Environmental Monitoring Solutions

GRETA

Geo Resistivimeter for Time-lapse Analysis

Electrical Resistivity Tomography (ERT) for Tailings and Earth Dams Monitoring

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Geophysical measurements: brief introduction

Key Points

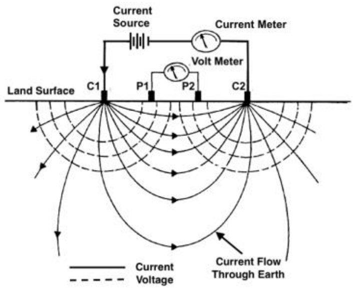
- **Non-invasive** measurements
- Based on **physical properties** of soil
- **Indirect** measurement of soil characteristics
- Different **methodologies**:
    - Seismic methods
    - Electro-magnetic methods
    - Gravimetric methods
    - Electrical methods
- Divided into:
    - **Passive**: detect variations within the natural fields associated with the earth, without transmitting signals in the ground
    - **Active**: artificially generated signals transmitted into the ground, that modifies the received signals in ways that are characteristic of the materials through which they travel

ERT measurements

ERT measurements: the operating principle

ERT (Electrical Resistivity Tomography) measurements:

- Geophysical indirect measurements
- Electrical field propagation due to soil properties
- Bidimensional reconstruction of soil electrical properties
- Electrical behavior connected to: soil composition, water content, presence of voids, fluid resistivity



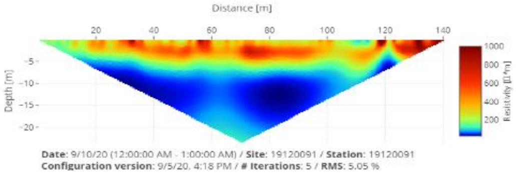
How does it work?

Geo-resistivimeter + electrodes in contact with soil + cables

➜ Injection of electric current and measurement of voltage across several quadrupoles

➜ 2^{nd} law of Ohm -> Raw Data

➜ Tomographic inversion -> Inverted Data



$$\rho_a = C\frac{\Delta V}{I}$$

PROS OF ERT MEASUREMENTS

- Good proxy of water content
- Bidimensional data (no punctual)
- Large investigated zones
- No coring needed

G.Re.T.A. system is: Automatic ERT monitoring

PROS OF AUTOMATIC ERT MONITORING

- Fixed installation: only the first time and standardized procedure
- In monitoring the most important aspect is the evolution of processes related mainly to water infiltrations or cavities/fractures formation
- Automatic inversion of data on cloud platform
- Automatic execution of measurements configurable from remote

What can you do with automatic ERT monitoring?

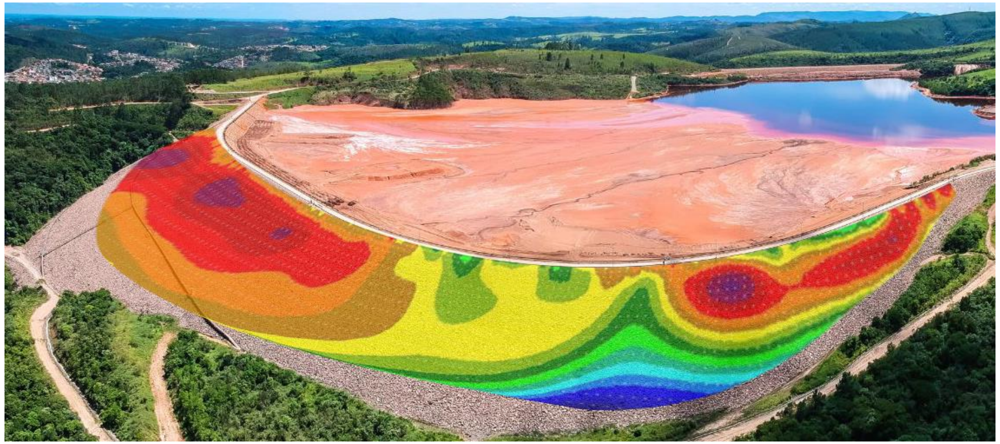
Follow the triggering/evolution of underground processes over time, addressing the problem before it's too late
(When you see it with your own eyes, it's too late)

Automatic ERT for TSF monitoring

Geoelectrical monitoring offers valuable insights for:

- Identifying concentrated seepages
- Detecting under-seepage
- Analyzing saturation, including in partially or unsaturated soils
- Monitoring saturation over time
- Assessing dewatering processes
- Evaluating groundwater levels

→ **Assessment of TSF stability over time**



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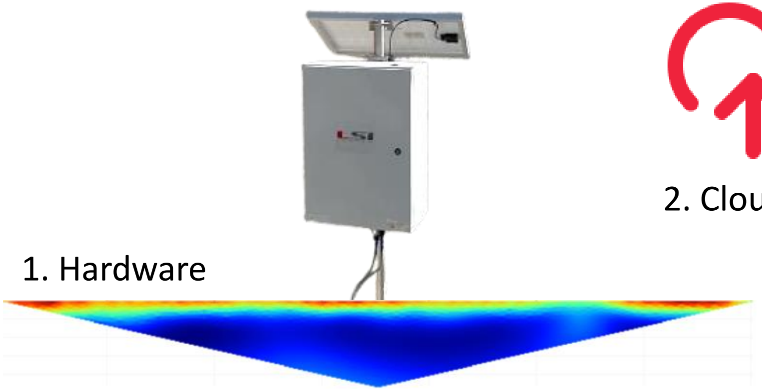
Geo Resistivimeter for Time-lapse Analysis

What is G.Re.T.A.?

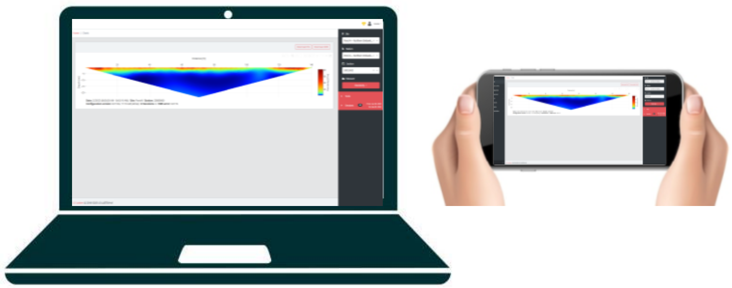
An off-the-shelf, autonomous, cloud based, fully automated **Geo-Resistivimeter** specifically designed for **Permanent ERT Monitoring**.

- Remote programming
- Real-time data
- Automatic data inversion
- Cloud based solution
- Possible integration of meteo station
- Possible connection of piezometers
- Analysis tools
- API for third-party platforms



1. Hardware

2. Cloud SW

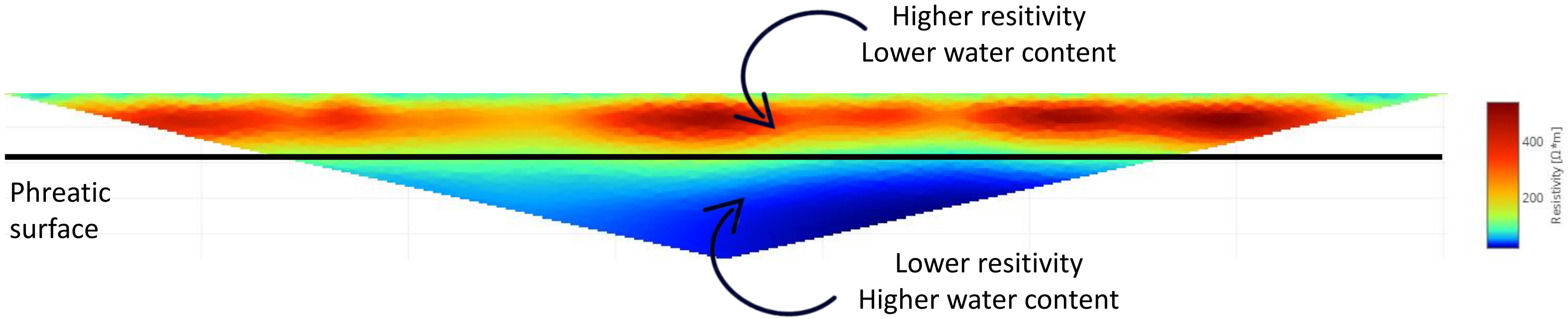


3. PC / mobile

What the advantages? Estimation of water content

- Resistivity and water content are inversely related: the higher the resistivity, the lower the water content and vice versa
- In a given soil, resistivity changes are mainly related to water content variation
- **In homogeneous soils (like most of TSF), resistivity is an excellent proxy of water content**

G.Re.T.A. assesses changes in water content and helps to proactively predict the creation of possible seepages or other anomalies that may eventually become a risk to the structural integrity of tailings or earth dams.



What the advantages? Early warning

As a fixed, self-powered installation, G.Re.T.A. enables continuous monitoring of soil resistivity changes over time.

This allows for the assessment of:

- Variations in water content
- Onset of seepages
- Formation of fractures

When predefined thresholds are exceeded, automated alerts can be triggered.

What the advantages? Comprehensive information

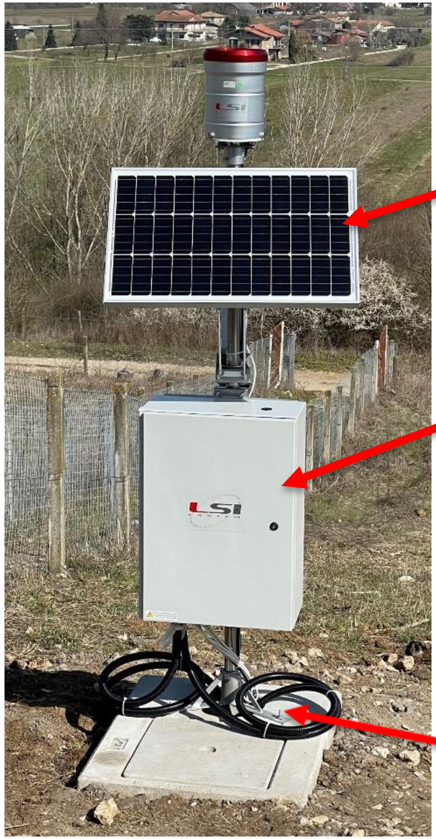
- Extensive coverage: unlike piezometers, which provide only localized data, G.Re.T.A. delivers soil insights along extensive profiles, spanning hundreds of meters in length and reaching significant depths.

- Enhanced water content monitoring: while piezometers only indicate groundwater levels, G.Re.T.A. estimates soil moisture percentage, even in unsaturated conditions.

- Proactive risk detection: unlike displacement monitoring systems that detect infiltration effects only after they occur, G.Re.T.A. helps predict and mitigate risks before they happen.

- Easy and fast installation: no need for borehole drilling—G.Re.T.A. is quick to set up with minimal effort.

Main components of G.Re.T.A. georesistivimeter



Solar Panel

IP66 Box

2 x Cables
Tot. 48 Electrodes

SSU Signals Switching Units (2)

MPU Main Processing Unit

4G Modem Router

SDU Signals Driving Unit

Power Unit

Cables Connections

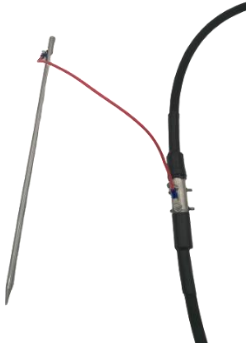
Battery

Two types of installation

Plate Electrodes
for Permanent
Installation

Cables are positioned inside a small trench

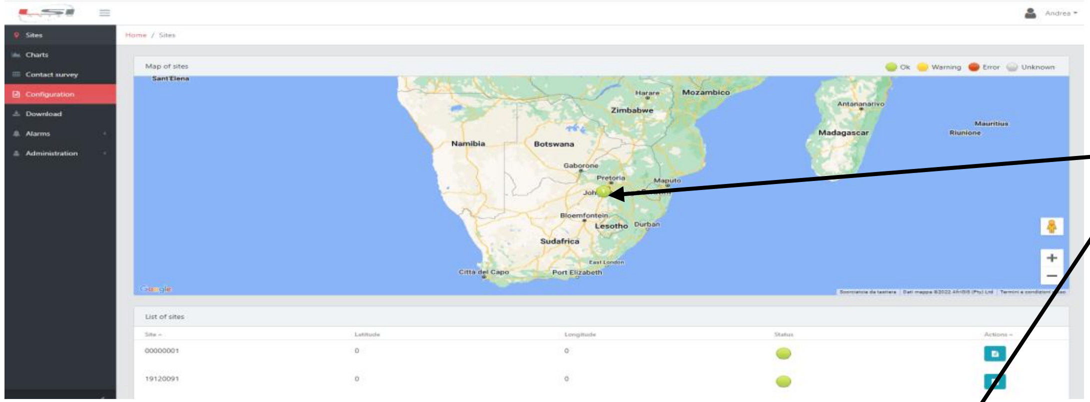
Rod Electrodes
for Temporary
Installation

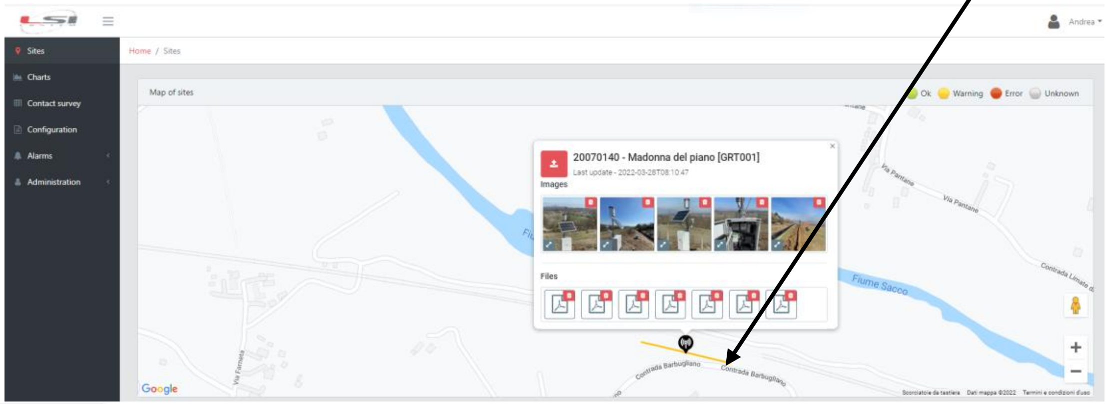


Cables are laid down on the soil's surface

Permanent connection to cloud-based software

Visualization, data processing and instrument configuration are seamlessly managed through LSI LASTEM's cloud software

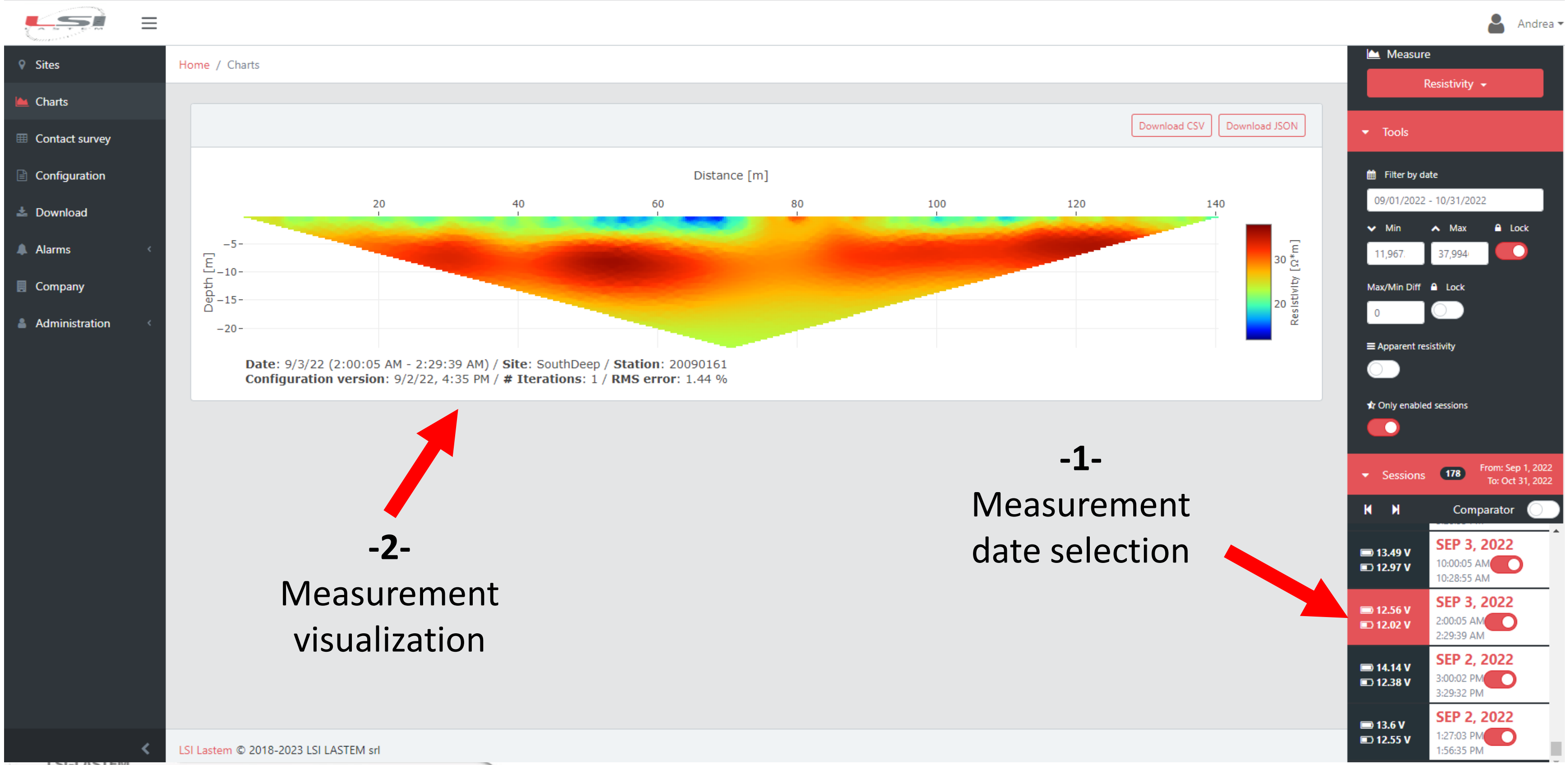




- Geo-localization of stations and related profiles on Google Maps
- Ability to upload pictures, documents and other meta data

Data management via cloud platform

Visualization and storage of
measurement data (resistivity profiles) over time

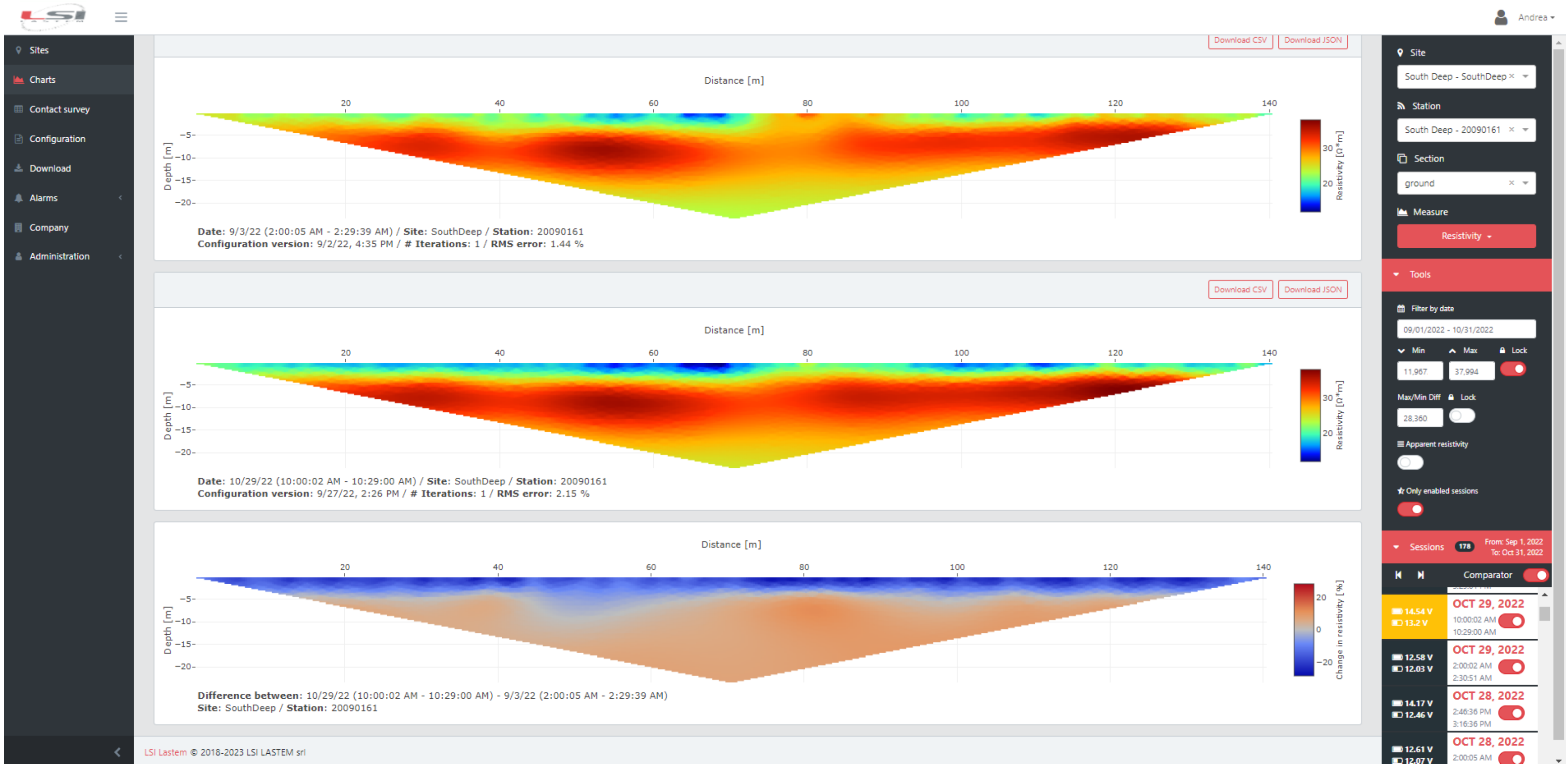


-2-
Measurement
visualization

-1-
Measurement
date selection

Comparisons of measurements over time

Easy comparison of resistivity profiles across any selected time interval

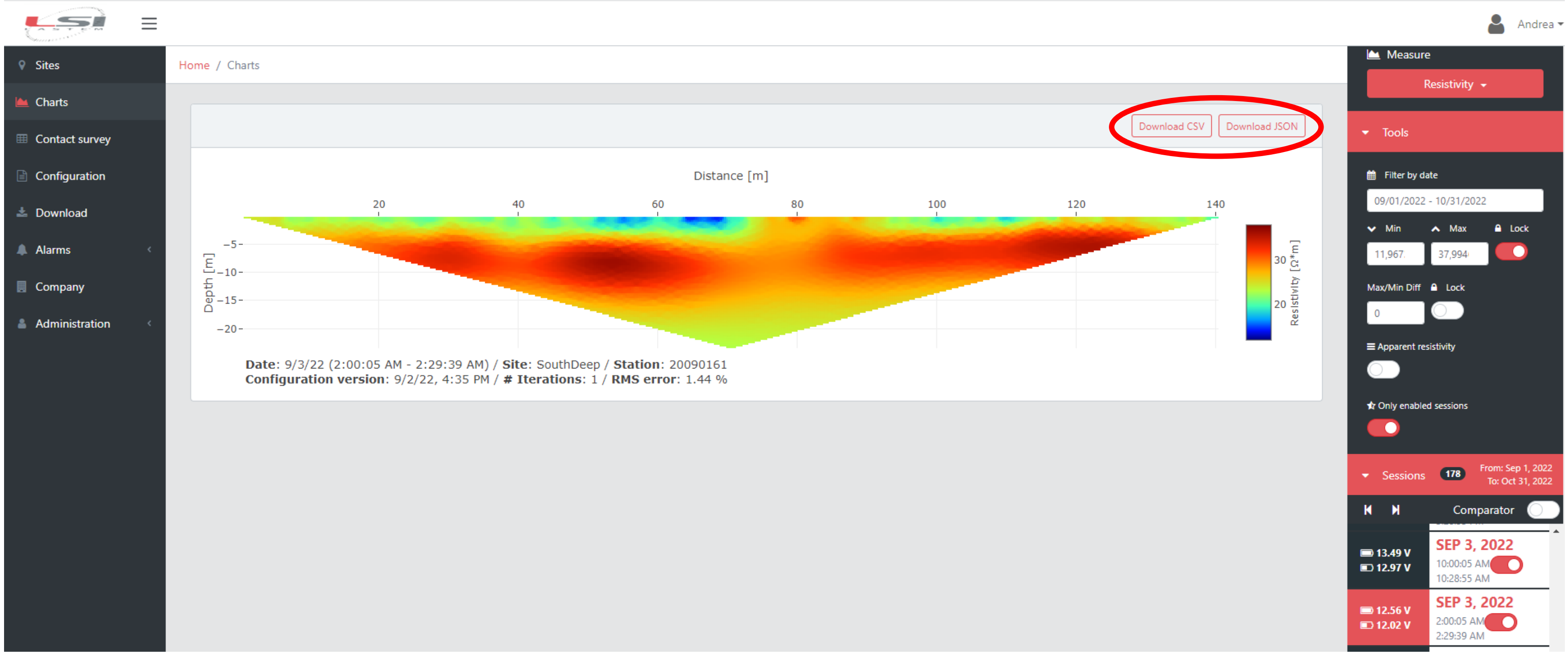


Slide - 14

Simplified data export

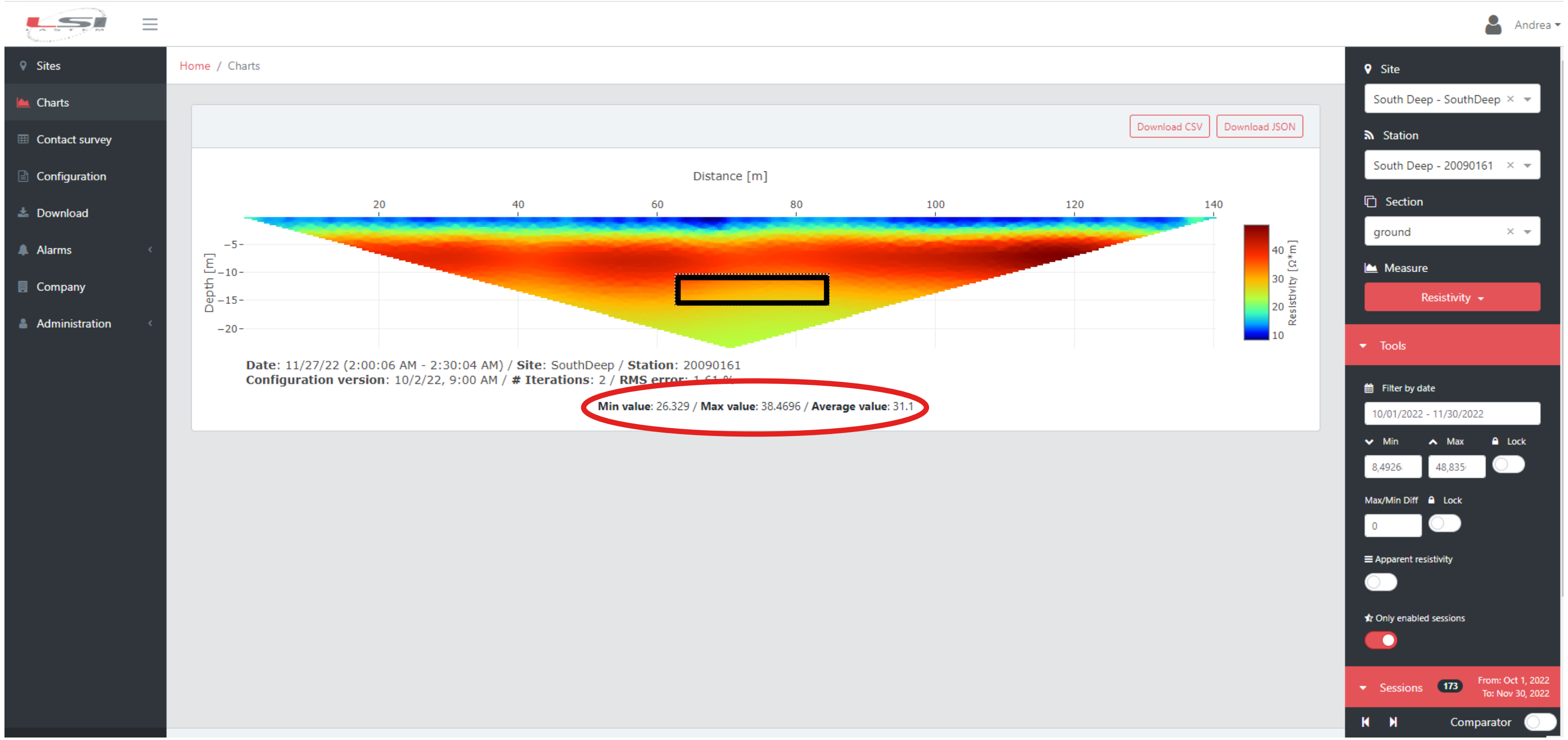
Data export is available in two ways:

- Manual Export: Selecting the desired period and format (CSV, JSON)
- Automatic Export: Seamless integration with third-party software via API



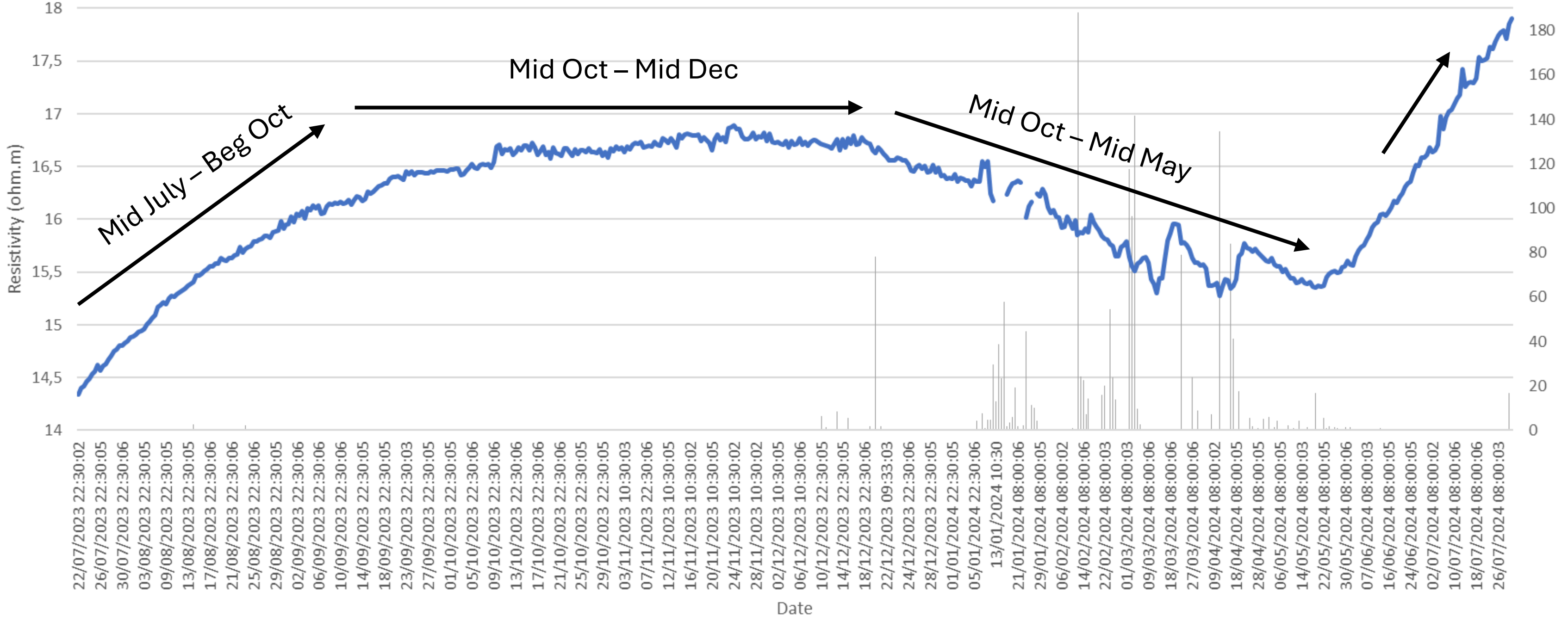
Quick analysis tools

Ability to quickly identify the min, max and avg resistivity values for any selected area



Easy time-lapse analysis

Possibility to quickly assess the evolution of min, max and avg resistivity values of any selected area over any period



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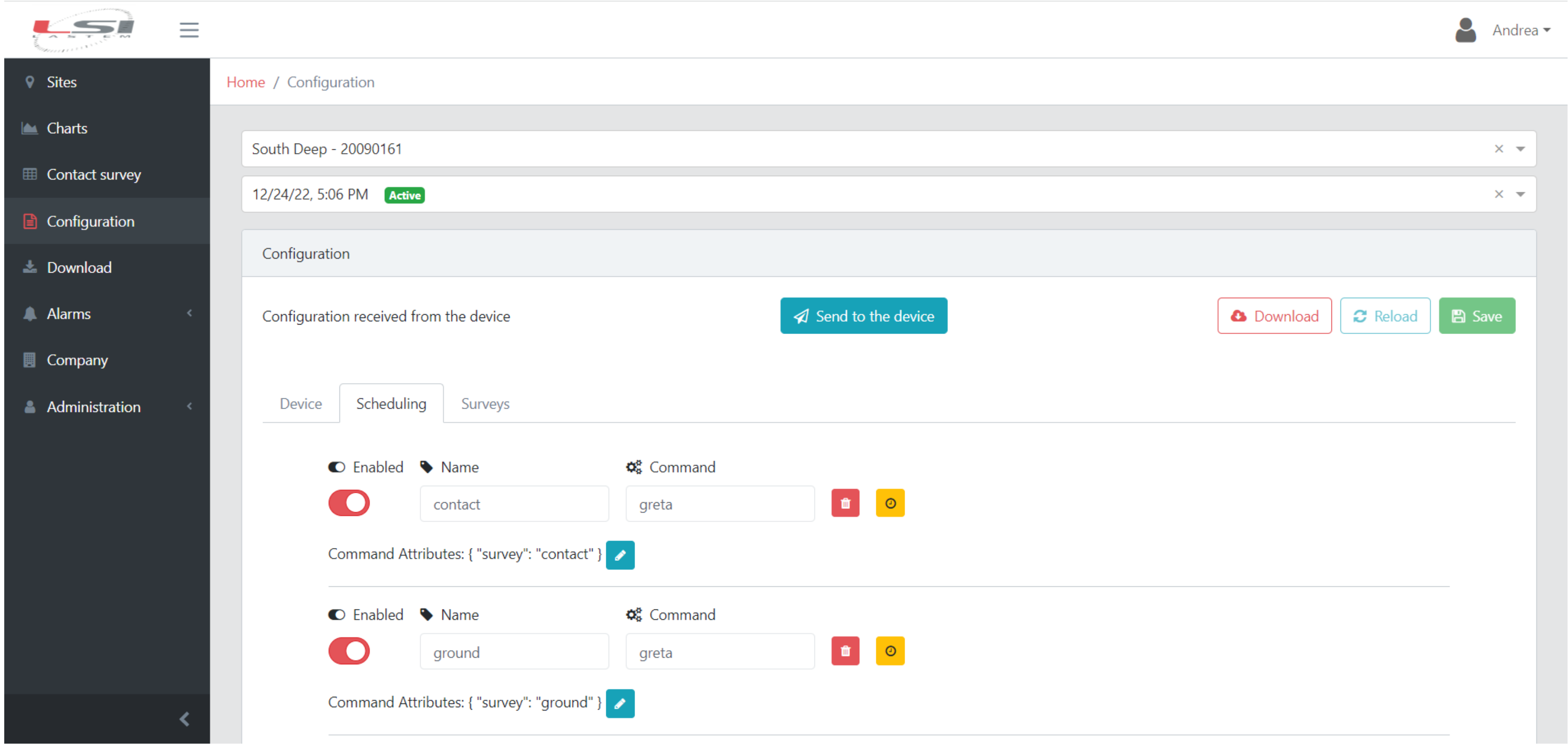
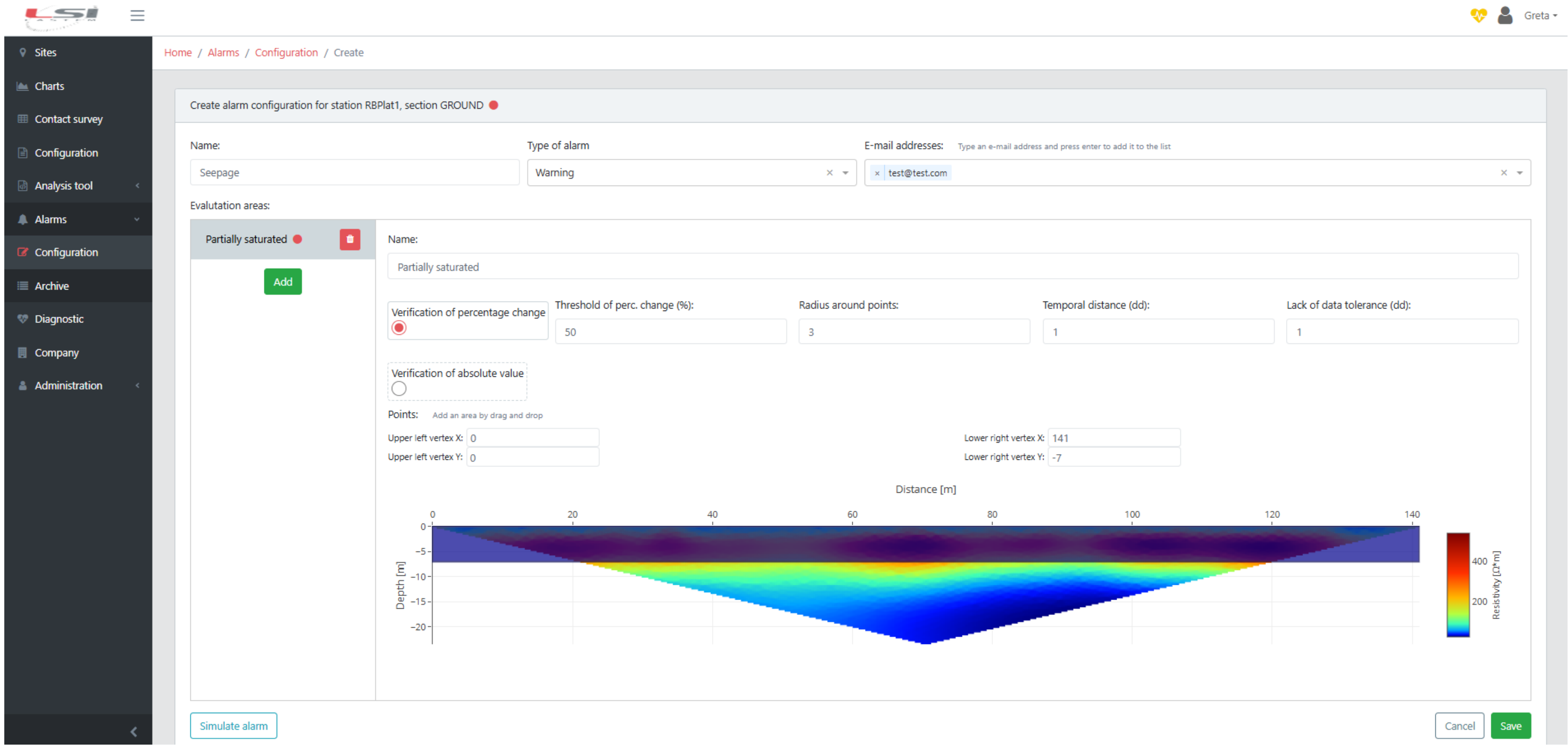
System configuration directly from cloud platform

Not only data visualization and analysis but also system configuration directly from cloud platform



Alarms setting

Alarm messages may be automatically sent
whenever preset resistivity thresholds are reached in selected areas



Additional data: environmental and piezometric

Environmental data (rainfall, T/RH, etc) and piezometric data on the same section

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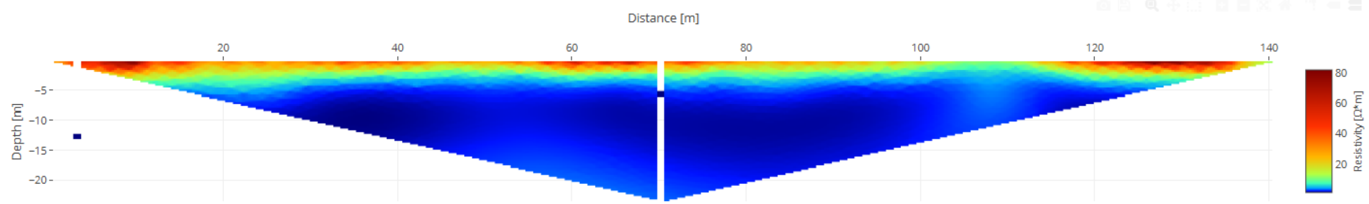
- Sites
- Charts
- Contact survey
- Configuration
- Analysis tool
- Alarms
- Diagnostic
- Company
- Administration



Date: 2/28/25 (8:00:03 AM - 8:43:19 AM) / **Site:** Pond4 / **Station:** 20080060
Configuration version: 2/21/24, 11:10 AM *(Active)* / **# Iterations:** 4 / **RMS error:** 3.01 %

Meteo data

Name	Unit	Value
Rainfall	mm	0
Rainfall 15m	mm	0
Rainfall 1h	mm	0
Rainfall 6h	mm	0
Rainfall 12h	mm	0
Rainfall 24h	mm	0

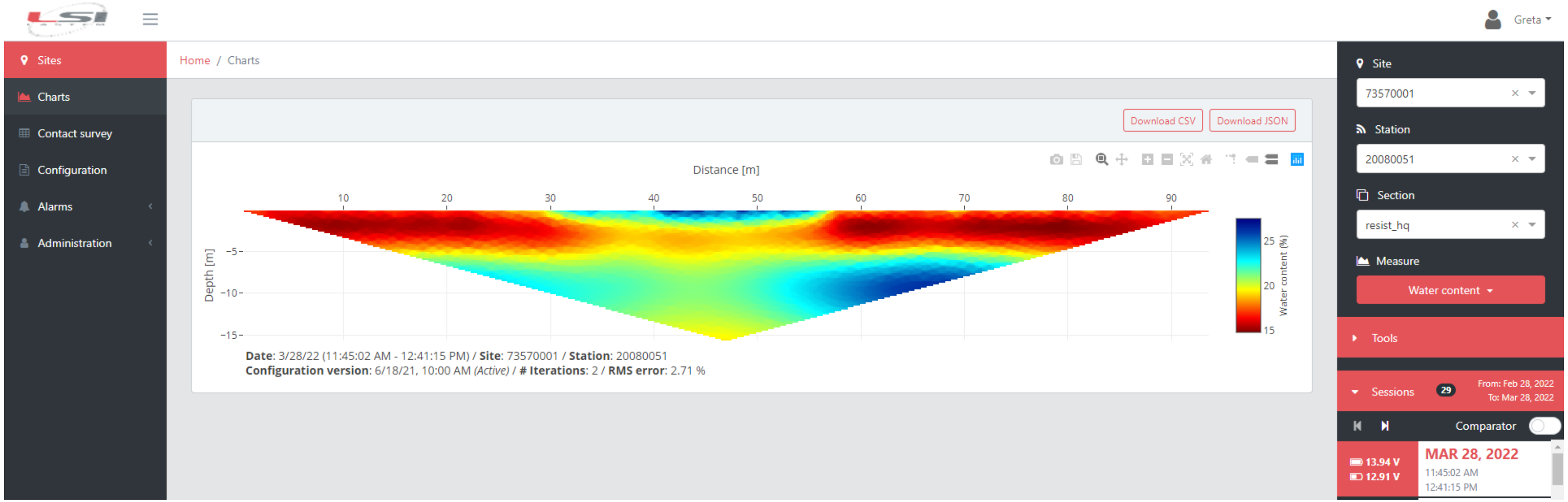
Piezometers' data

Name	Unit	Water depth	Position
P4-875-22.5-VW-E_Freq	m	5.278	70

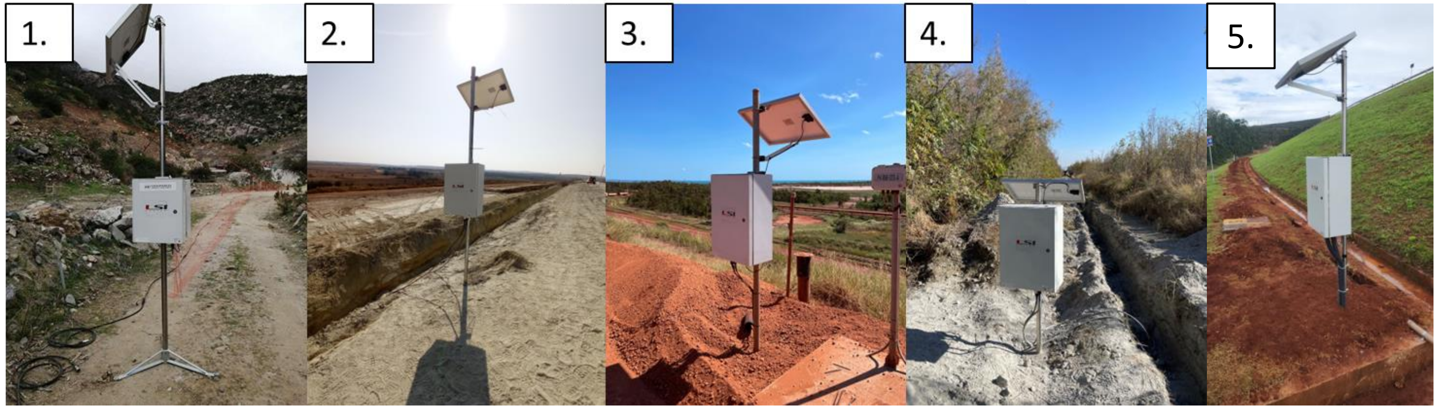
Site: Pond 4 – Northern Embank...
Station: Pond 4 – Northern Embank...
Section: GROUND
Measure: Resistivity
Tools
Filter by date: 01/28/2025 - 02/28/2025
Min: 1,1874 Max: 82,300 Lock
Max/Min Diff: 0 Lock
Apparent resistivity / piezometers
Additional data / Only enabled sessions
Sessions 30 From: Jan 28, 2025 To: Feb 28, 2025

Soil's % water content calculation after system calibration

After system calibration through core samples extracted at different depths



– Case Studies –
ERT for Tailings Dams Monitoring



1. Copper mine in Chile
2. Gold mine in South Africa
3. Bauxite mine in Australia
4. Platinum mine in South Africa
5. Iron Mine in Brazil

LSI LASTEM Environmental Monitoring Solutions

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Geo Resistivimeter for Time-lapse Analysis

Case Study #2

September 2022

Tailings Dam Monitoring
Gold Mine in South Africa

Installation in a gold mine’s TSF in South Africa

Step 0 (in office)

- Modem Router Configuration with local SIM card
- https://www.youtube.com/watch?v=xDZm4GDoWfQ&pp=ugMICgJpdBABGAE%3D

Installation in a gold mine's TSF in South Africa

Actual installation took less than 4 hours (6 Steps)

Step 1

- Plynth installation
- Trench excavation

Step 2

- Box and solar panel mounting

Installation in a gold mine's TSF in South Africa

Step 3

- •Cables laying down
- •Electrodes assembly

Step 4 - 5

- •Electrodes coverage
- •Contact resistence test

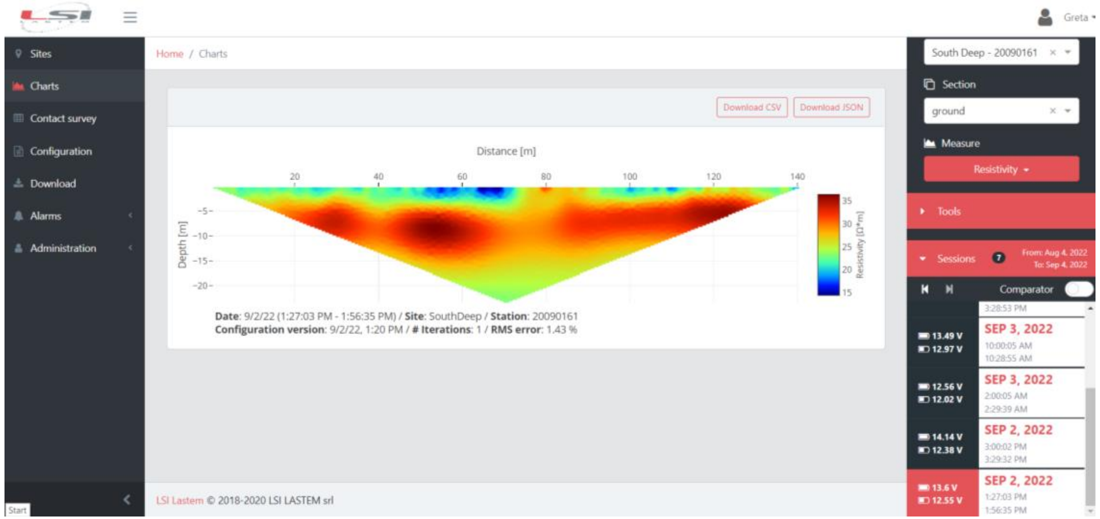
Im	R
0	50
1	66
2	89
3	77
4	79
5	77
6	86
7	75
8	80
9	82
10	69
11	74
12	70
13	72
14	76
15	80
16	71
17	71
18	86
19	68
20	56
21	61

Installation in a gold mine’s TSF in South Africa

Step 6

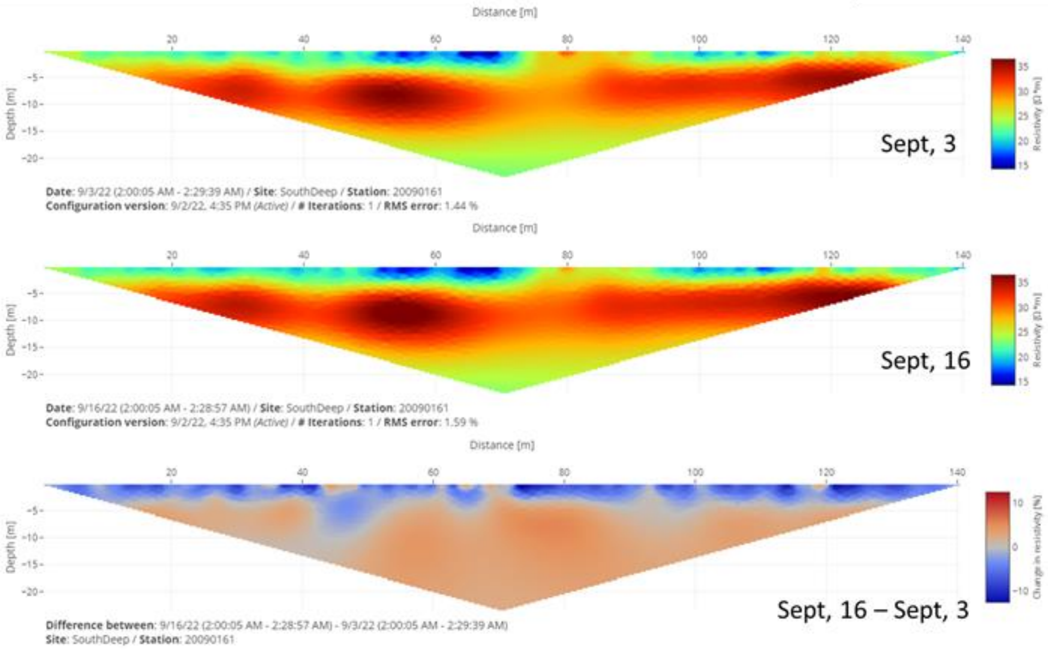
- Trench closure

- Once turned on, the system automatically sent measures to the cloud platform



Installation in a gold mine's TSF in South Africa

- Quite homogenous soil with low resistivity: 15 - 35 Ωm
- Phreatic level (corresponding to resistivity ~ 25 Ωm) almost at 15 m depth
- Rainfall infiltration caused -10% in resistivity in the first 2 to 5 m



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Geo Resistivimeter for Time-lapse Analysis

Case Study #3
July 2023

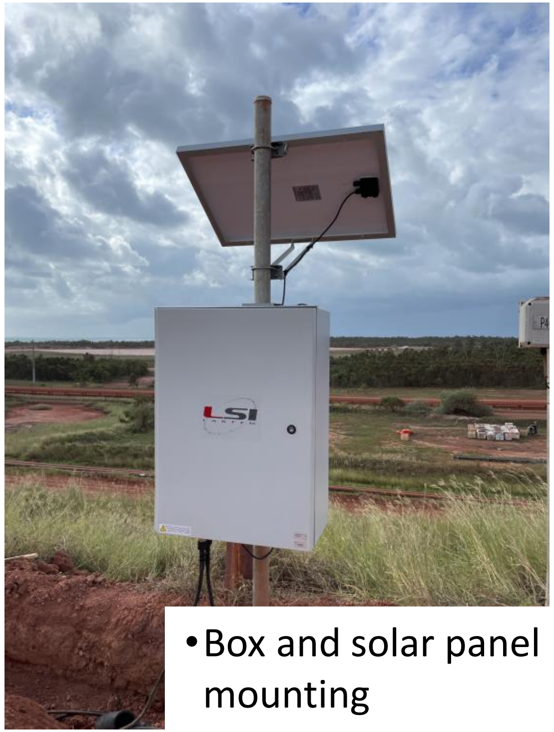
Tailings Dam Monitoring
Bauxite Mine in Australia

Installation in a bauxite mine's TSF in Australia

Step 1

- Trench excavation
- Plynth installation

Step 2



- Box and solar panel mounting

Installation in a bauxite mine’s TSF in Australia

Step 3

•Cables laying down
•Electrodes assembly

Step 4

•Electrodes coverage

Installation in a bauxite mine’s TSF in Australia

Step 5

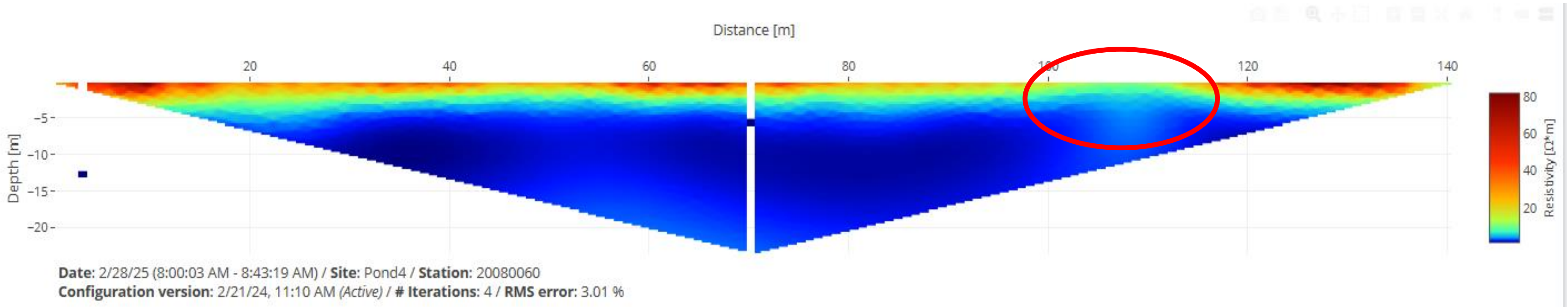
- Contact resistence test

Im	R
0	78
1	137
2	94
3	96
4	78
5	62
6	69
7	64
8	62
9	60
10	62
11	60
12	66
13	83
14	76
15	70
16	93
17	86
18	103
19	101
20	122
21	115
22	117
23	185
24	147
25	247
26	120
27	95
28	57
29	98
30	69
31	80
32	85
33	55
34	87
35	79
36	47
37	42
38	44
39	62
40	62
41	52
42	67
43	74
44	68
45	76
46	61
47	67

Step 6

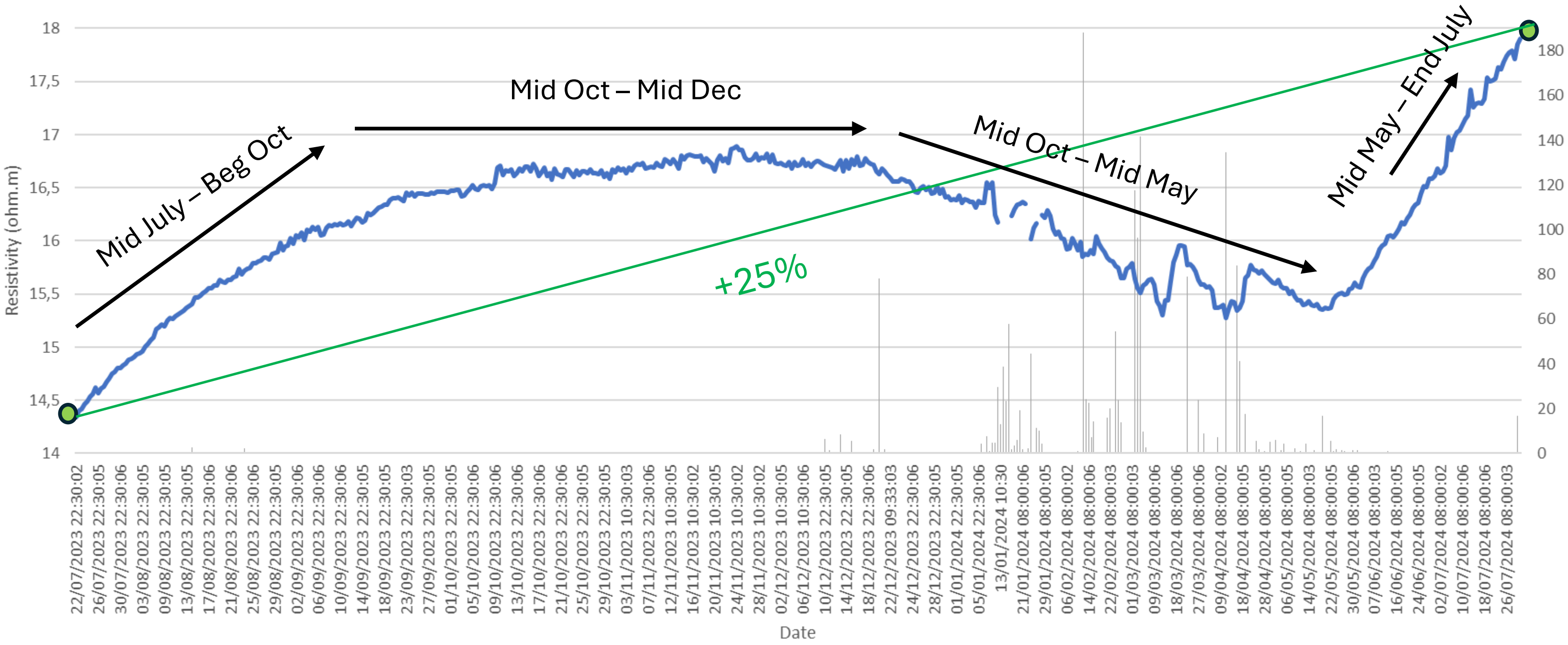
- Trench closure

Results



- High quality measurements (standard deviation < 2%)
- Low resistivities and stratification with small variation along the profile. On average:
  - 0-2 m: 65-10 Ωm
  - 2-5 m: 10-3 Ωm
  - 5-15 m: 2-1 Ωm
  - 15-22 m: 2-3 Ωm
- From m 100 to 115 low resistivity in shallow depth

1 Year time-lapse analysis
0-4 m cross section – Average resistivity



- Average resistivity values of first 4 m: increased during dry period, levelled for 3 months, then started decreasing during rainfall
- Average resistivity values @ end July ‘ +25% higher than @ beginning of monitoring ➔ assessment of dewatering process

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Geo Resistivimeter for Time-lapse Analysis

Case Study #4
August 2023

Tailings Dam Monitoring
Platinum Mine in South Africa

Installation in a platinum mine's TSF in South Africa

Step 1

- Trench excavation
- Plynth installation

Step 2

- Box and solar panel mounting

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Installation in a platinum mine's TSF in South Africa

Step 3

- Cables laying down
- Electrodes assembly

Step 4

- Electrodes coverage
Mix of Bentonite/Water/Soil

Installation in a platinum mine's TSF in South Africa

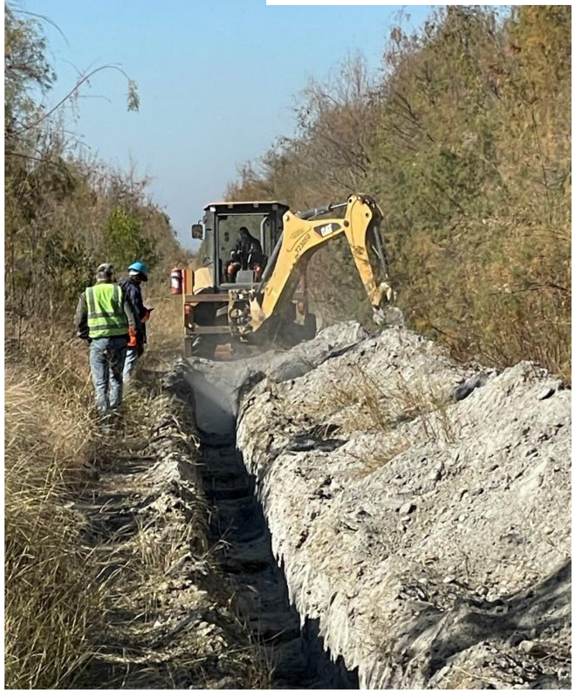
Step 5

- Contact resistence test

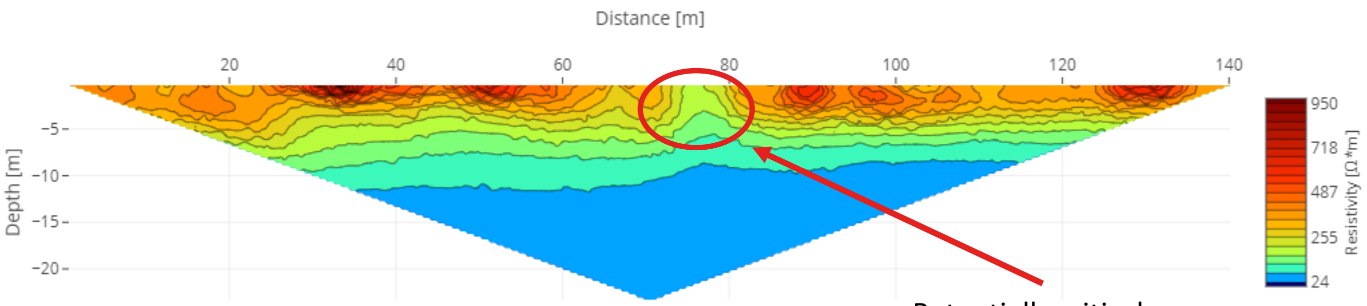
Im	R
0	342
1	380
2	331
3	338
4	355
5	275
6	236
7	155
8	256
9	356
10	419
11	311
12	329
13	400
14	357
15	297
16	307
17	392
18	358
19	484
20	521
21	371
22	377
23	317
24	300
25	314
26	318
27	368
28	473
29	308
30	541
31	315
32	464
33	397
34	400
35	283
36	319
37	290
38	267
39	413
40	393
41	307
42	473
43	422
44	427
45	579
46	551
47	329

Step 6

- Trench closure



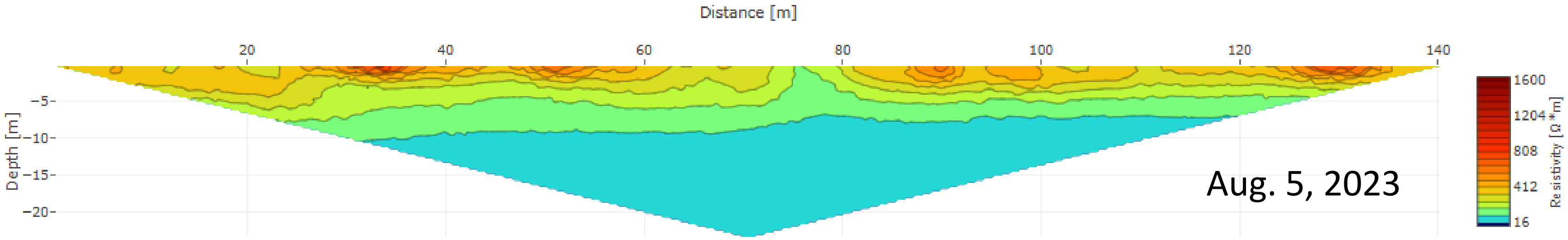
Results



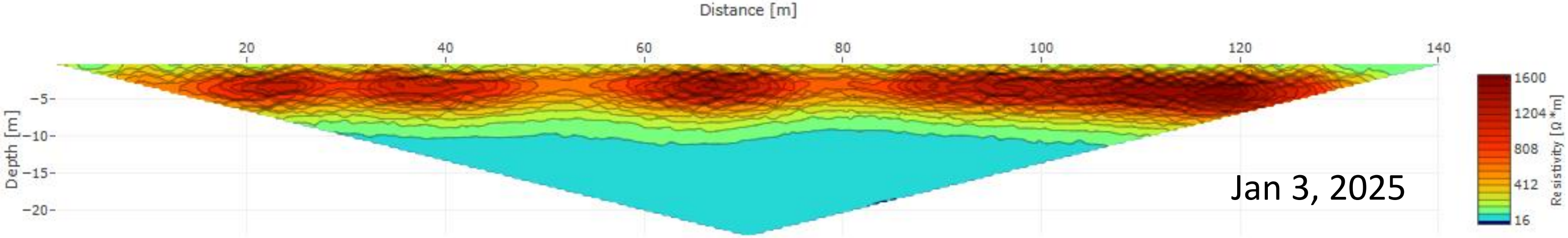
- **High Quality Measurements**:
  - standard deviation << 1%, usually <0.2%
  - really low RMS <3%

- **Vertical Stratification** with small variation along the profile (lower resistivity between 75-80 m). On average:
  - surface: 500-900 Ωm
  - 1-5 m: 500-200 Ωm
  - 5-8/10 m: 200-100 Ωm
  - below 10 m: <100 Ωm → likely saturated: piezometric data not present for correlation

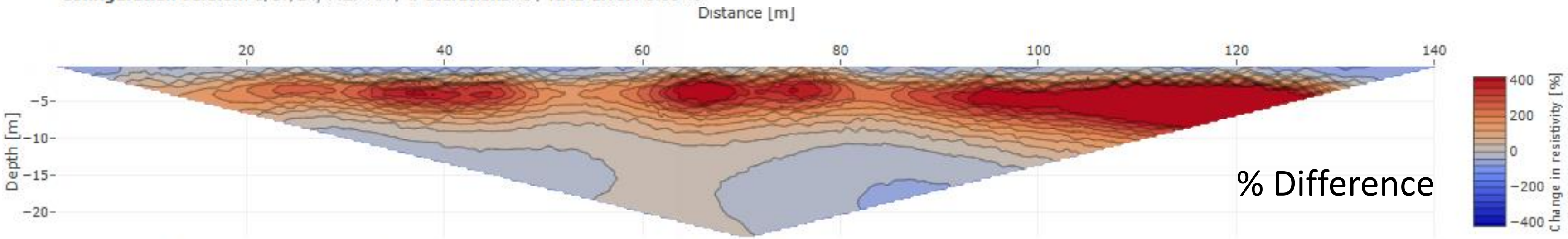
Resistivity comparison – Extreme drought



Date: 8/5/23 (9:00:06 AM - 9:35:36 AM) / **Site:** RBPlat / **Station:** RBPlat1
Configuration version: 8/4/23, 2:40 PM / **# Iterations:** 4 / **RMS error:** 2.55 %

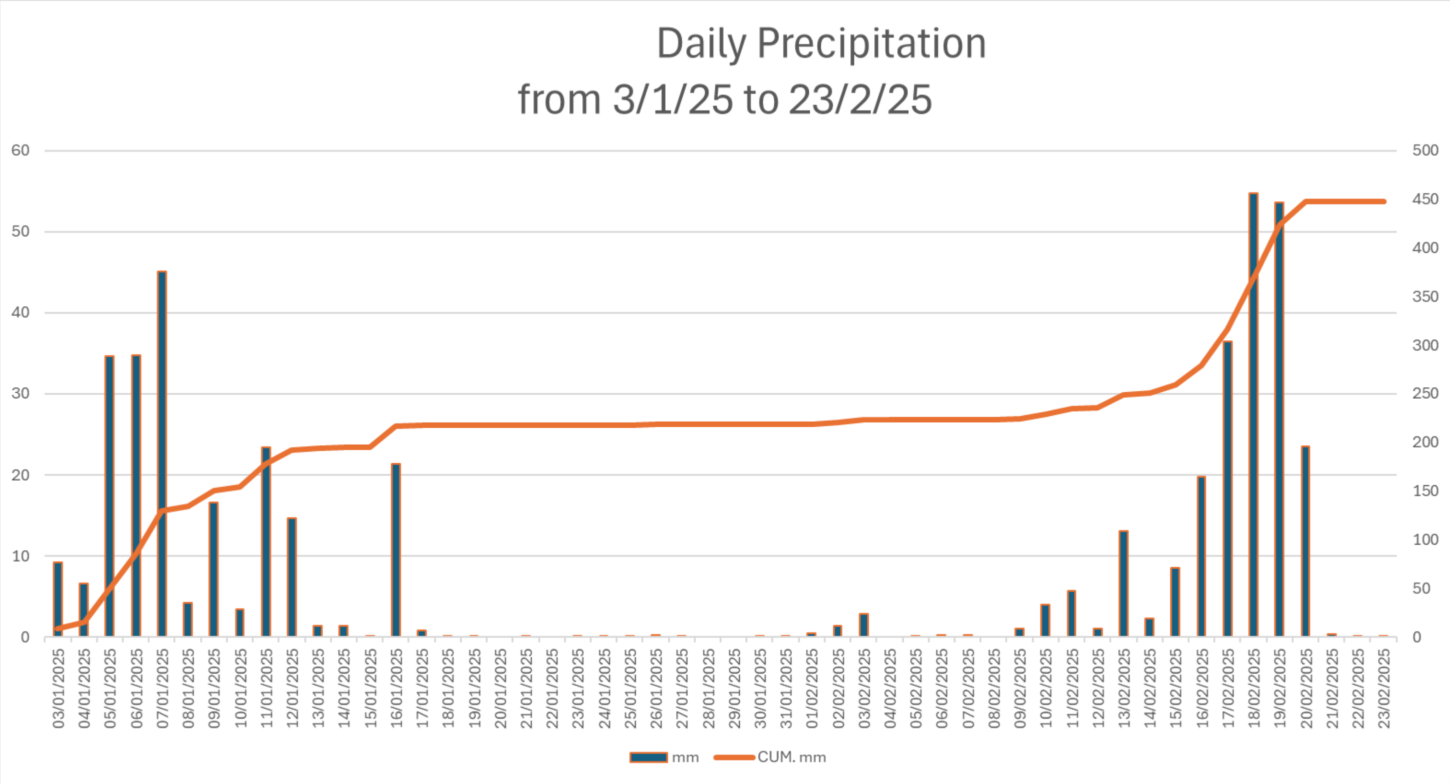


Date: 1/3/25 (9:00:04 AM - 9:30:31 AM) / **Site:** RBPlat / **Station:** RBPlat1
Configuration version: 5/17/24, 7:27 AM / **# Iterations:** 8 / **RMS error:** 8.86 %



Difference between: 1/3/25 (9:00:04 AM - 9:30:31 AM) - 8/5/23 (9:00:06 AM - 9:35:36 AM)
Site: RBPlat / **Station:** RBPlat1

Resistivity comparison – Wet season



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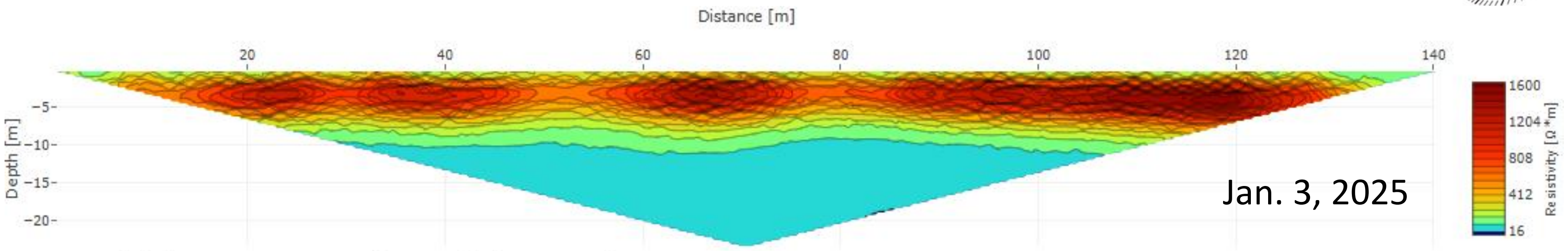
Resistivity comparison – Wet season



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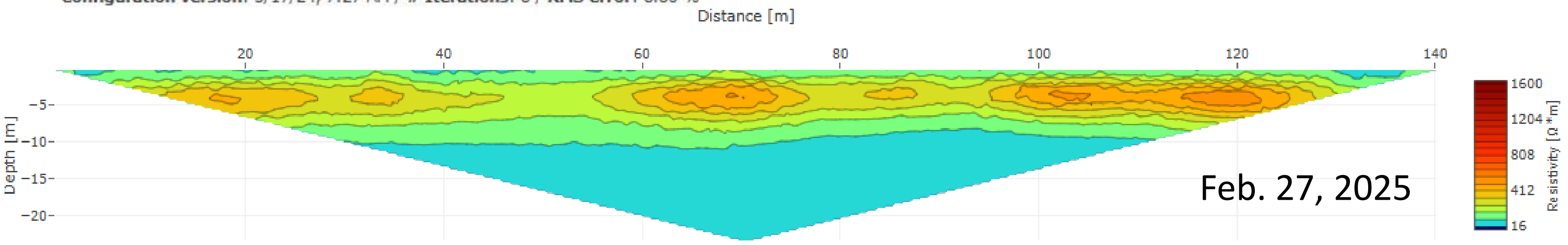
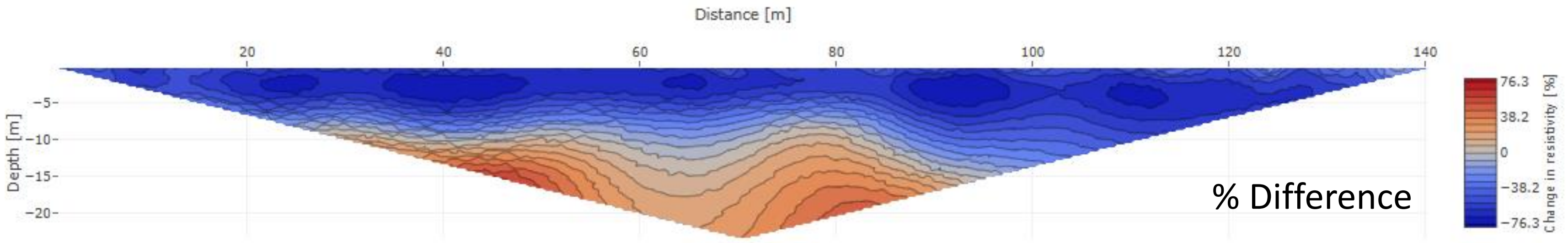
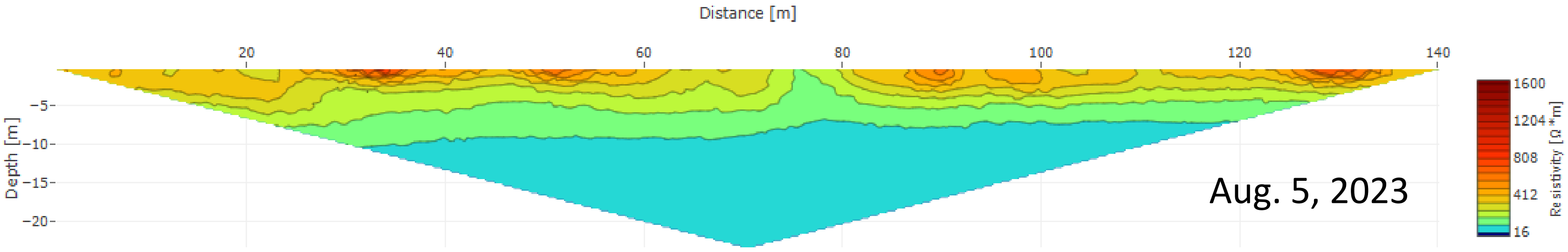


Date: 2/27/25 (6:00:06 PM - 6:52:00 PM) / **Site**: RBPlat / **Station**: RBPlat1
Configuration version: 2/24/25, 3:55 PM *(Active)* / **# Iterations**: 9 / **RMS error**: 4.44 %



Difference between: 2/27/25 (6:00:06 PM - 6:52:00 PM) - 1/3/25 (9:00:04 AM - 9:30:31 AM)
Site: RBPlat / **Station**: RBPlat1

Resistivity comparison – Entire period



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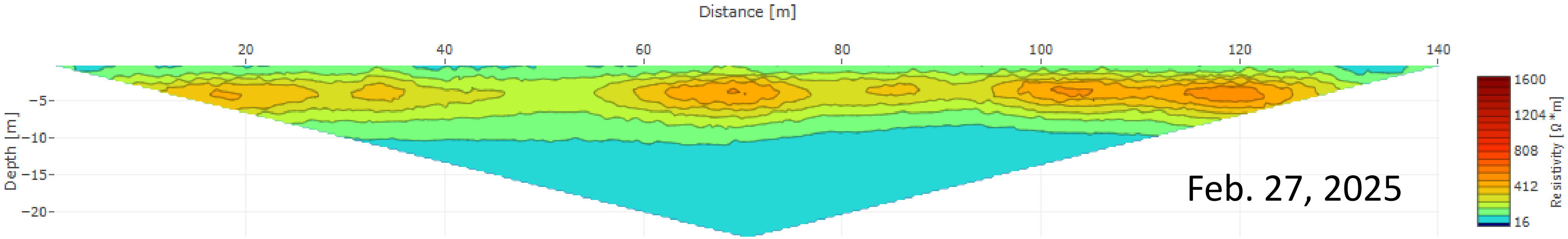
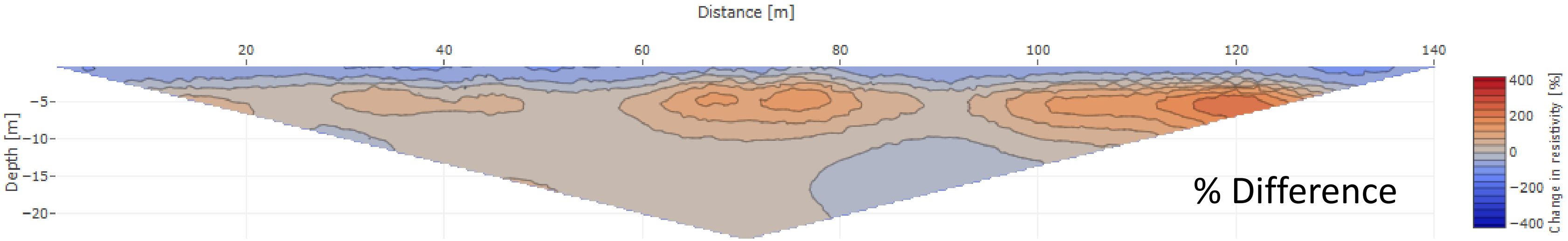
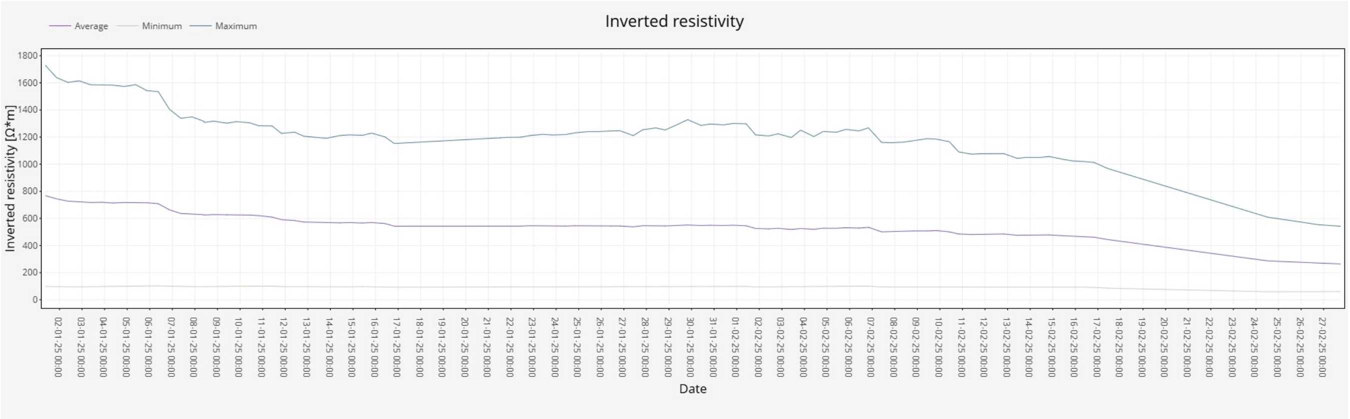


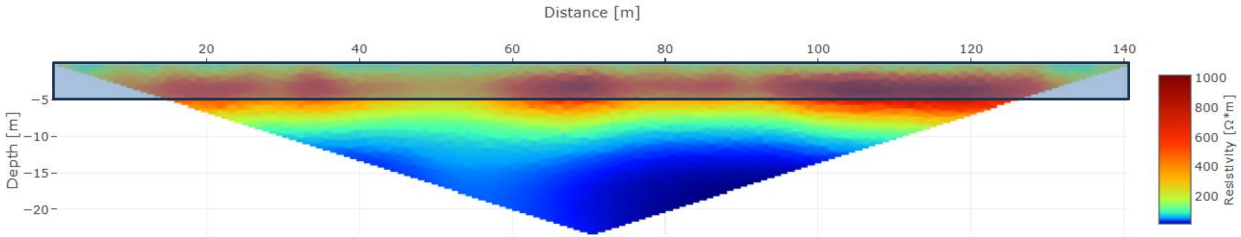
Date: 2/27/25 (6:00:06 PM - 6:52:00 PM) / **Site:** RBPlat / **Station:** RBPlat1
Configuration version: 2/24/25, 3:55 PM *(Active)* / **# Iterations:** 9 / **RMS error:** 4.44 %



Difference between: 2/27/25 (6:00:06 PM - 6:52:00 PM) - 8/5/23 (9:00:06 AM - 9:35:36 AM)
Site: RBPlat / **Station:** RBPlat1

Time lapse 0 – 5m
01/01/25 – 27/02/25

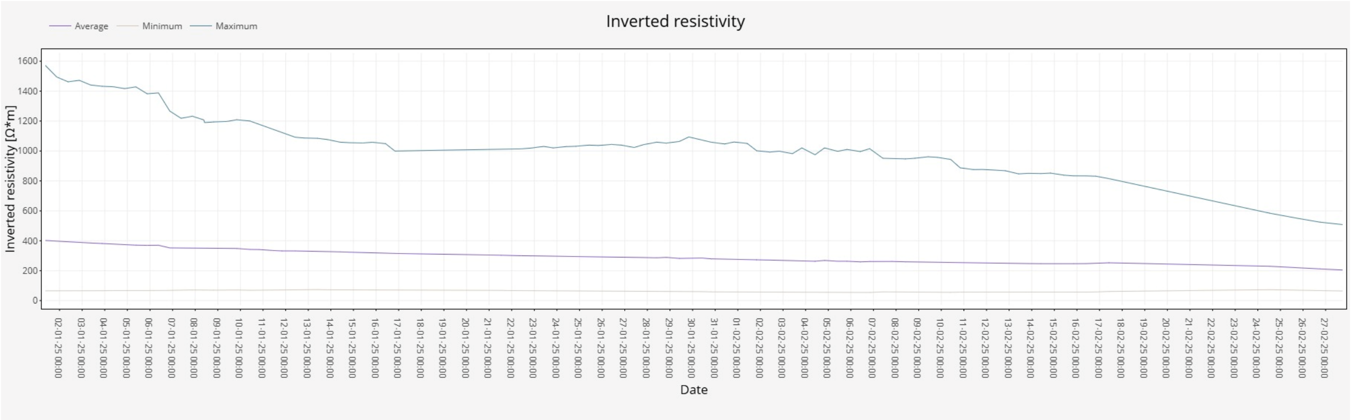


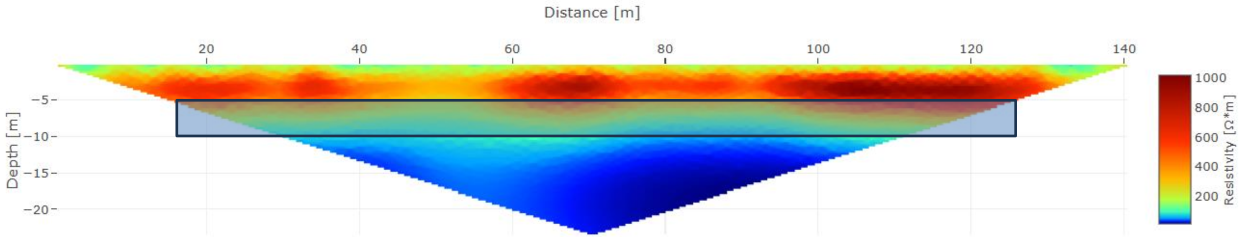


The time-lapse analysis of the 0-5 m section underlines:

- Resistivity values ranging between 150-1700 Ωm
- Decreasing of average and maximum values due to rainy period

Time lapse 5 – 10 m
01/01/25 – 27/02/25





The time-lapse analysis of the 5-10 m section underlines:

- Resistivity values ranging between 50-1600 Ωm
- Similar trend to surface: decreasing values due to rain infiltrating into deeper stratification

LSI LASTEM Environmental Monitoring Solutions

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Geo Resistivimeter for Time-lapse Analysis

Case Study #5
December 2024

Tailings Dam Monitoring
Iron Mine in Brazil

Installation in an iron mine's TSF in Brazil

Step 1

- Trench excavation
- Plynth installation

Step 2

- Box and solar panel mounting

Installation in an iron mine’s TSF in Brazil

Step 3

- Cables laying down
- Electrodes assembly

Step 4

- Electrodes coverage

Installation in an iron mine's TSF in Brazil

Step 5

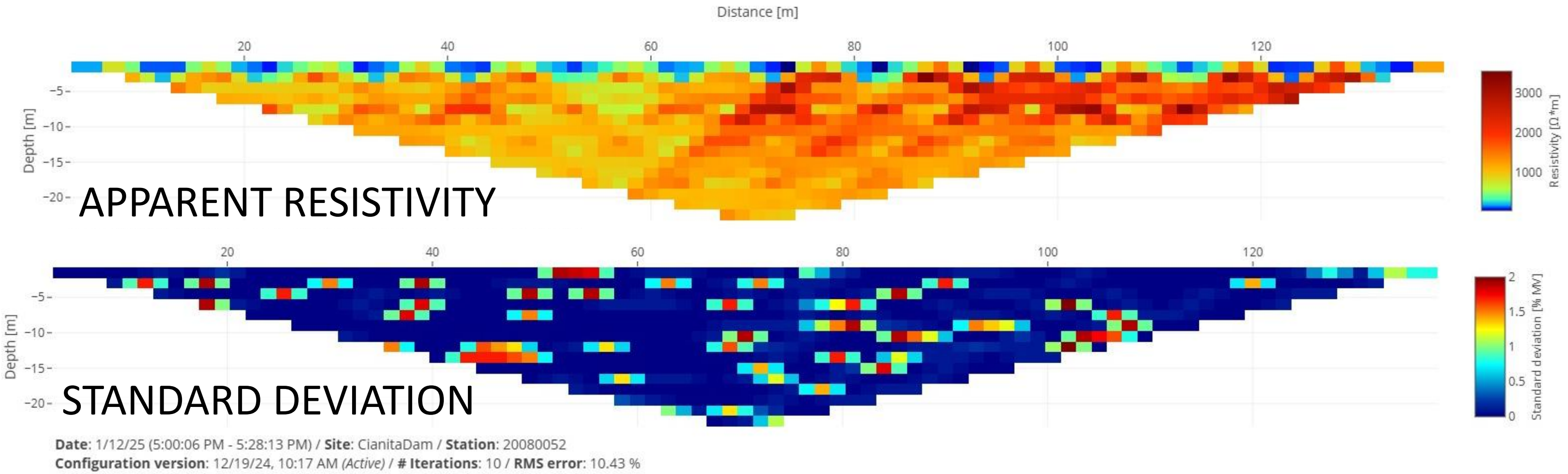
- Contact resistence test

Im	R
0	162
1	163
2	158
3	154
4	161
5	168
6	166
7	176
8	196
9	178
10	169
11	174
12	162
13	158
14	202
15	191
16	176
17	144
18	125
19	134
20	159
21	171
22	154
23	115
24	131
25	159
26	151
27	184
28	211
29	265
30	192
31	174
32	181
33	172
34	143
35	146
36	129
37	164
38	195
39	179
40	251
41	173
42	195
43	172
44	173
45	177
46	169
47	211

Step 6

- Trench closure

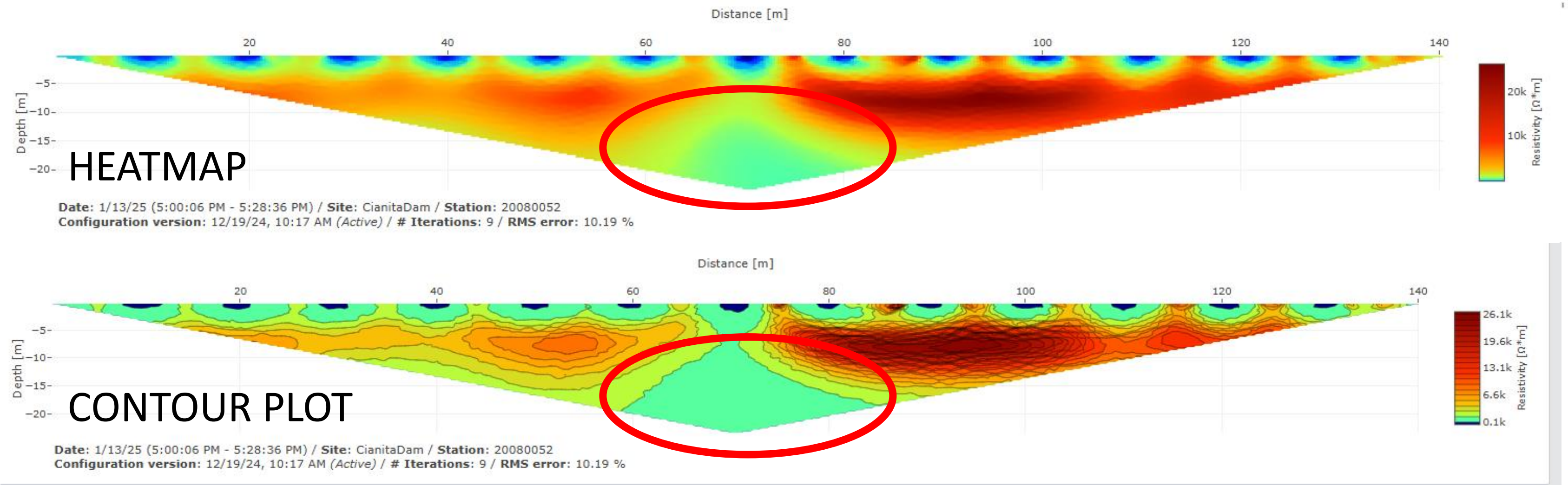
Results – Apparent resistivity



- High contrast between measured apparent resistivites:
  - Main body between 1,000-3,000 Ωm
  - On the surface extremely low resistivity values (100-200 Ωm) every 10 m

- Low standard deviations -> good data quality

Results – Inverted resistivity



- Low resistivity zones at the surface, spaced exactly 10 m each, probably related to underground structures: metal pipes, metallic grid (?)
- Low resistivity area (400-500 Ωm) in the bottom central part (m. 65-80) underlying water infiltration -> critical area that needs to be monitored

Conclusions

GRETA
Geo Resistivimeter for Time-lapse Analysis

- **Geoelectrical measurements** provide useful information for tailings and earth dams management for seepage detection, saturation monitoring, dewatering processes assessment, since resistivity is related to water content.
- **Geoelectrical automatic monitoring** over time is the key to follow the evolution of underground water-related-processes in real-time.
- **G.Re.T.A.** is an effective and innovative off-the-shelf solution that represents a strong opportunity for the mining industry to significantly improve TSF monitoring strategy as requested by GISTM.


GLOBAL INDUSTRY STANDARD ON TAILINGS MANAGEMENT

AUGUST 2020

Cloud Platform Live Demo

Q&A Session

Environmental
Monitoring Solutions

GRETA
Geo Resistivimeter for Time-lapse Analysis

Electrical Resistivity Tomography (ERT) for Tailings and Earth Dams Monitoring

12 March 2025

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thank you

Upcoming events

ICOLD 2025
16 – 23 May
Chengdu (China)
Booth B134

Mine Waste & Tailings 2025
29 – 30 July
Brisbane (Australia)
Booth #61

Tailings 2025
3 – 5 September
Santago (Chile)
Booth #6

Tailings and Mine Waste 2025
2 – 5 November
Banff (Canada)
Booth TBD

For any further information, please contact

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