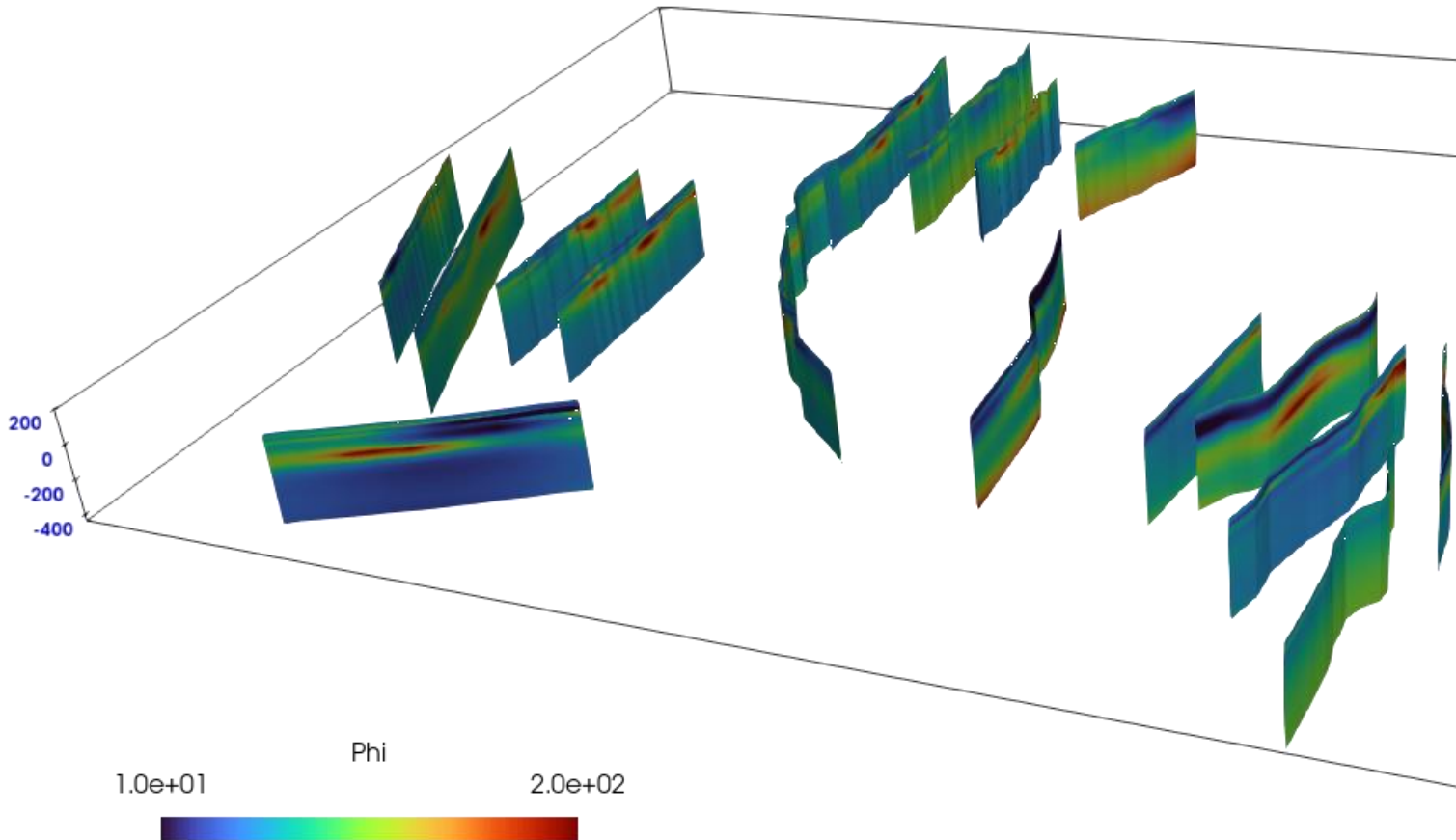
AEM per esplorazione mineraria

- Indipendent
inversions



AEM per esplorazione mineraria

- Indipent
inversions



Ground IP

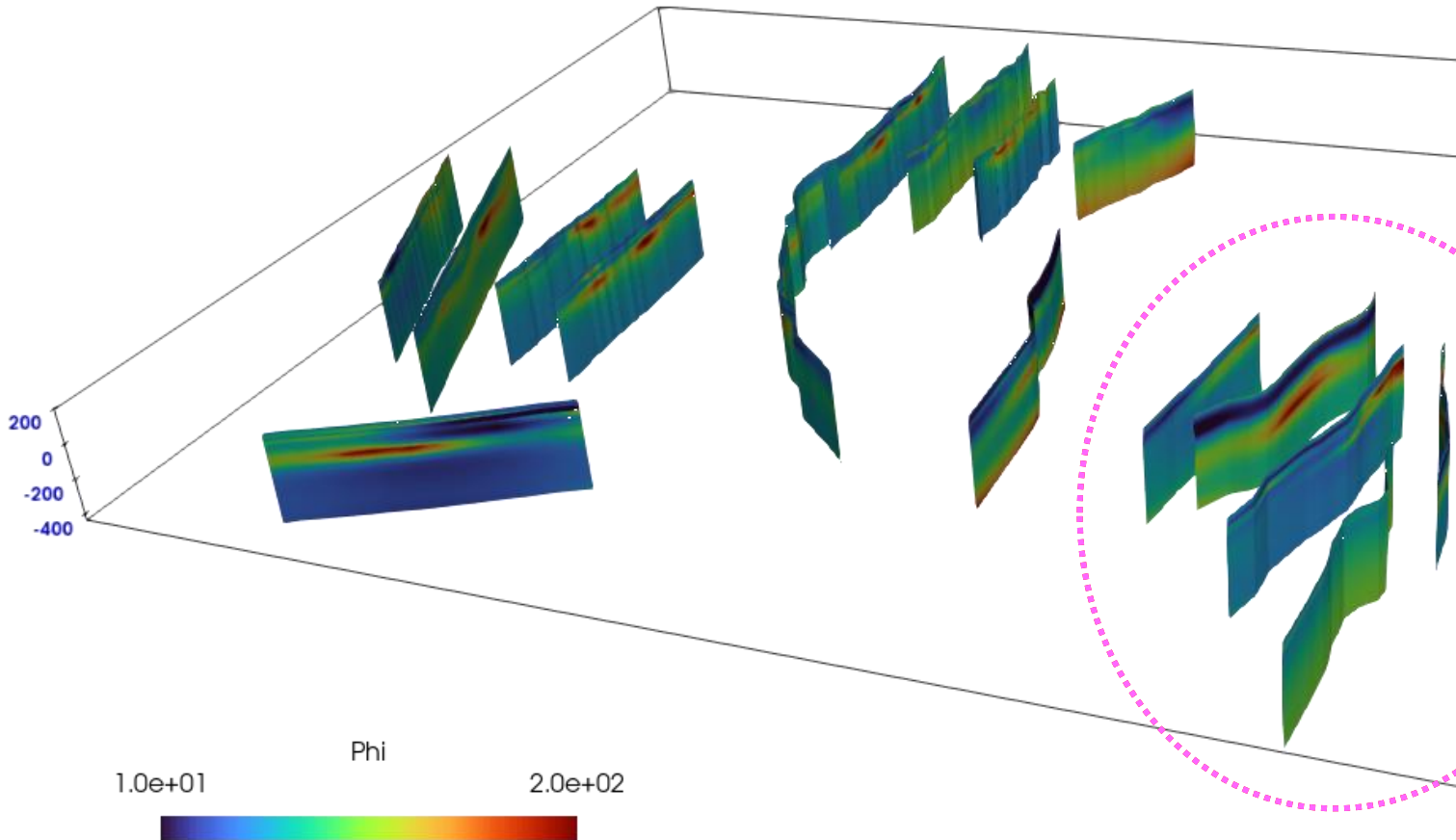
(SE-NW view)



Esplorare il sottosuolo volando.

AEM per esplorazione mineraria

- Indipent
inversions



Ground IP

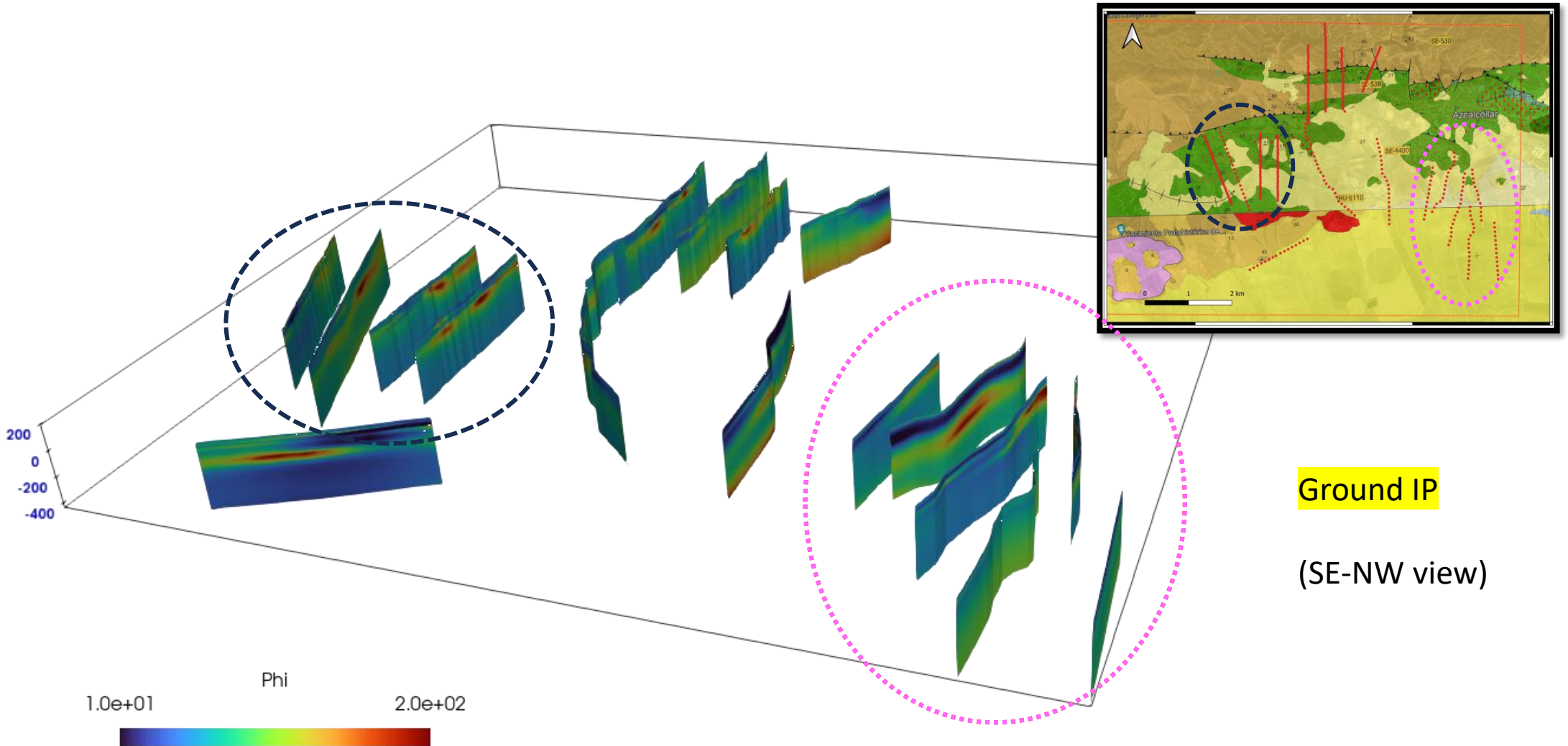
(SE-NW view)



Esplorare il sottosuolo volando.

AEM per esplorazione mineraria

- Indipent
inversions



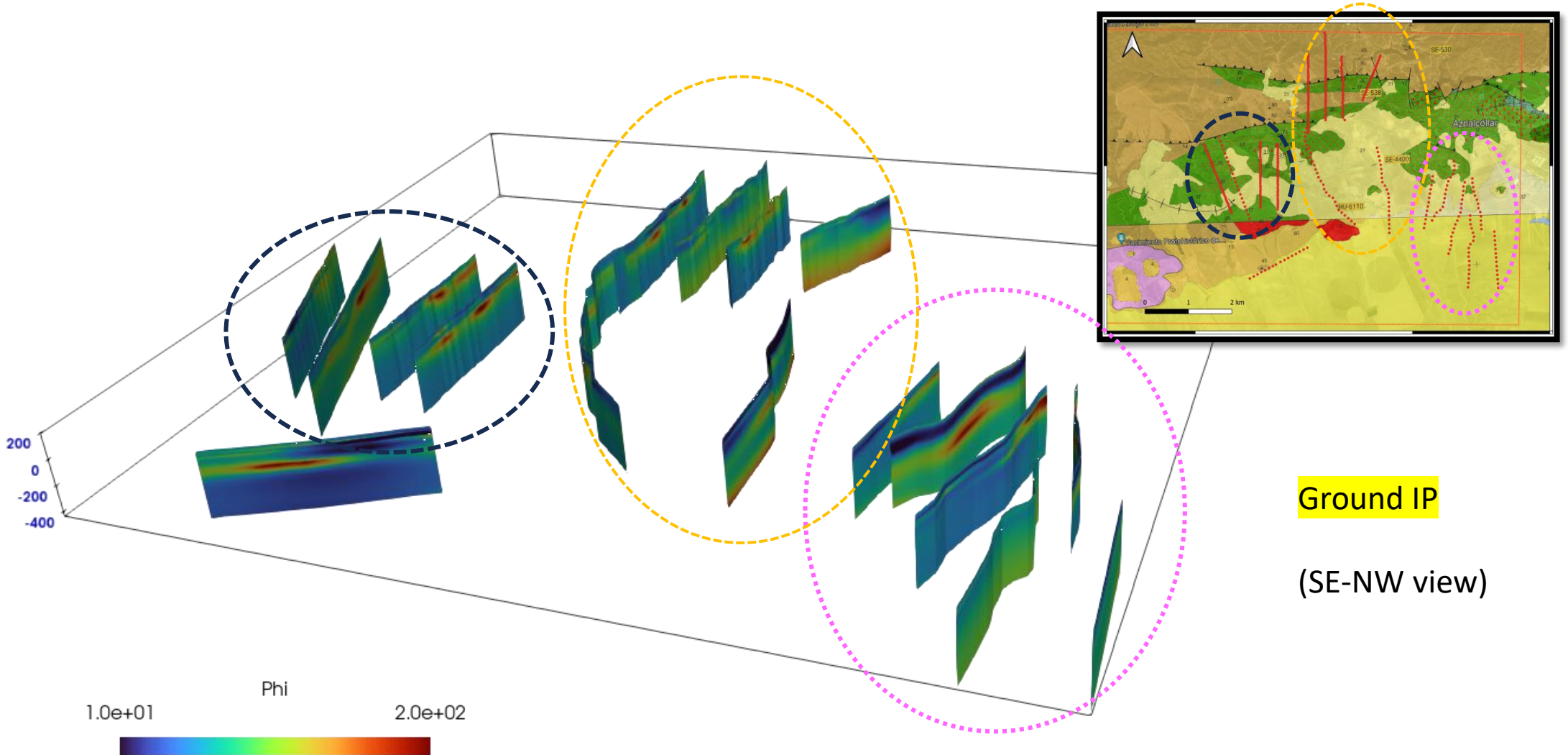
Ground IP

(SE-NW view)

Esplorare il sottosuolo volando.

AEM per esplorazione mineraria

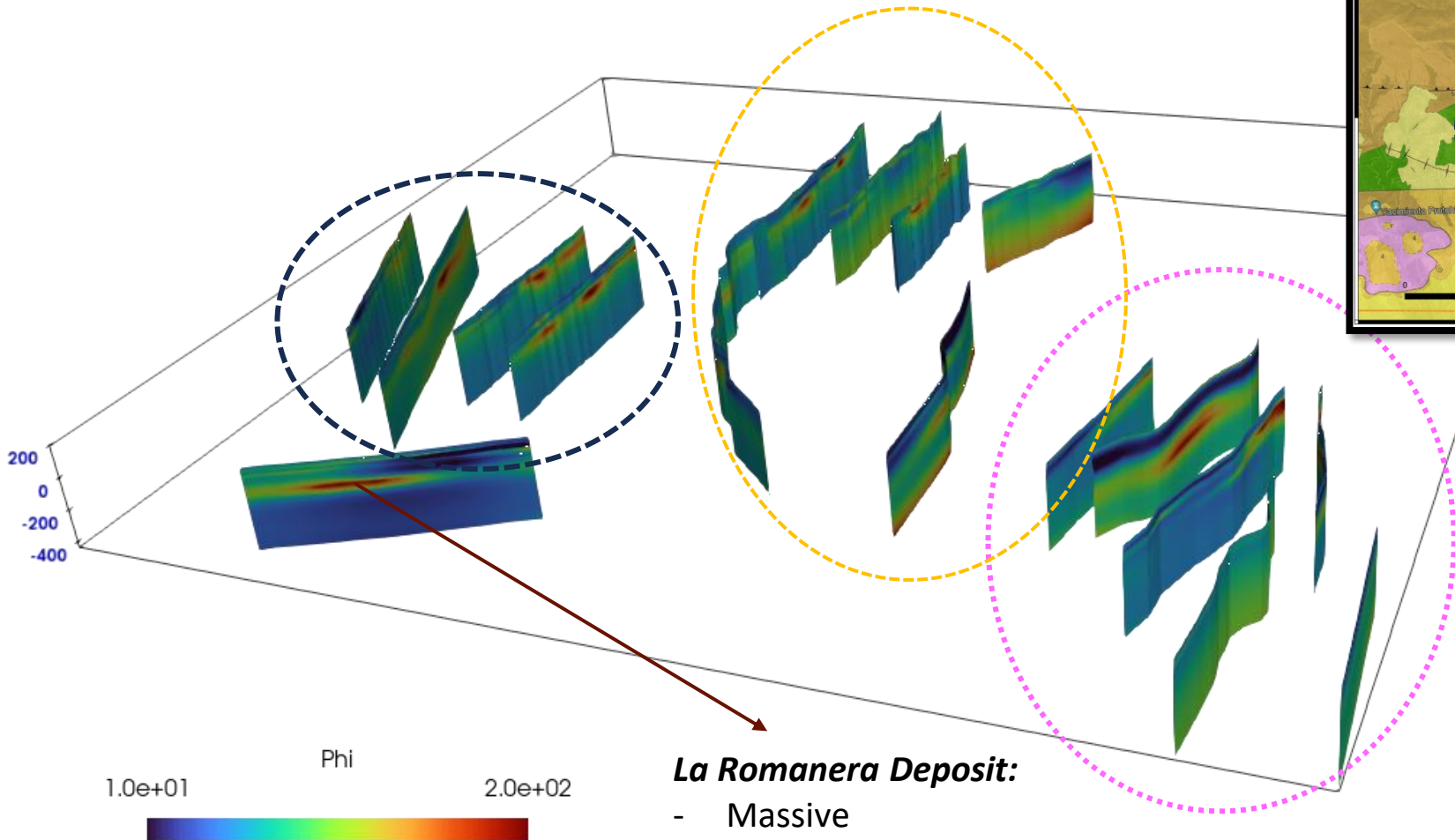
- Indipent
inversions



Esplorare il sottosuolo volando.

AEM per esplorazione mineraria

- Indipent
inversions



Ground IP

(SE-NW view)

La Romanera Deposit:

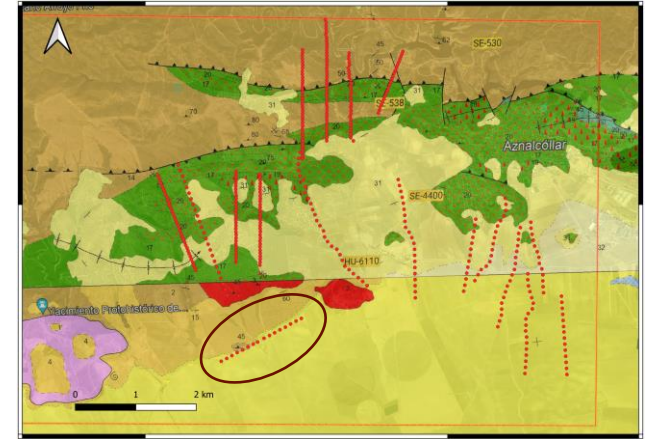
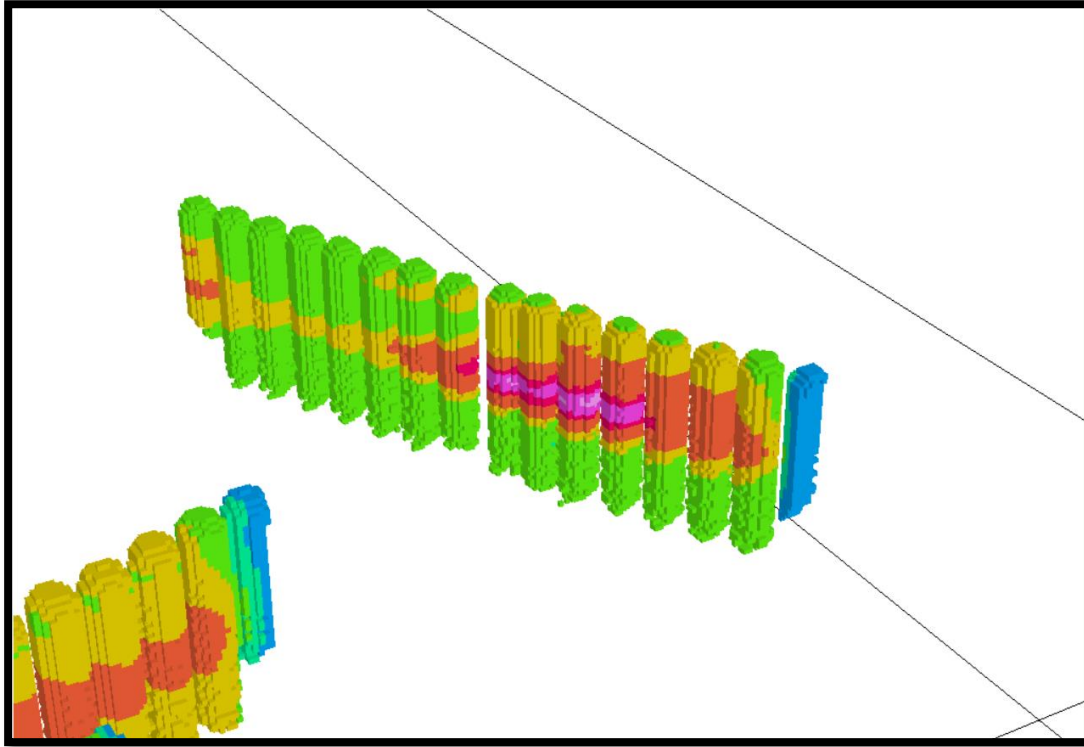
- Massive
- Cu-Sn, Cu, Zn
- Depth: ~100m

Esplorare il sottosuolo volando.



AEM per esplorazione mineraria

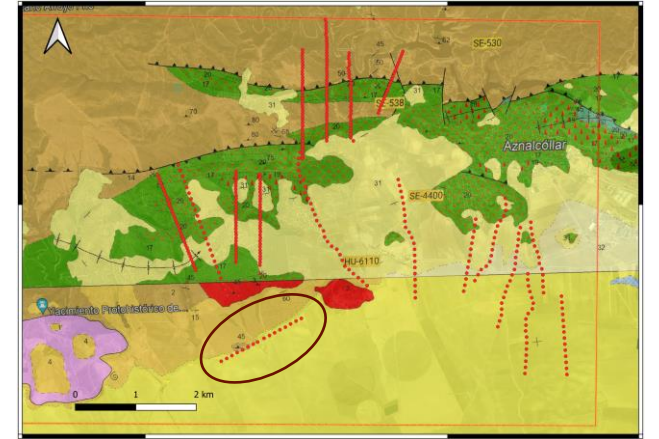
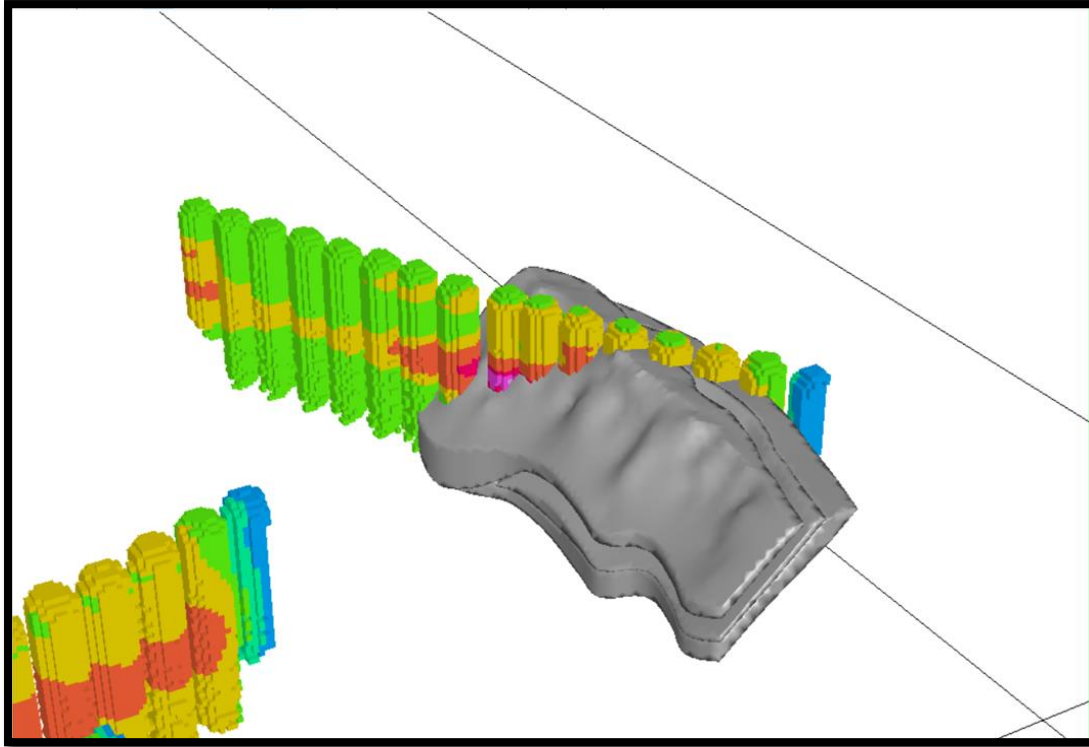
- Indipendent
inversions



Ground IP and
known
mineralization
model

AEM per esplorazione mineraria

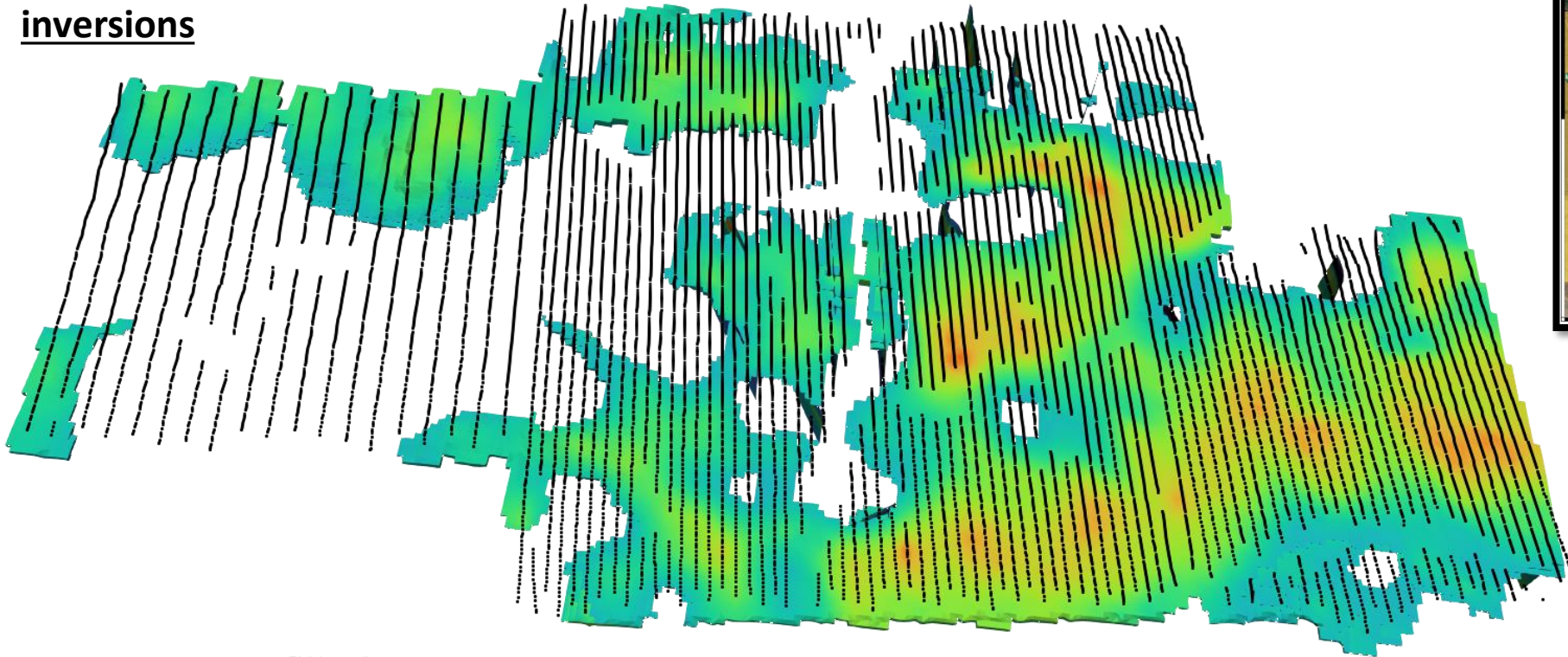
- Indipent
inversions



Ground IP and
known
mineralization
model

AEM per esplorazione mineraria

- Independent inversions



1.5e+01 Phi (mrad) 1.0e+02



*Airborne phase volume
cropped from a minimum
value of 25 mrad*

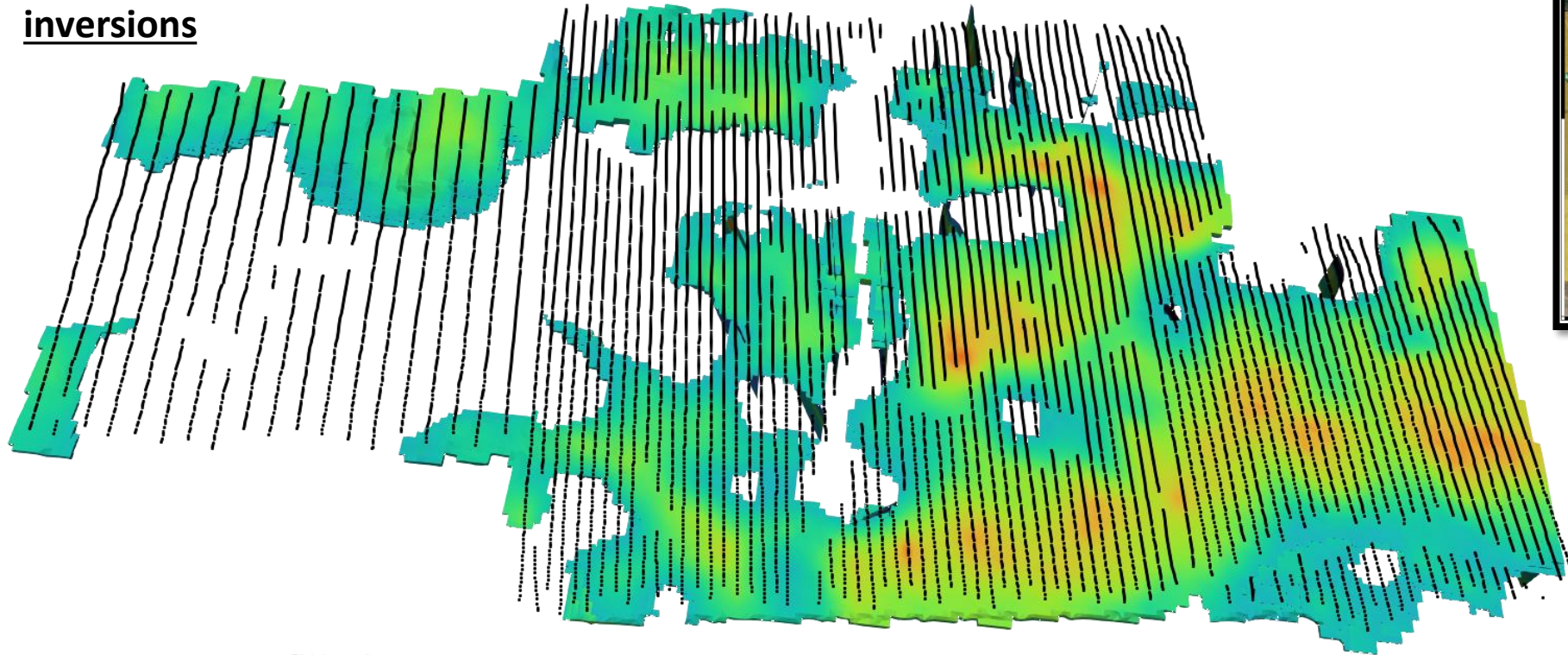


Airborne IP
vs
Ground IP

Esplorare il sottosuolo volando.

AEM per esplorazione mineraria

- Independent inversions



1.5e+01 Phi (mrad) 1.0e+02



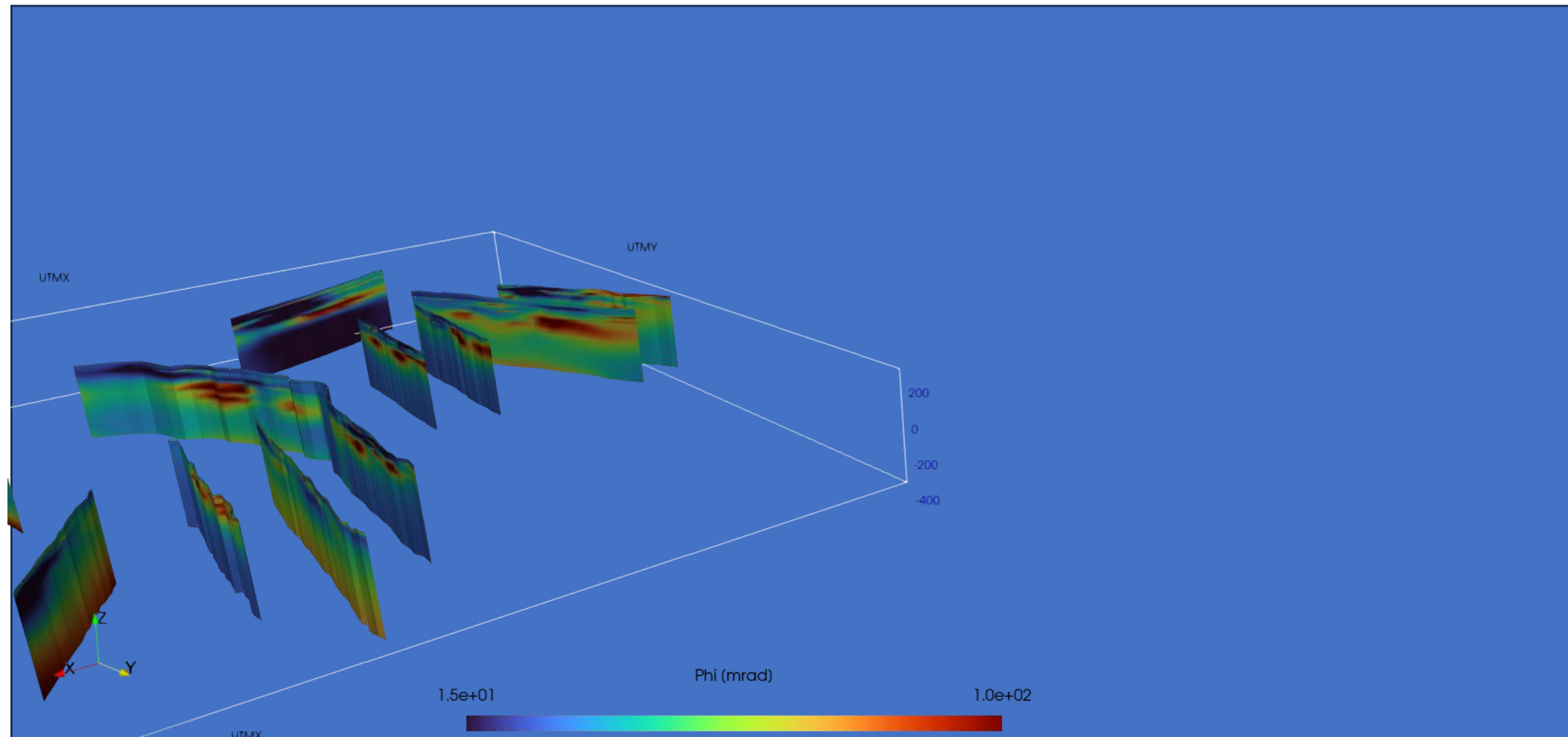
*Airborne phase volume
cropped from a minimum
value of 25 mrad*



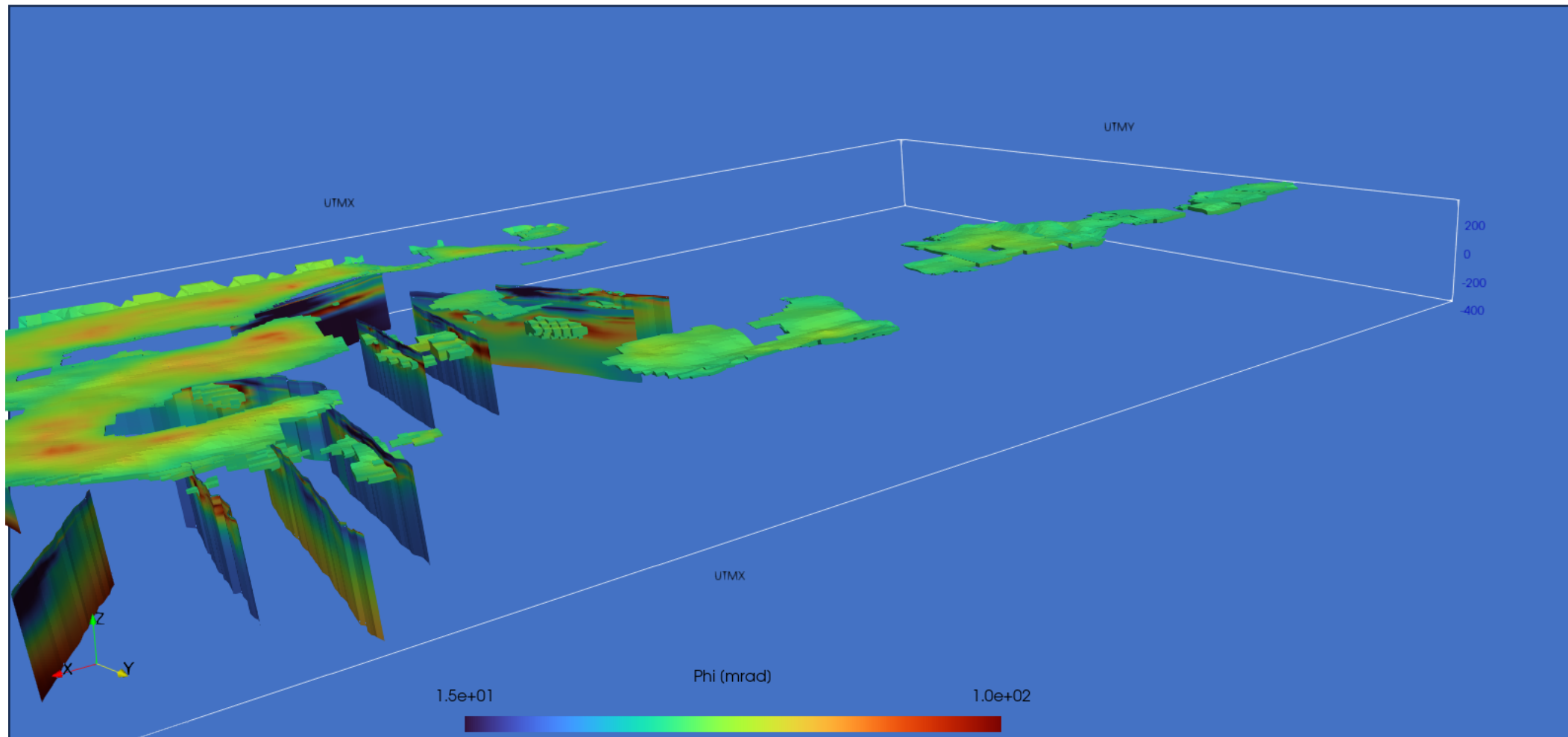
What's
beneath the
cover...?

Esplorare il sottosuolo volando.

AEM per esplorazione mineraria



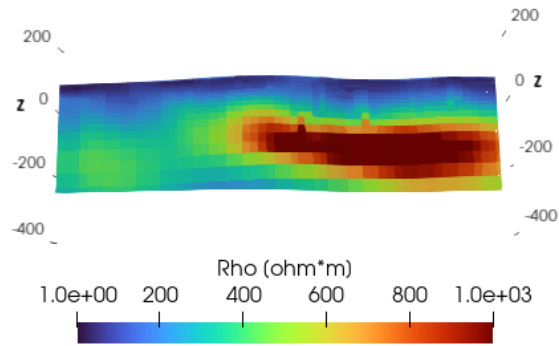
AEM per esplorazione mineraria



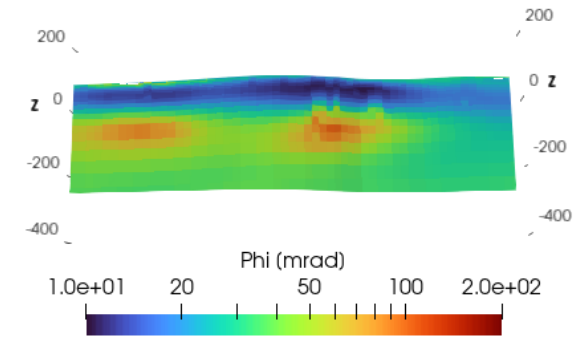
AEM per esplorazione mineraria

Joint

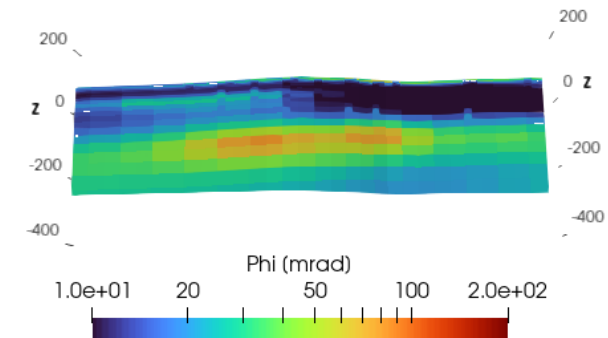
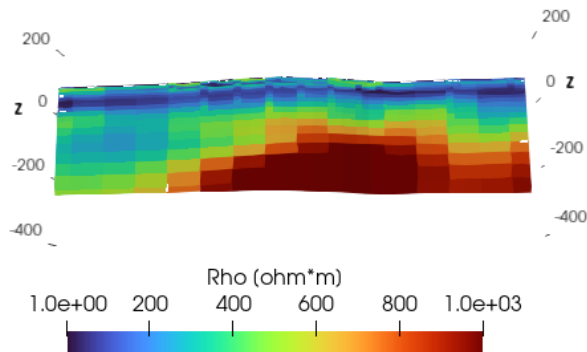
Resistivity



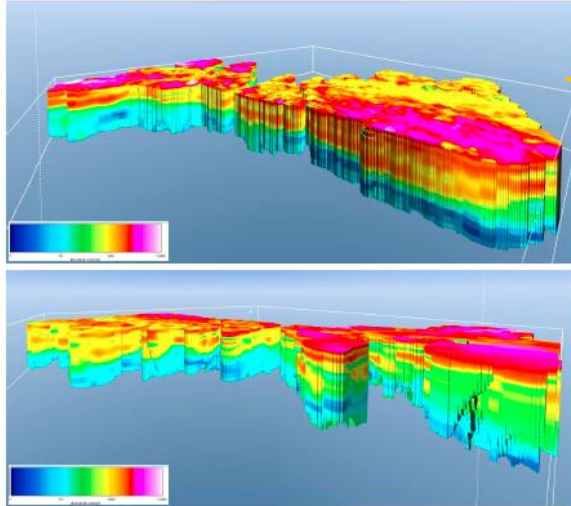
Phase



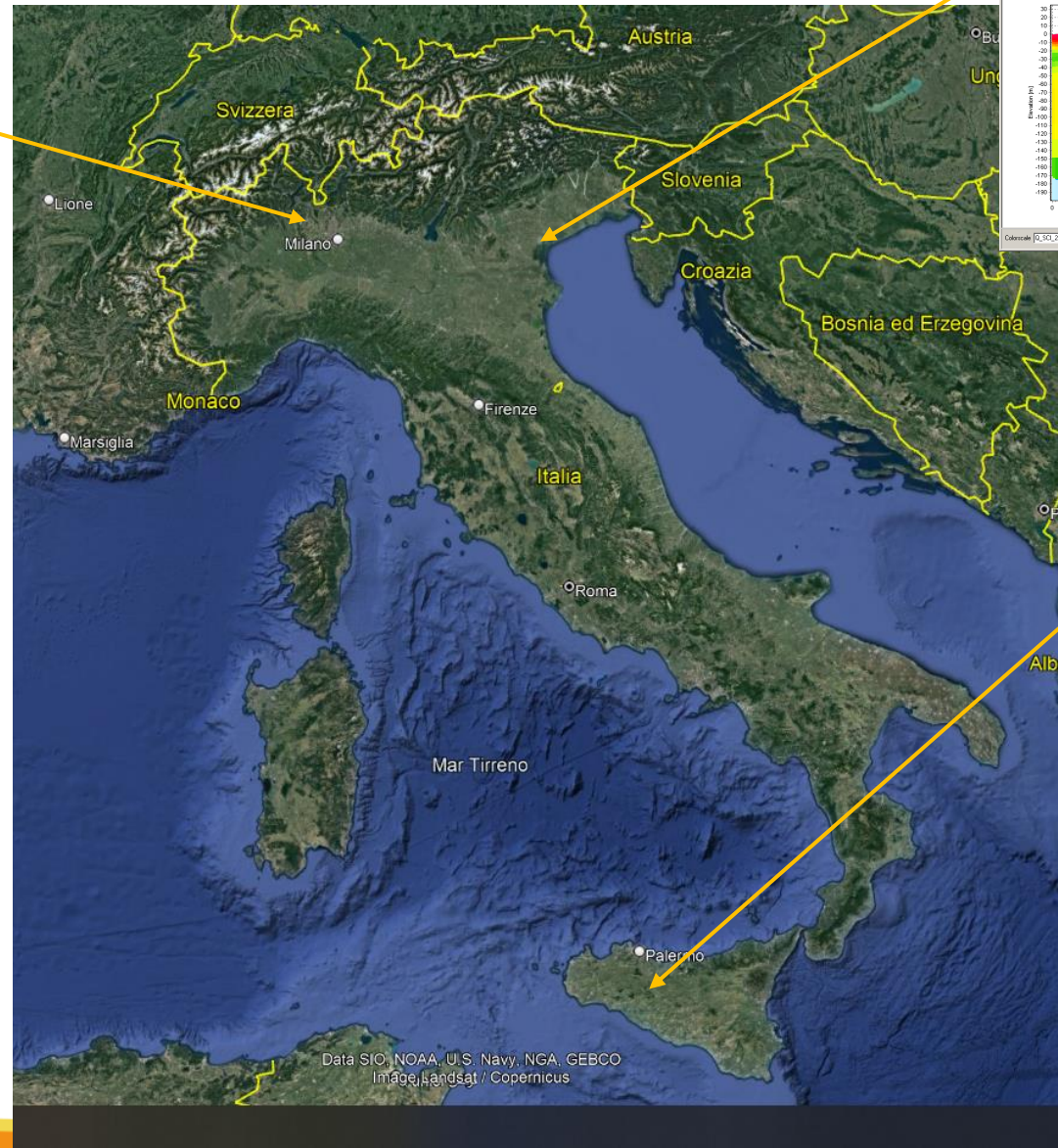
Ground IP



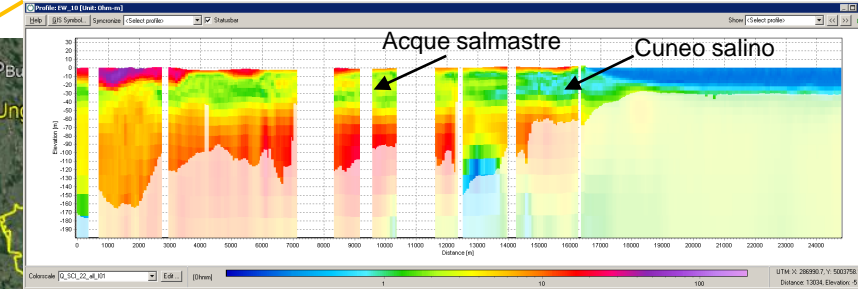
Esperienze Italiane



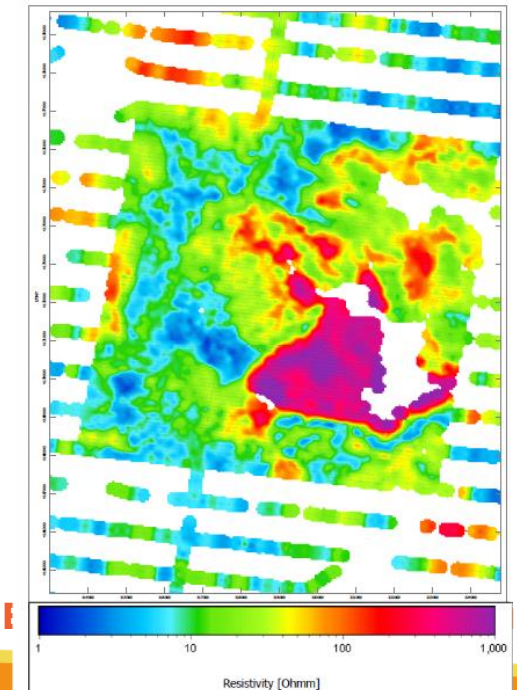
CAP Holding, Milano, Magenta (2018)



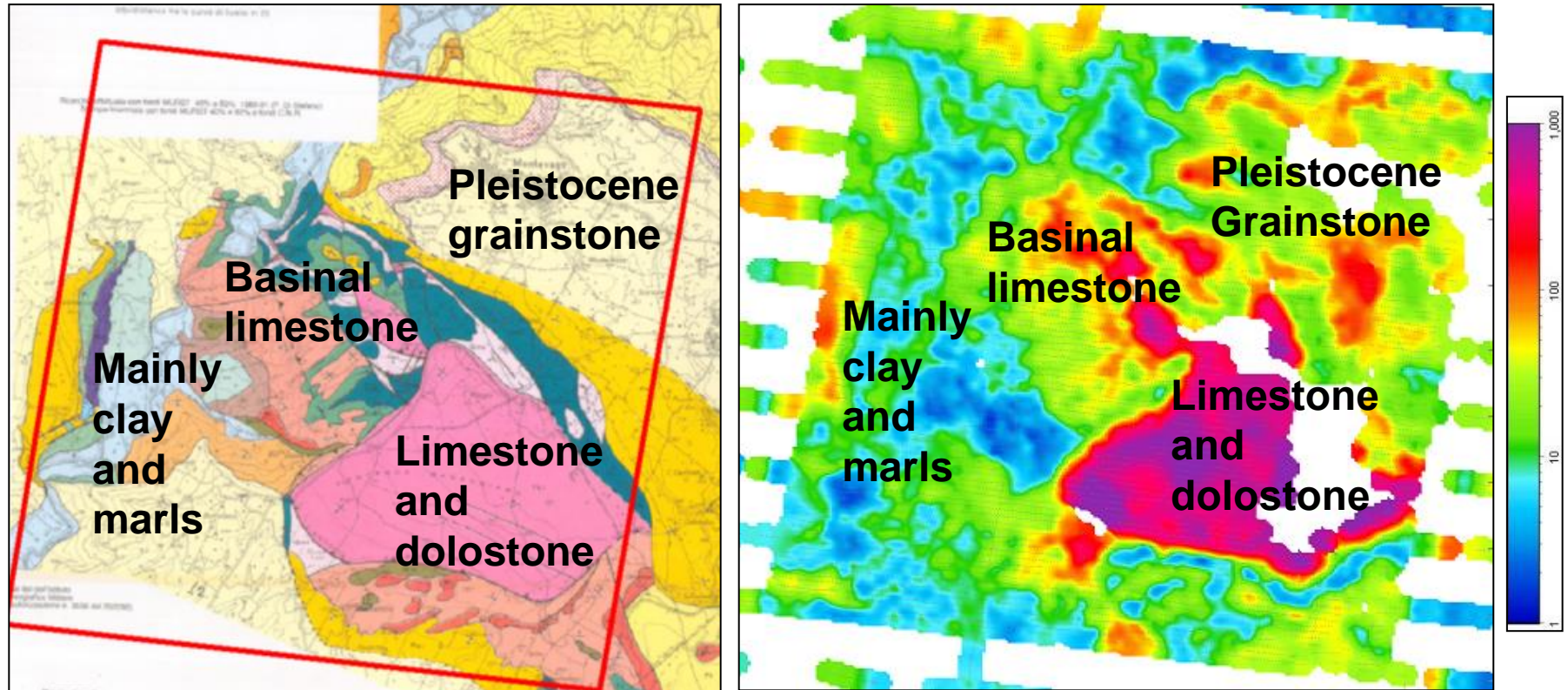
CNR Laguna di Venezia (2009, 2013)



CNR Progetto VIGOR
Sicilia Occidentale (2011)



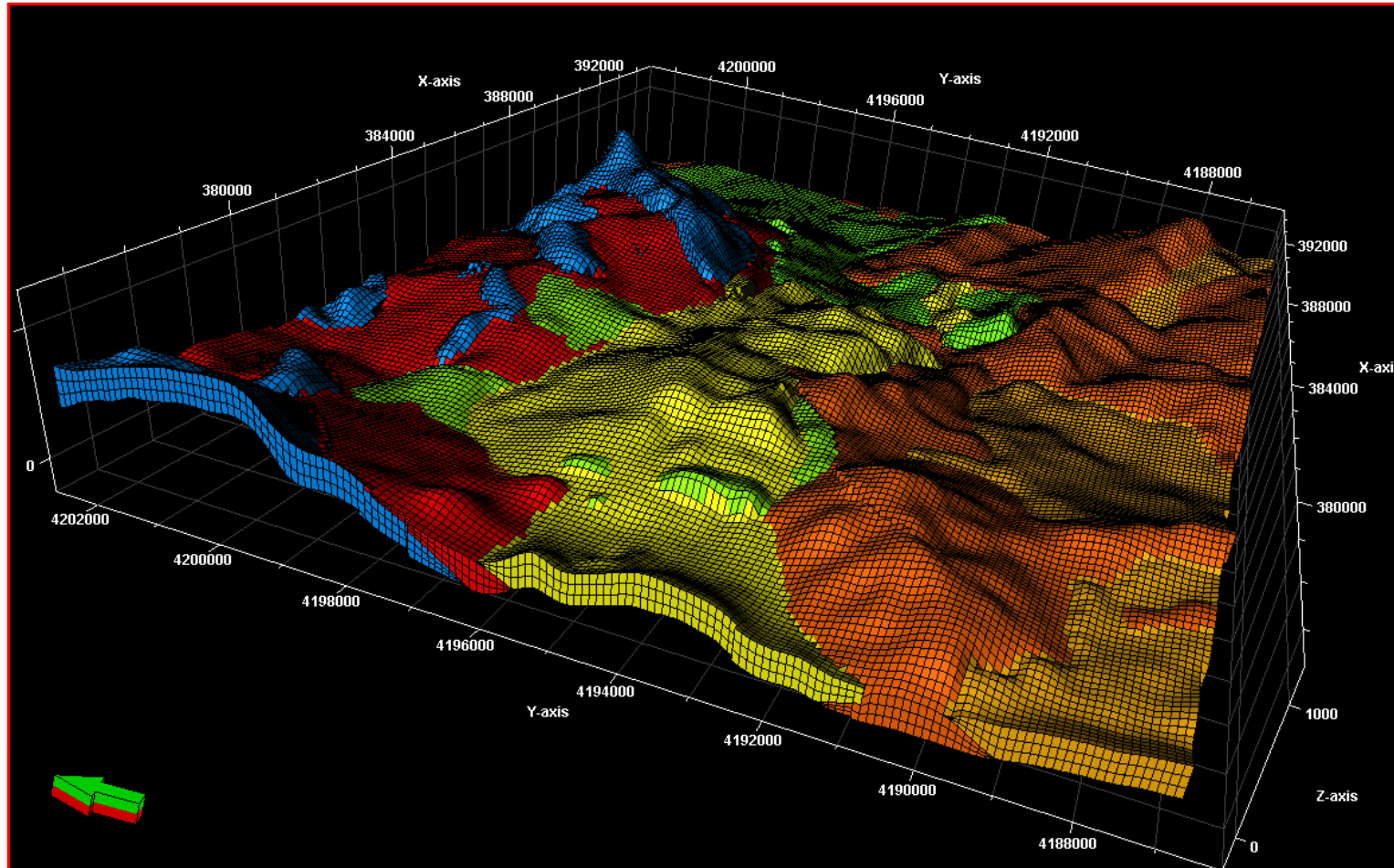
Sicilia Occidentale. Progetto VIGOR CNR



emergo

- **Quaternary deposits** (200 ohm/m for Montevago Grainstone to 10 ohm/m for Marls)
 - **Neogene deposits** (mainly <10 ohm/m)
- **Miocene-Cretaceous Carbonate "Saccense" Domain** (from 10 to 80 Ohm/m)
 - **Cretaceous-Jurassic Carbonate "Saccense" Domain** (200-1000 ohm/m)

VIGOR – 3D Geological Model



Neogene Deposits
(Miocene-Pliocene)

Tavernola Fm.
(Miocene)

Numidian Flysch GS member
(Oligocene-Miocene)

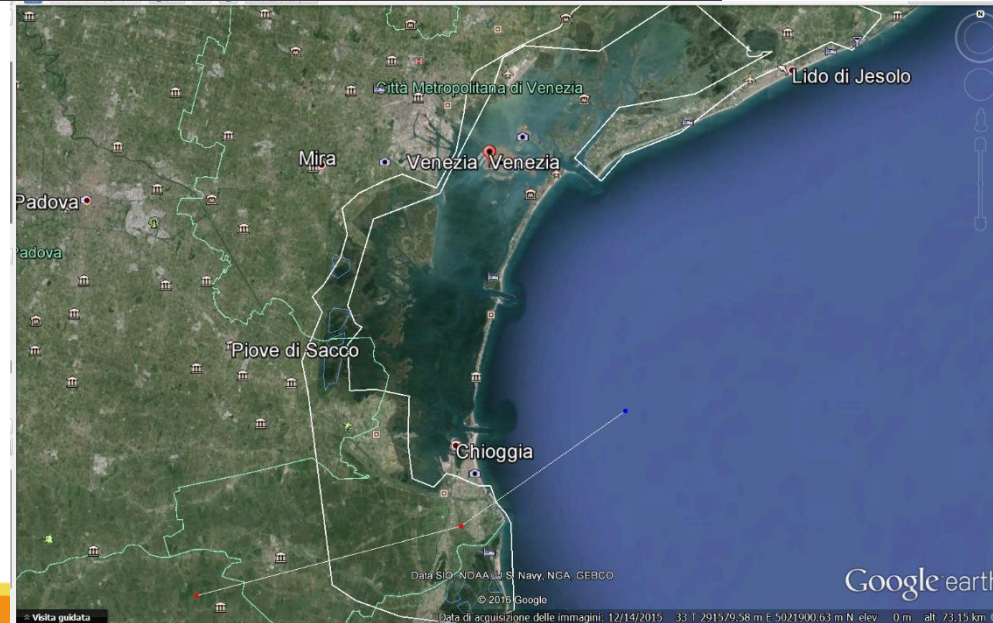
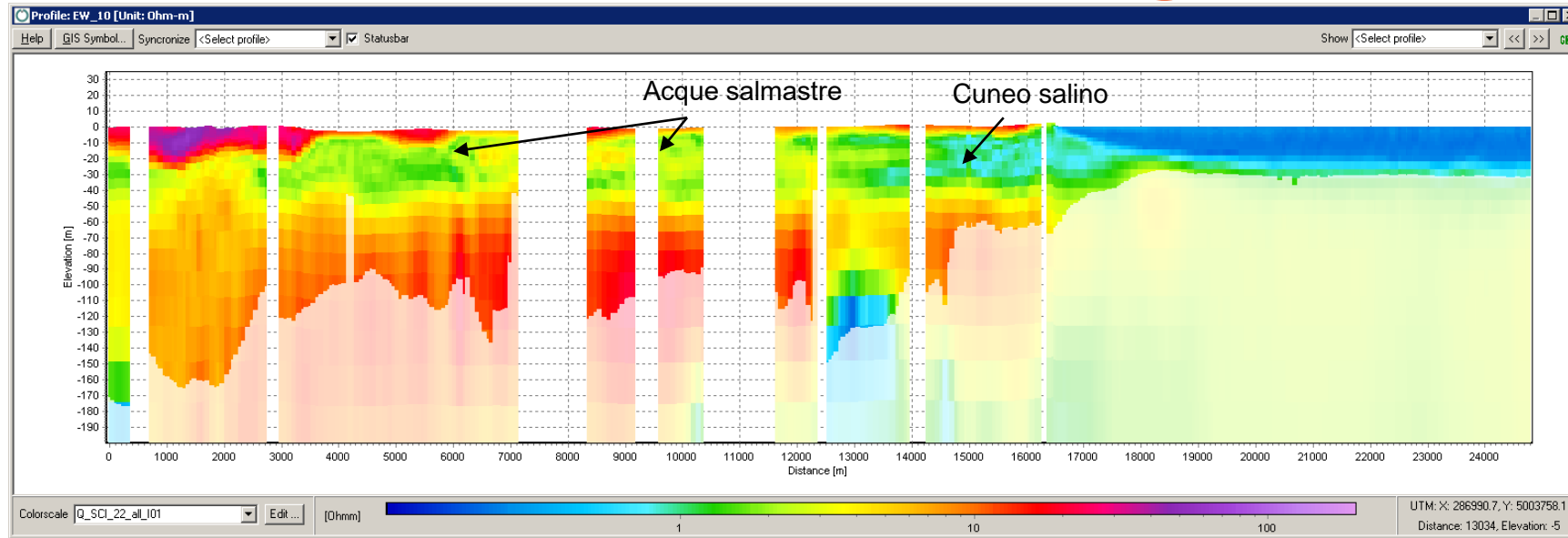
Numidian Flysch PC member
(Oligocene-Miocene)

Sicilide Domain
(Cretaceous-Eocene)

Carbonate Imerese Domain
(Triassic-Oligocene)

suolo volando.

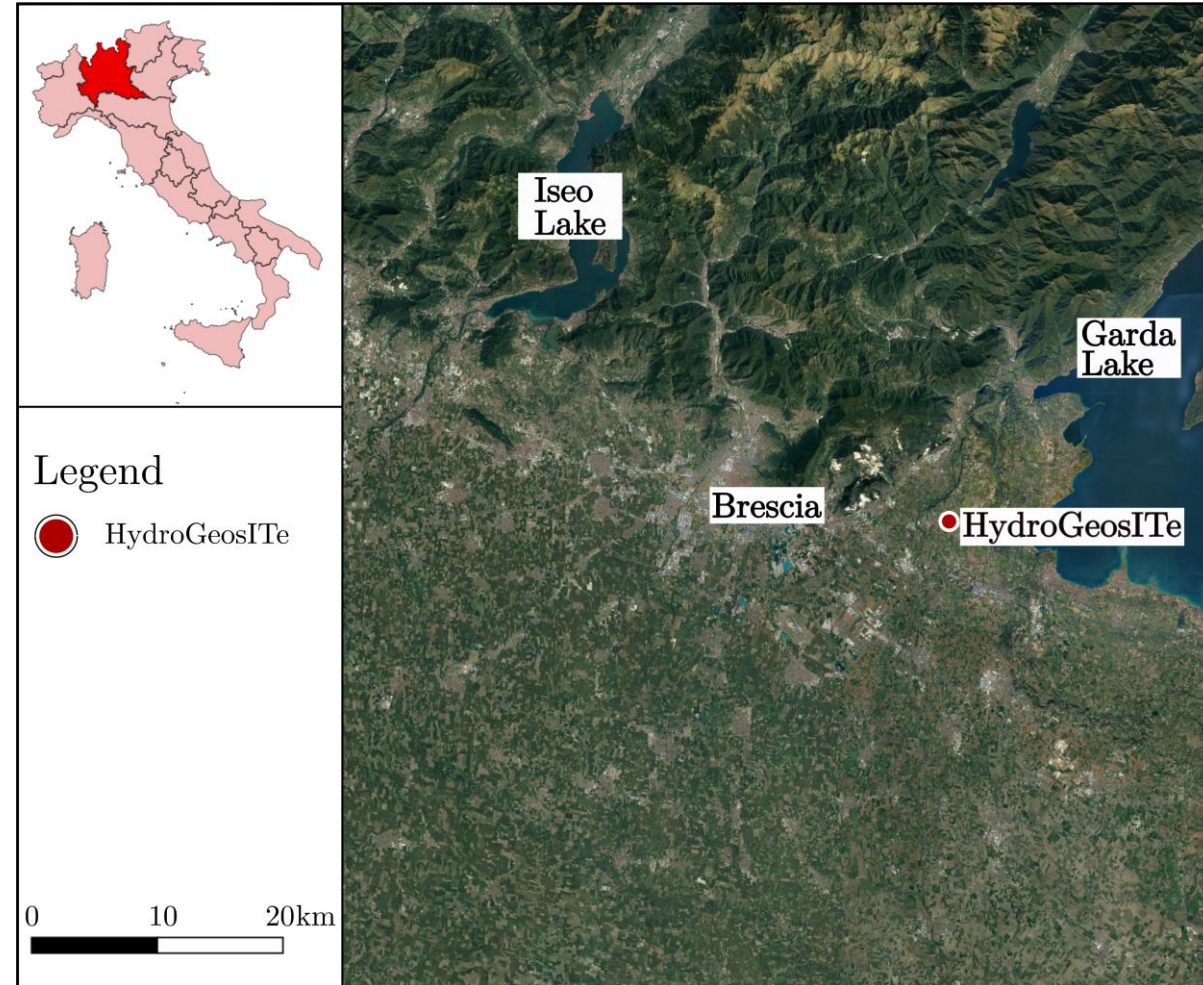
CNR Ismar-UNIPD: laguna di Venezia



AEM nella provincia di Brescia (2021-2023)

La più grande campagna AEM mai condotta in Italia

- **Provincia di Brescia province**, pianura e montagna
- Progetto coordinato dall'**ATO Brescia** e portato avanti da **A2A Ciclo Idrico** e **Acque Bresciane**
- Tre dottorati cofinanziati:
 - **HydroGeosITe**, il sito italiano di calibrazione e riferimento per metodi elettrici ed elettromagnetici
 - **MuountainHydro**, sostenibilità dell'approvvigionamento idrico da sorgenti in Val Sabbia
 - **LakEMaging**, interazione acque superficiali ed acque sotterranee sulla sponda sud del lago di Iseo

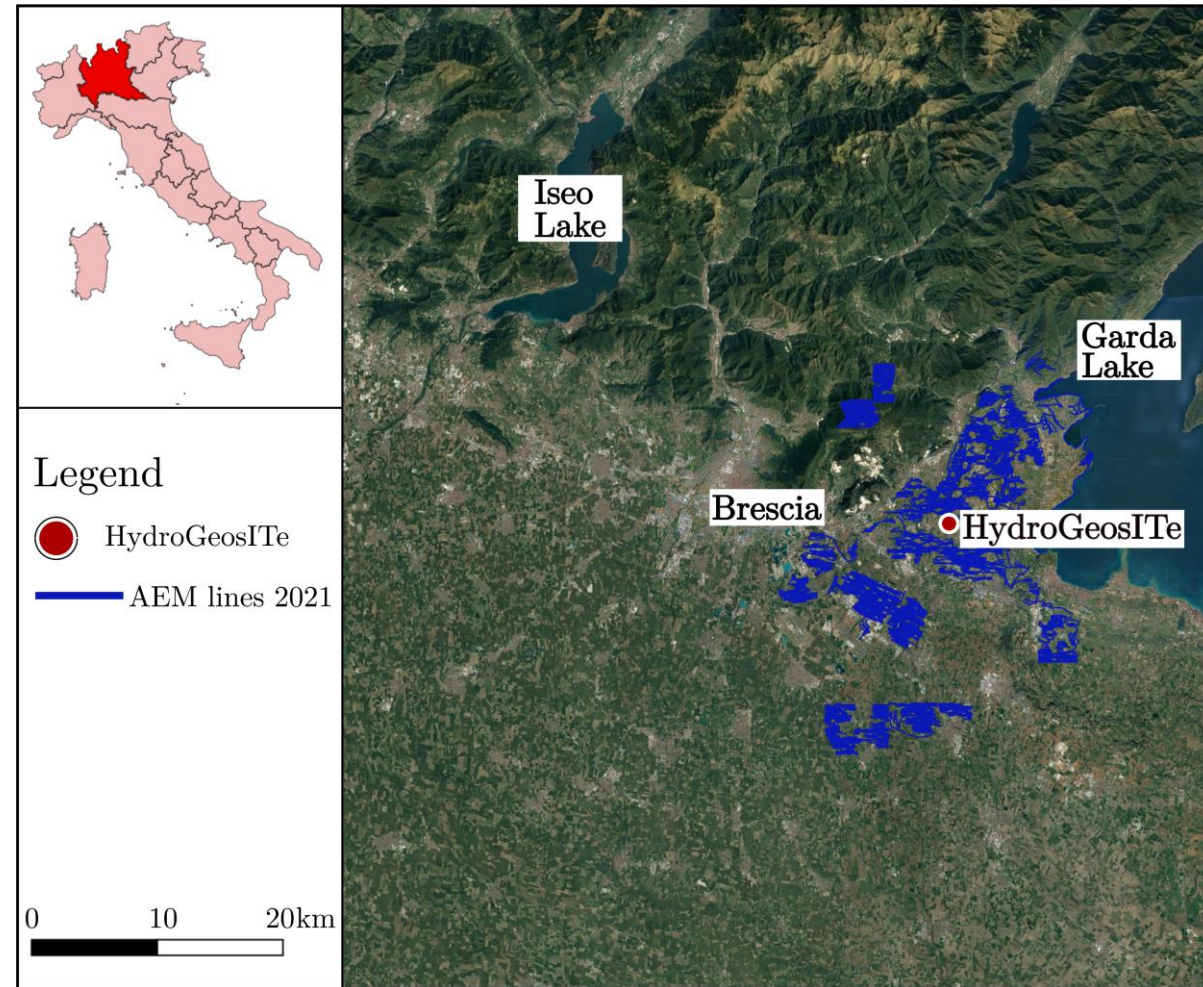


Esplorare il sottosuolo volando.

AEM nella provincia di Brescia (2021-2023)

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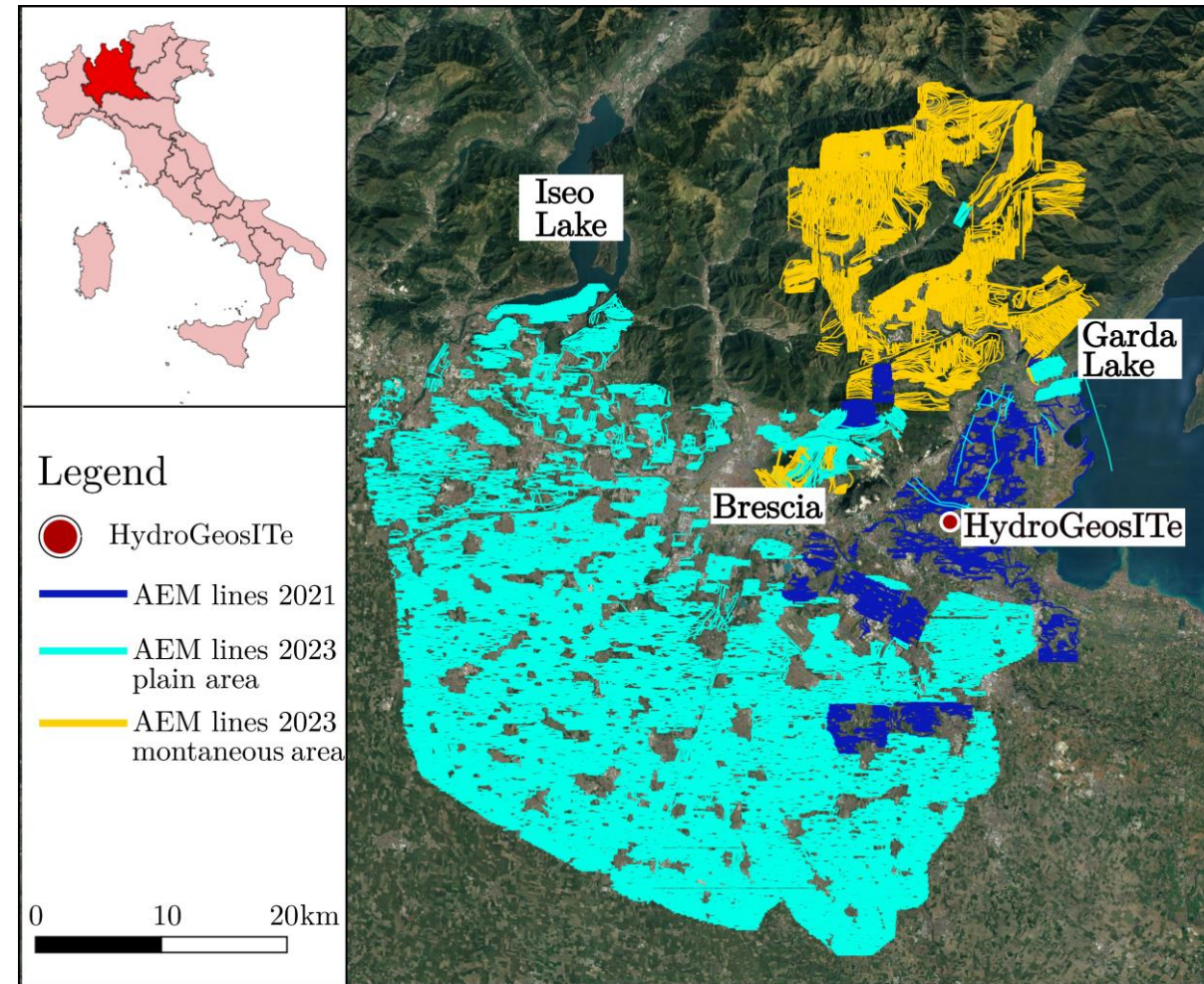


Esplorare il sottosuolo volando.

AEM nella provincia di Brescia (2021-2023)

La più grande campagna AEM mai condotta in Italia

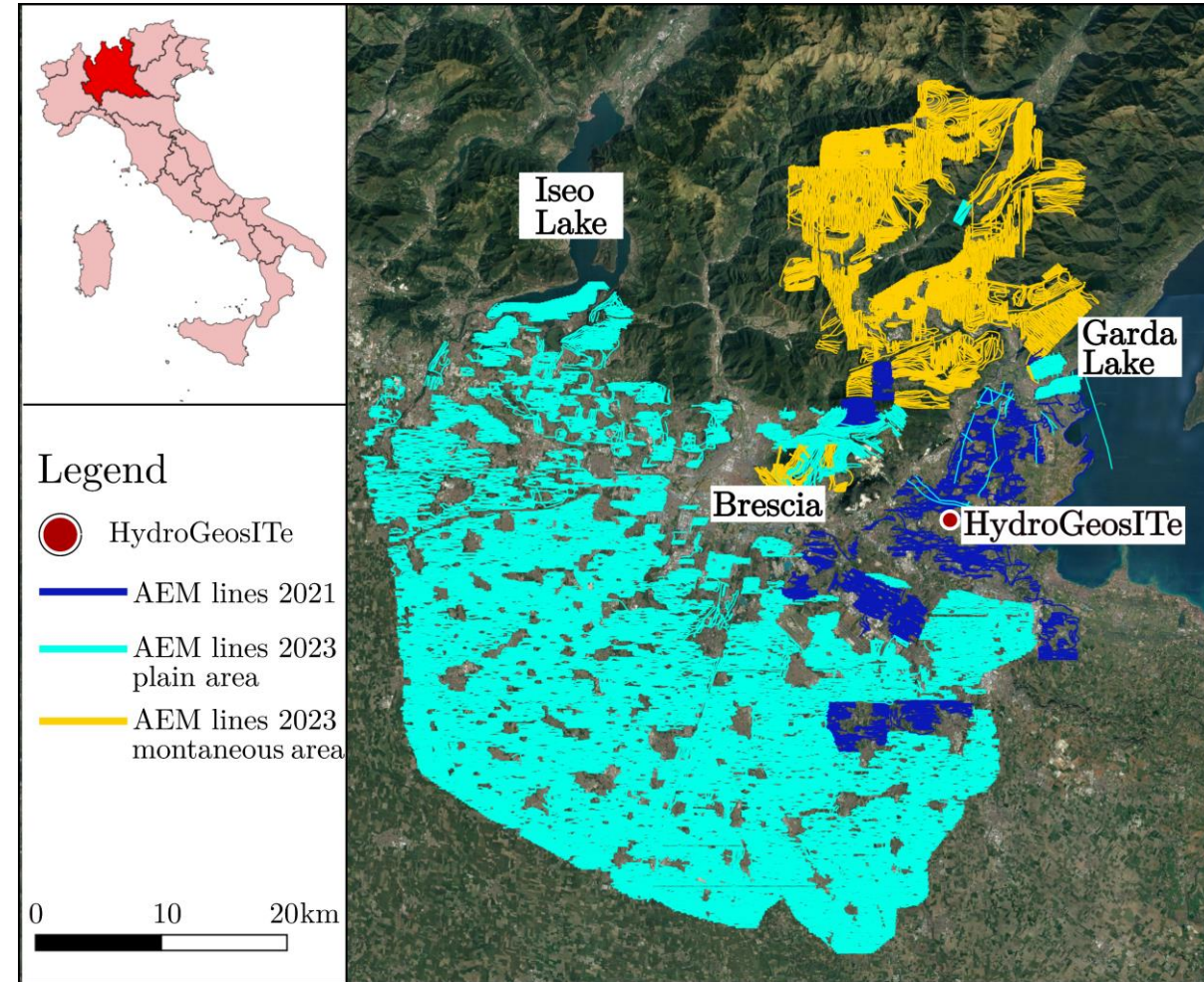
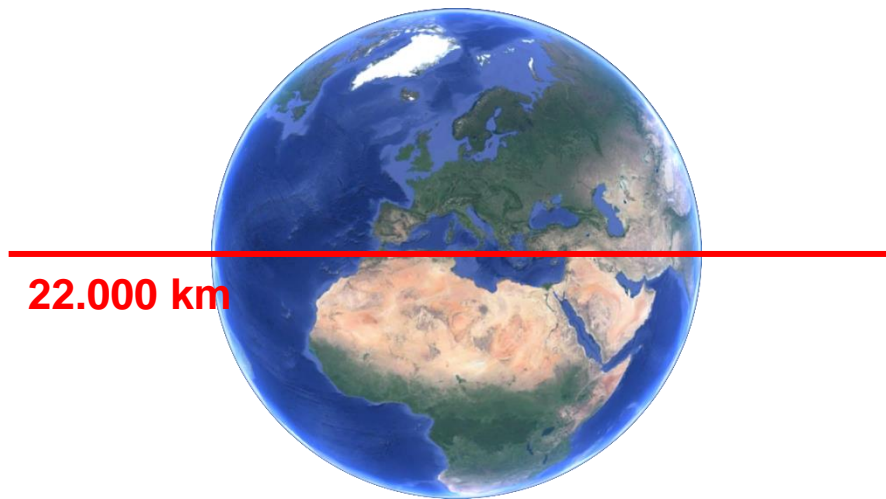
- **Provincia di Brescia province**, pianura e montagna
- Progetto coordinato dall'ATO Brescia e portato avanti da **A2A Ciclo Idrico** e **Acque Bresciane**
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Esplorare il sottosuolo volando.

AEM nella provincia di Brescia (2021-2023)

La più grande campagna AEM mai condotta in Italia



Esplorare il sottosuolo volando.

The background of the slide is a light blue map of Italy. Overlaid on the map is a grid of blue squares, each containing a small black dot. Some squares are highlighted with green or pink borders. The title 'The HydroGeosITe project' is written in large, bold, orange letters across the center of the map.

The HydroGeosITe project

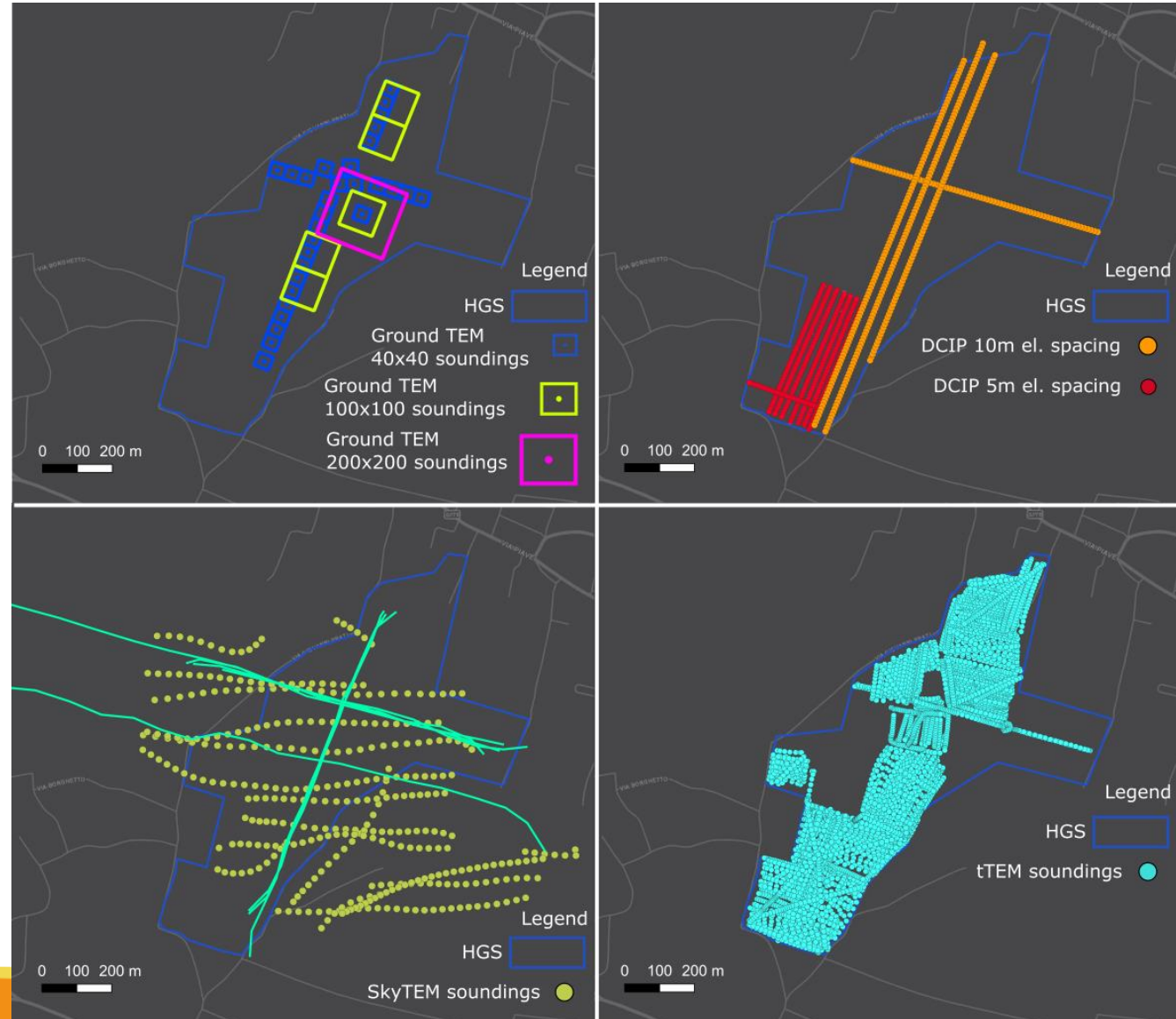
The **HydrogeosITe** – First Italian **calibration** and **reference** site for Electric and Electromagnetic (**E & EM**) methods for hydrogeological applications

The HydroGeosITe project

Reference site

Per l'**interpretazione** della campagna AEM
2023 (+20,000 line km)

- Stabilito in un'area rappresentativa del setting idrogeologico
- Depositi glaciali e fluvioglaciali
- complessa sovrapposizione e interdigitazione di depositi morenici e fluviali

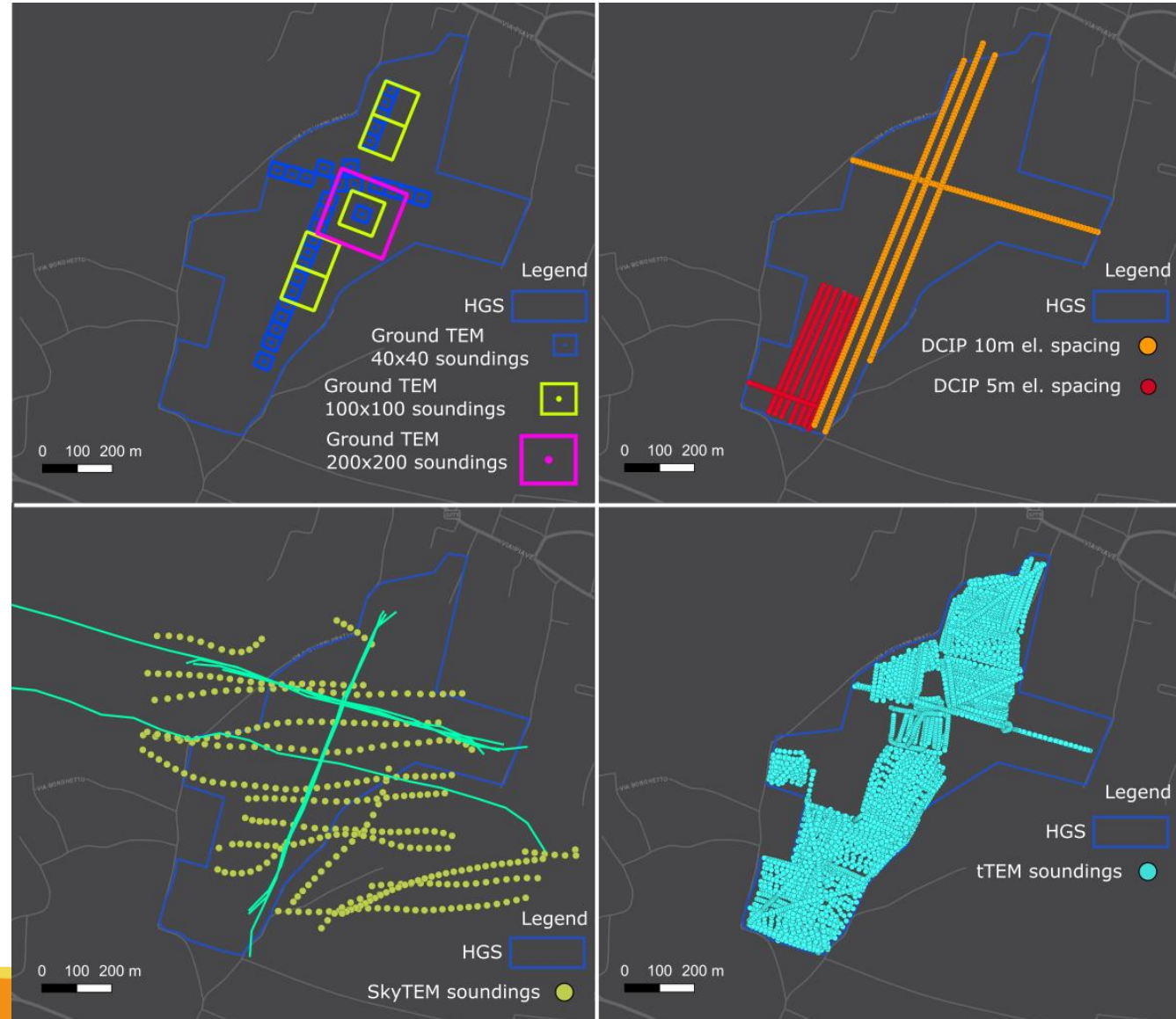


The HydroGeosITe project

Calibration Site

Per stabilire un modello geofisico di riferimento per la calibrazione di sistemi geofisici diversi:

- Data coverage **molto denso** (sia **E & EM**)
- **Caratterizzazione** di proprietà elettriche sia in termini di **conduzione** che di **polarizzazione** elettrica
- **Inversione congiunta di dati E & EM**
- Perforazioni con descrizione litologica e log in foro (profonde 200 m e 350 m)



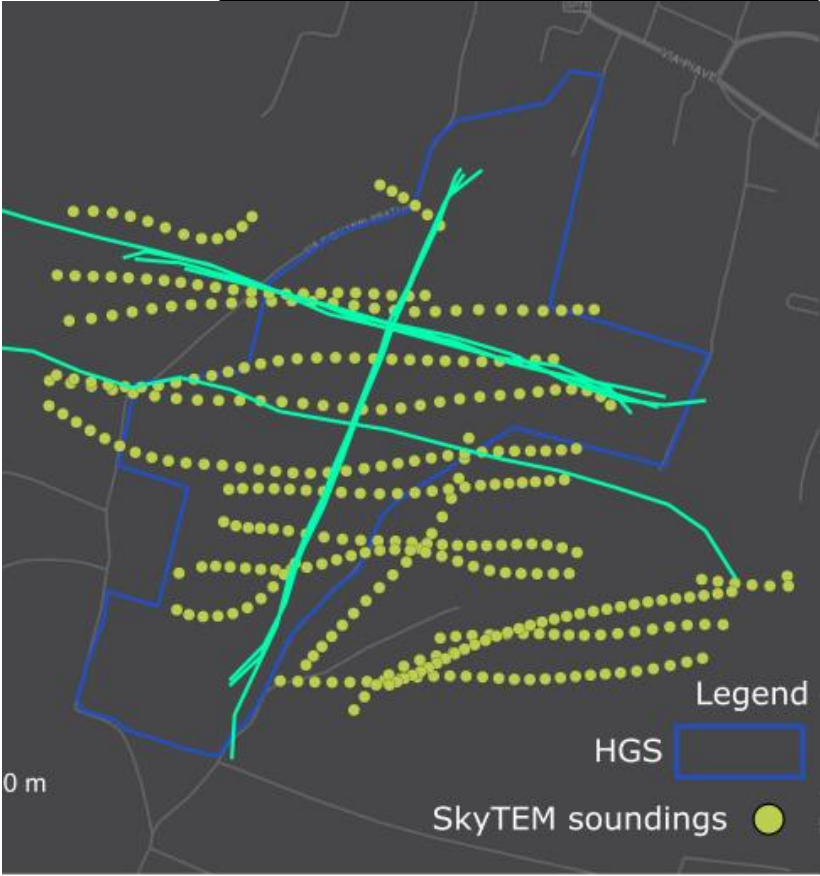
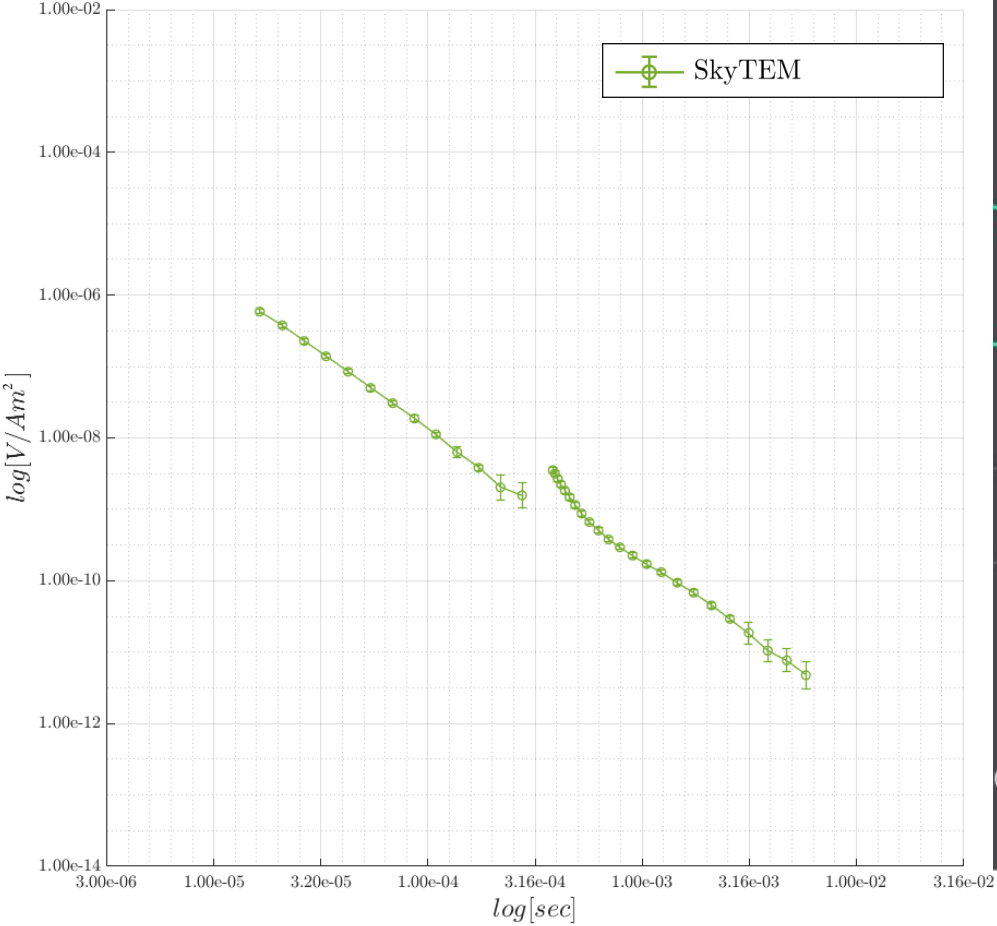
Data coverage



Data coverage

Airborne EM: **SkyTEM**

	LM	HM
Moment [nIA]	$2.7 \cdot 10^4$	$4.3 \cdot 10^5$
Current [Amps]	6.8	106.5
Tx_area [m ²]	342	
Tx_turns	12	
MinMax GateTime [s]	$1.6 \cdot 10^{-5}$	$3.8 \cdot 10^{-4}$
	$5.5 \cdot 10^{-4}$	$1.3 \cdot 10^{-2}$
# meas.	350	

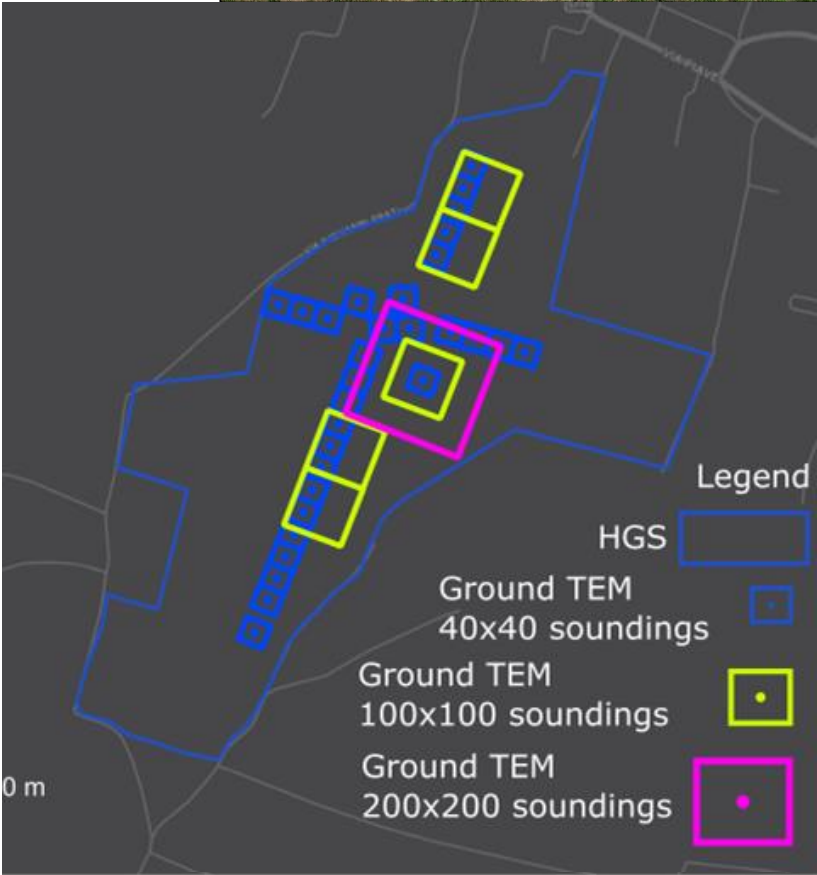
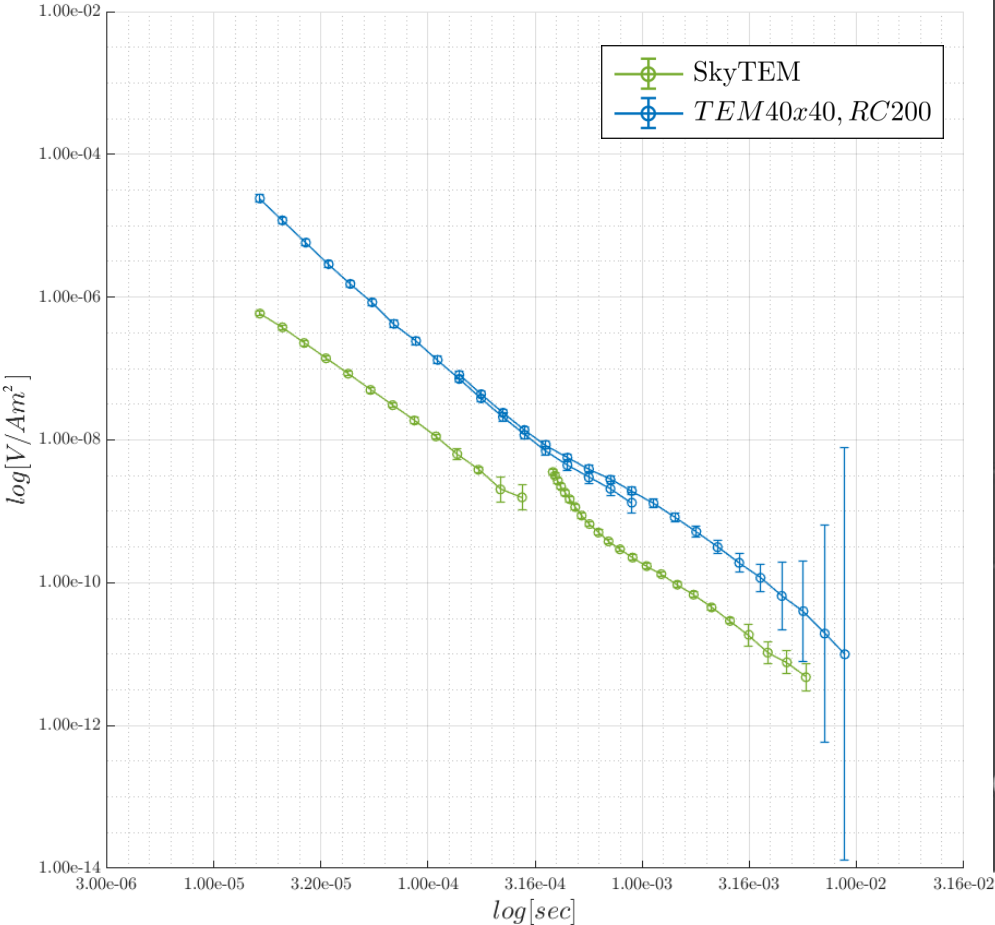


Esplorare il sottosuolo volando.

Data coverage

Ground EM: **TEM 40x40**

	LM	HM
Moment [nIA]	$\approx 3.5e^{03}$	$\approx 2.5e^{04}$
Current [Amps]	2.0	15.3
Tx_area [m ²]	1600	
Tx_turns	1	
MinMax GateTime [s]	$1.63e^{-05}$	$1.40e^{-04}$
	$8.95e^{-04}$	$8.84e^{-03}$
# meas.	30	

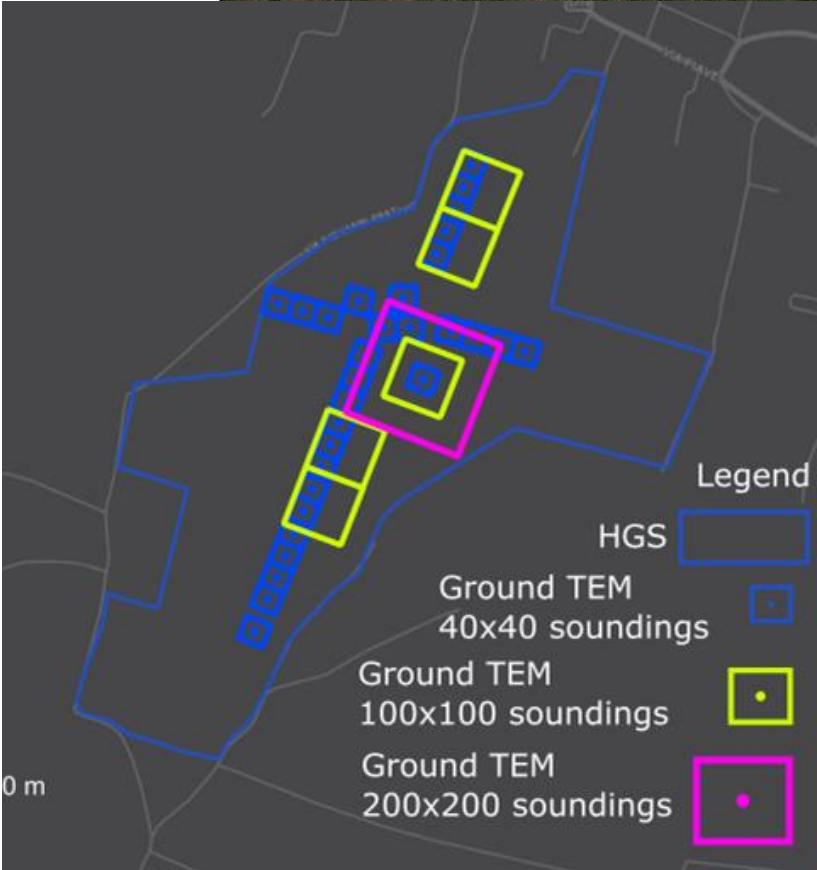
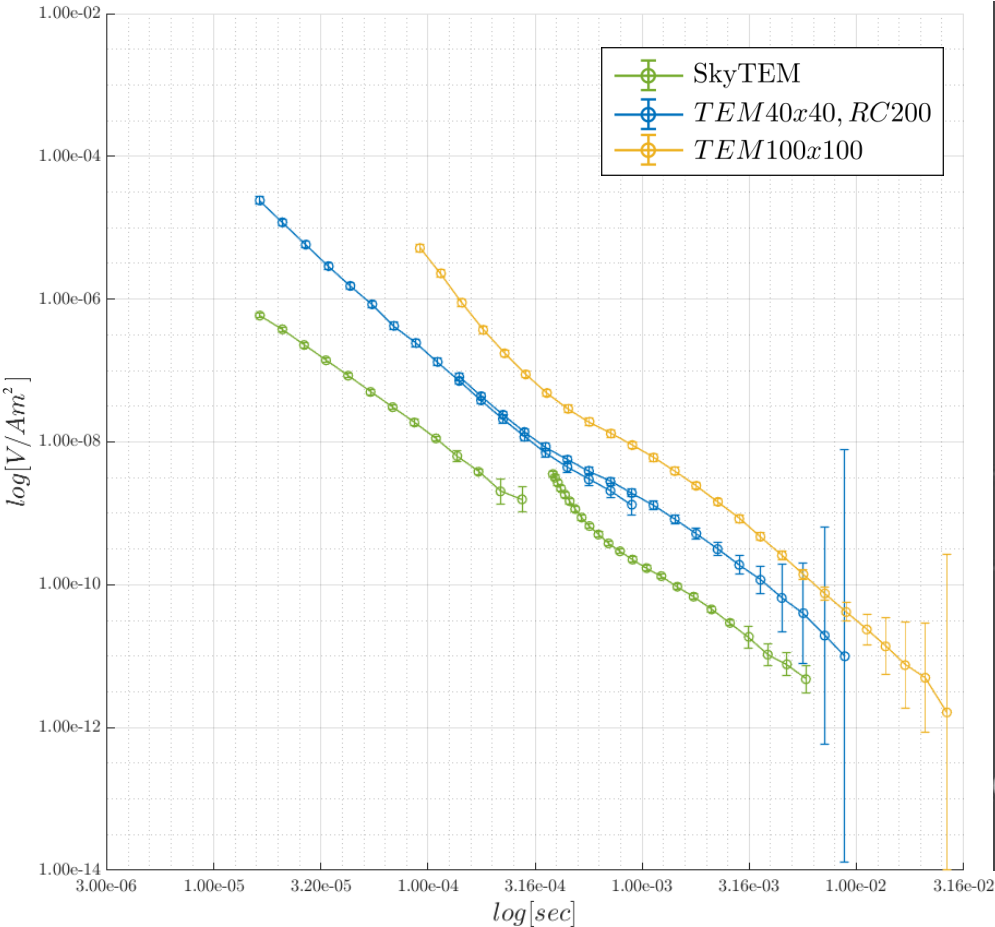


Esplorare il sottosuolo volando.

Data coverage

Ground EM: **TEM 100x100**

	LM	HM
Moment [nIA]	/	$\approx 4.2e^{05}$
Current [Amps]	/	42.3
Tx_area [m ²]	10000	
Tx_turns	1	
MinMax GateTime [s]	/	$9.16e^{-05}$
	/	$2.0e^{-02}$
# meas.	5	

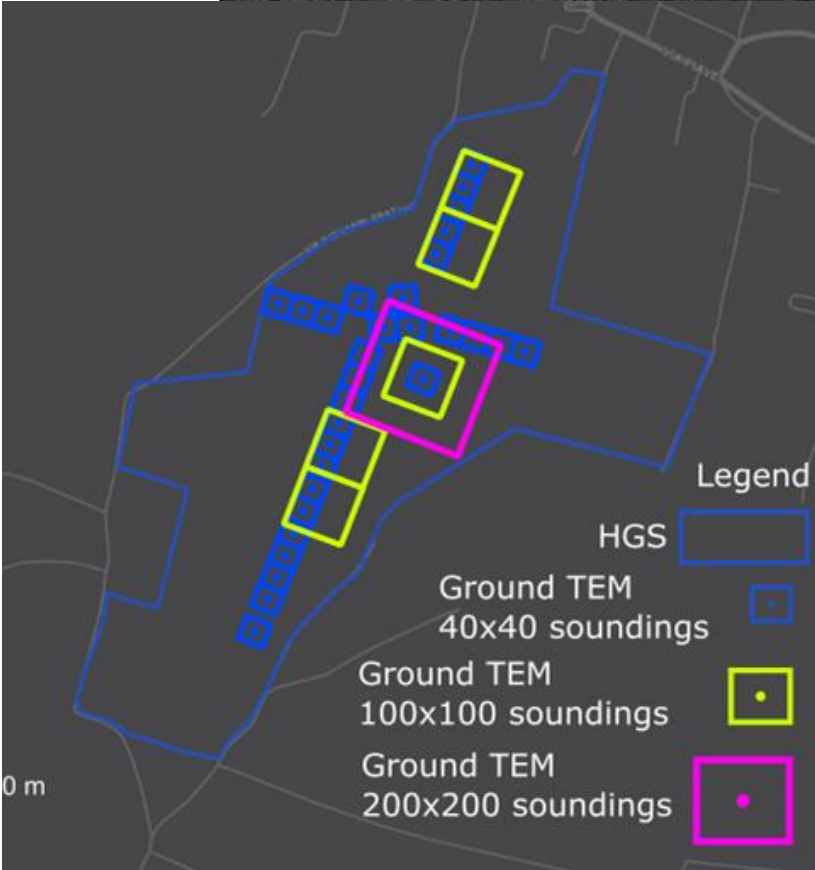
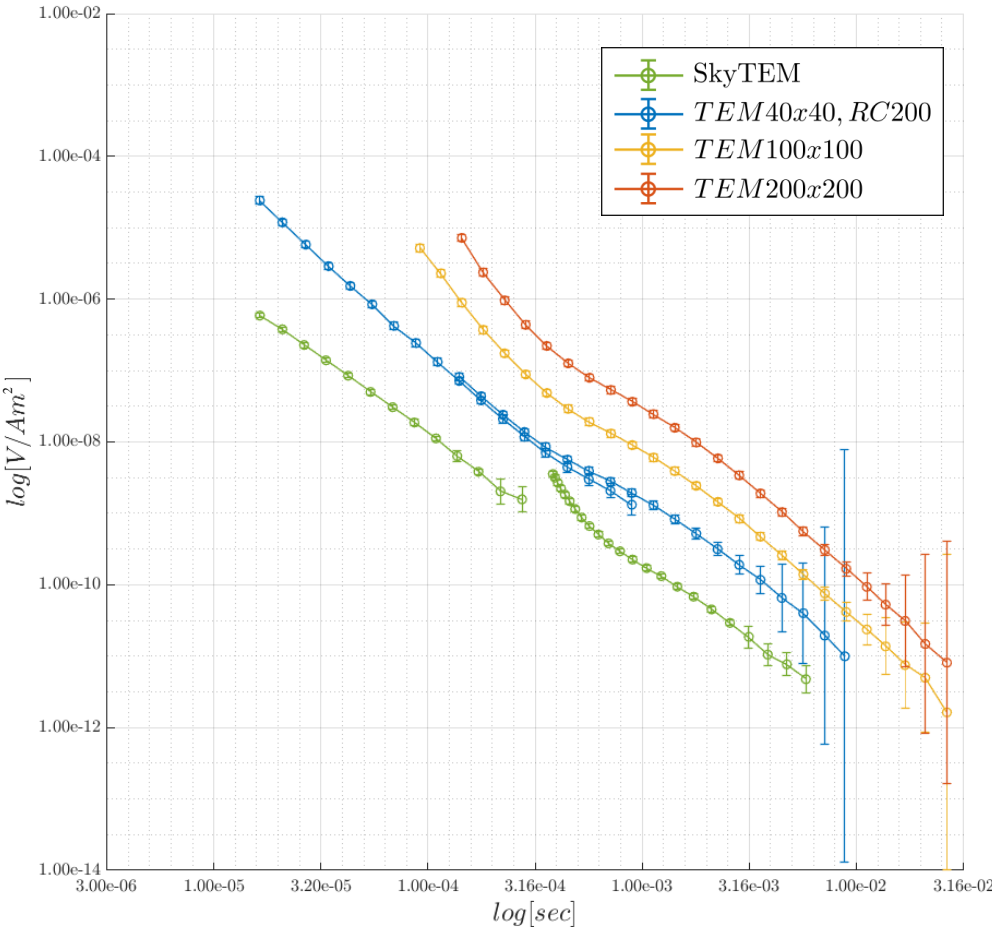


Esplorare il sottosuolo volando.

Data coverage

Ground EM: **TEM 200x200**

	LM	HM
Moment [nIA]	/	$\approx 1.4e^6$
Current [Amps]	/	35.5
Tx_area [m ²]	40000	
Tx_turns	1	
MinMax GateTime [s]	/	$1.4e^{-04}$
	/	$3.0e^{-02}$
# meas.	1	

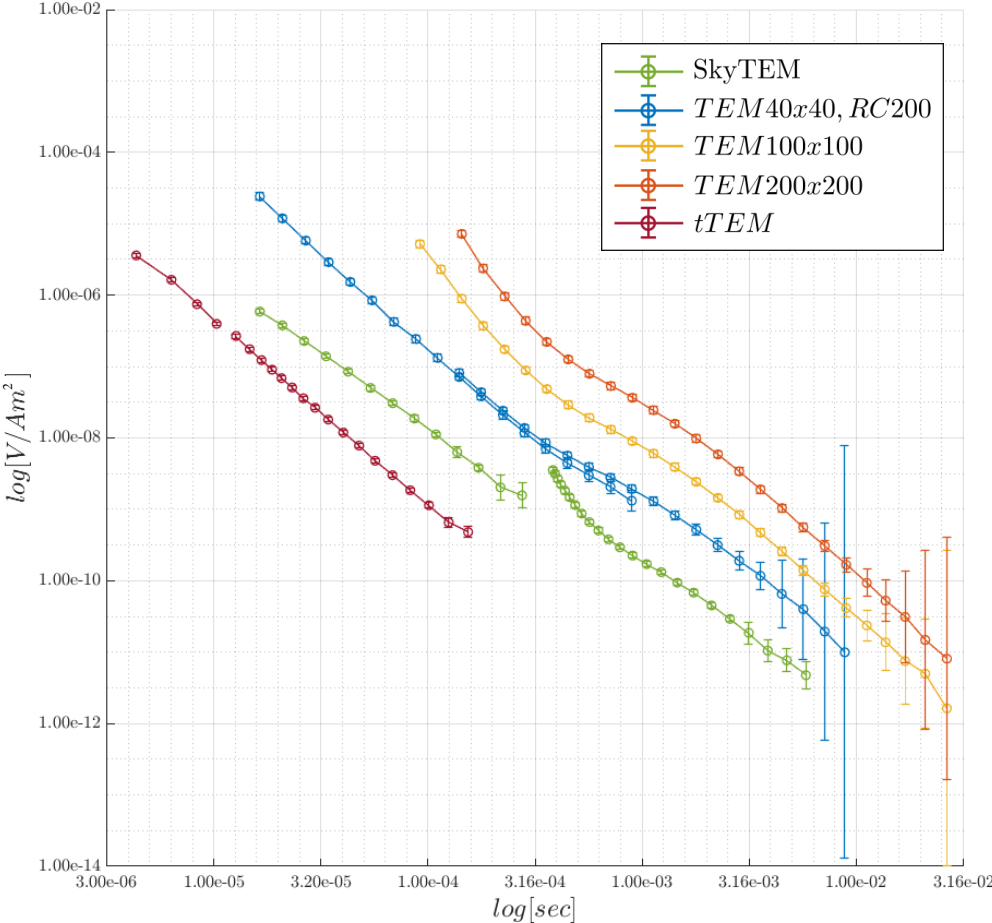


Esplorare il sottosuolo volando.

Data coverage

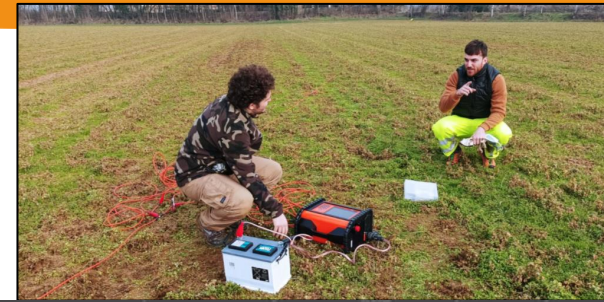
Ground EM: **tTEM**

	LM	HM
Moment [nIA]	$\approx 2.5e^{01}$	$\approx 2.5e^{02}$
Current [Amps]	3.0	30.0
Tx_area [m ²]	8.41	
Tx_turns	1	
MinMax GateTime [s]	$6.34e^{-06}$	$1.26e^{-05}$
	$1.03e^{-05}$	$1.9e^{-04}$
# meas.	55 km (≈ 5000 soundings)	



Esplorare il sottosuolo volando.

Data coverage

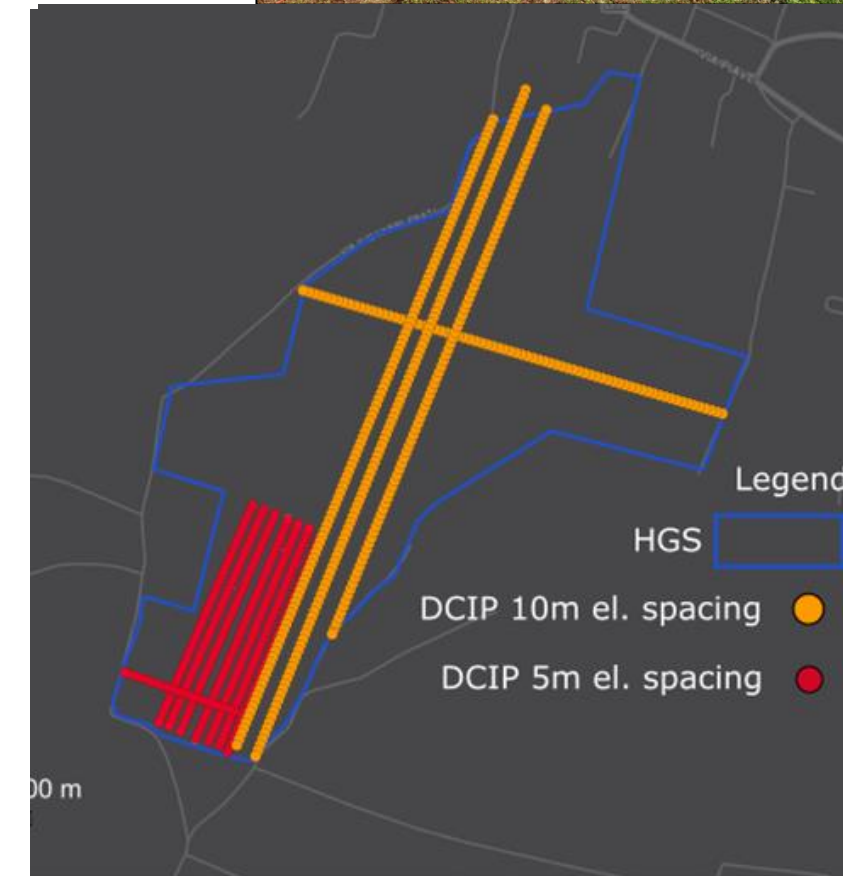


Ground DCIP: **Terrameter LS2**

DC and IP noise Processing

- **Harmonic denoising**
- **Drift removal**
- **DC and IP manual data processing**

Profile length	4 km el spac. 10 m (orange profiles)
	2.8 km el spac. 5 m (red profiles)
Current	0.5 Amps (mean)
	Gradient Array
	100 % Duty Cycle
Protocol	12 sec ONTIME
	Fullwaveform (4 kHz)
Stack	2
# quads	MIN 1400 MAX 2700



Esplorare il sottosuolo volando.

Data Modelling e inversione congiunta

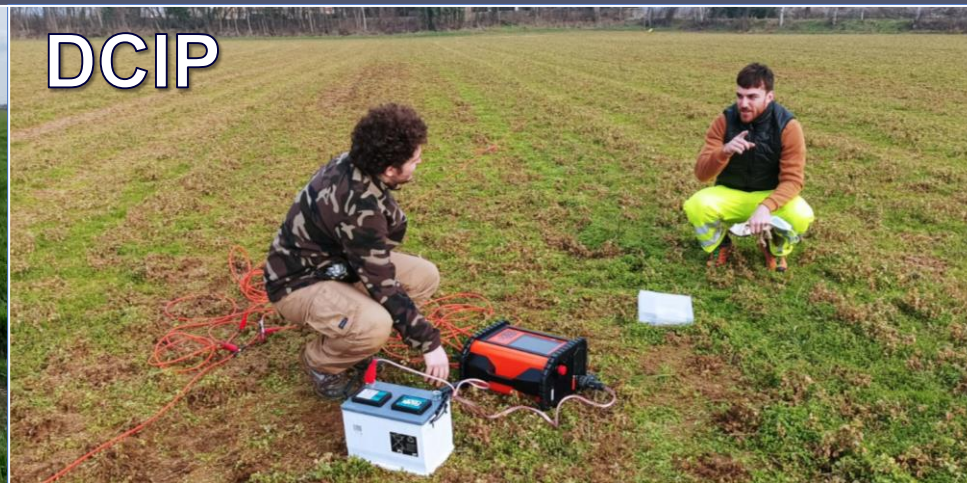
Data Modelling e inversione congiunta

Tutti i dati invertiti indipendentemente

- **Galvanici**
- **Induttivi**

Inversione congiunta, per migliorare la risoluzione!

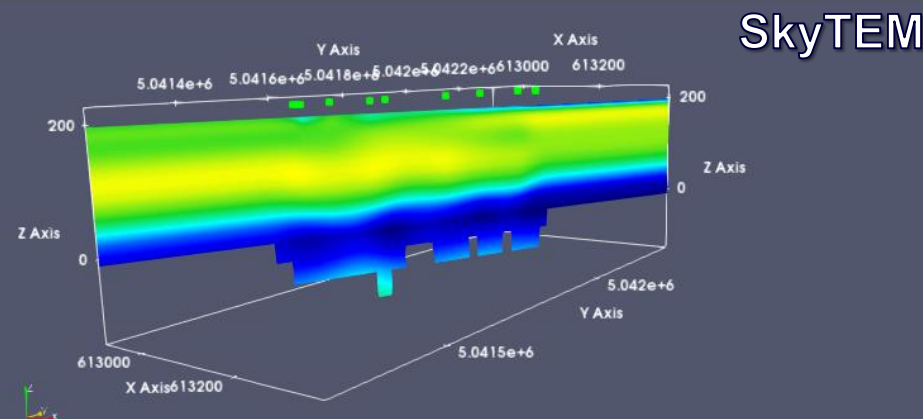
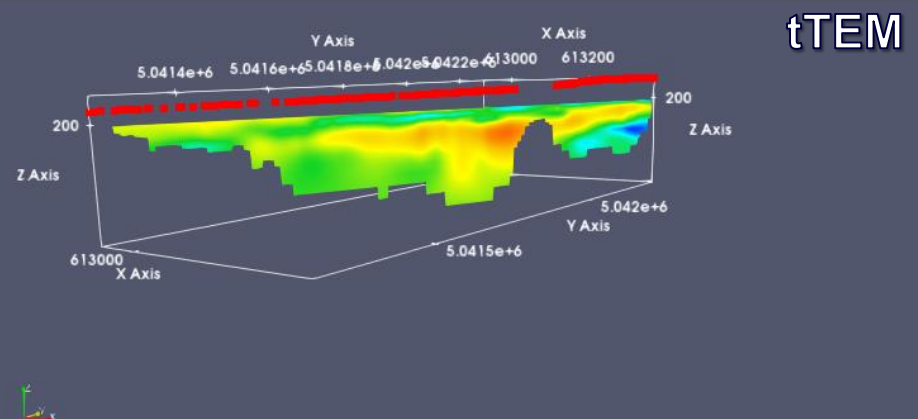
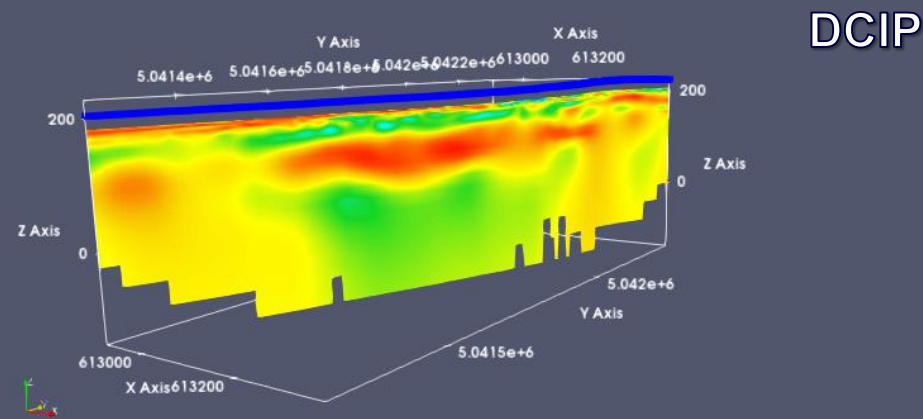
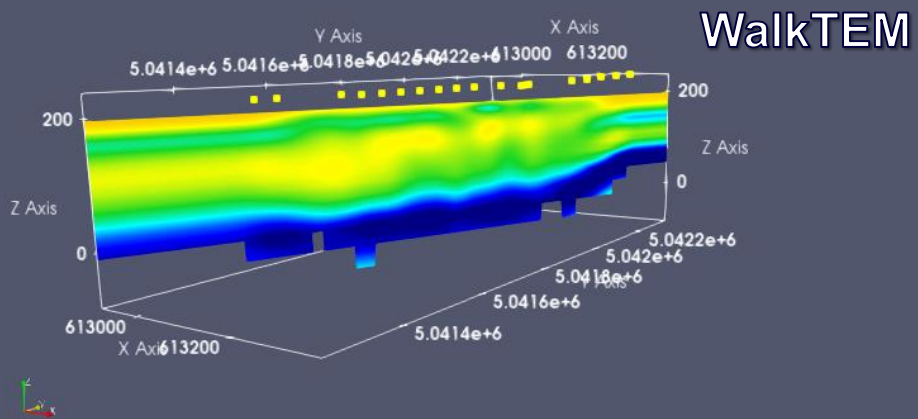
Data Modelling e inversione congiunta



Let's now look at the independent models:

- Different models due to different systems sensitivities
- Different hardware features

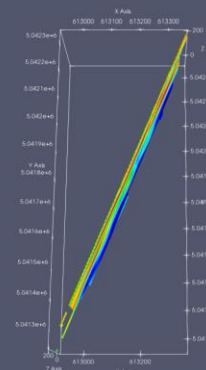
Data Modelling e inversione congiunta



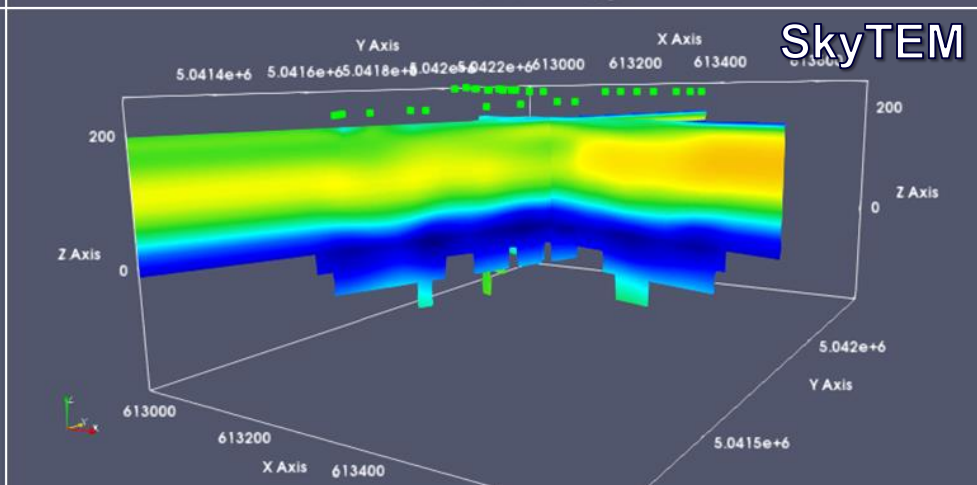
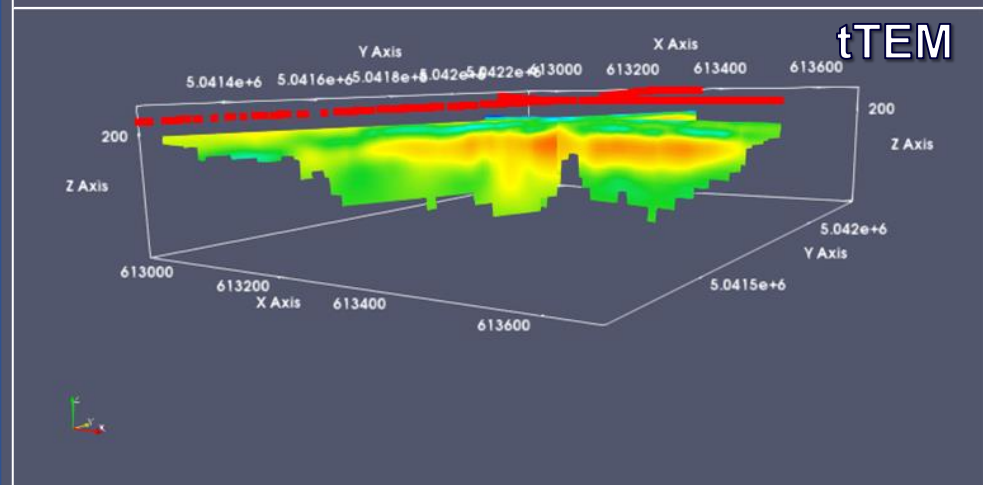
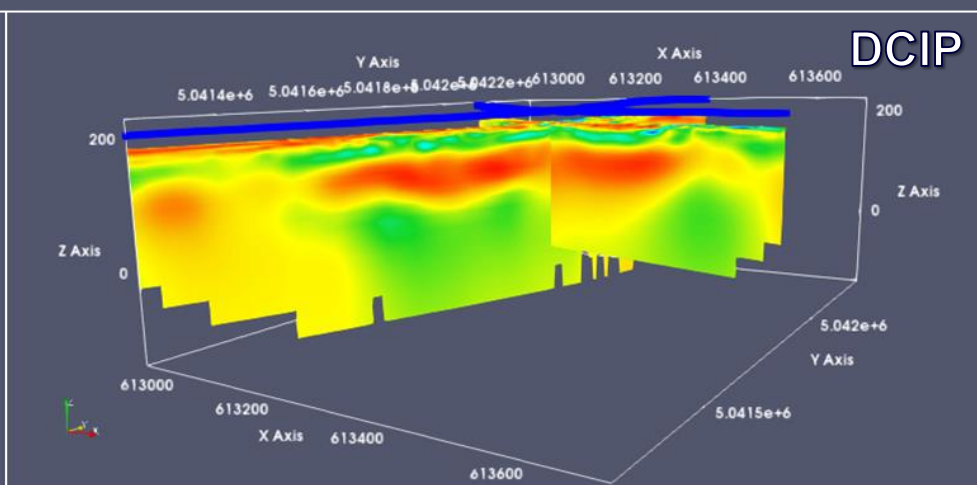
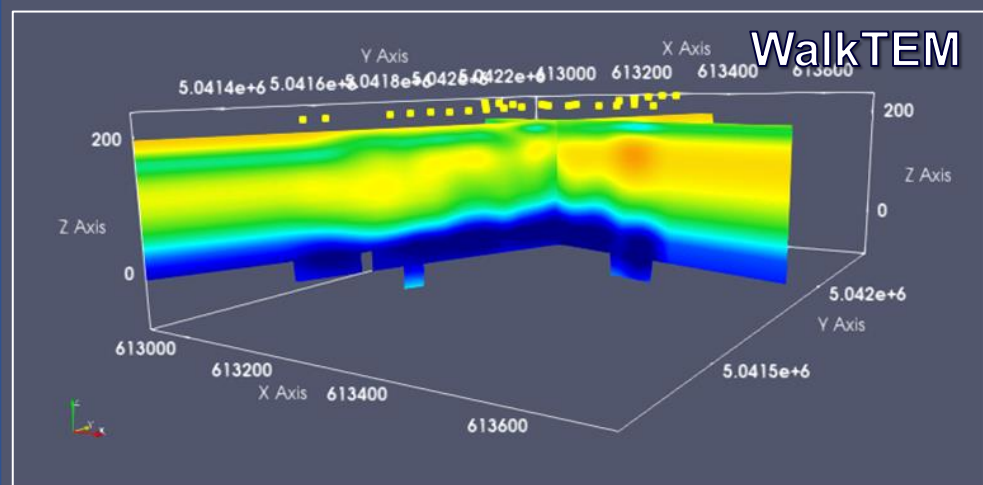
DataMisfit Joint Inversions	
	HGS01
Ground TEM (RC5 – RC200)	1.72 - 2.42
DC	1,46
IP	1,59
tTEM	1.83
SkyTEM	1.69



HGS_01



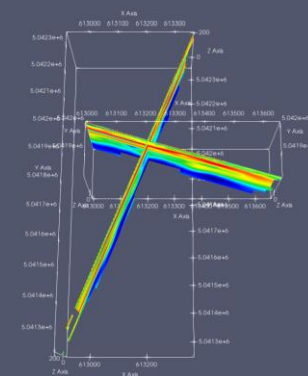
Data Modelling e inversione congiunta



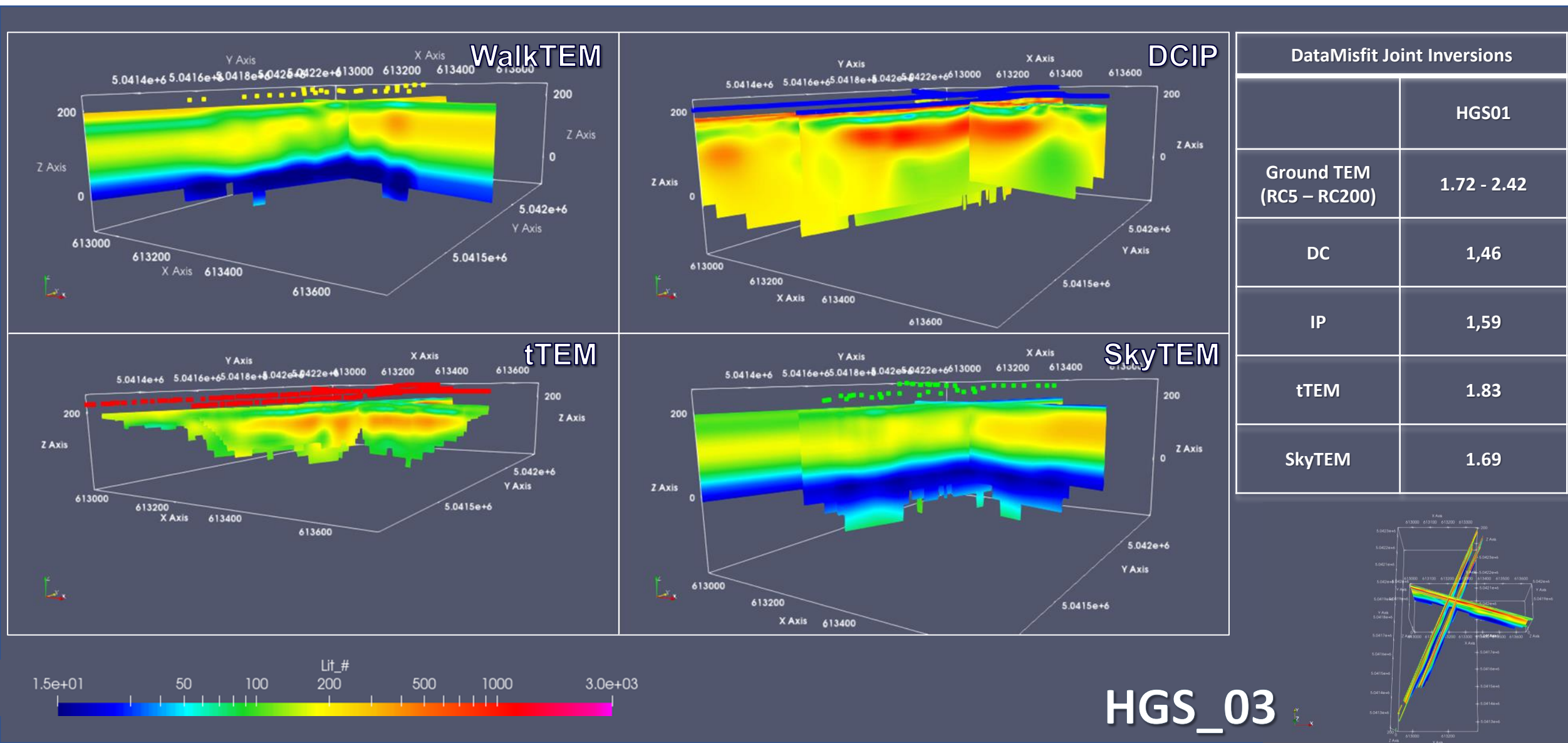
DataMisfit Joint Inversions	
	HGS01
Ground TEM (RC5 – RC200)	1.72 - 2.42
DC	1,46
IP	1,59
tTEM	1.83
SkyTEM	1.69



HGS_02



Data Modelling e inversione congiunta



Data Modelling e inversione congiunta



Joint inversion of electrical and electromagnetic (E & EM) data within a unified framework:

- Finding the model that simultaneously fits all available data
- This approach aims to seamlessly integrate both E & EM datasets

WalkTEM



tTEM



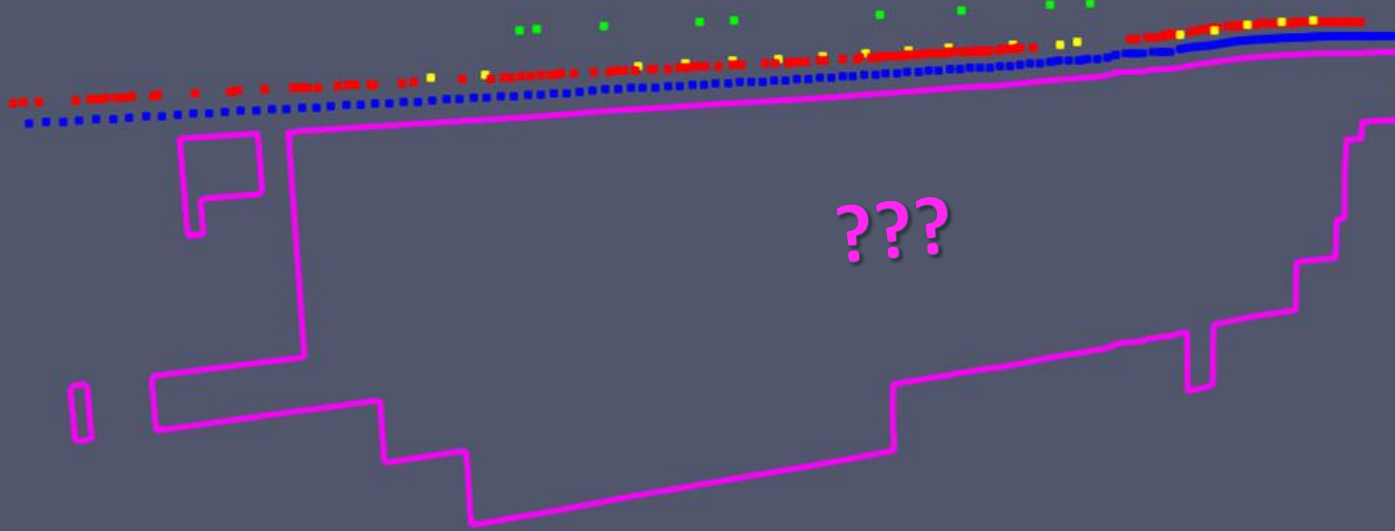
DCIP



SkyTEM



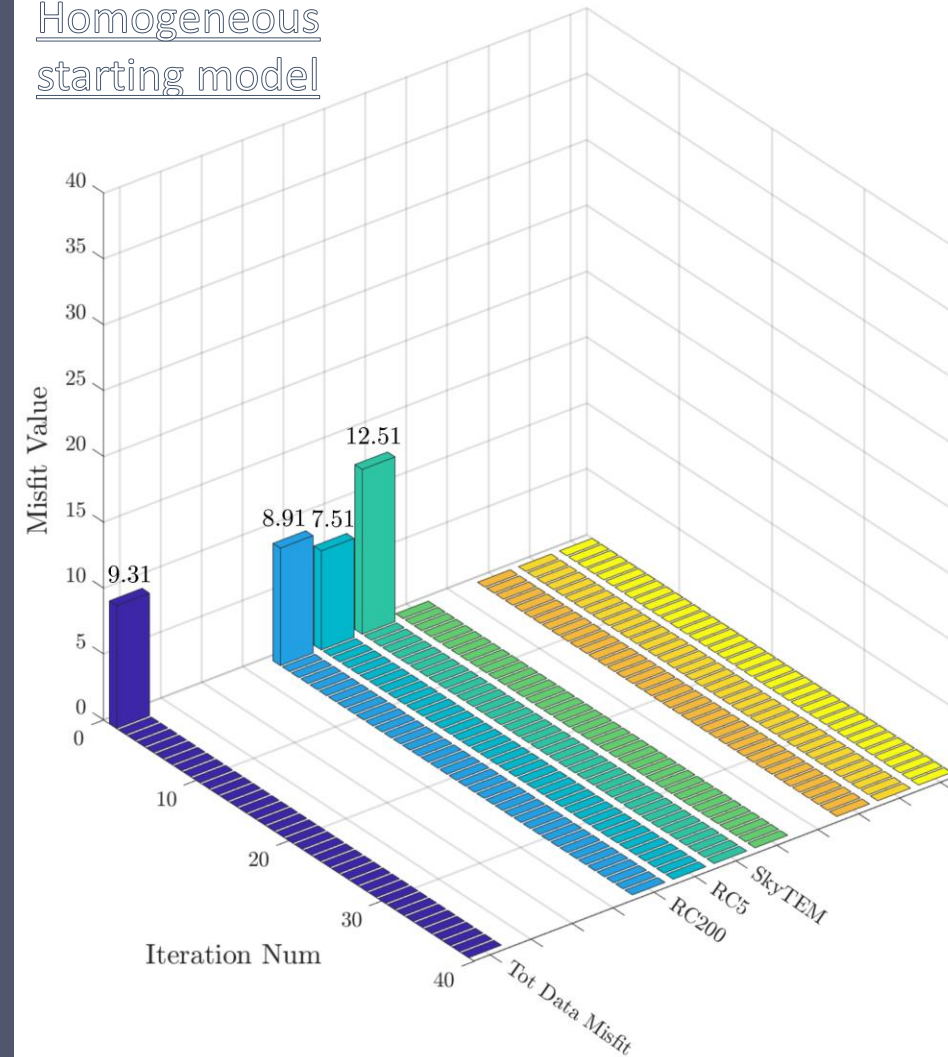
Data Modelling e inversione congiunta



EEMverter Multy-cycle inversion scheme:

Quick look at how the inversion misfit converges seeking for the final model

Iteration 00:
Homogeneous
starting model



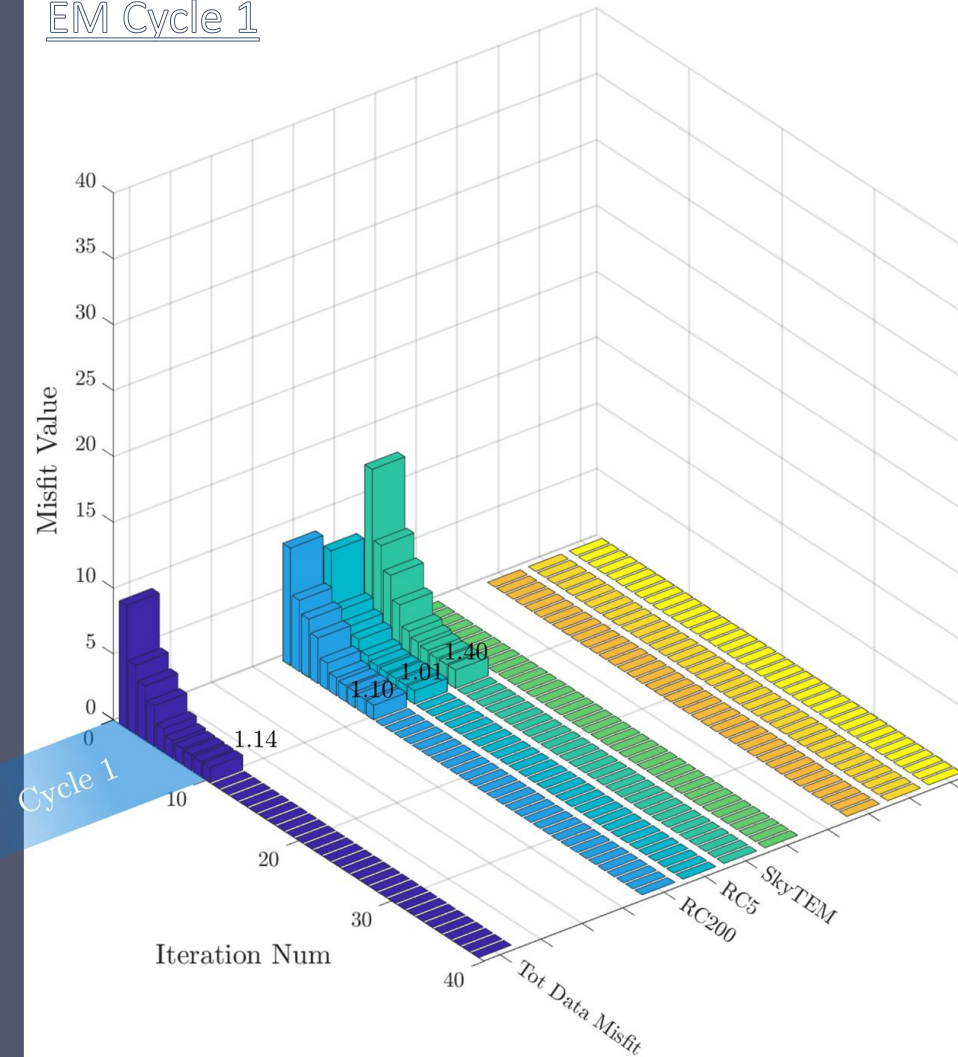
Data Modelling e inversione congiunta



EEMverter Multi-cycle inversion scheme:

Quick look at how the inversion misfit converges seeking for the final model

Iteration 10:
EM Cycle 1



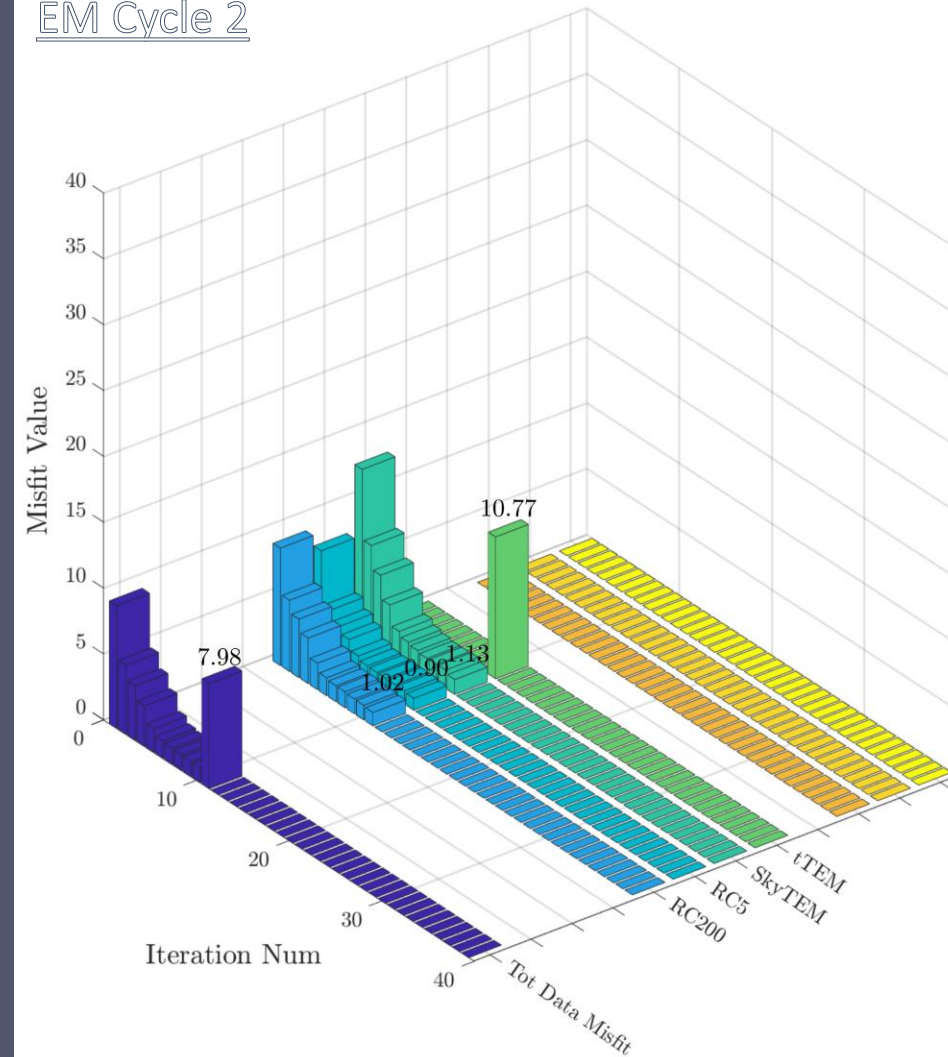
Data Modelling e inversione congiunta



EEMverter Multy-cycle inversion scheme:

Quick look at how the inversion misfit converges seeking for the final model

Iteration 11:
EM Cycle 2



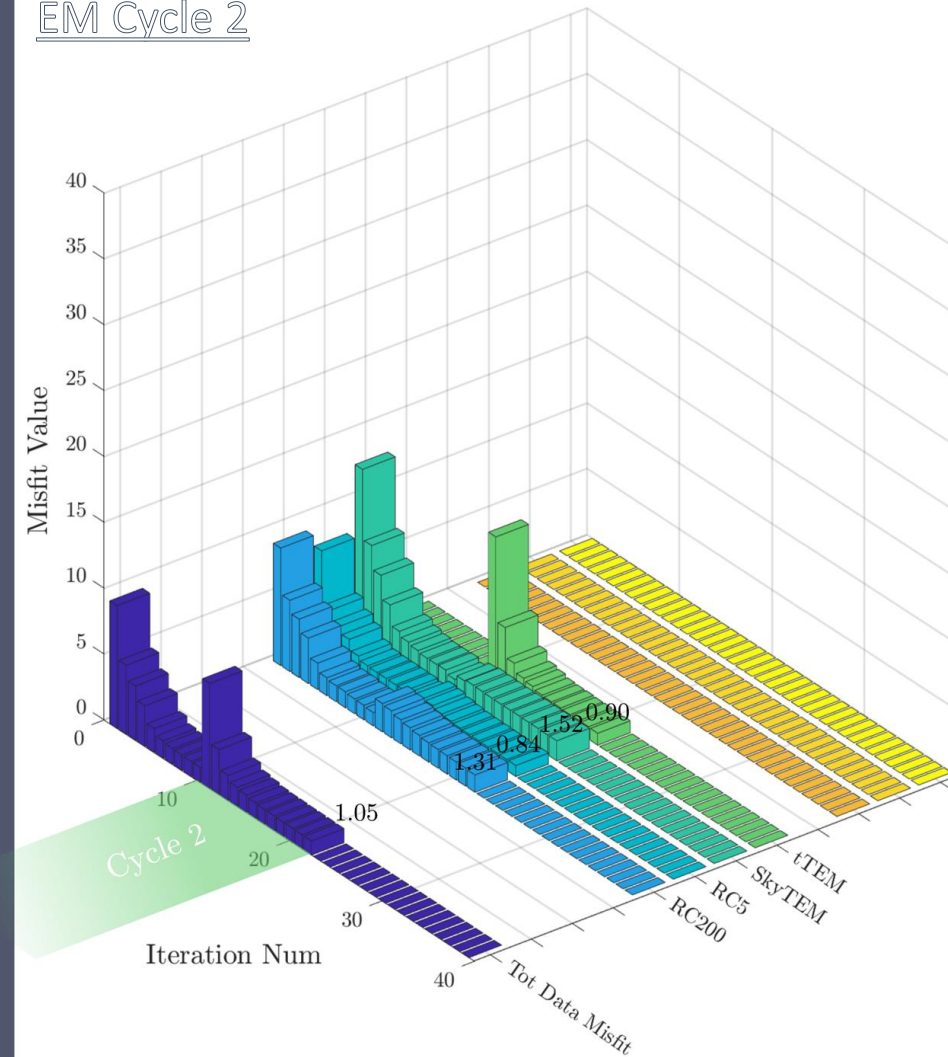
Data Modelling e inversione congiunta



EEMverter Multy-cycle inversion scheme:

Quick look at how the inversion misfit converges seeking for the final model

Iteration 22:
EM Cycle 2



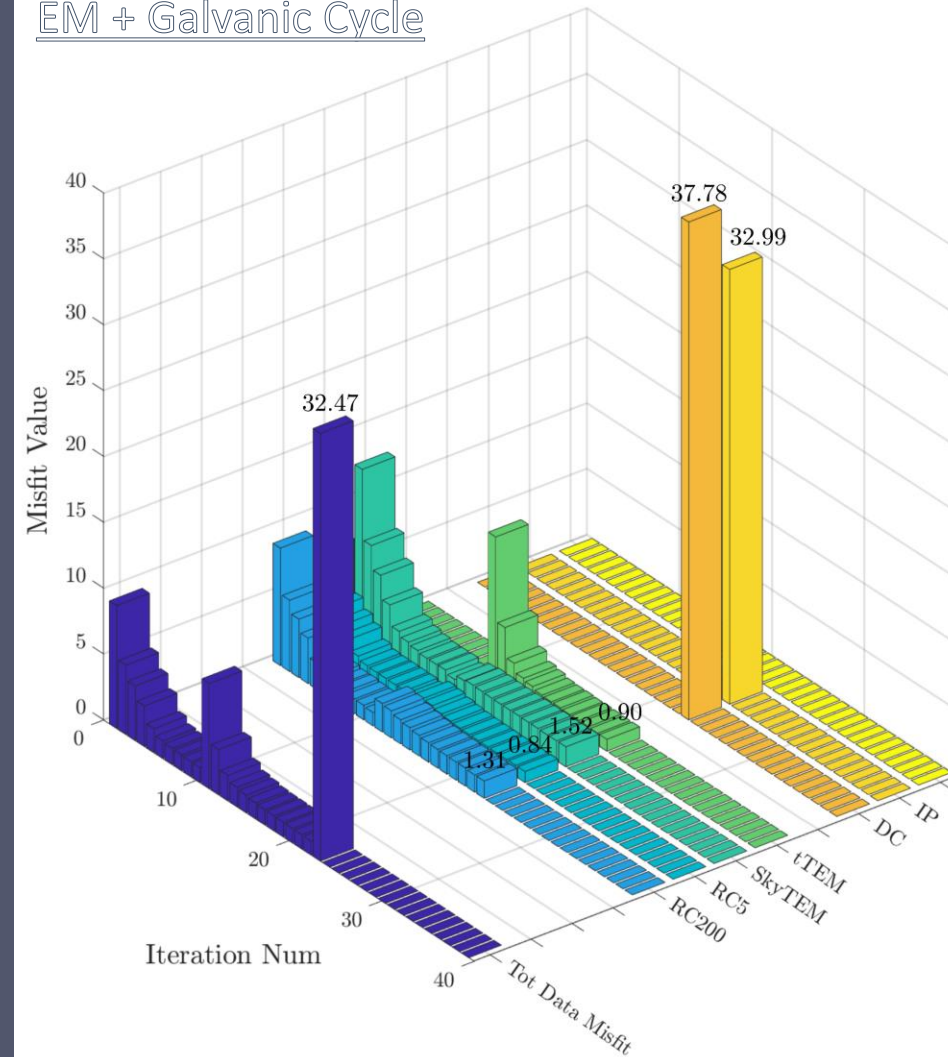
Data Modelling e inversione congiunta



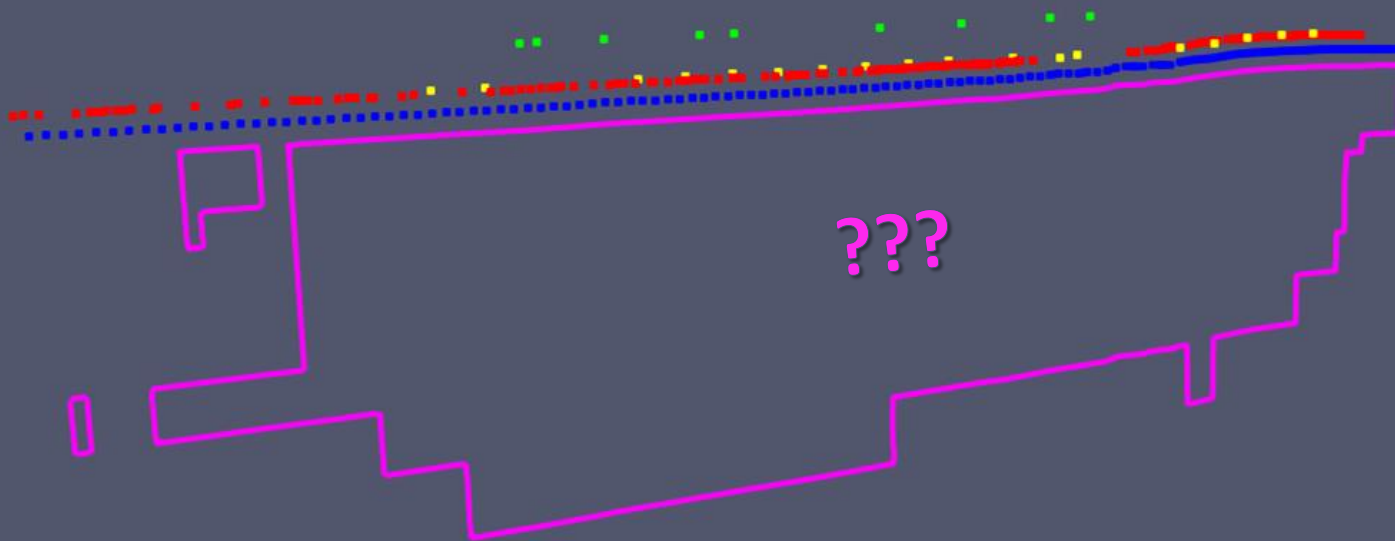
EEMverter Multi-cycle inversion scheme:

Quick look at how the inversion misfit converges seeking for the final model

Iteration 23:
EM + Galvanic Cycle



Data Modelling e inversione congiunta

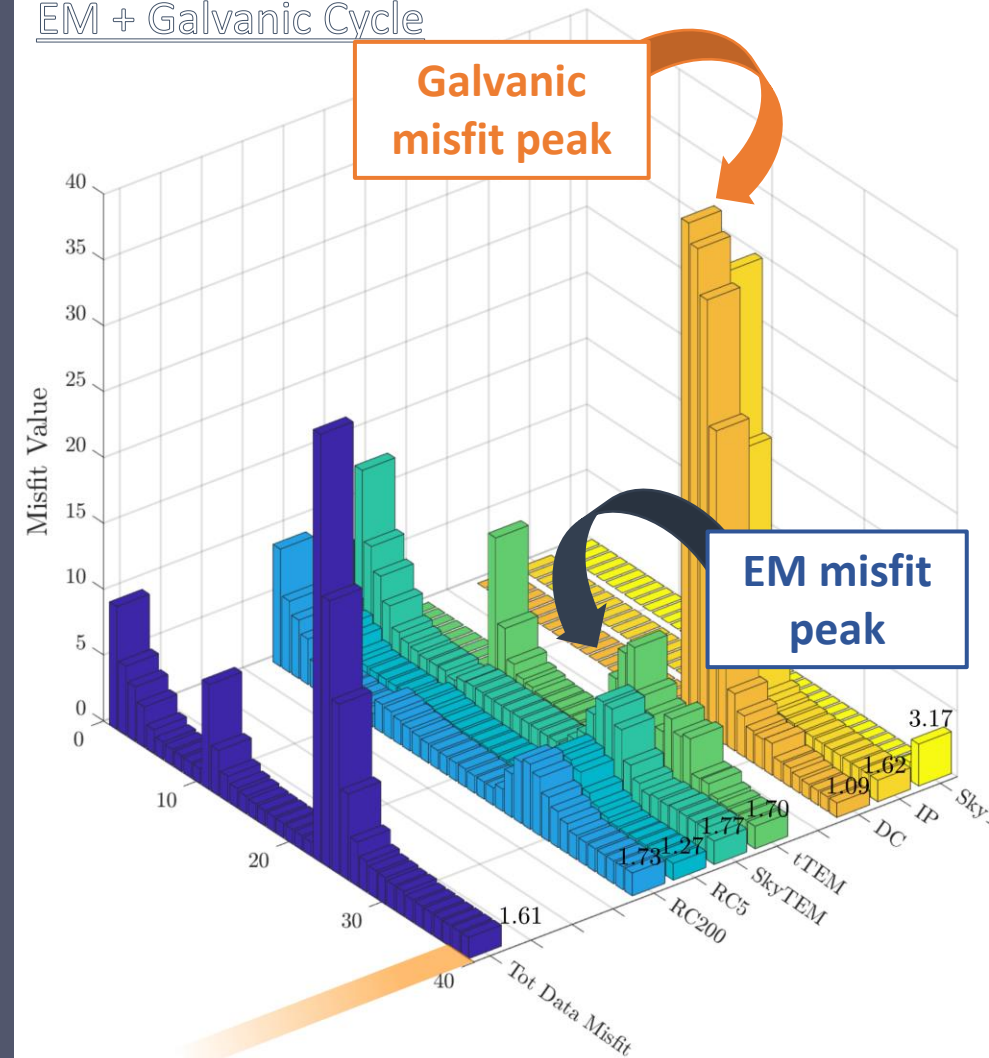


EEMverter Multi-cycle inversion scheme:

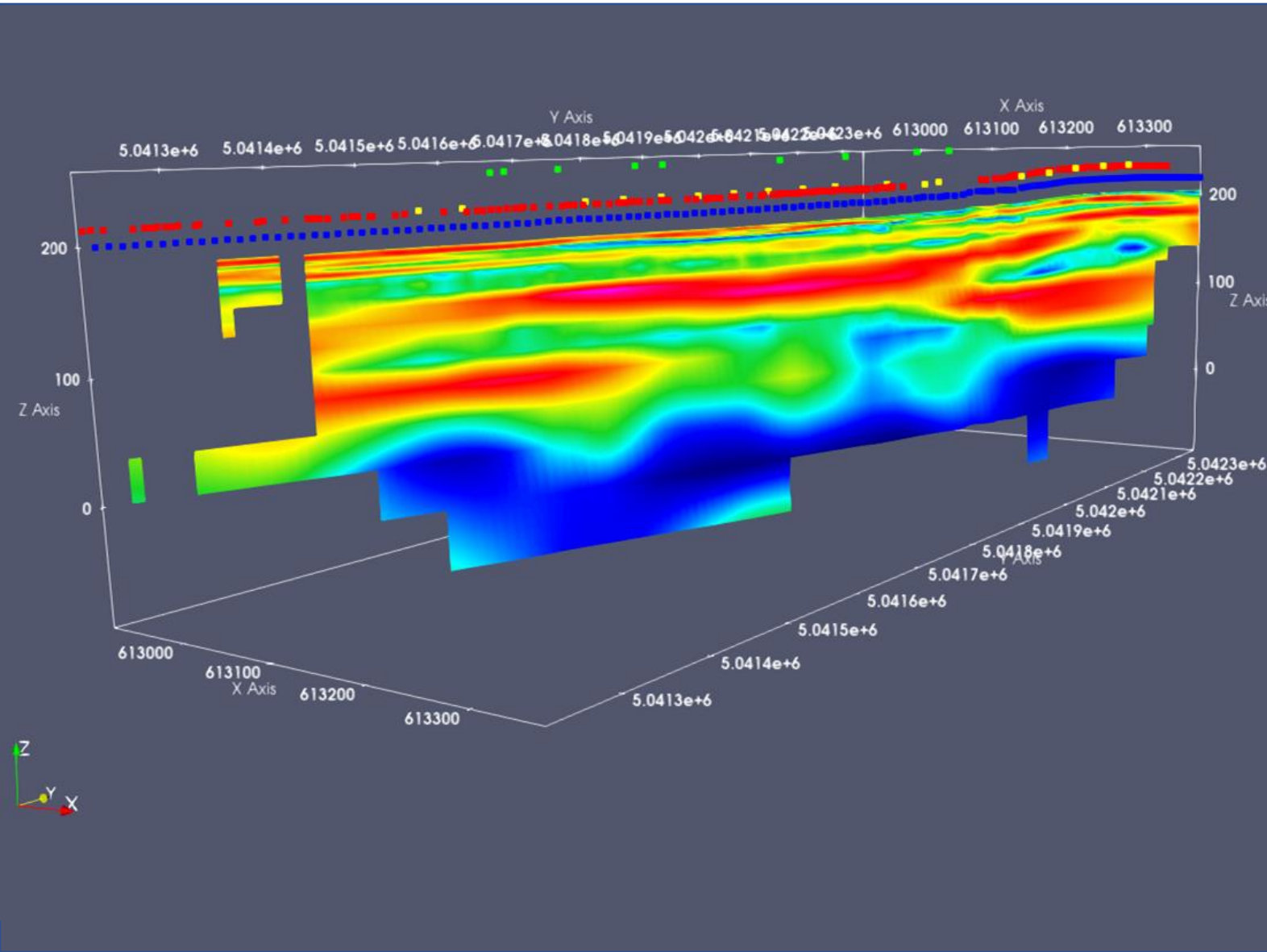
Quick look at how the inversion misfit converges seeking for the final model

Iteration 37:

EM + Galvanic Cycle

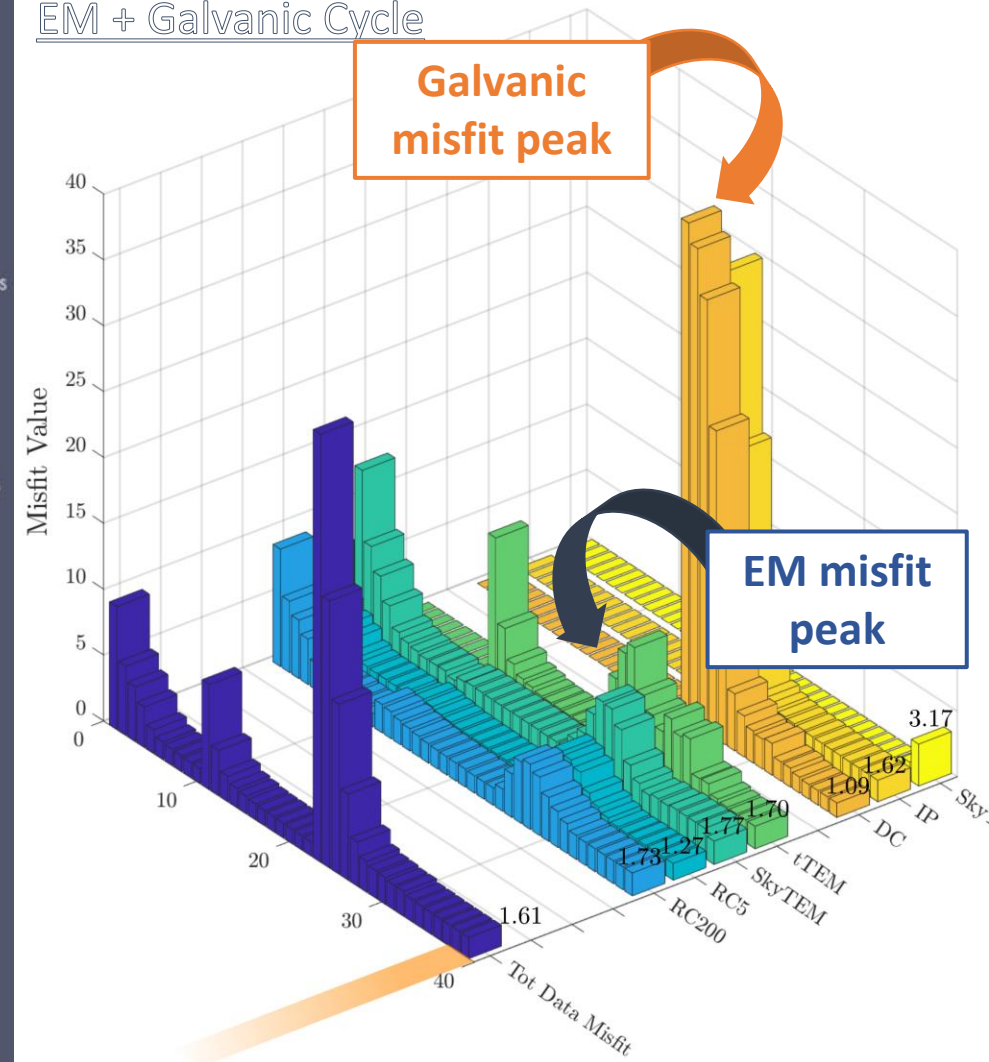


Data Modelling e inversione congiunta

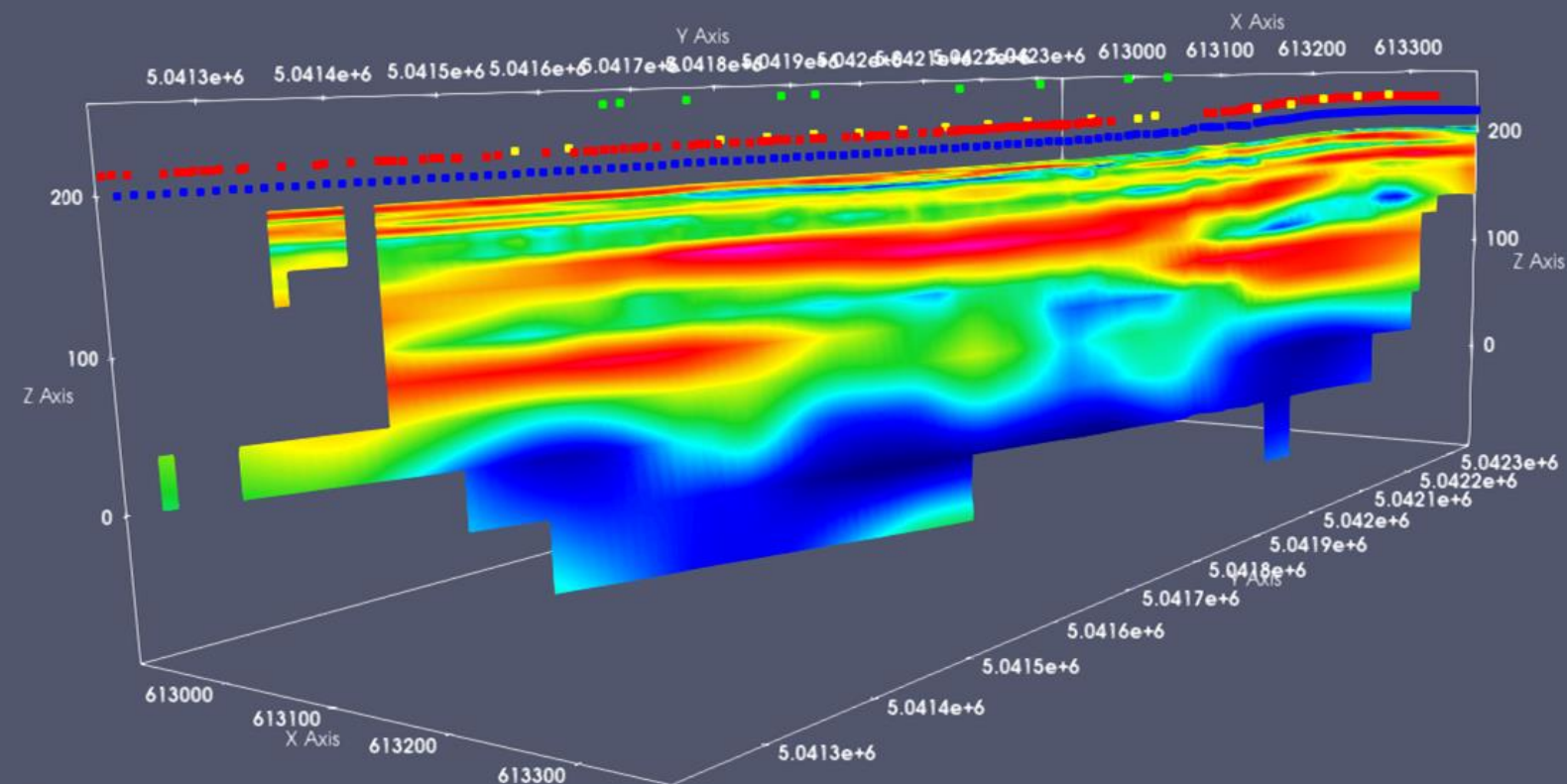


Iteration 37:

EM + Galvanic Cycle

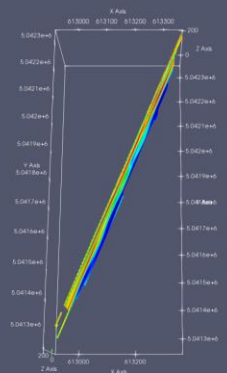


Data Modelling e inversione congiunta

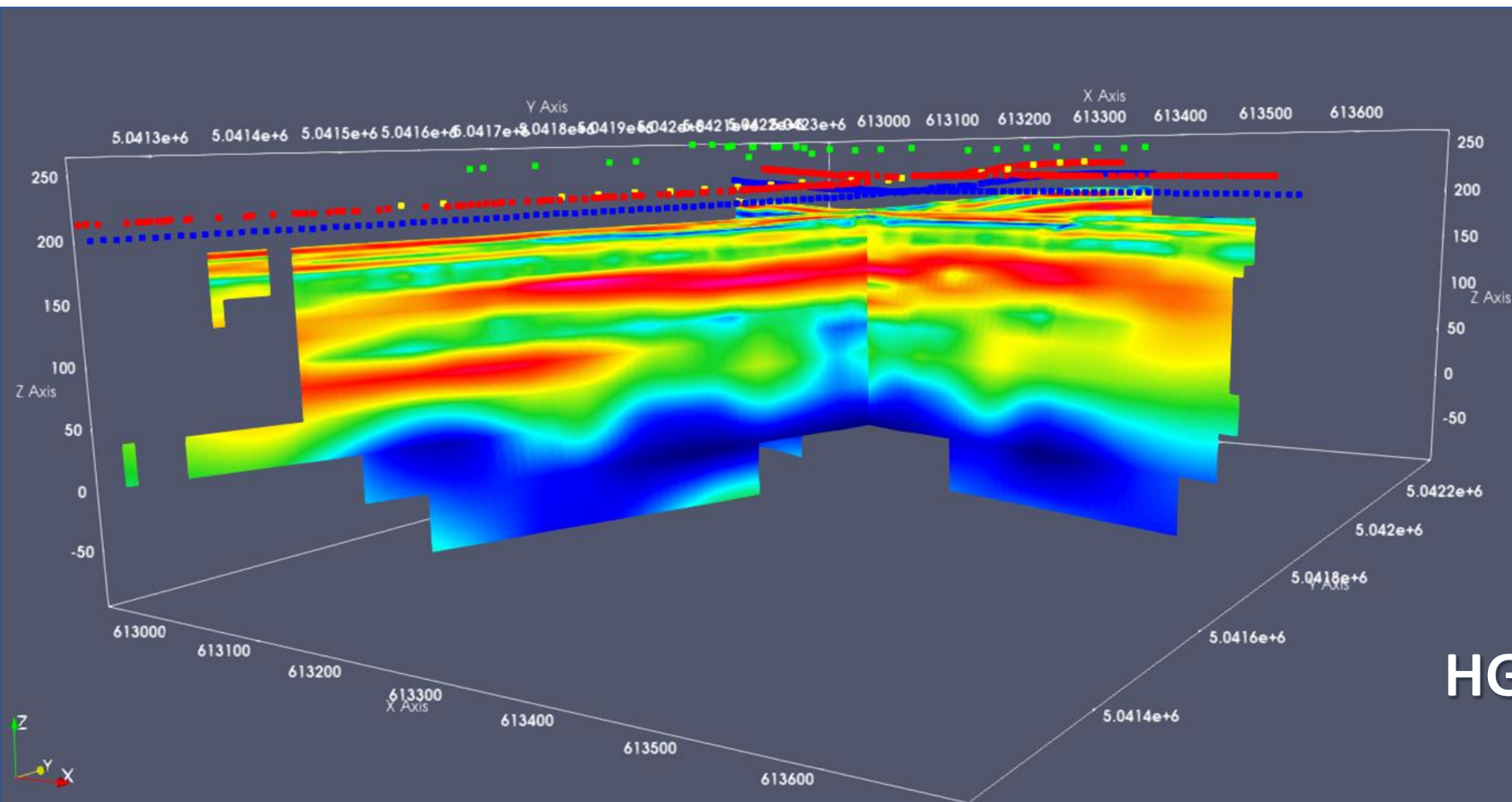


DataMisfit Joint Inversions	
	HGS01
Ground TEM (RC5 – RC200)	1.72 - 2.42
DC	1,46
IP	1,59
tTEM	1.83
SkyTEM	1.69

HGS_01

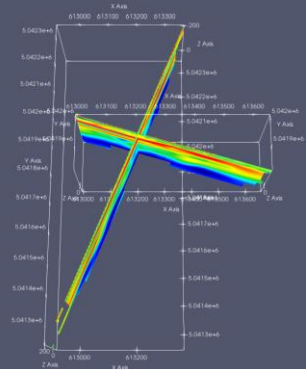


Data Modelling e inversione congiunta

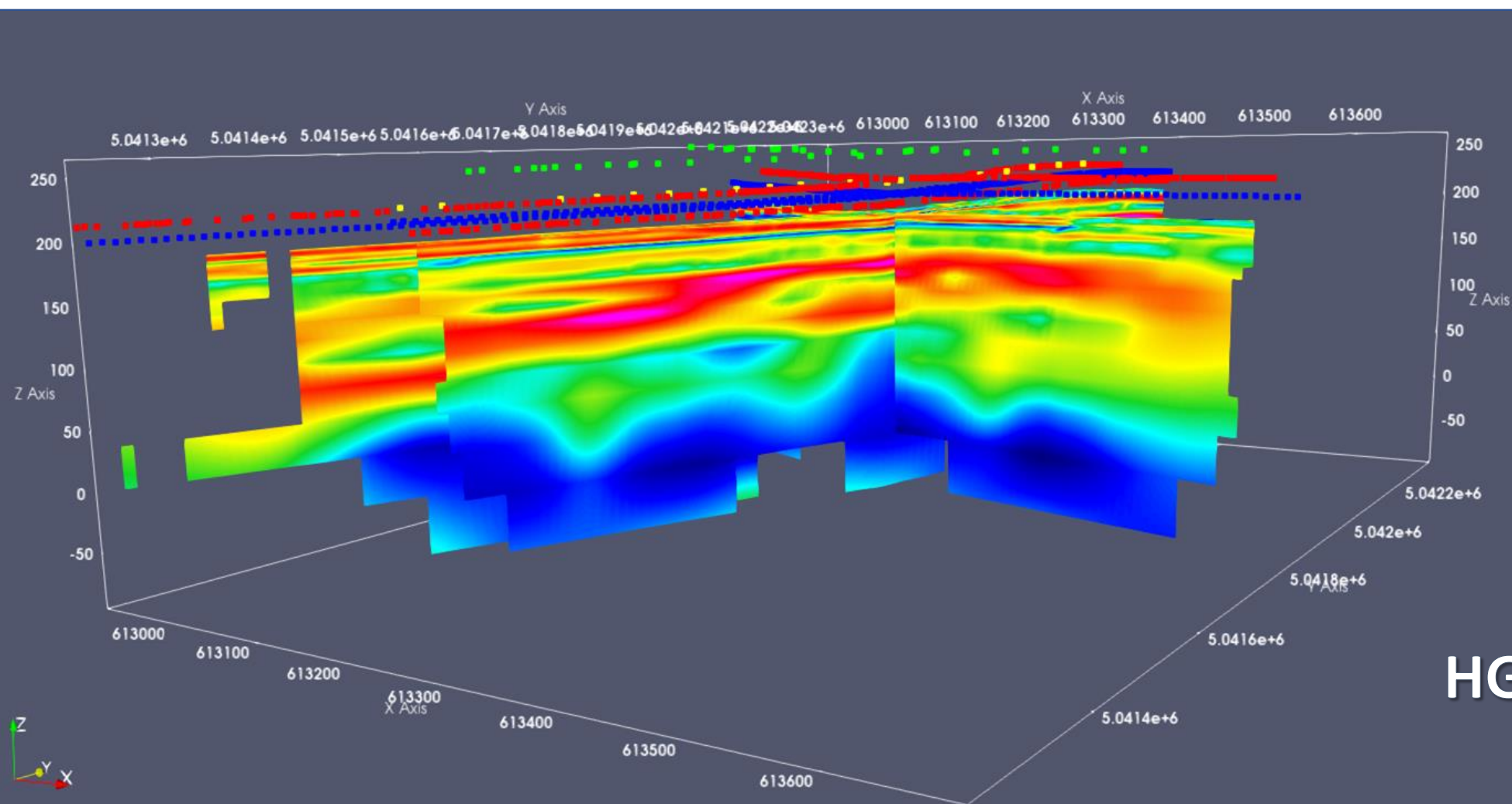


DataMisfit Joint Inversions	
	HGS02
Ground TEM (RC5 – RC200)	1.91 - 2.49
DC	2.63
IP	1.27
tTEM	1.95
SkyTEM	1.91

HGS_02



Data Modelling e inversione congiunta



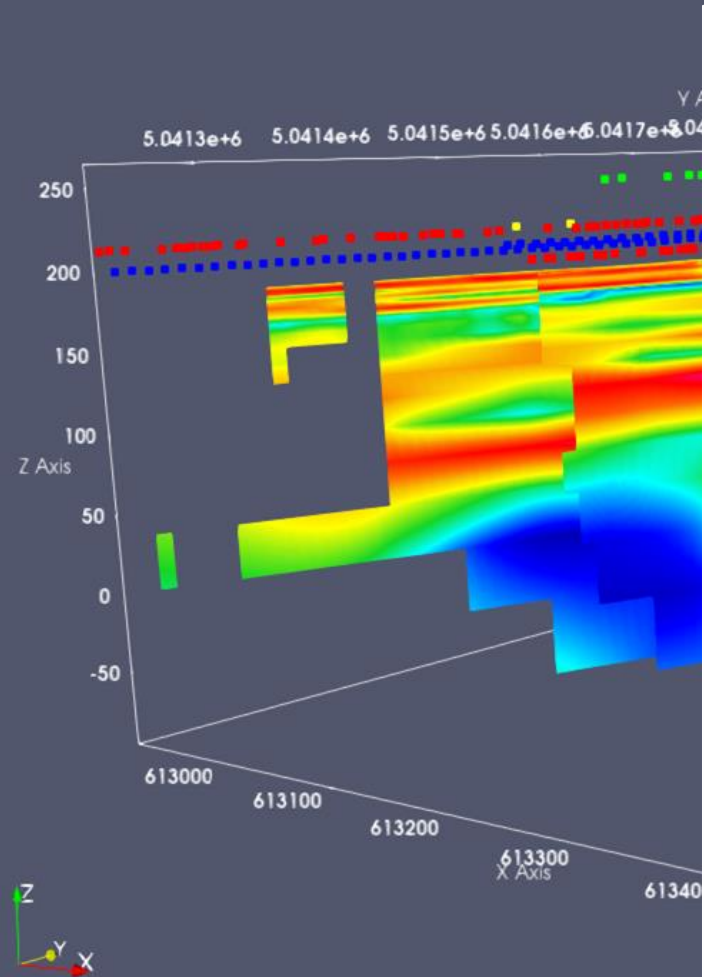
DataMisfit Joint Inversions	
	HGS03
Ground TEM (RC5 – RC200)	1.88 - 2.74
DC	1.96
IP	1.47
tTEM	2.14
SkyTEM	1.80

HGS_03

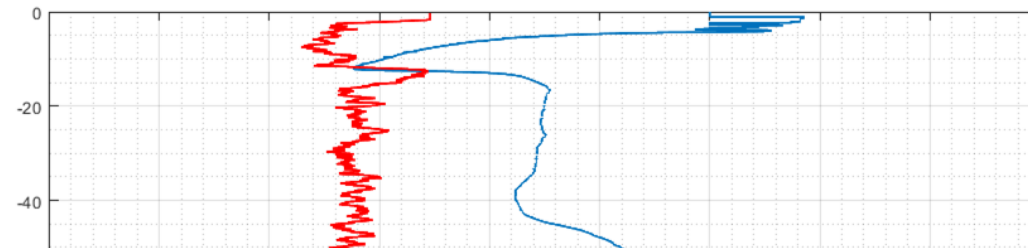
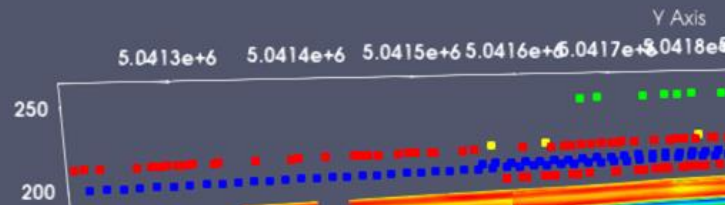


Ma tutta questa struttura ha senso?

Data Modelling e inversione congiunta



Data Modelling e inversione congiunta



GAMMA log:
Per identificare
gli strati di
argilla
accuratamente

Resistivity log:

- Una misura più diretta
- Influenzata dal fluido di perforazione

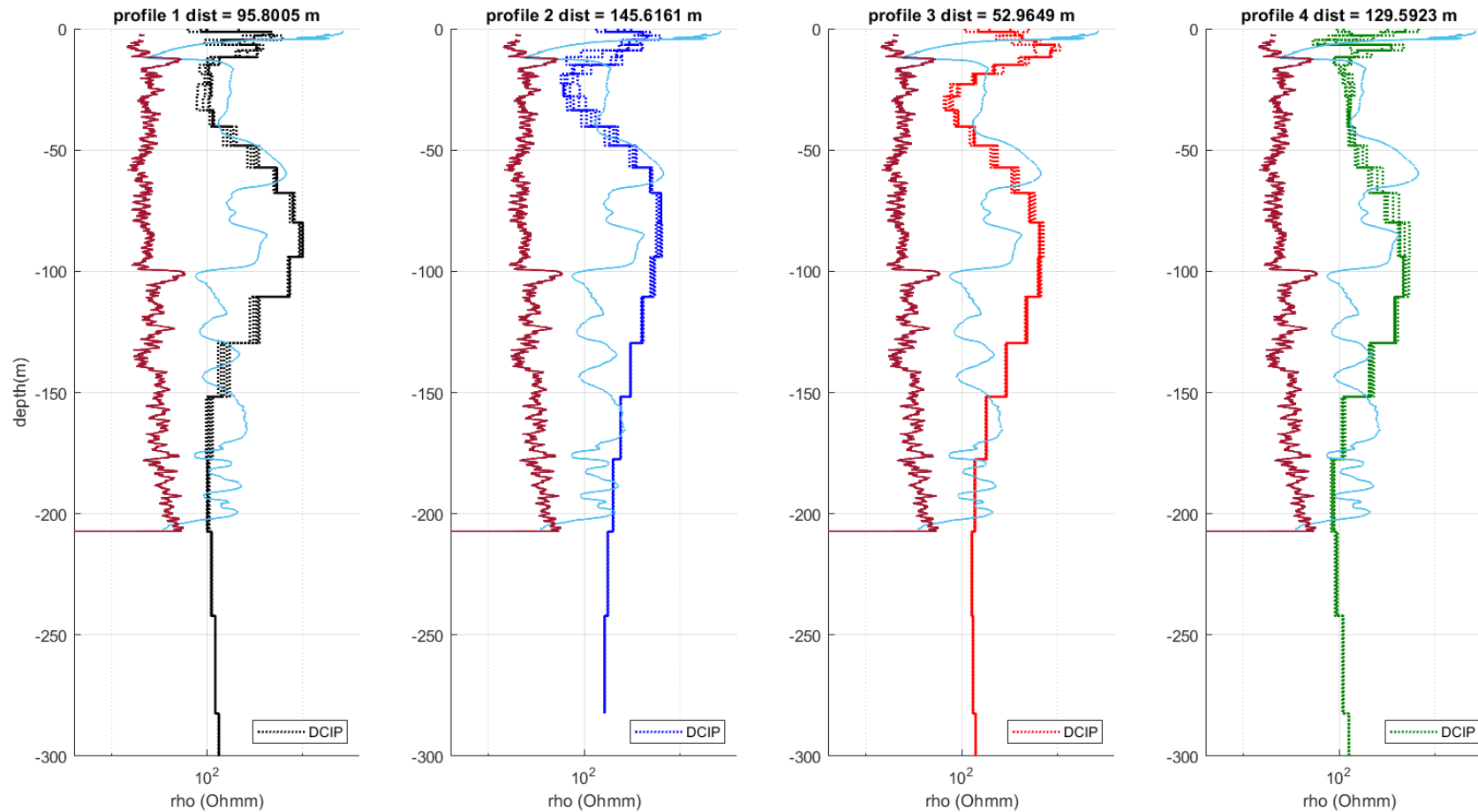


— BHL-EMlog [log10(Ohmm)]
— GAMMA [API]

log10(rho) [ohm.m]

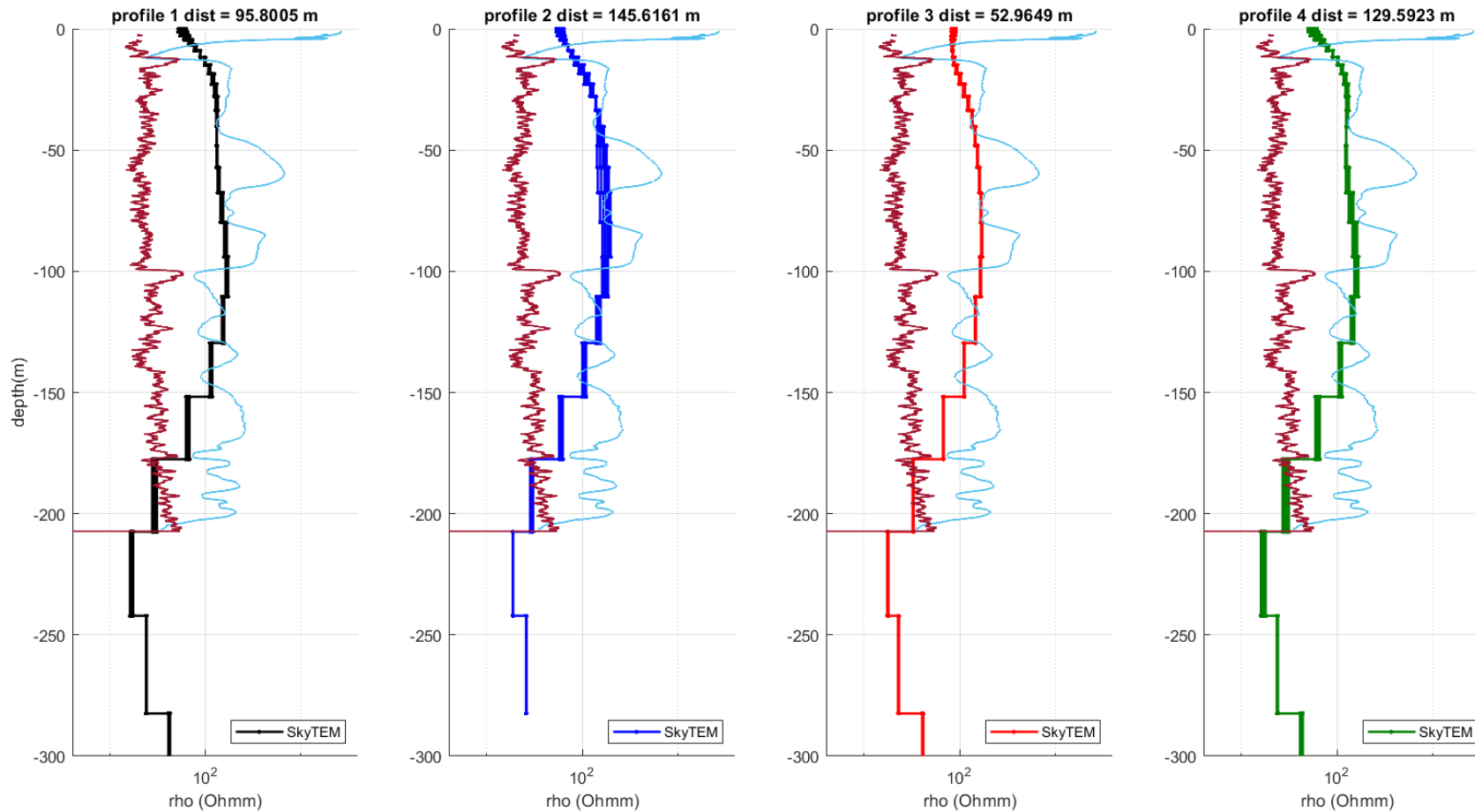
Data Modelling e inversione congiunta

- Comparazione con i modelli galvanici



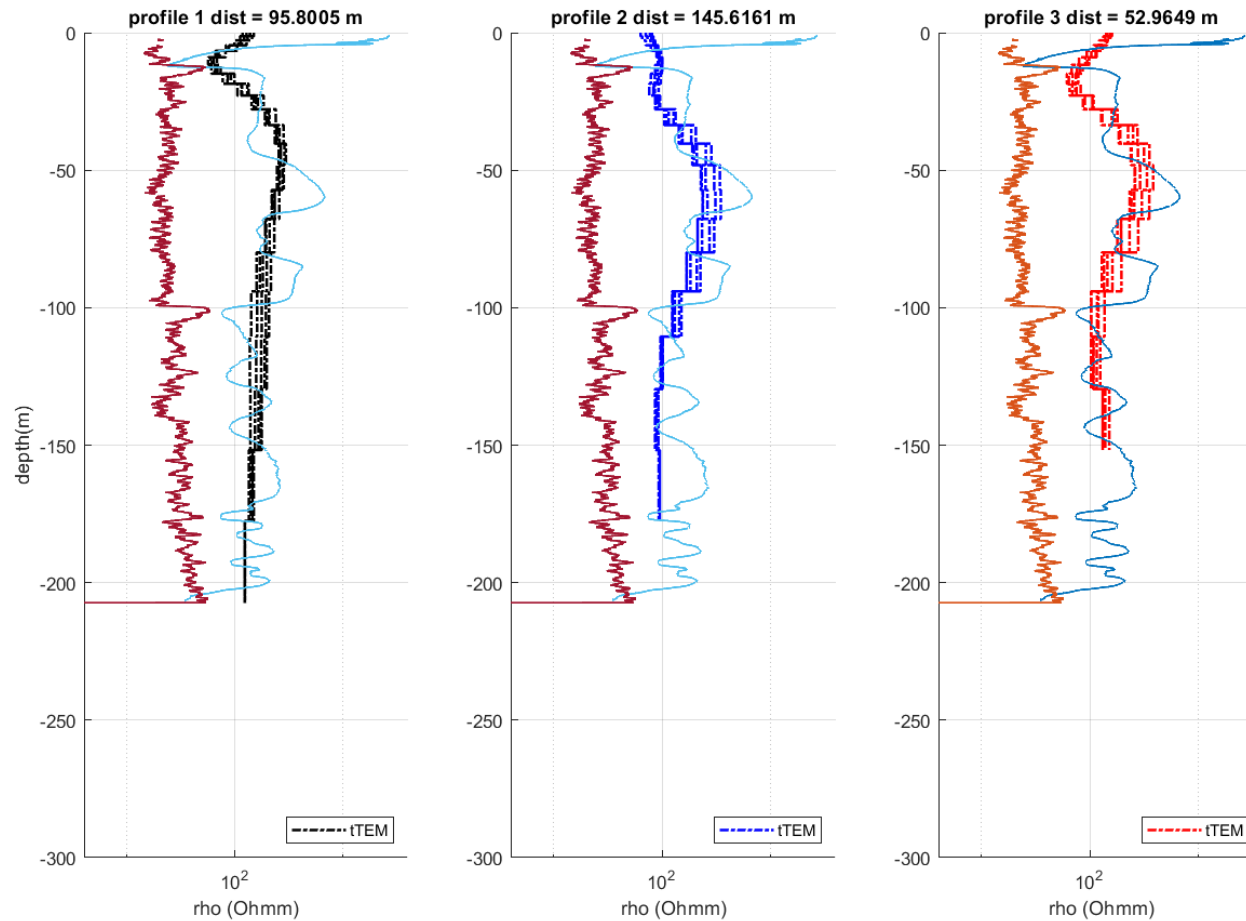
Data Modelling e inversione congiunta

- Comparazione con i modelli AEM



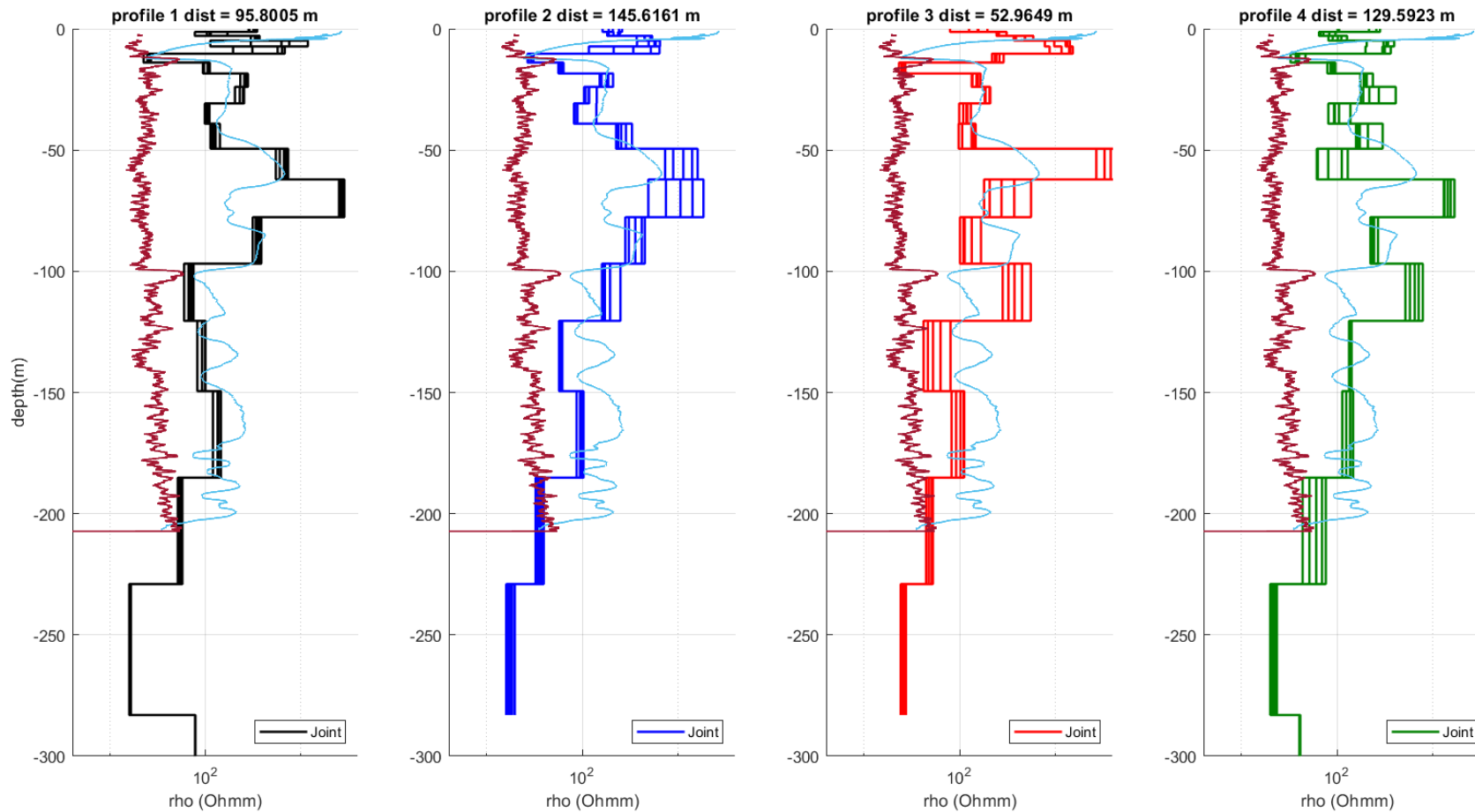
Data Modelling e inversione congiunta

- Comparazione con i modelli tTEM

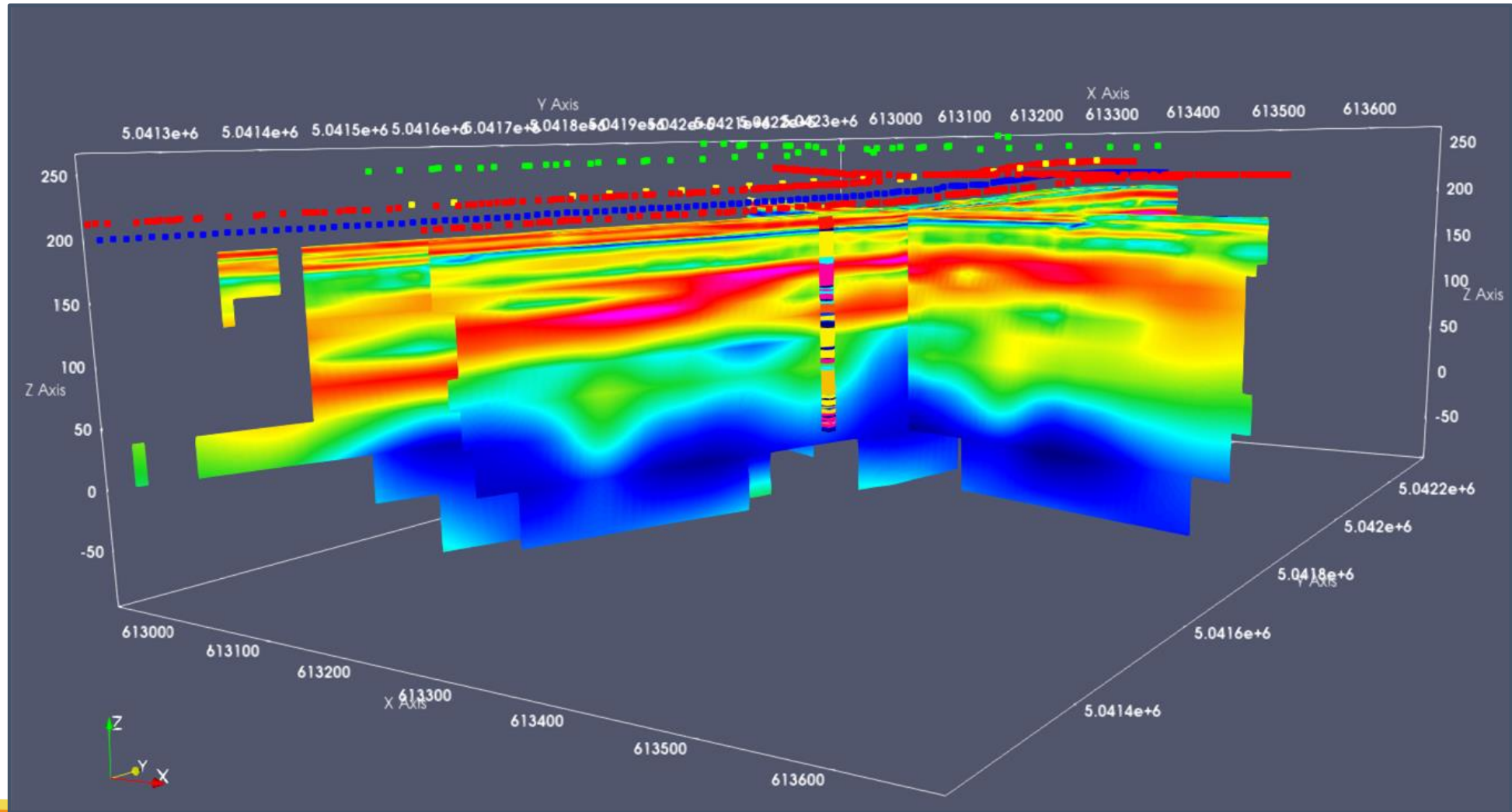


Data Modelling e inversione congiunta

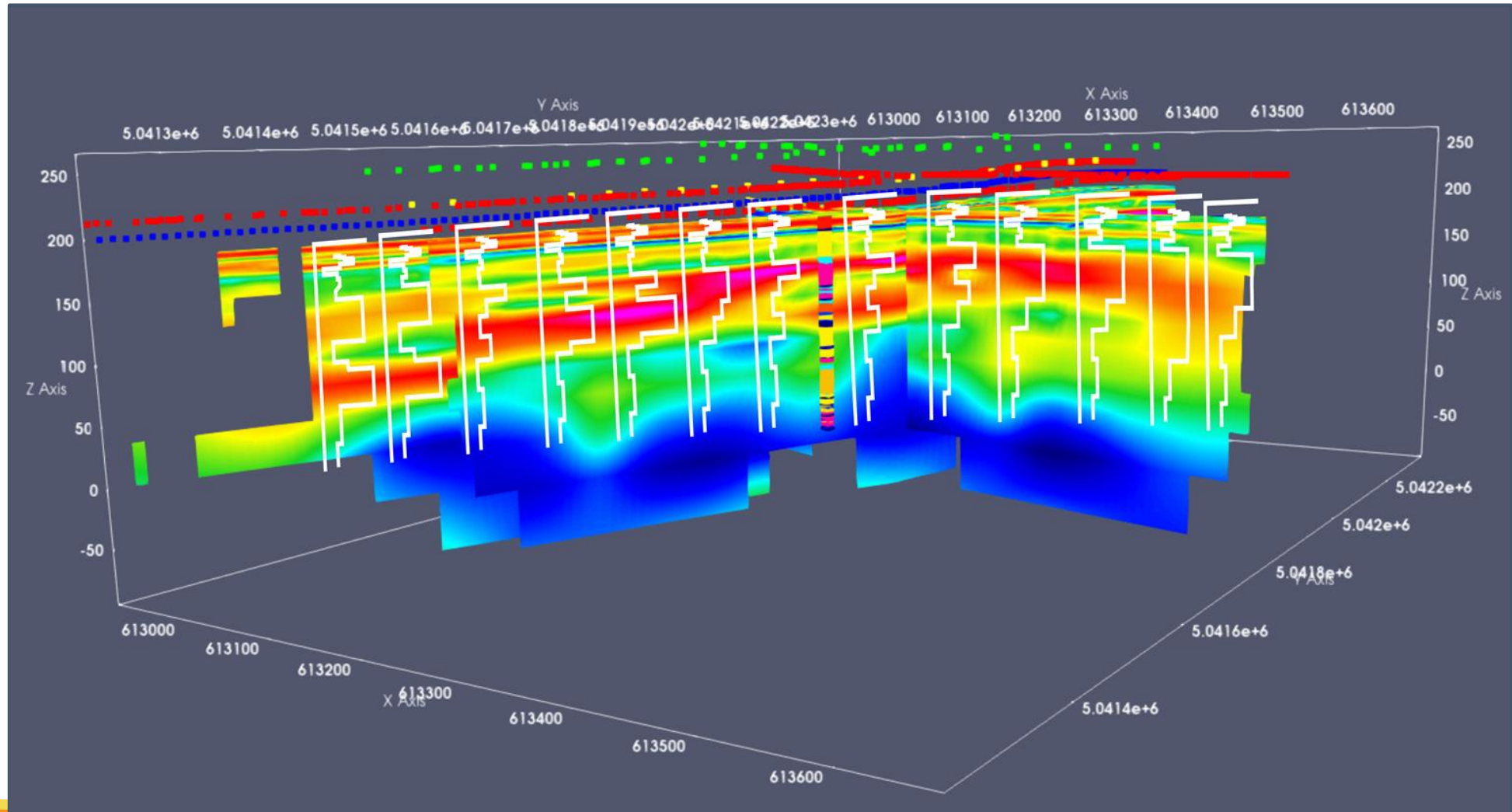
- Comparazione con i modelli congiunti



Data Modelling e inversione congiunta



Data Modelling e inversione congiunta



MapPO, AEM & waterborne/ground EM

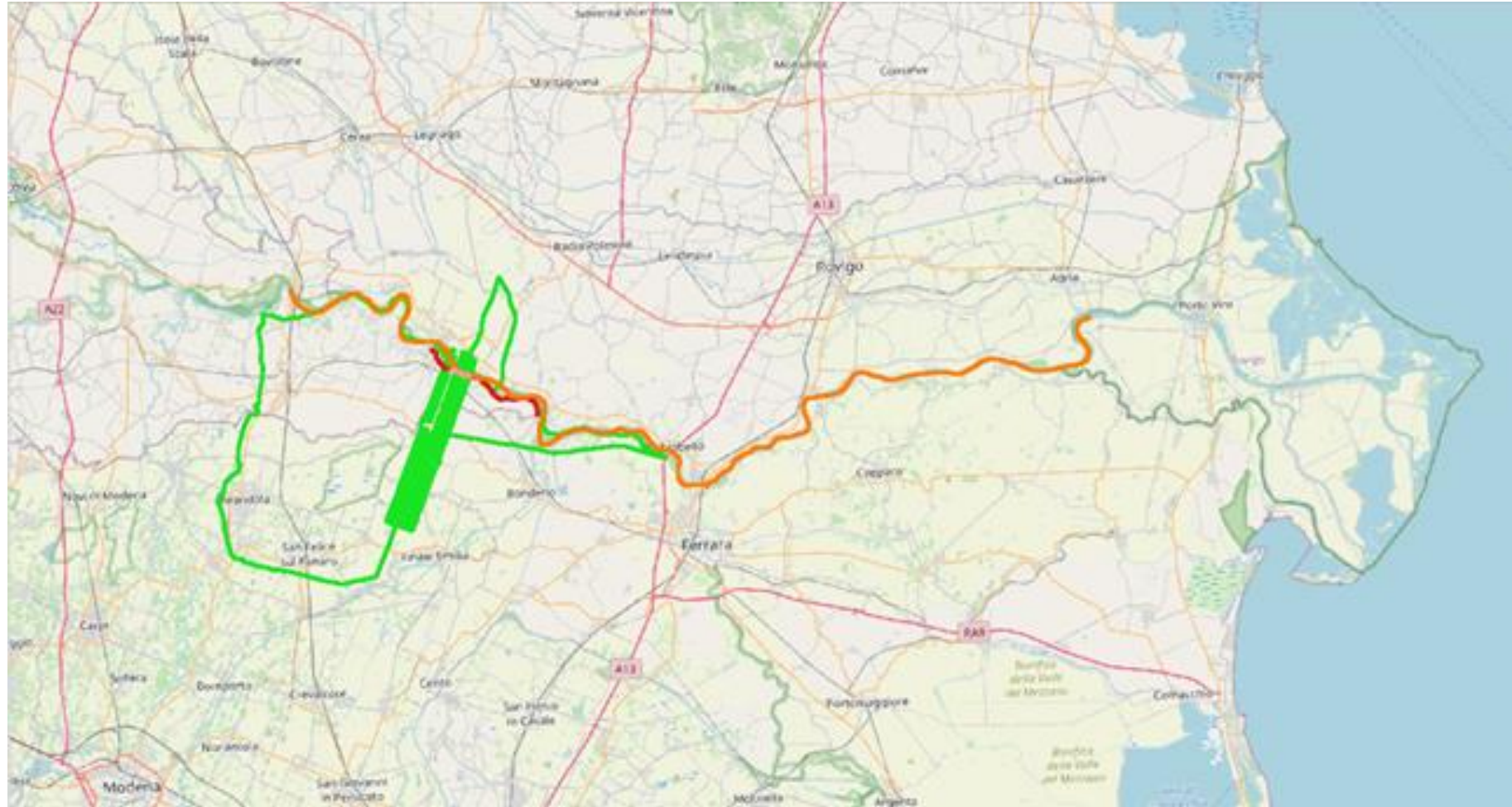
Fine misure 2023 a Brescia: what's next?

Dove fare un progetto dimostrativo per innescare nuove campagne di misura?



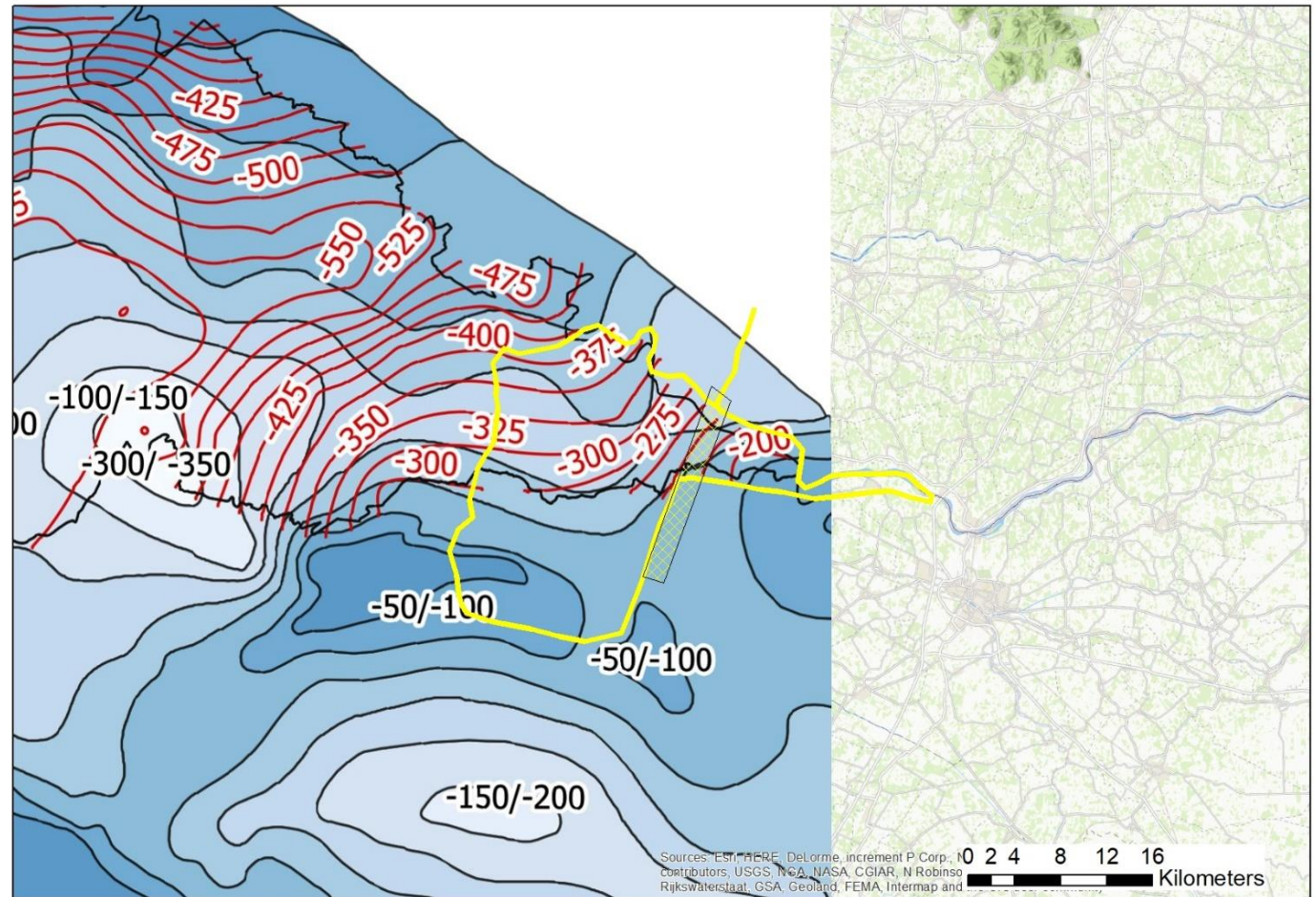
UNIVERSITÀ DEGLI STUDI
DI MILANO
DIPARTIMENTO DI SCIENZE
DELLA TERRA "ARDITO DESIO"

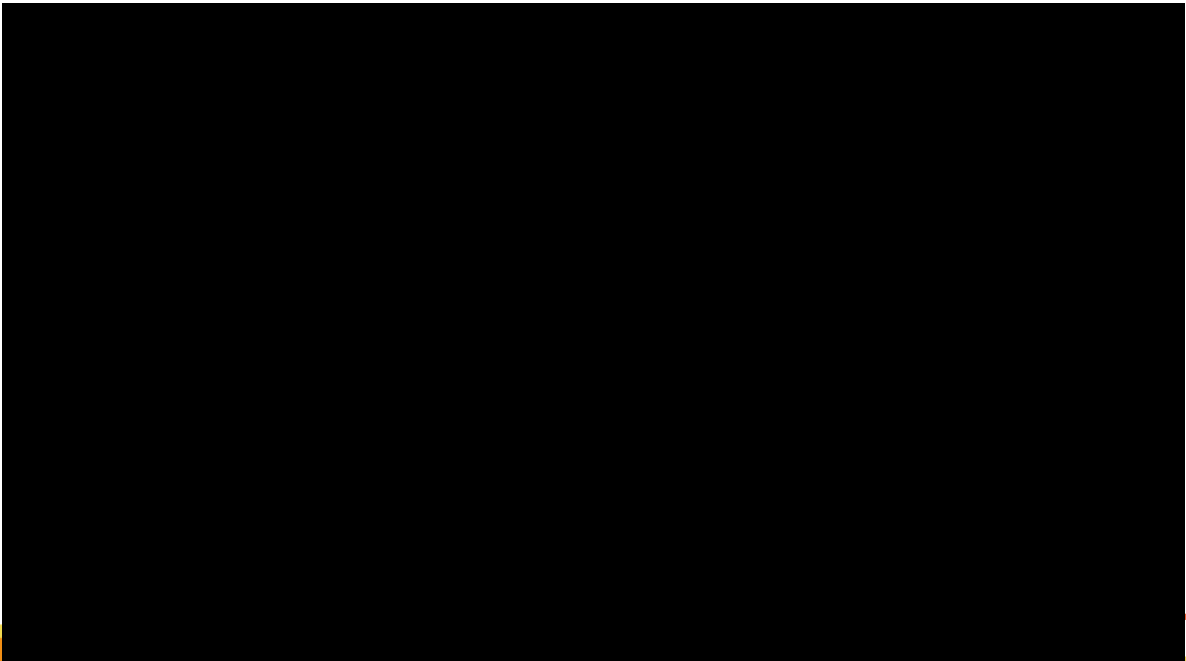
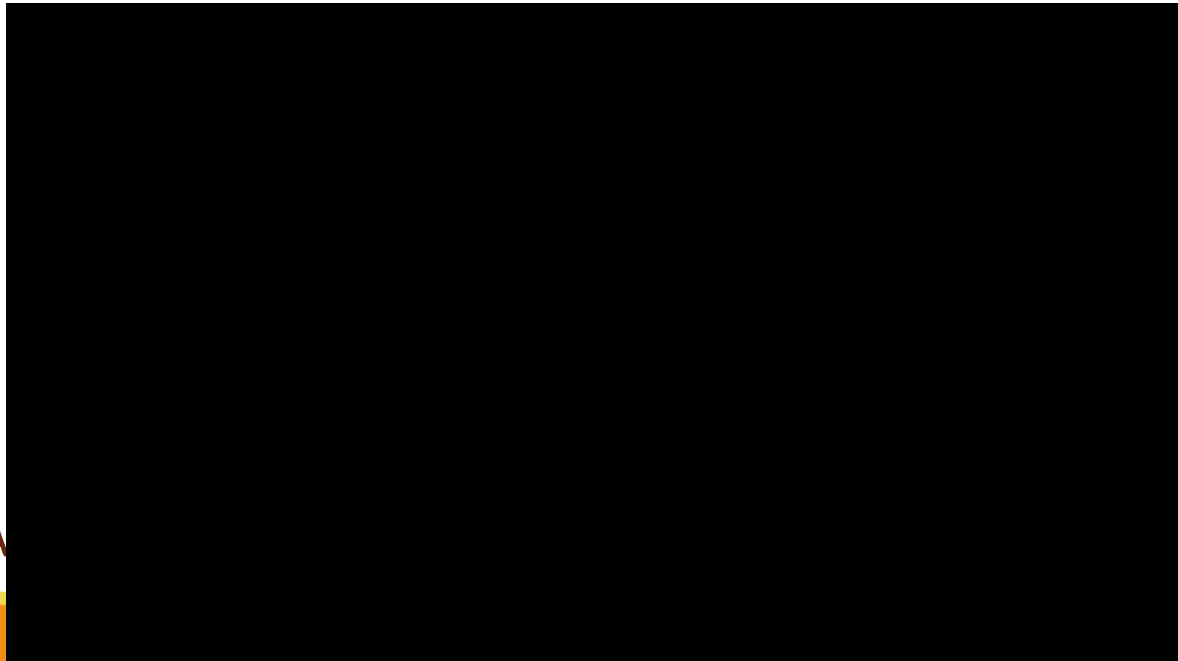
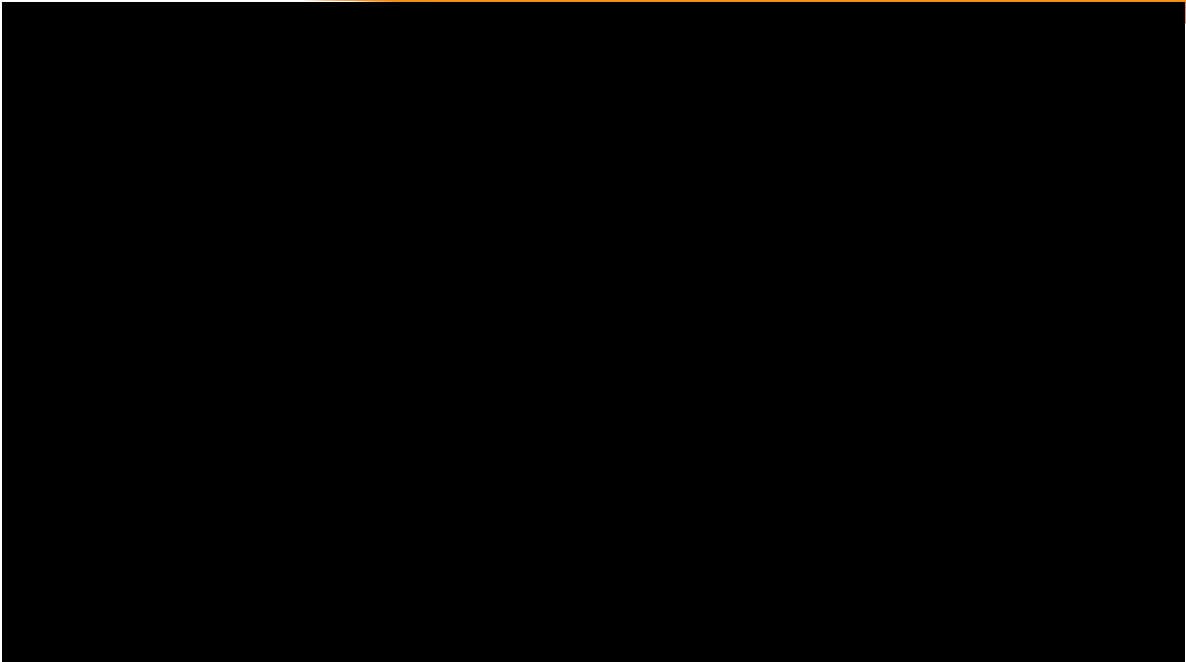
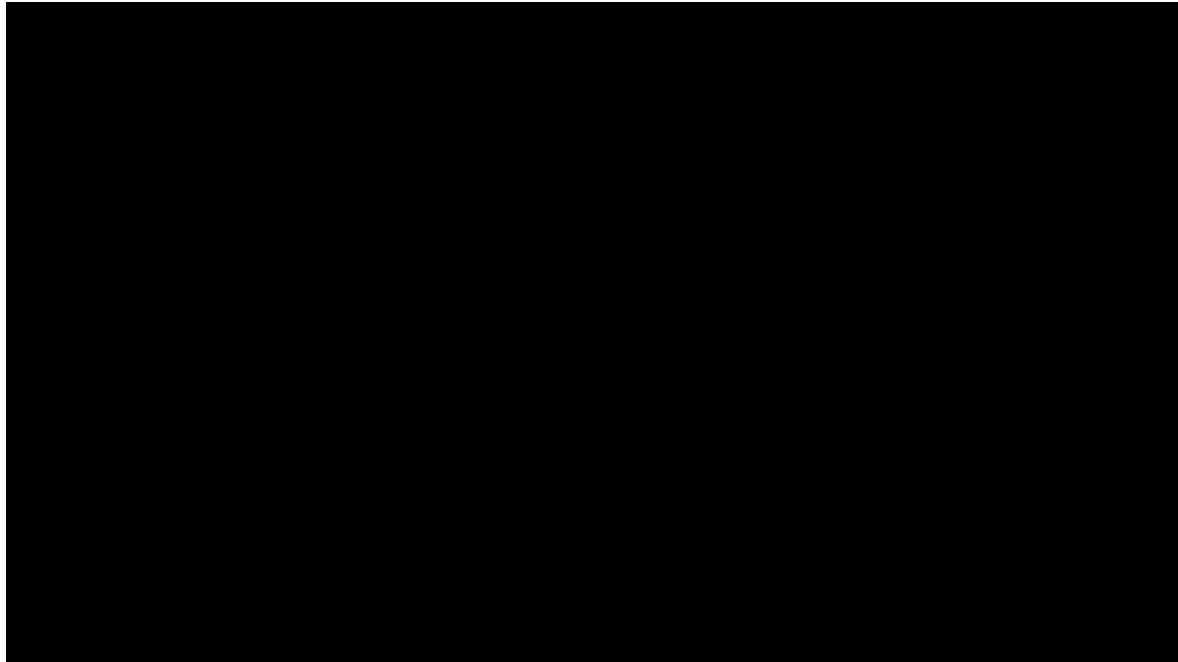
MapPO, AEM & waterborne/ground EM



Esplorare il sottosuolo volando.

MapPO, AEM & waterborne/ground EM





Schedule

- **24 Luglio 2023**
 - Mattina: 28 km FloaTEM



Schedule

- **24 Luglio 2023**
 - Mattina: 28 km FloaTEM + 175 km SkyTEM
 - Pomeriggio: 20 km tTEM + 175 km SkyTEM



colorare il sottosuolo volando.

Schedule

- **24 Luglio 2023**

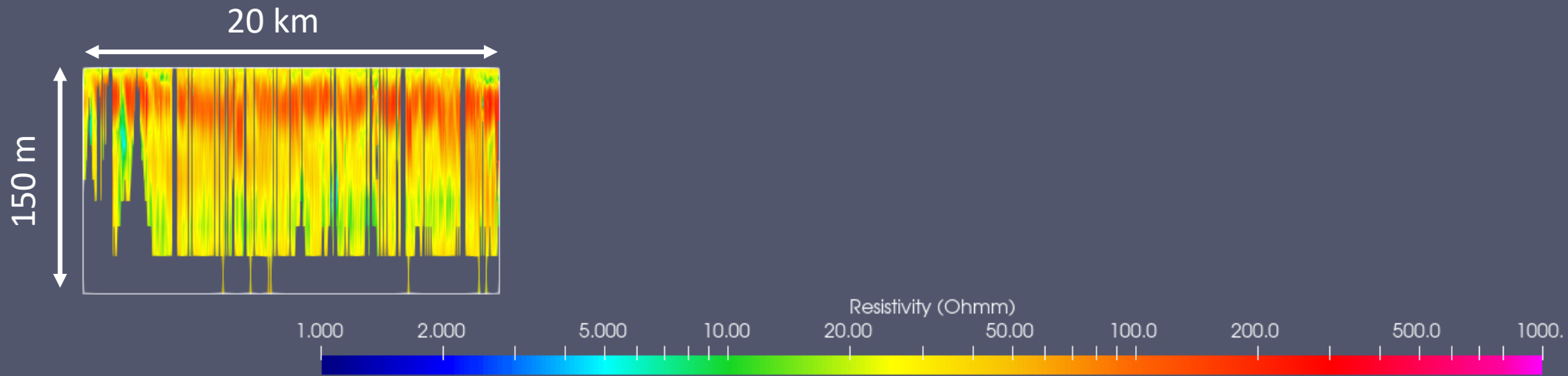
- Mattina: 28 km FloaTEM + 175 km SkyTEM
- Pomeriggio: 20 km

- **25 Luglio 2023**

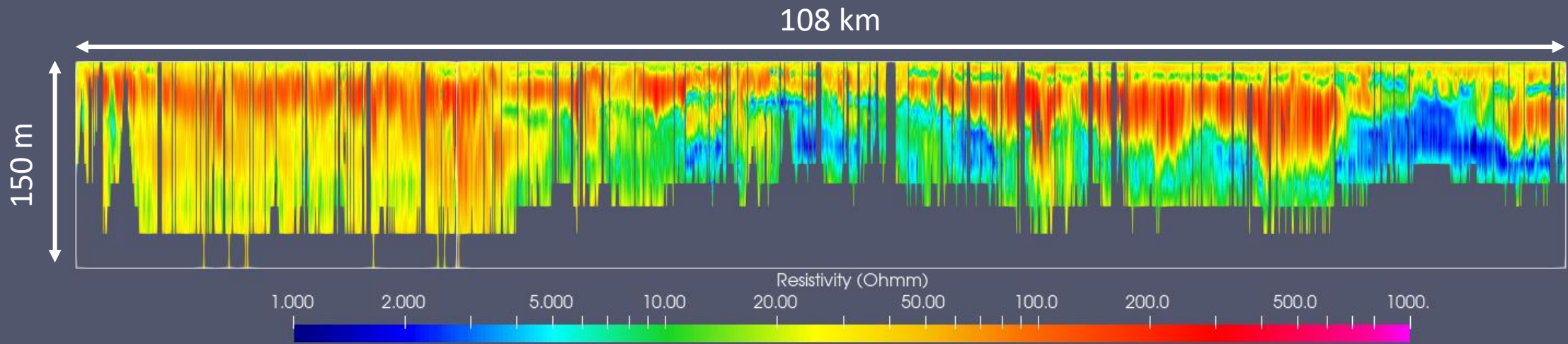
- 1.9 km DCIP
- 80 km FloaTEM



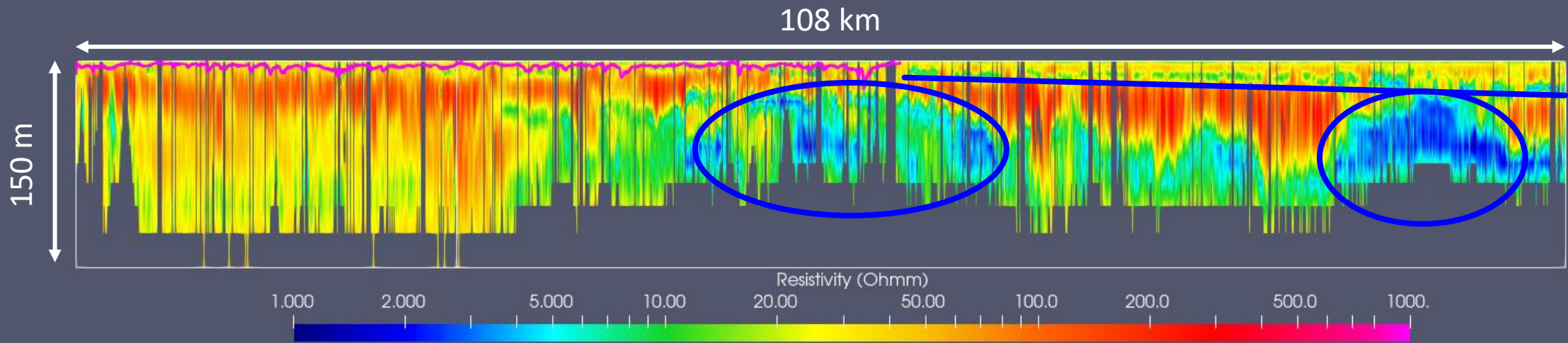
FloaTEM



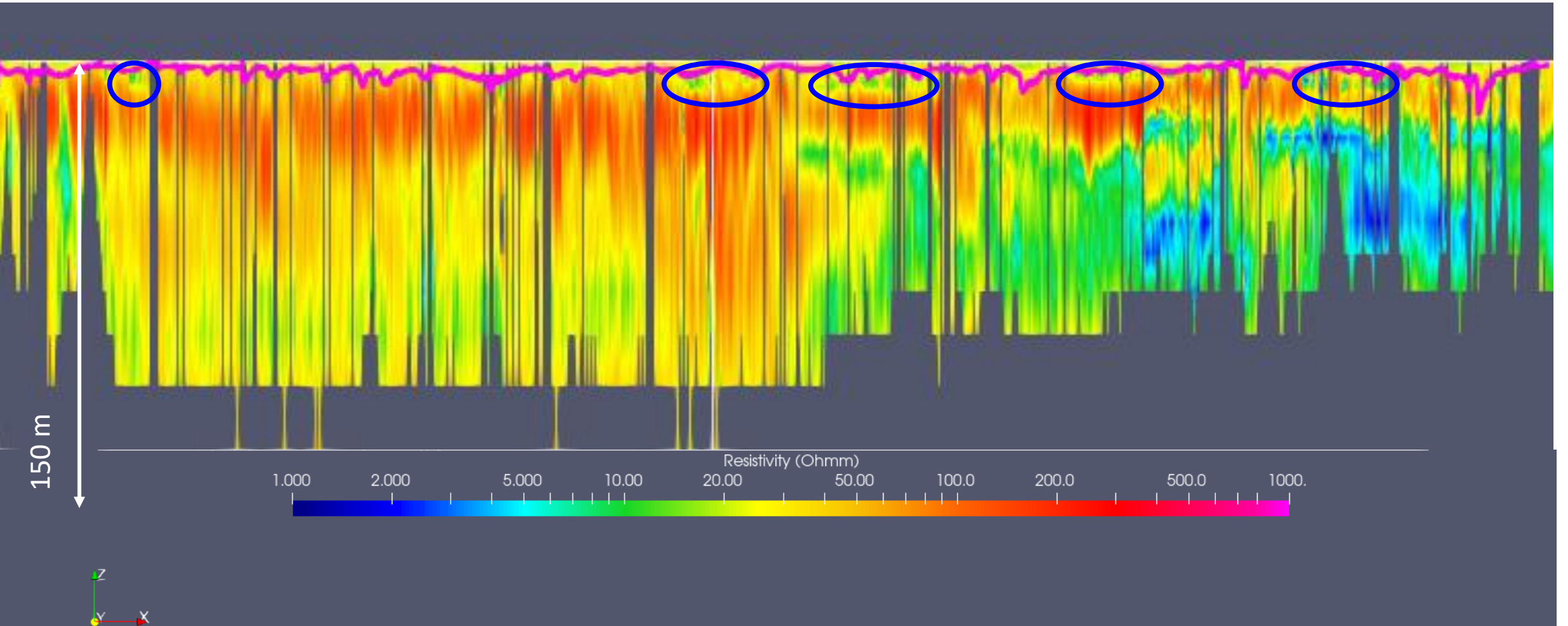
FloaTEM



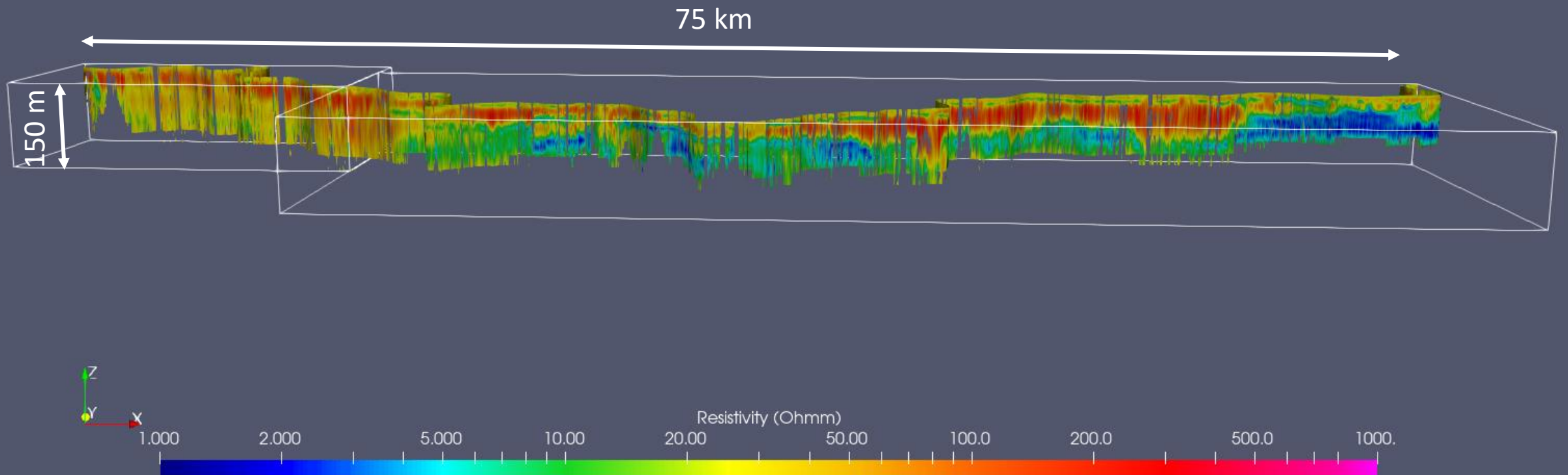
FloaTEM



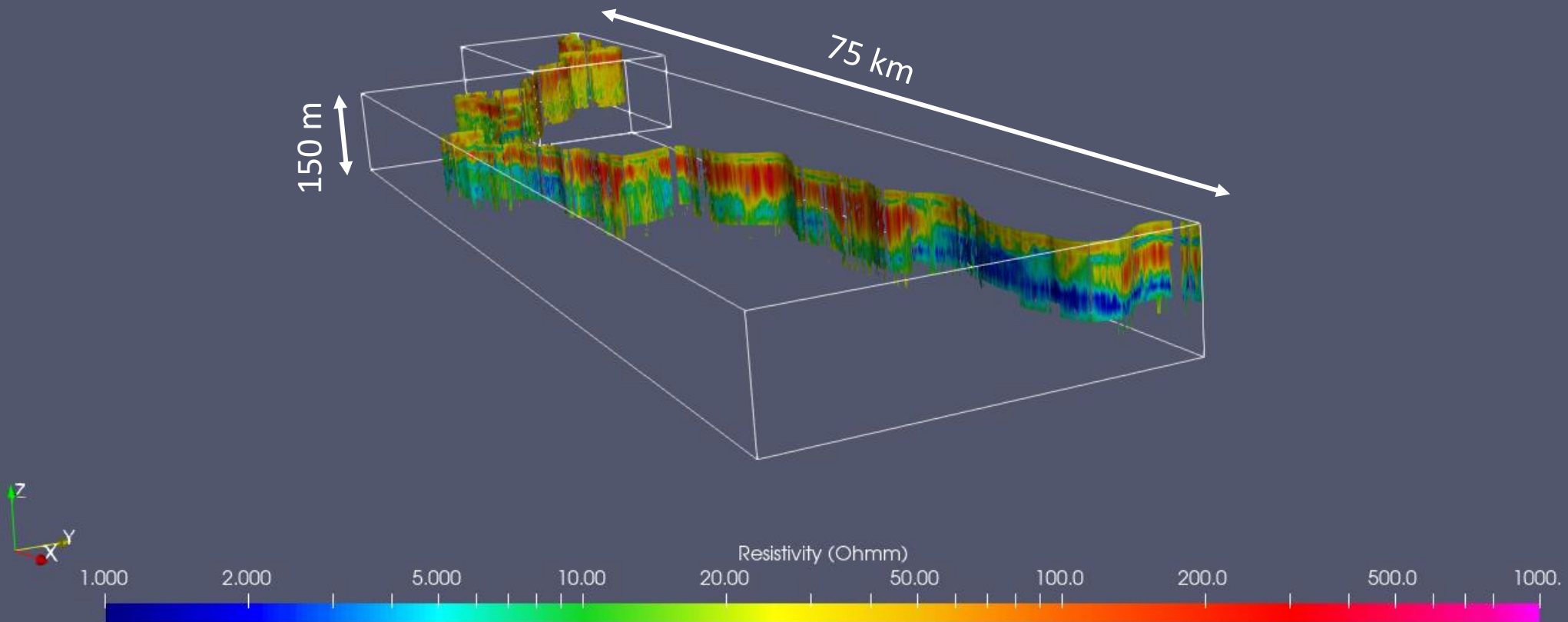
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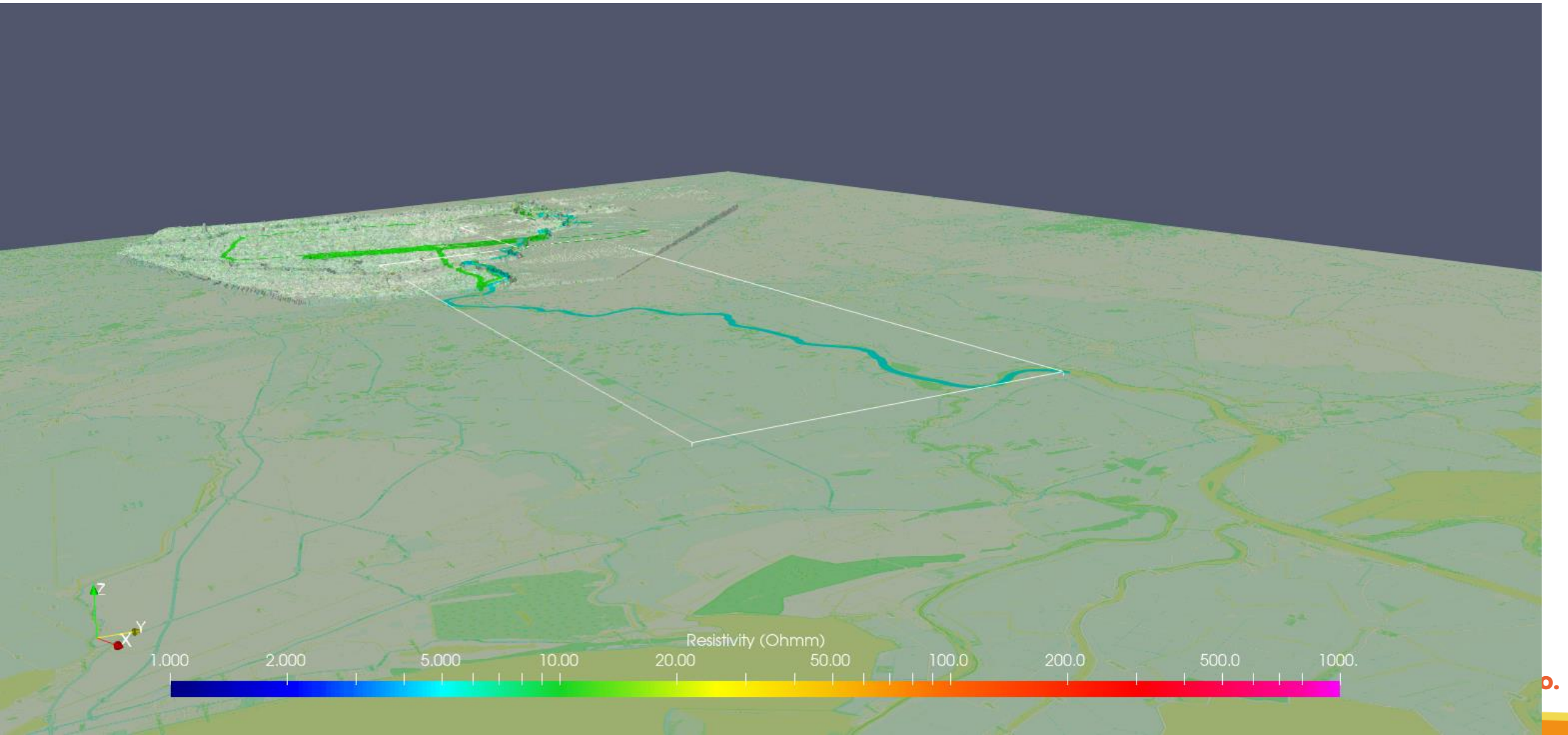
FloaTEM



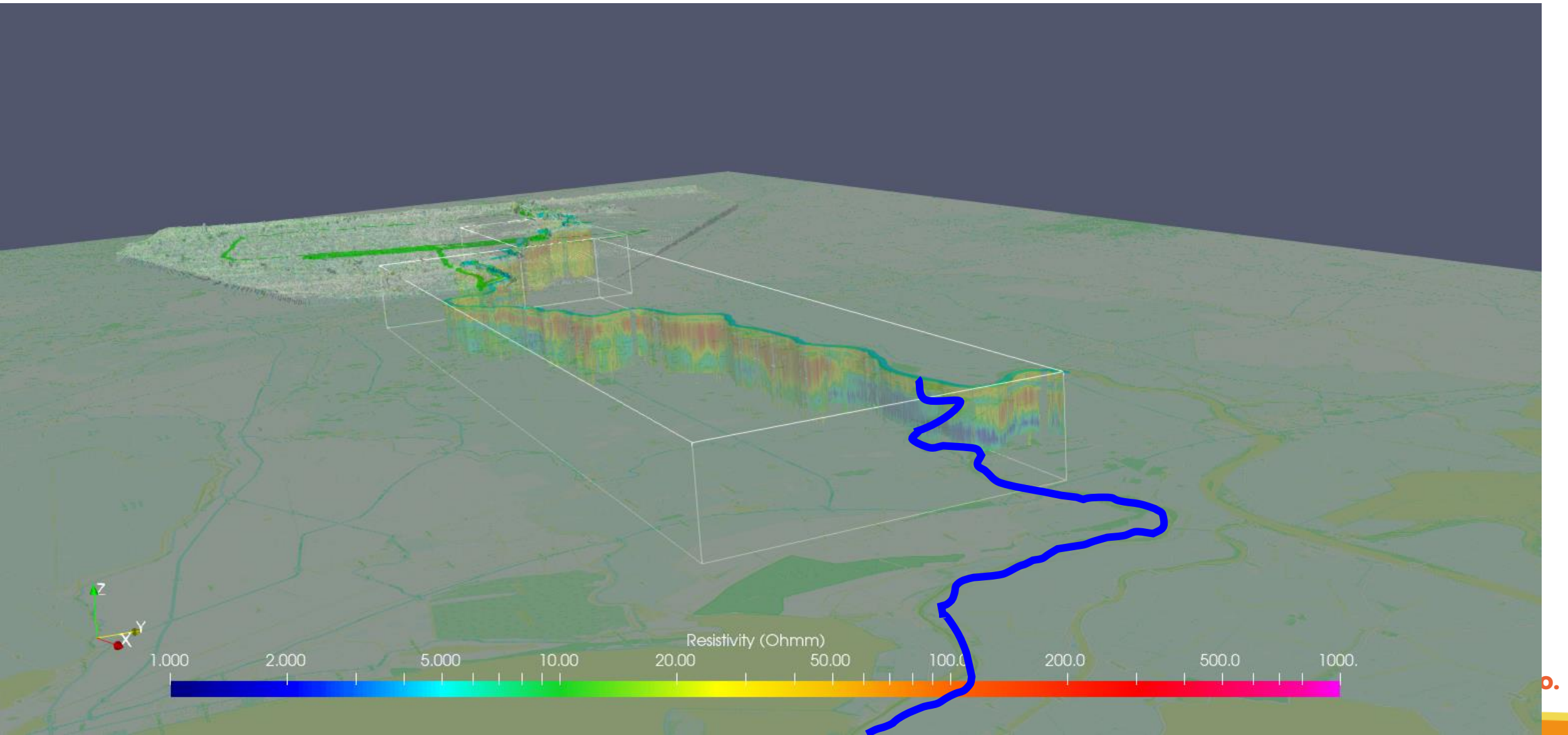
FloaTEM



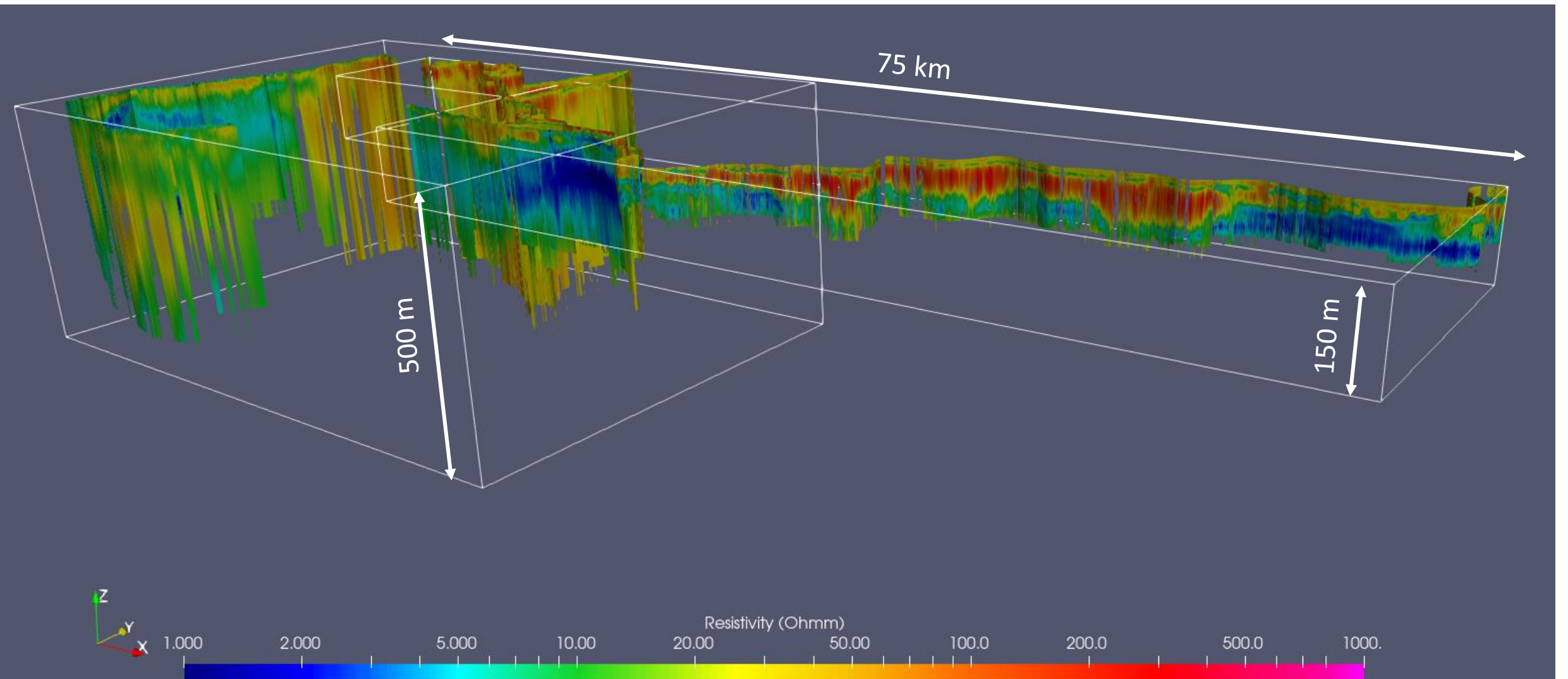
FloaTEM



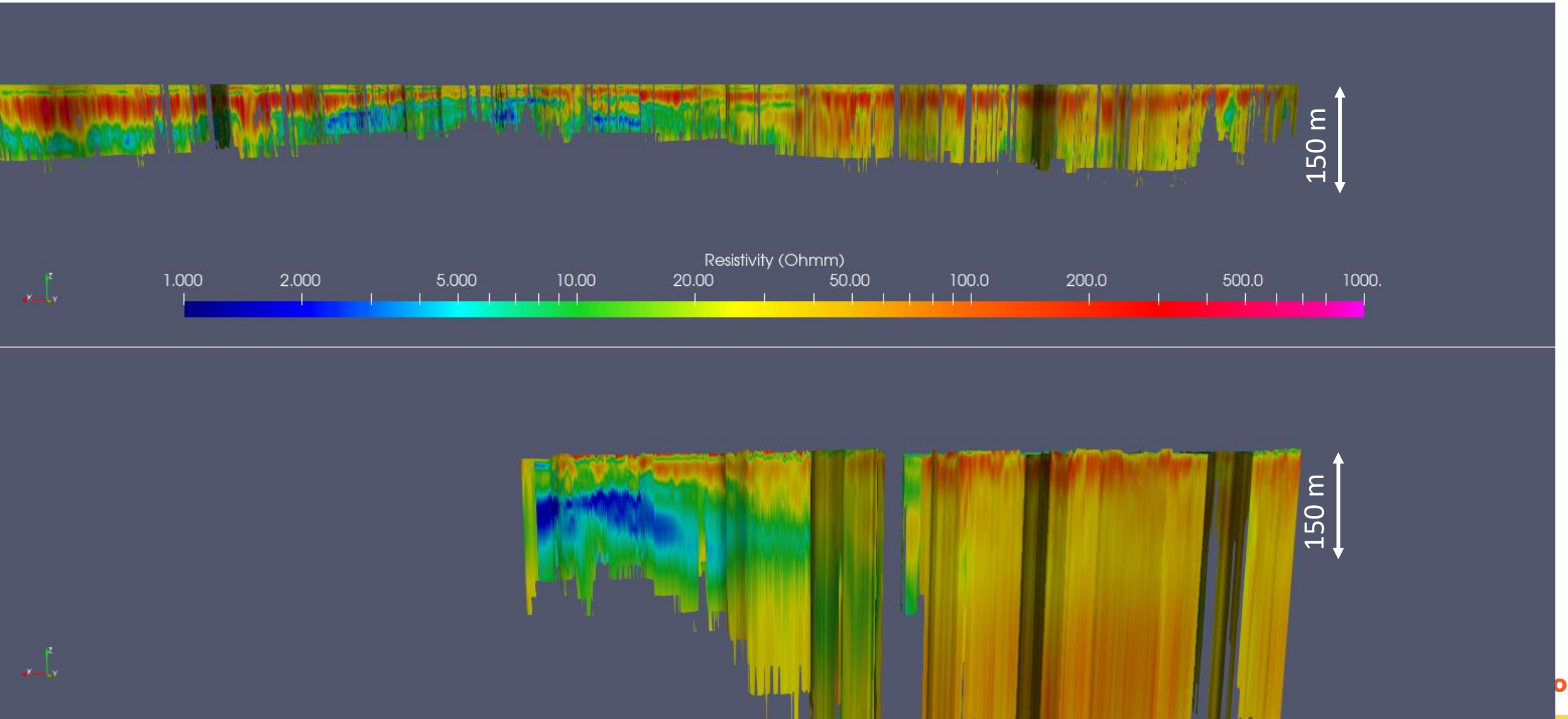
FloaTEM



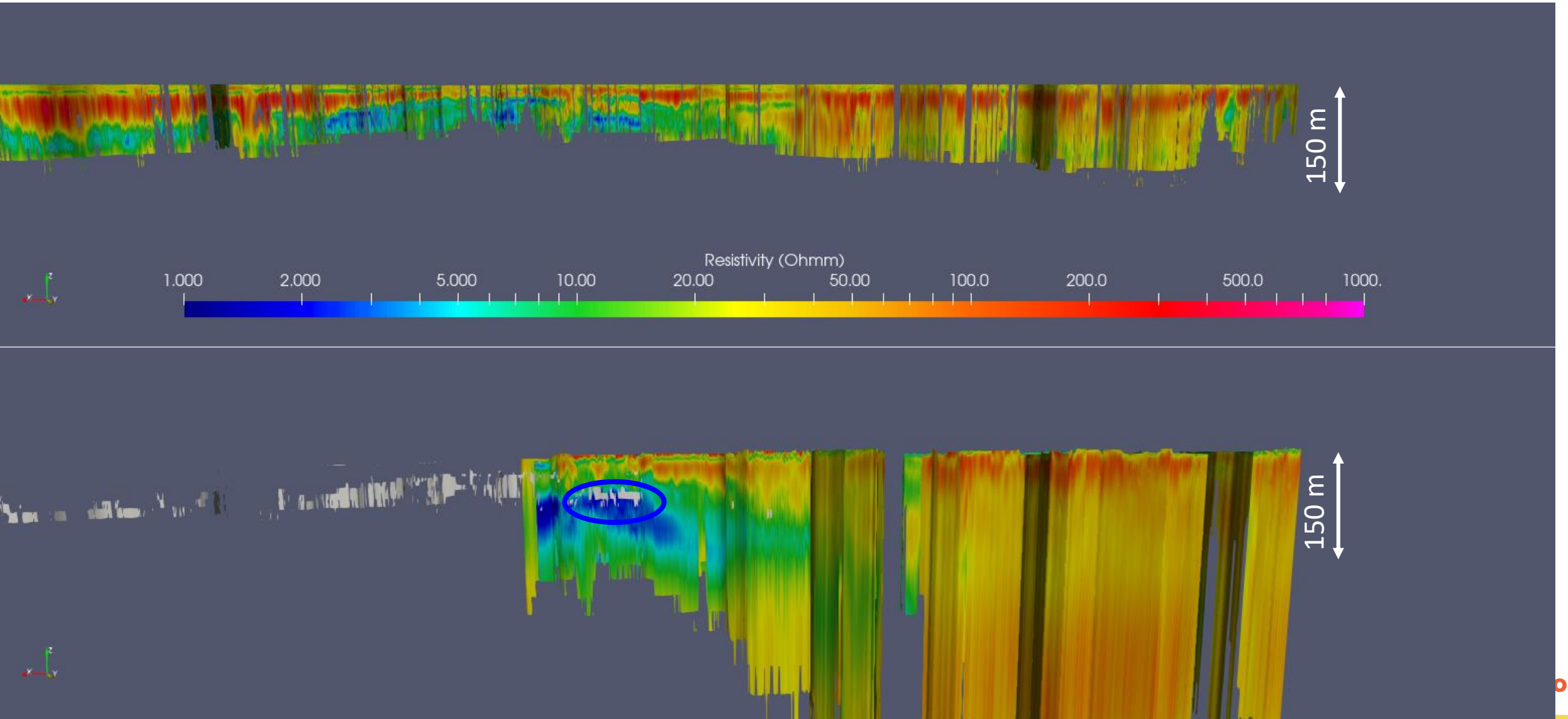
FloaTEM + SkyTEM



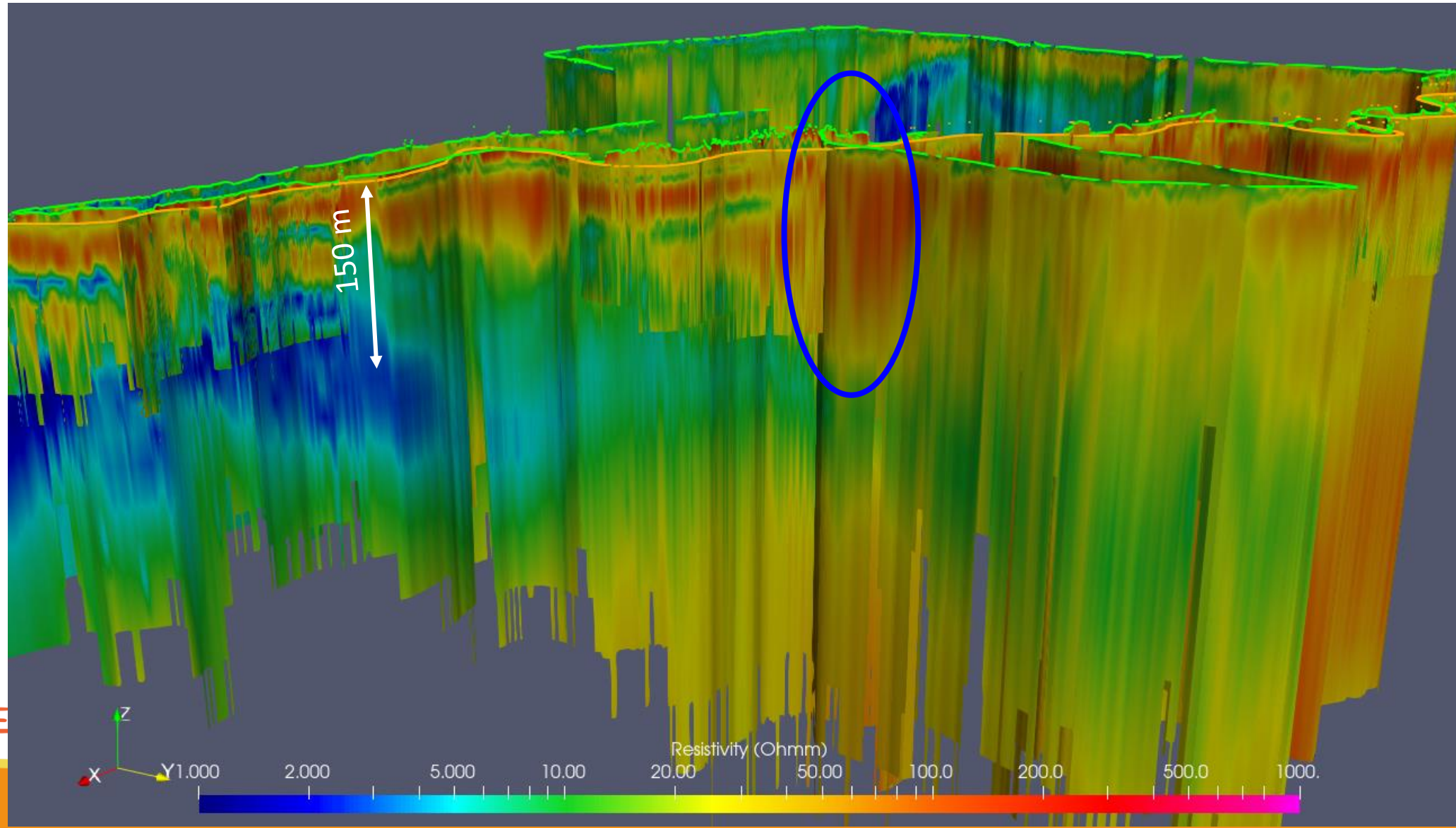
FloaTEM + SkyTEM



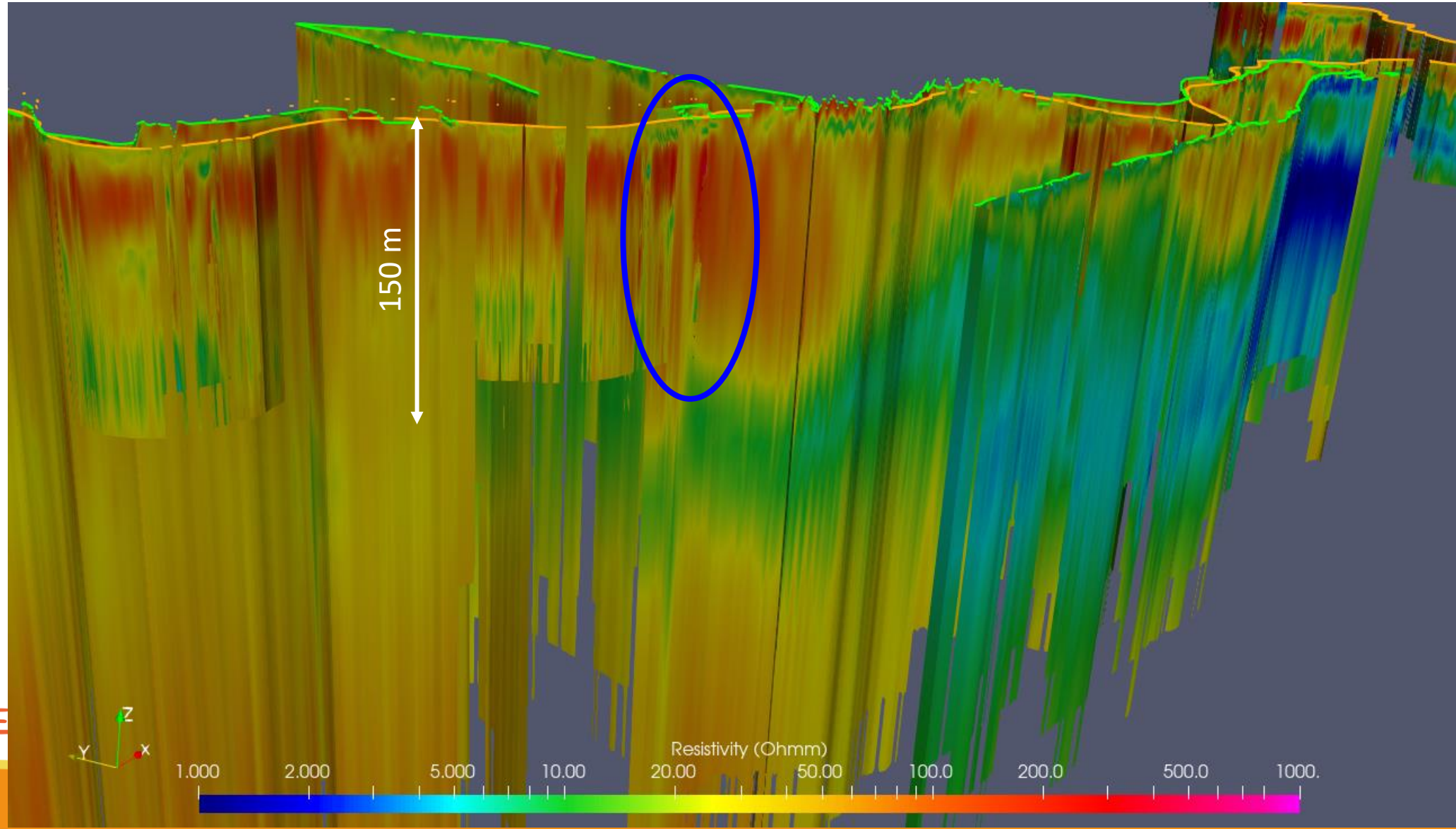
FloaTEM + SkyTEM



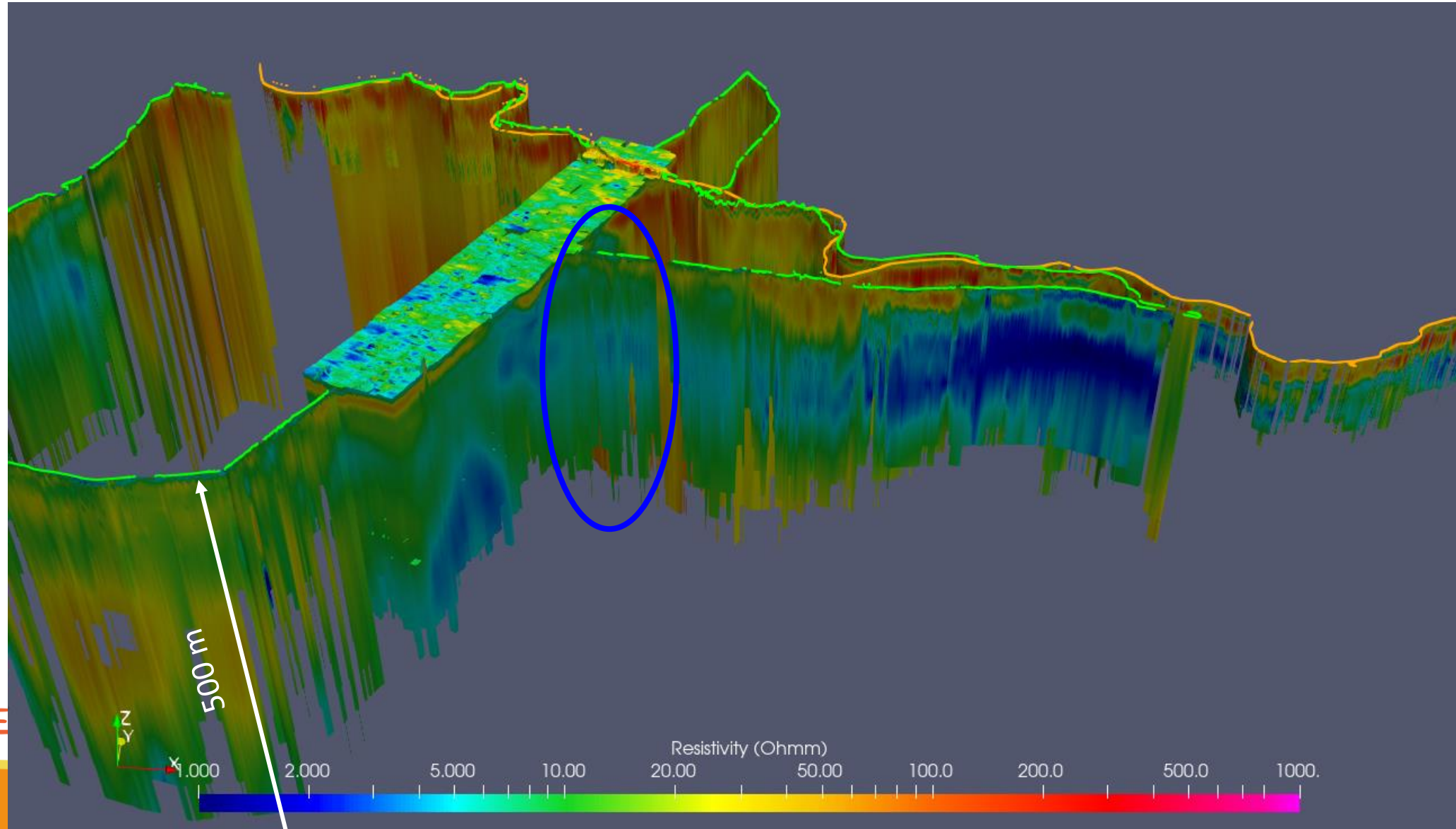
FloaTEM + SkyTEM



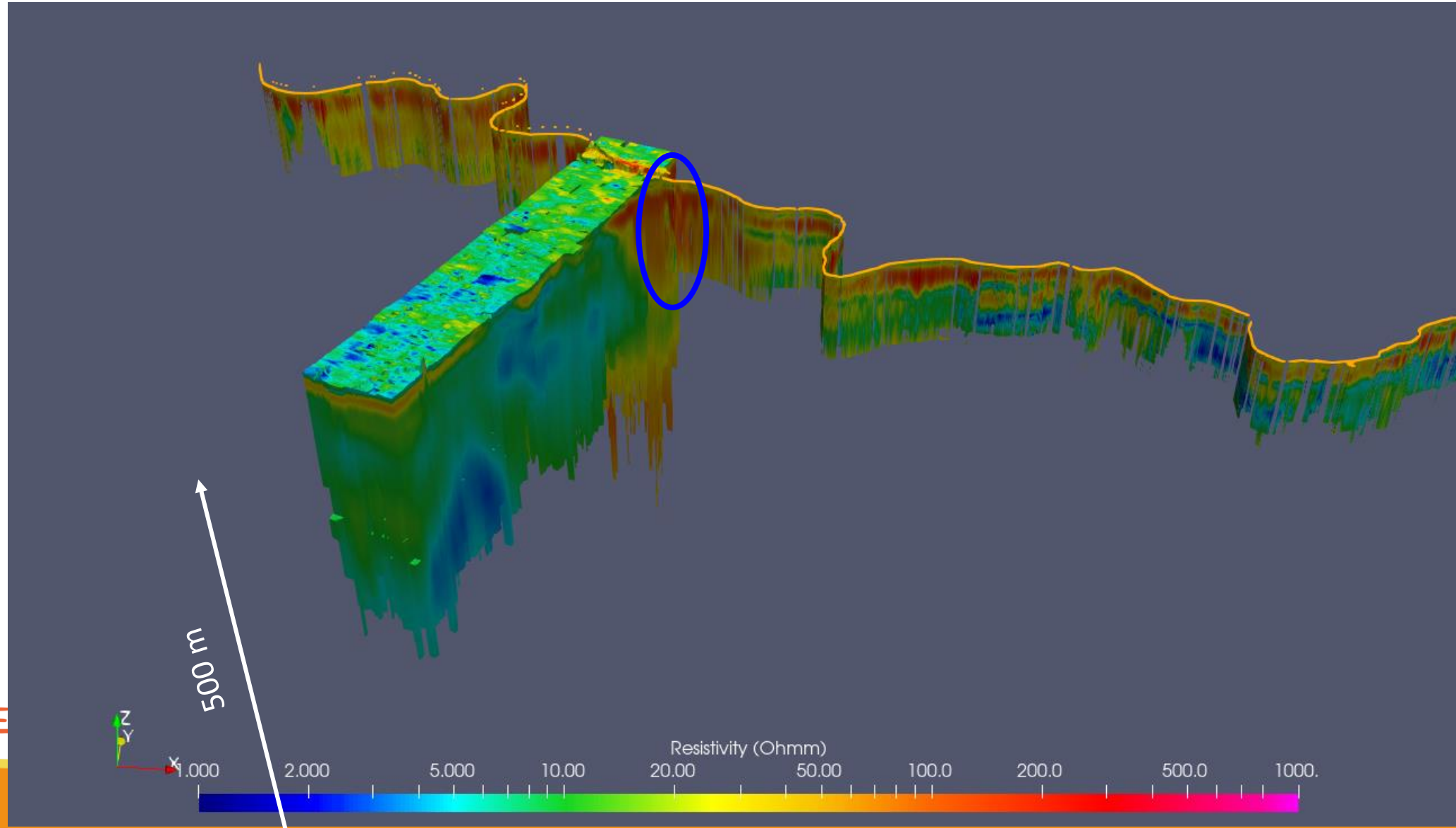
FloaTEM + SkyTEM



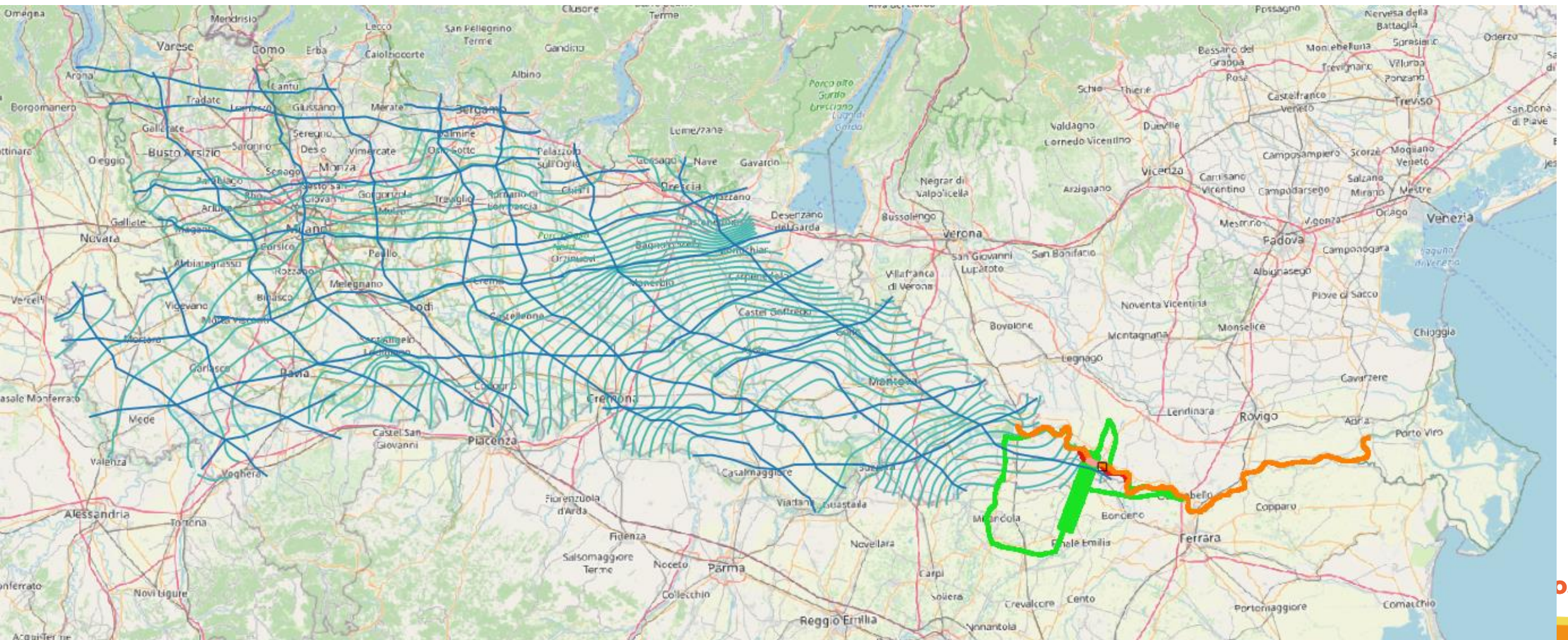
FloaTEM + SkyTEM



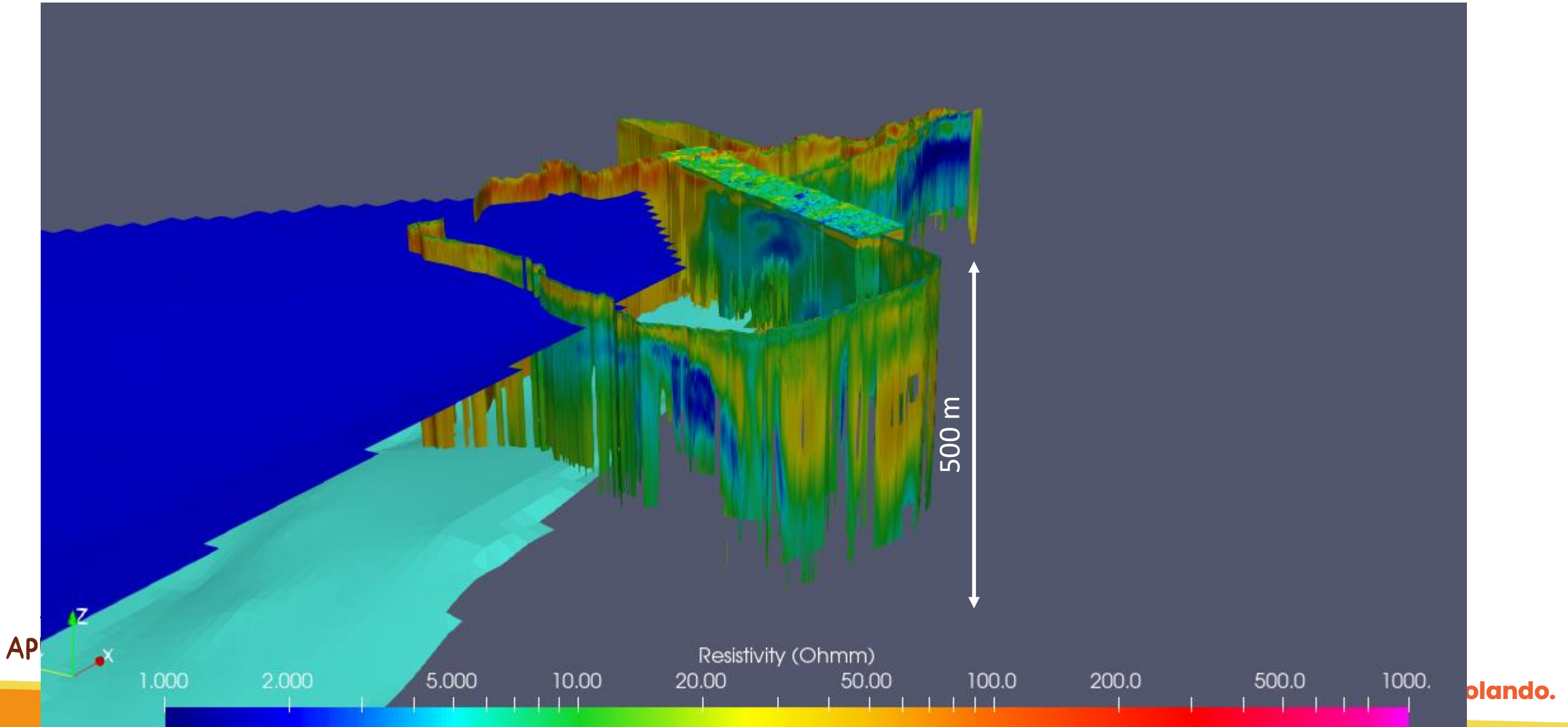
FloaTEM + SkyTEM



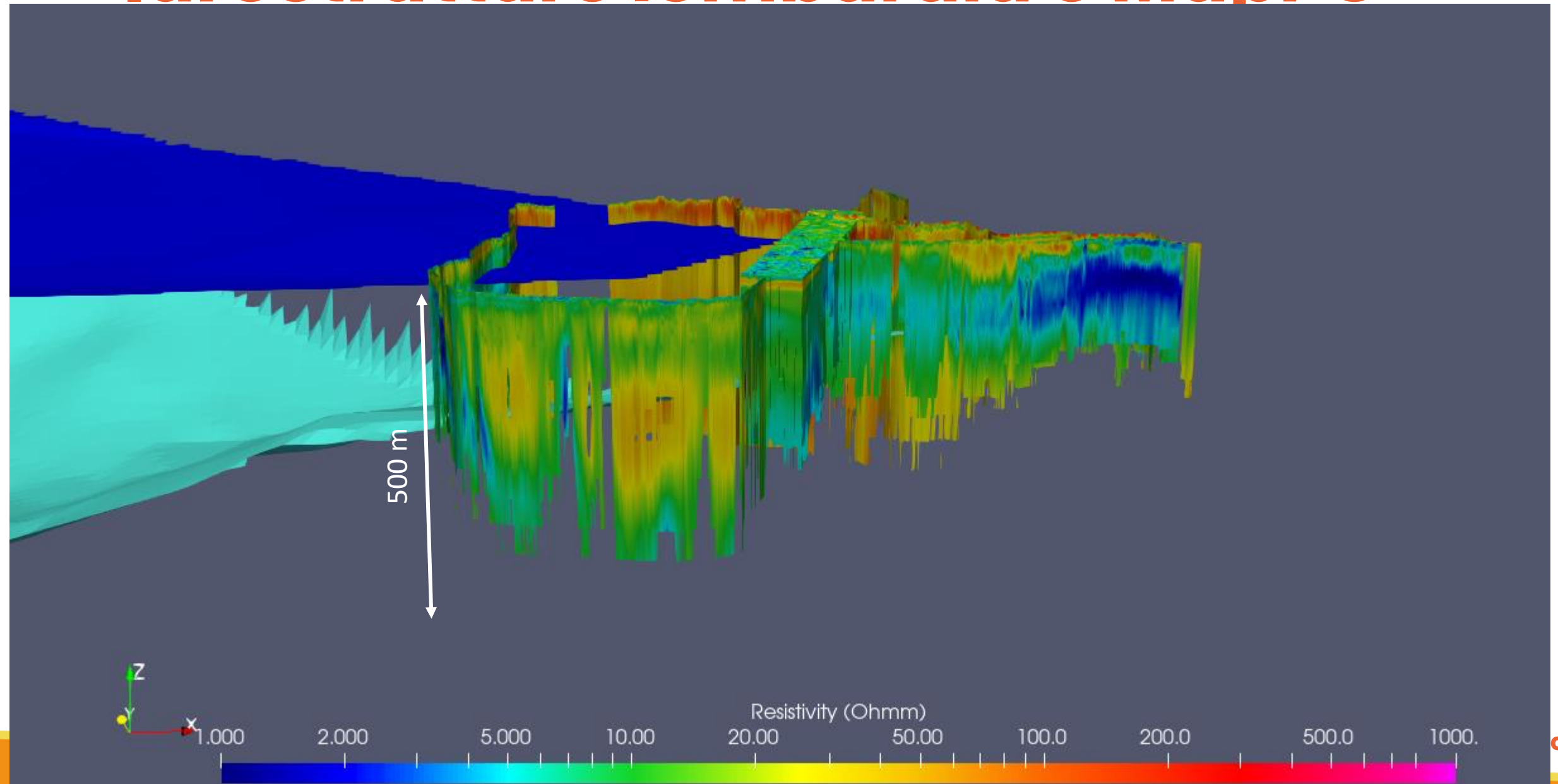
Idrostrutture lombardia e MapPO



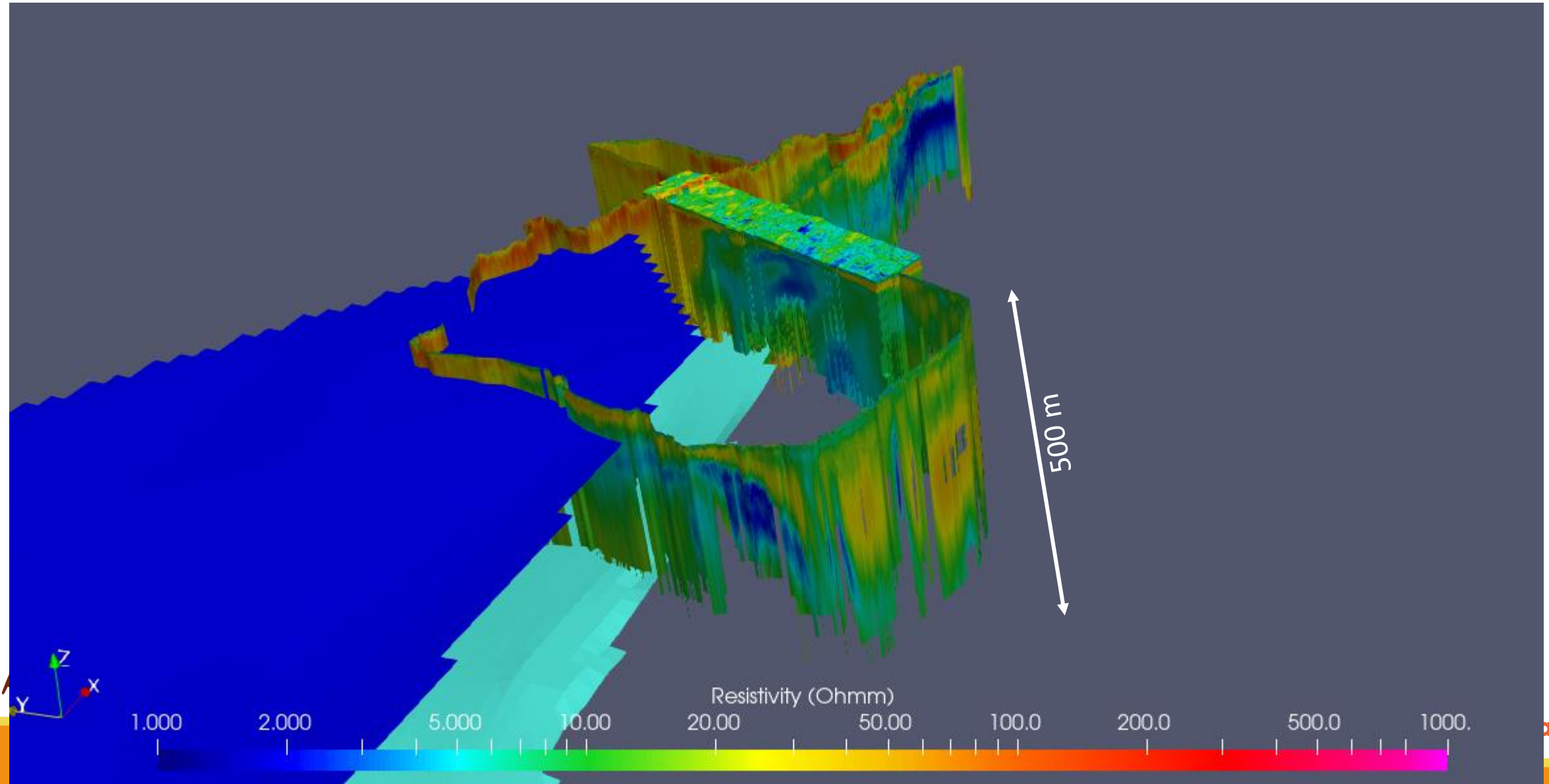
Idrostrutture lombardia e MapPO



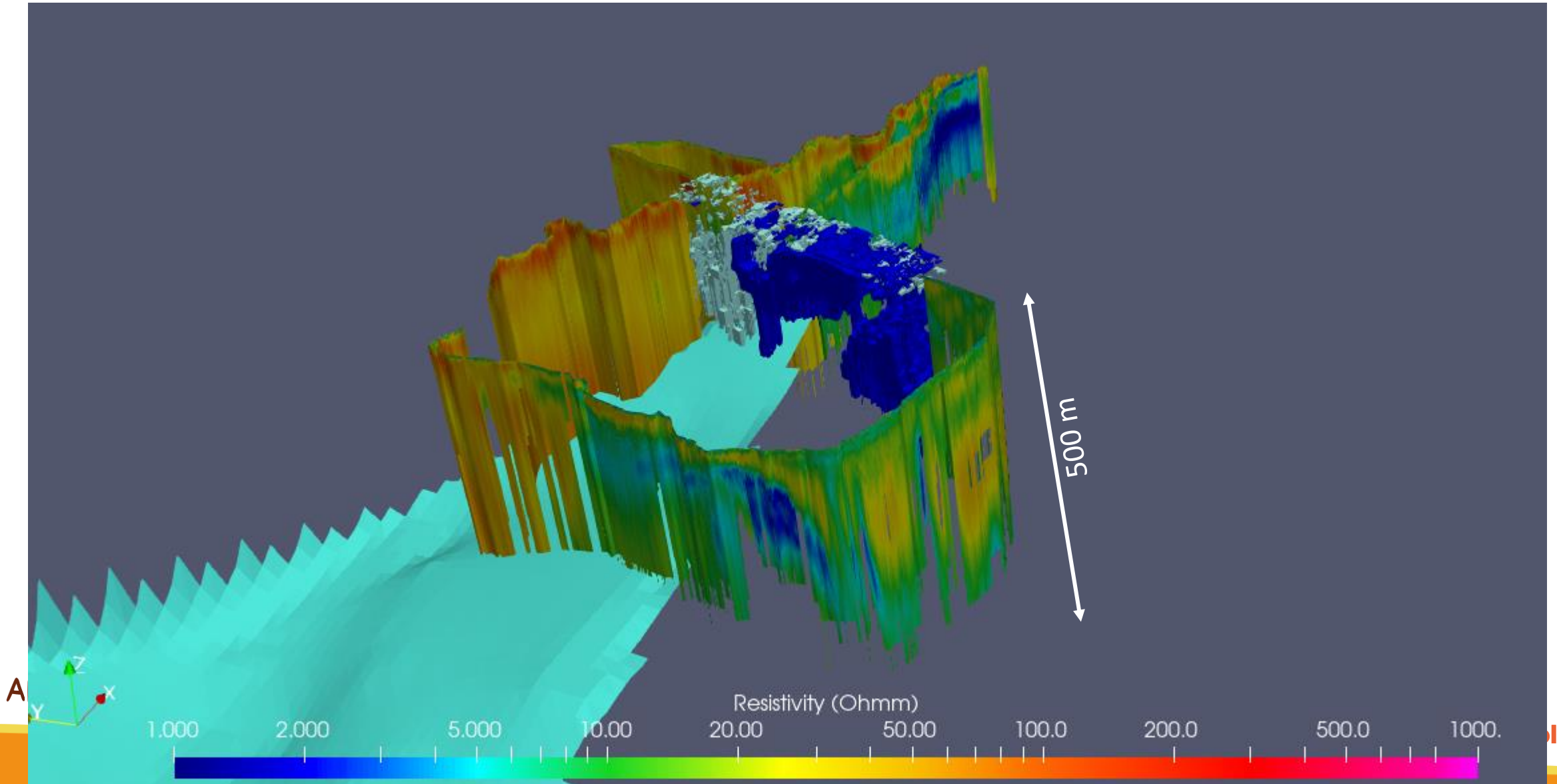
Idrostrutture lombardia e MapPO

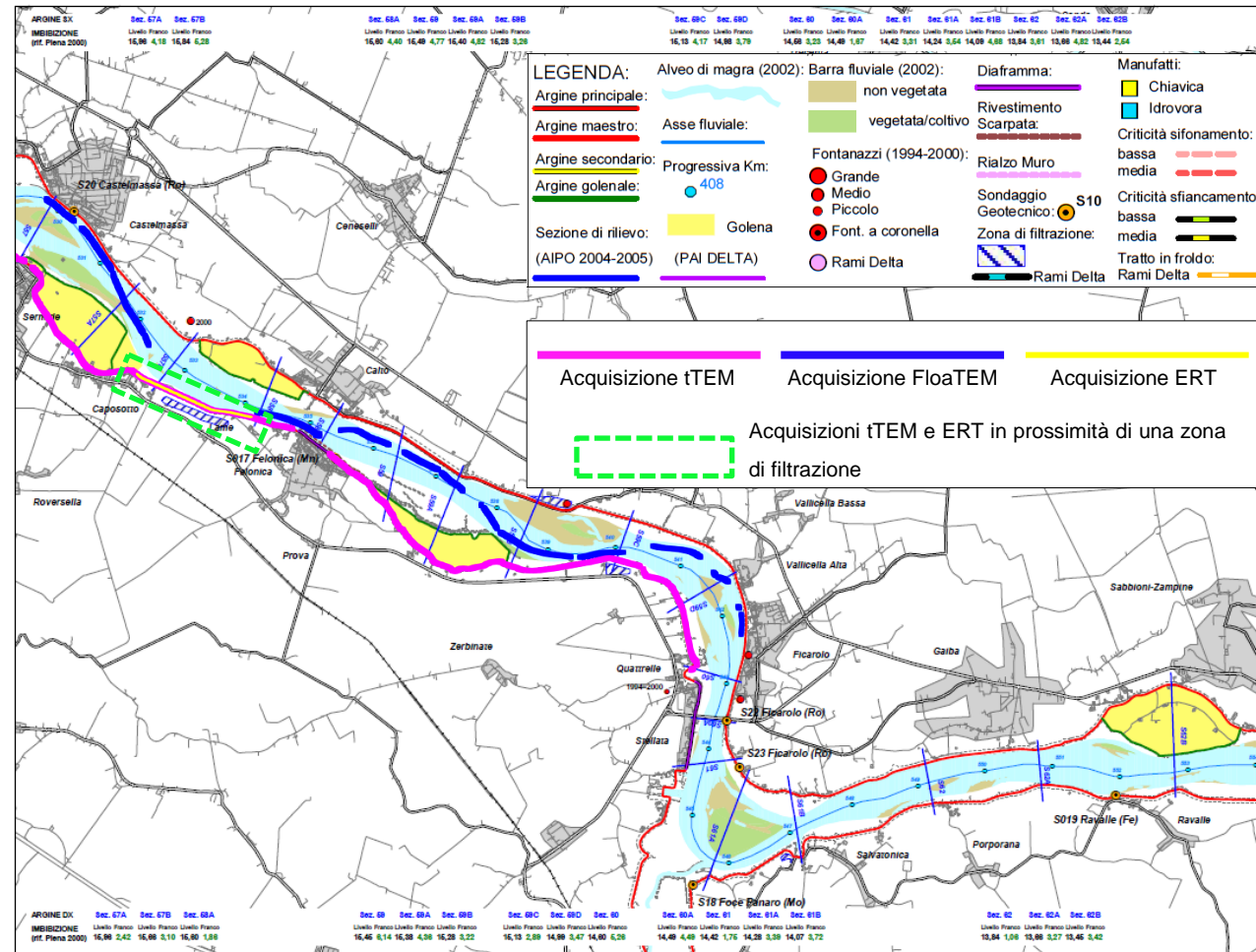


Idrostrutture lombardia e MapPO

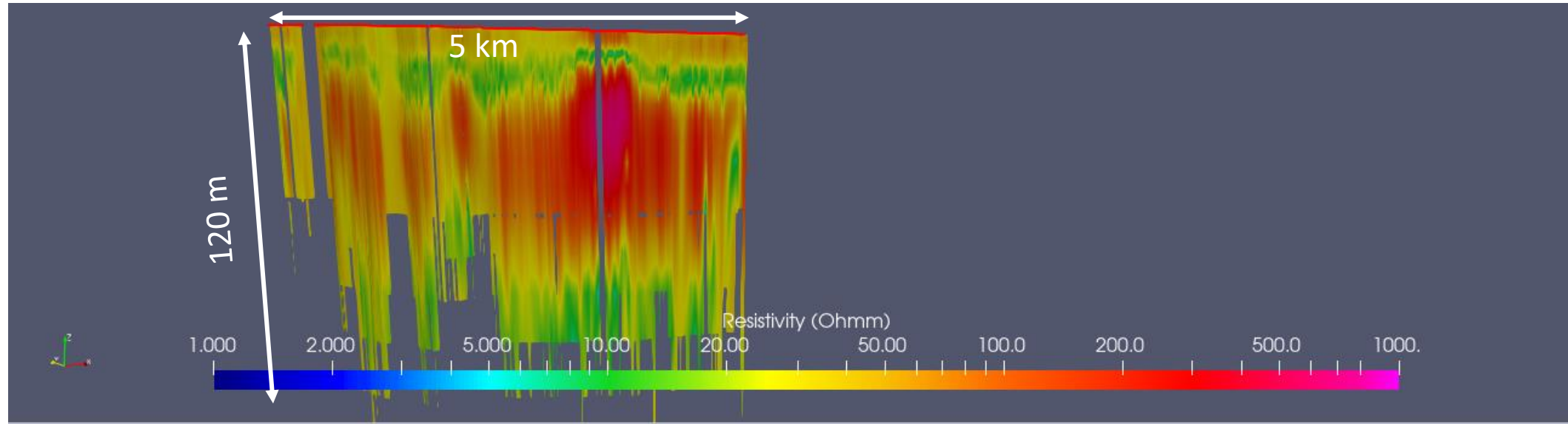


Idrostrutture lombardia e MapPO

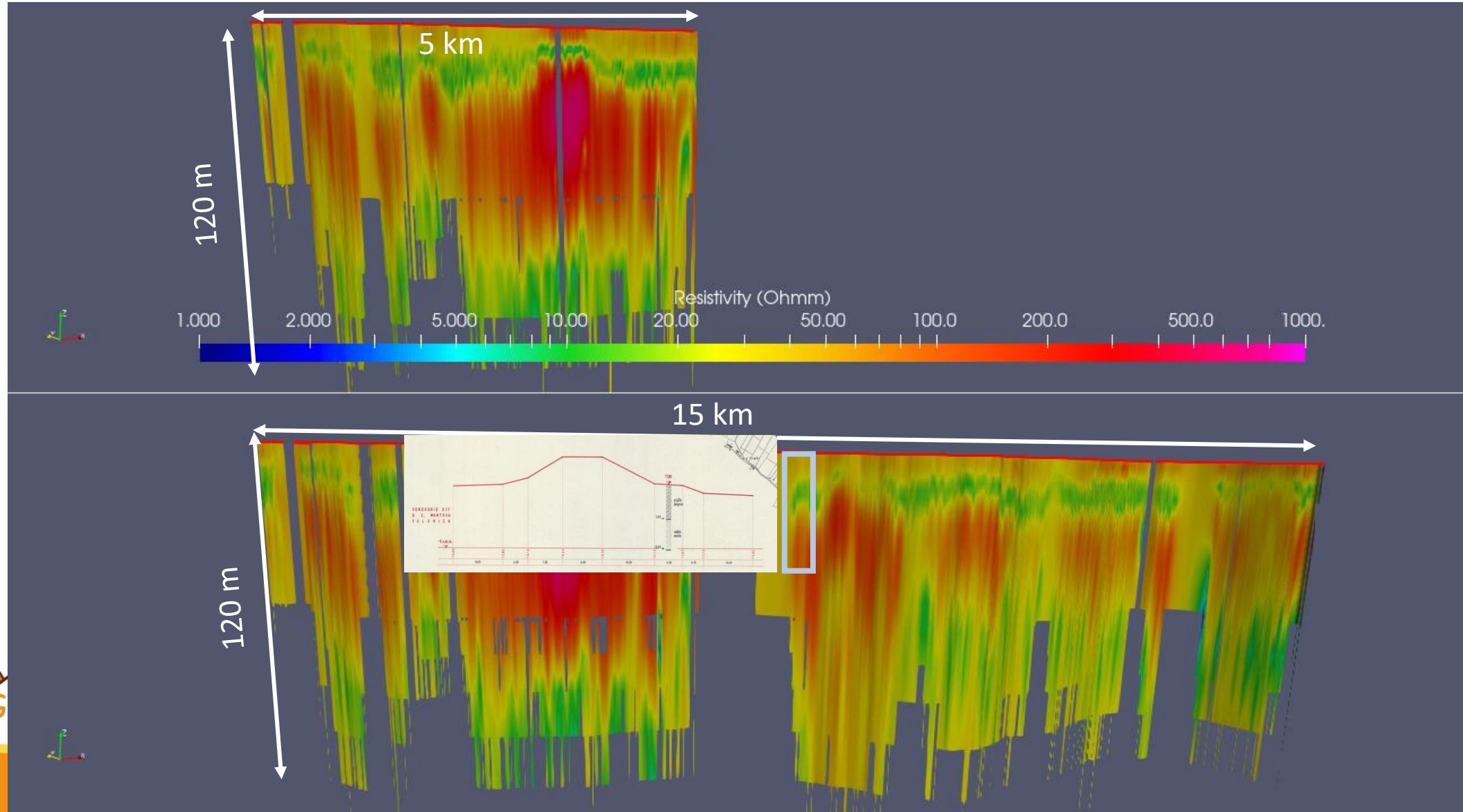




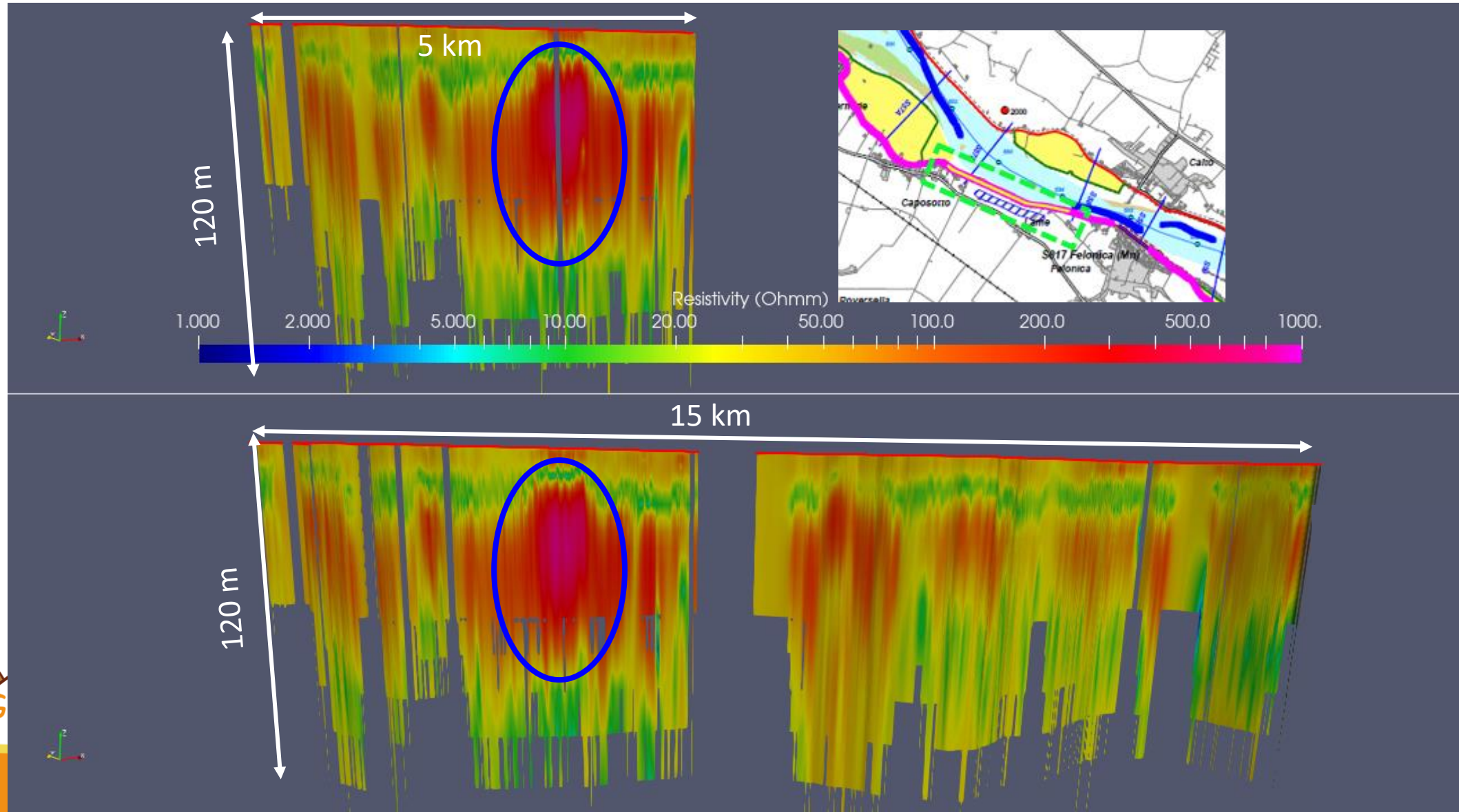
tTEM



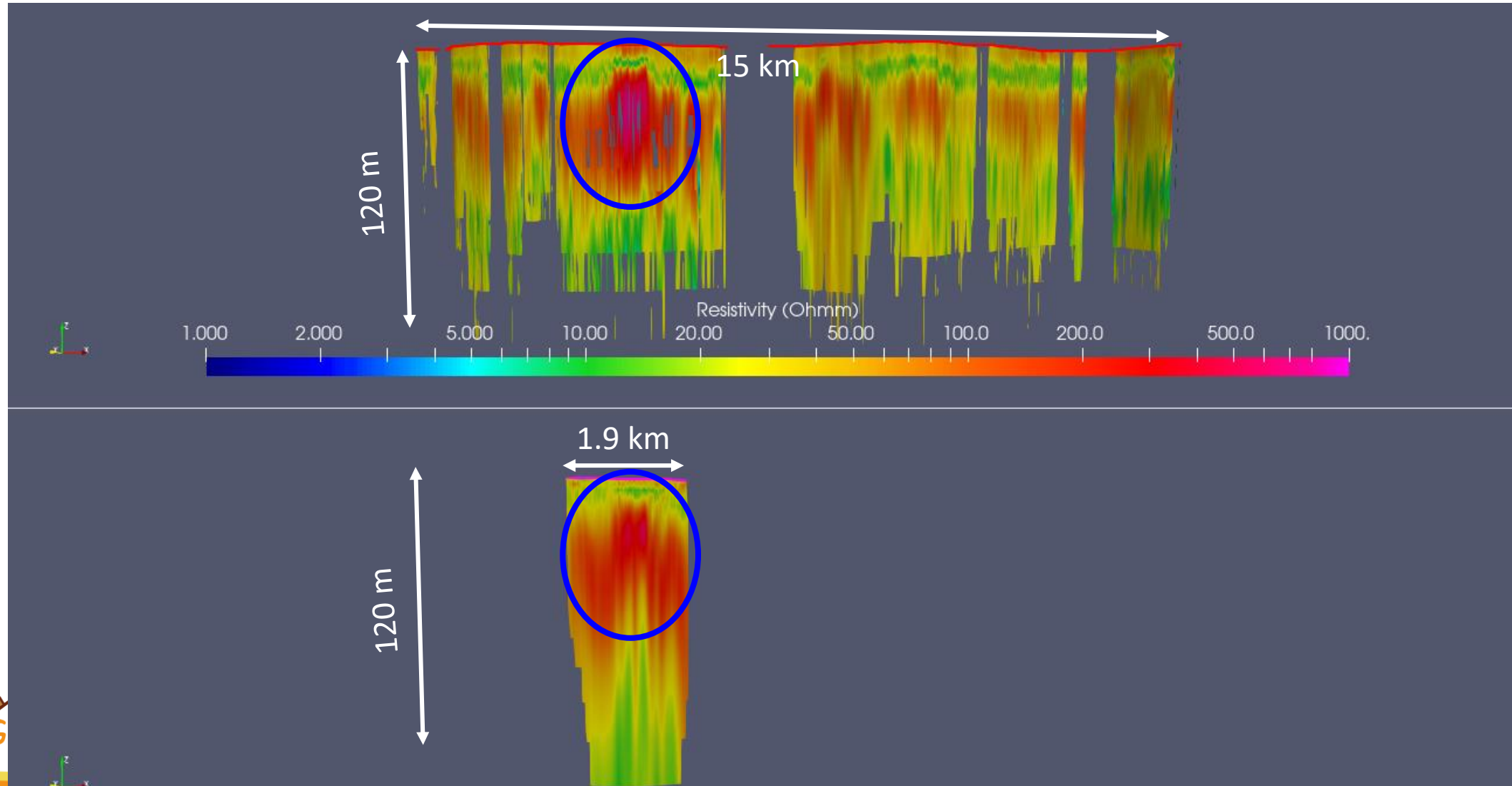
tTEM



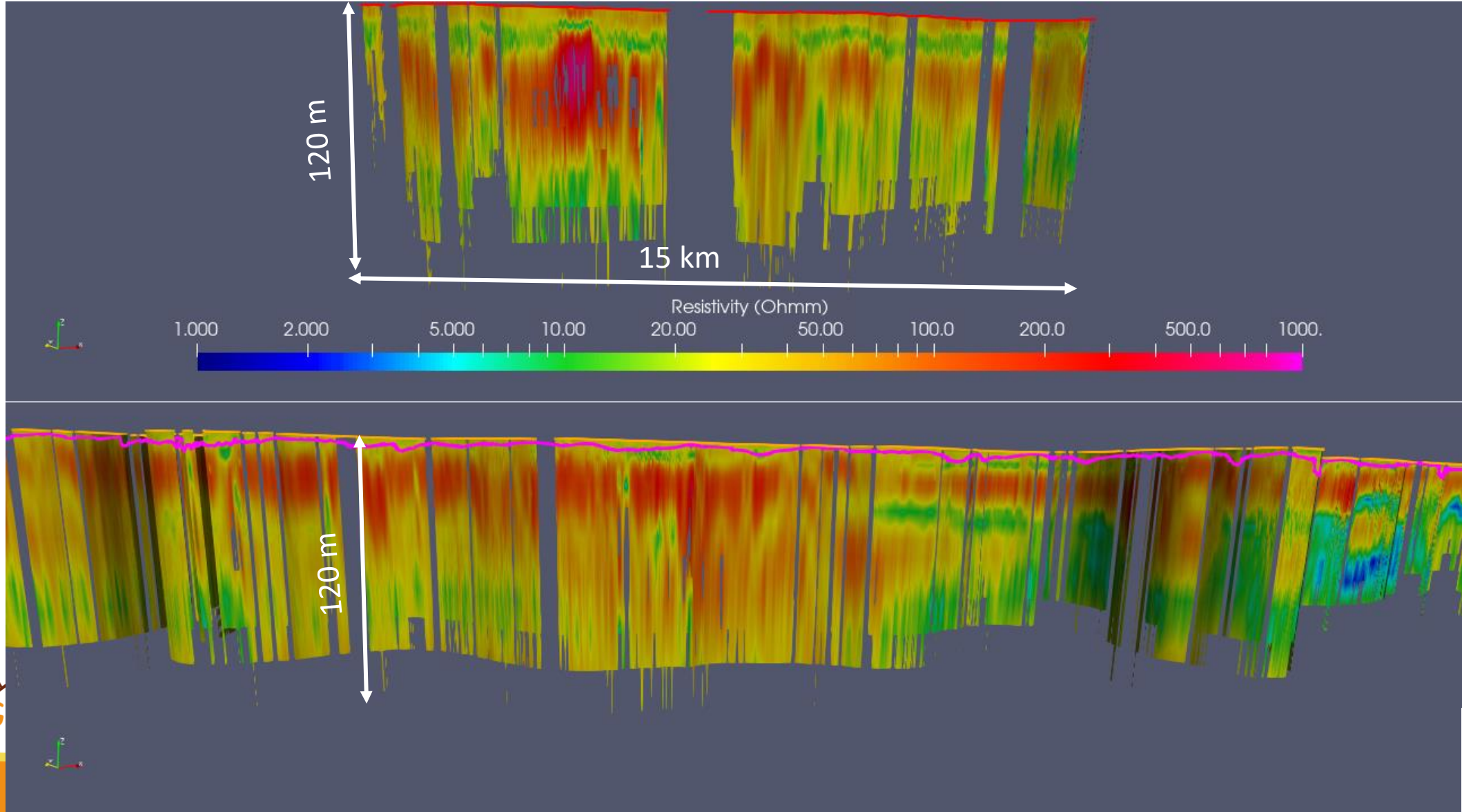
tTEM



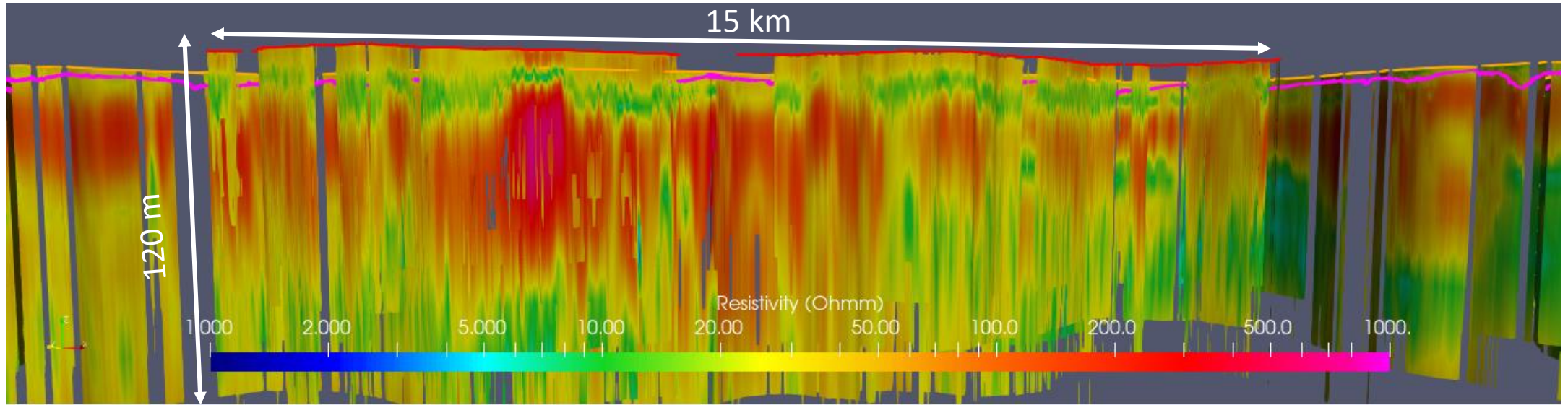
tTEM + ERT



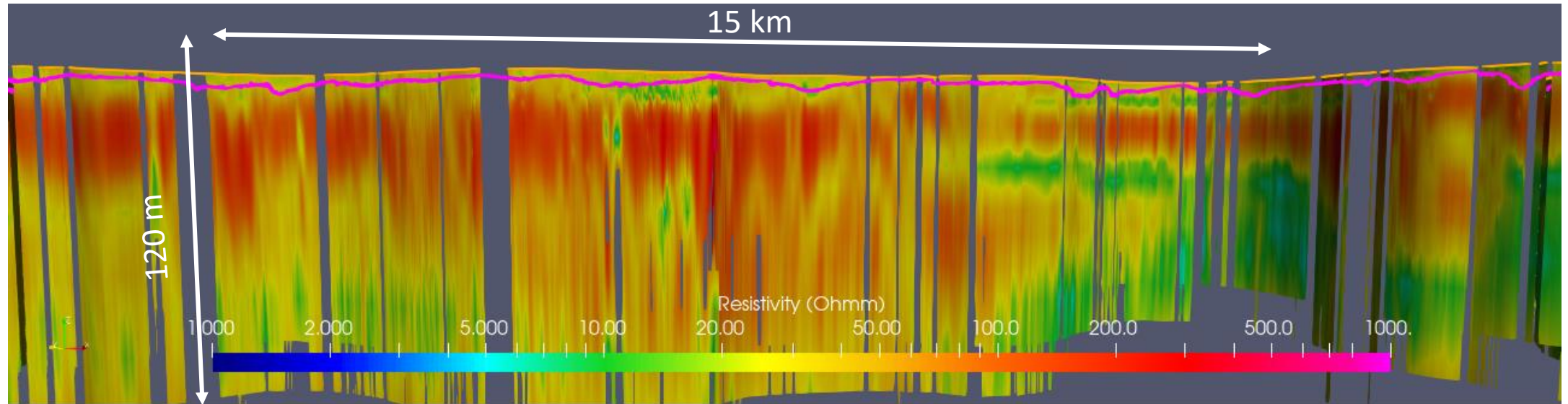
tTEM + floatTEM



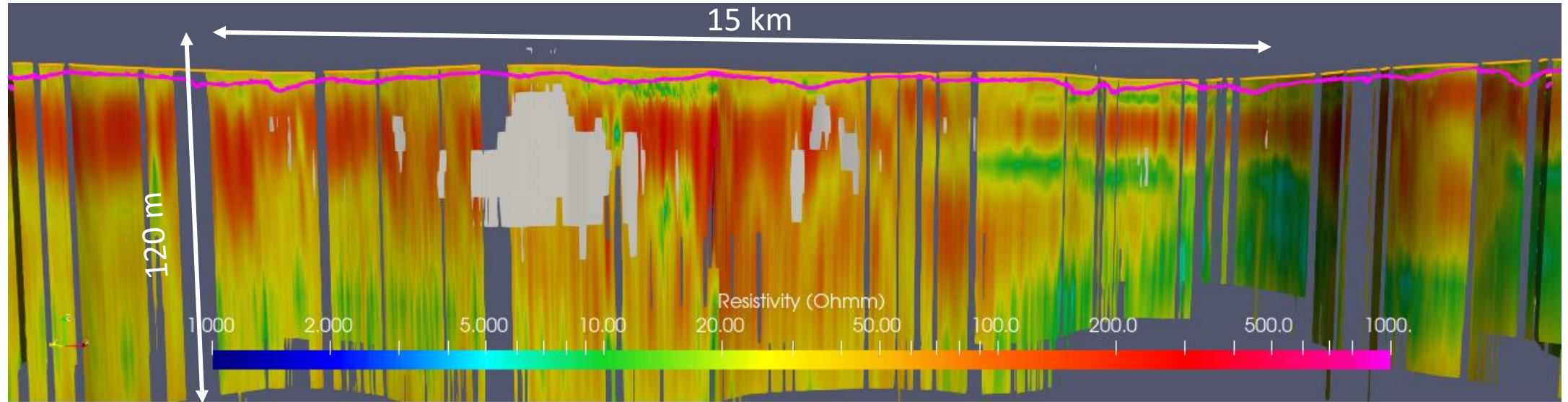
tTEM + floatTEM



tTEM + floatTEM



tTEM + floatTEM



E adesso?



PoEM?

