Development of Low Cost Autonomous Electrical Resistivity Monitoring Systems for continuous active-layer monitoring in harsh environment

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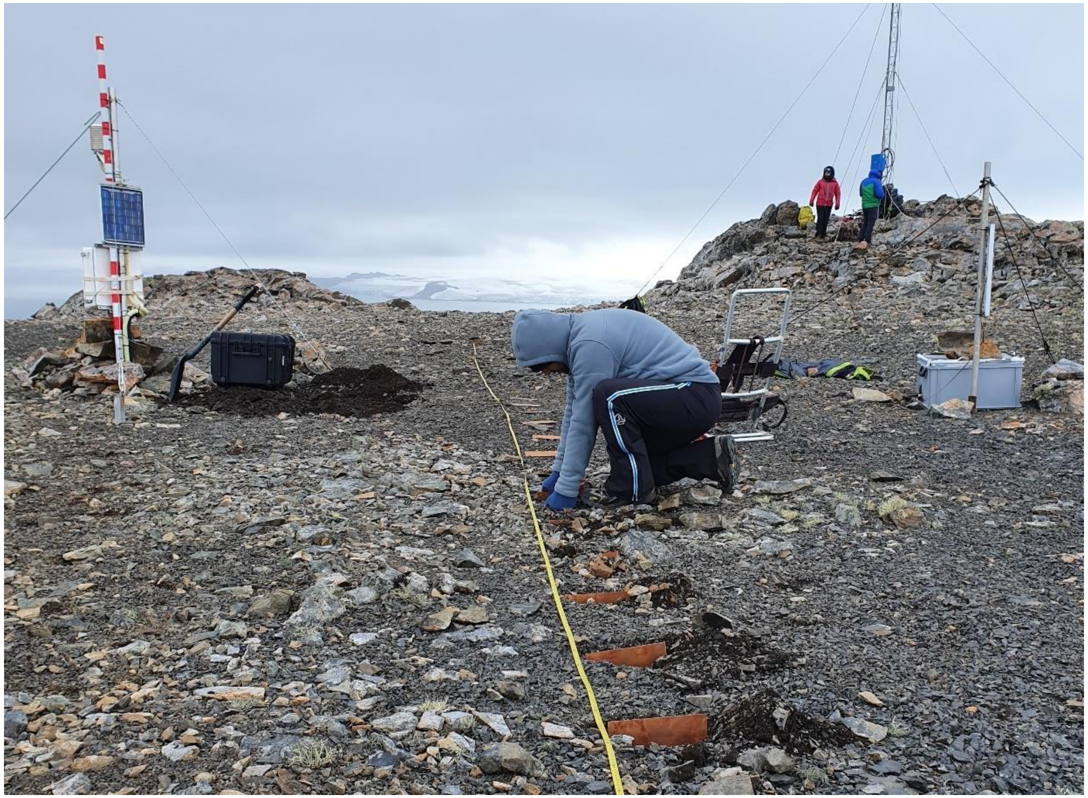


Outline

- Background
- ANTERMON- ANTarctic Electrical Resistivity Monitoring Network
- Development of Low Cost A-ERT Systems
- Environmental monitoring setup (Deception Island)
- Example of observational data
- Example of A-ERT results
- Conclusion and outlook

Background

- Western Antarctic Peninsula (WAP) is also one of Earth's regions with strongest air temperature increase, at least since the 1950's. The last overview of the thermal state also shows that permafrost is close to 0ºC in the region suggesting that the region is near its climatic boundary. A continuous monitoring of the active layer is therefore essential to understand the permafrost dynamics and its potential impacts on climate feedback and local ecology.

- Monitoring of the active layer/permafrost dynamics in Antarctica was conducted using only 1-dimensional borehole and meteorological data:
    i. Restricted the analysis to point information that often lack representatives at the field scale.
    ii. Drilling is very expensive in Antarctica.
    iii. Being an invasive technique, drilling of boreholes disturbs the subsurface and is not feasible to conduct over large areas, especially in environmentally sensitive ecosystems such as the Antarctic.
    iv. Freeze-thaw process of active layer cannot be easily assessed by temperature loggers as phase changes are not clearly seen.
    v. Does not provide information about ice/water content.
    vi. Does not provide information about transient layer.
    vii. Does not provide enough information to study the impact of extreme short-lived meteorological events on active layer and permafrost dynamics.

ANTERMON: ANTarctic Electrical Resistivity Monitoring Network

❖ ANTERMON aims to establish an observation network in Antarctica based on the soil electrical resistivity monitoring using geophysical techniques to improve the spatio-temporal understanding of active layer and permafrost dynamics with minimal environmental disturbance.

✓ A-ERT systems are installed in the Global Terrestrial Network for Permafrost (GTN-P) and the Circumpolar Active Layer Monitoring (CALM) sites, where air, surface and ground temperatures as well as snow thickness and thaw depth are being monitored. A-ERT systems are monitoring electrical resistivity in 6h interval at the same times in all sites.

➢ Main Objectives

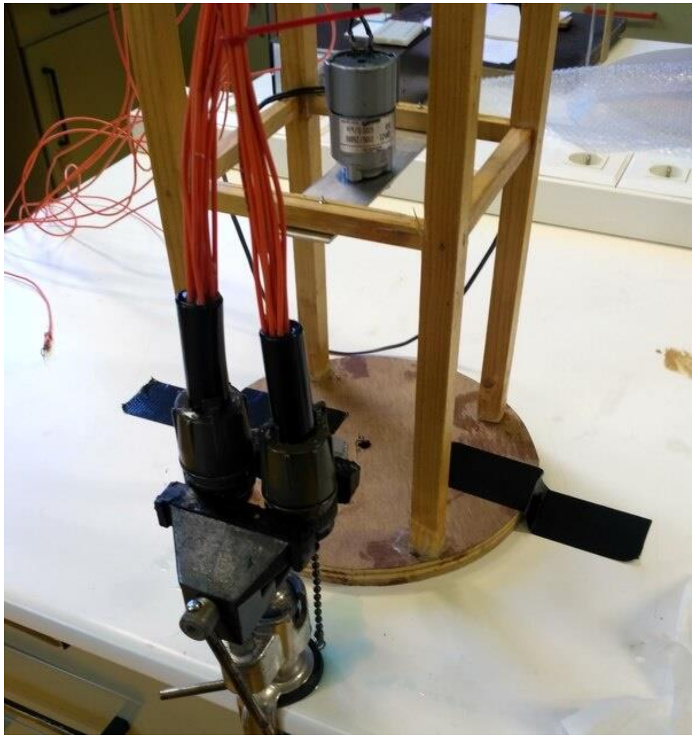
I) Evaluating the feasibility of installing and running automatic ERT monitoring stations in remote and extreme environment of Antarctica.

II) Monitor subsurface freezing and thawing processes on daily and seasonal basis.

III) Study the impact of extreme short-lived meteorological events on active layer and permafrost dynamics.

IV) Study the ice/water content and investigate how freezing and thawing processes impact the transient layer.

Development of a Low Cost A-ERT System



System requirements

- Weatherproof
- Autonomous and low-power
- Low cost

Rationale

Weatherproof:

- Antarctica => harsh environment

Autonomous/low-power:

- The staions are only summer operetated: time lapse between field campaigns ~ at least 10 months;
- account for several weeks without solar power due to meteorological conditions (even though system locations far north of polar circle)

Low-cost:

- tight budget

Development of a Low Cost A-ERT System

System development

Weatherproof:

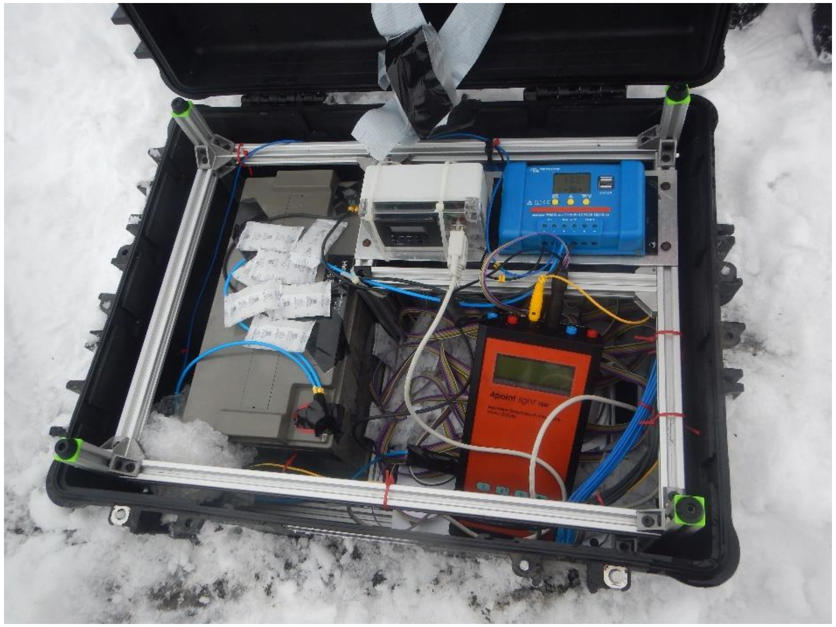
- costumized water resistant case (IP67 and MIL 810F rated)
- ruggedized mil rated connectors for cabling (power and electrodes)

Autonomous/low-power:

- Resistivity meter 4POINTLIGHT_10W in autonomous/monitoring mode;
- oversized deep cycle gel battery (110Ah cold rated, roughly 3 months of operation w/o solar power);
- simple timer programmed to switch on/switch off the resistivity meter before/after each data aquisition instance (4xday, 6hrs interval; less power drain on the system);
- 2 small solar panels (30W, near vertical tilt, northern orientation)

Low-cost:

- tight budget



Total cost

- current system configuration ~2k€ (w/o switch box and resistivity meter):
  - w/ switch box ~4k€
- hardware and supplies costs only; no build man/hours accounted

Bills of Materials (BOM):

- Open source BOM here:
  - https://octopart.com/bom-tool/U9ucfBuV (85% complete)
  - battery solar panels and controller ~370€
  - water resistant case ~330€
  - The supporting structure ~300€

Development of a Low Cost A-ERT System

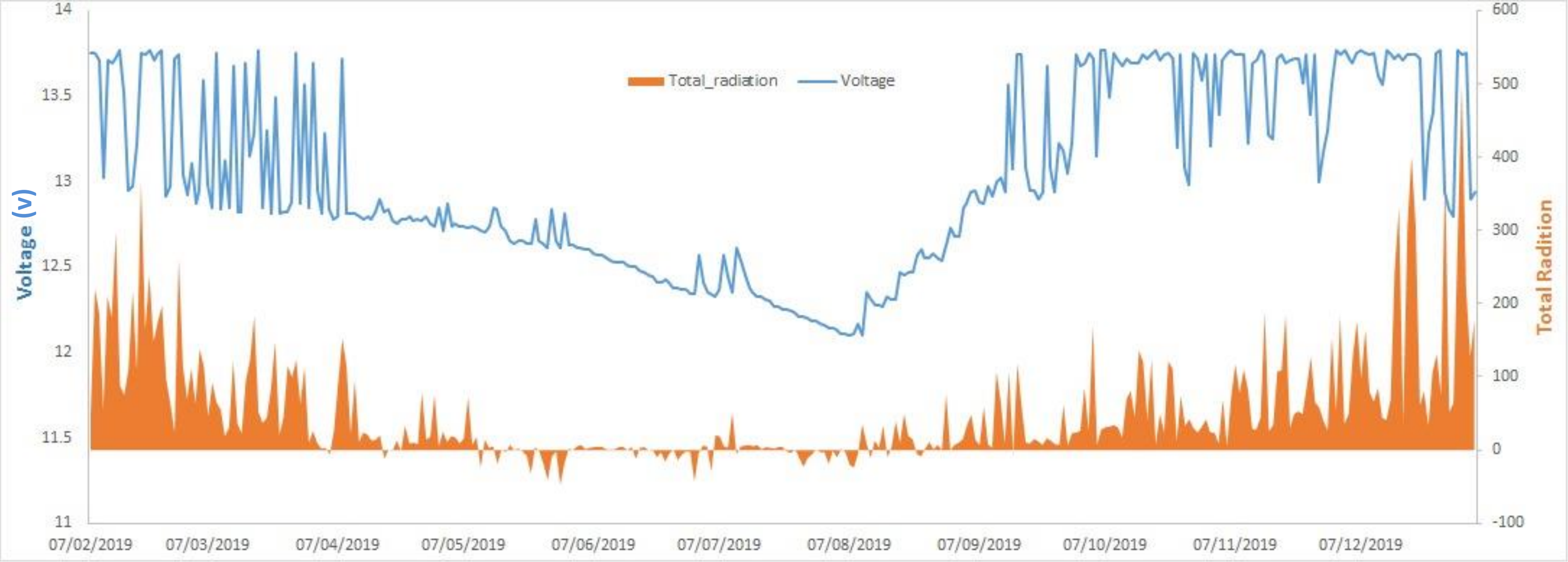
In the field

Weatherproof:

- system #1 (Decepcion) w/o issues after 2 years of continuous operation, The last visit in early 2021.
- system #2 (Livingstone) no inspection has been made yet since the first instalation in early 2020.

Power:

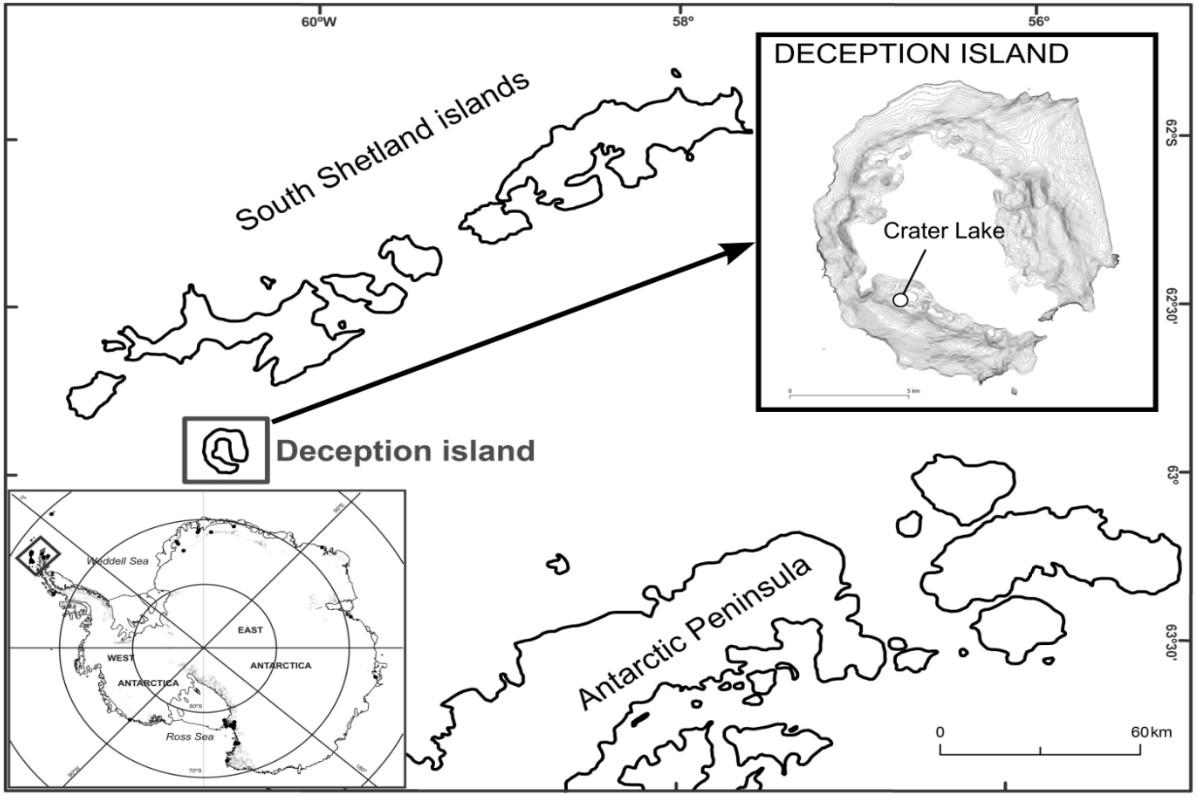
- systems capable of withstanding winter months w/o (or at minimum level) solar power (battery voltage never dropped below 12V, see graph below)



Environmental monitoring setup (Deception Island)

Deception Island

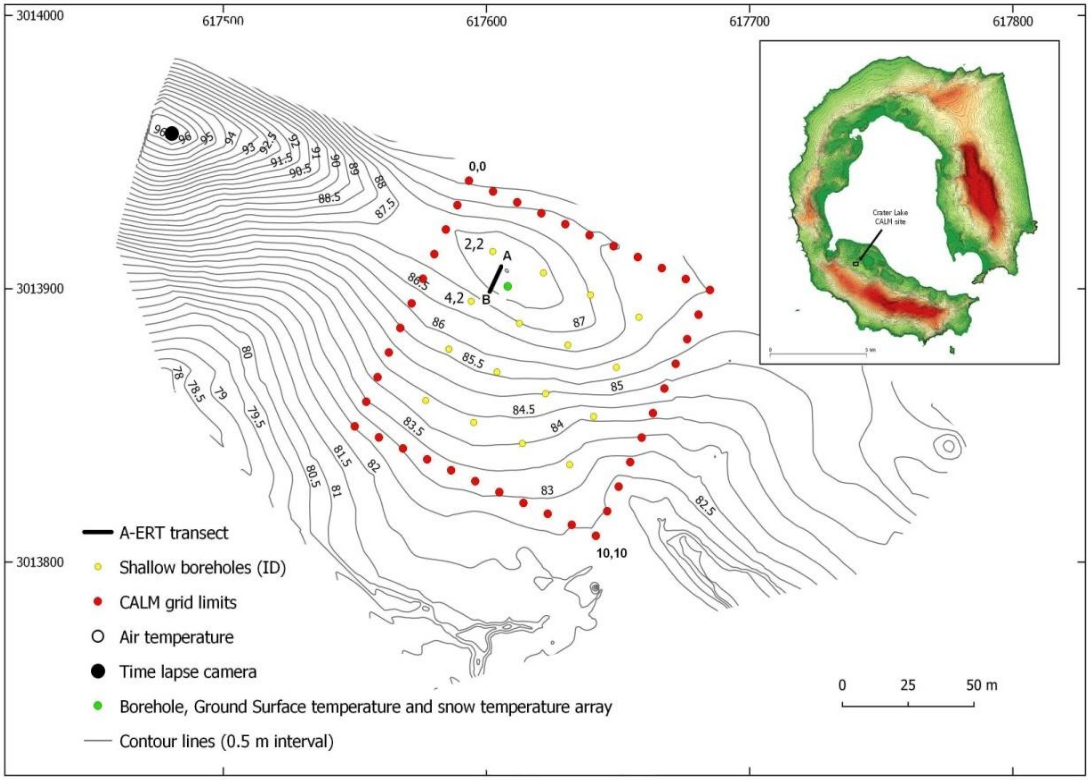
- Permafrost temperatures are slightly below 0 °C in this island, showing that the region is near its climatic boundary, thus being probably one of the regions with highest sensitivity to climate change in the Antarctic.



Location of Deception Island and Crater Lake CALM-S site in Antarctica

Environmental monitoring setup (Deception Island)

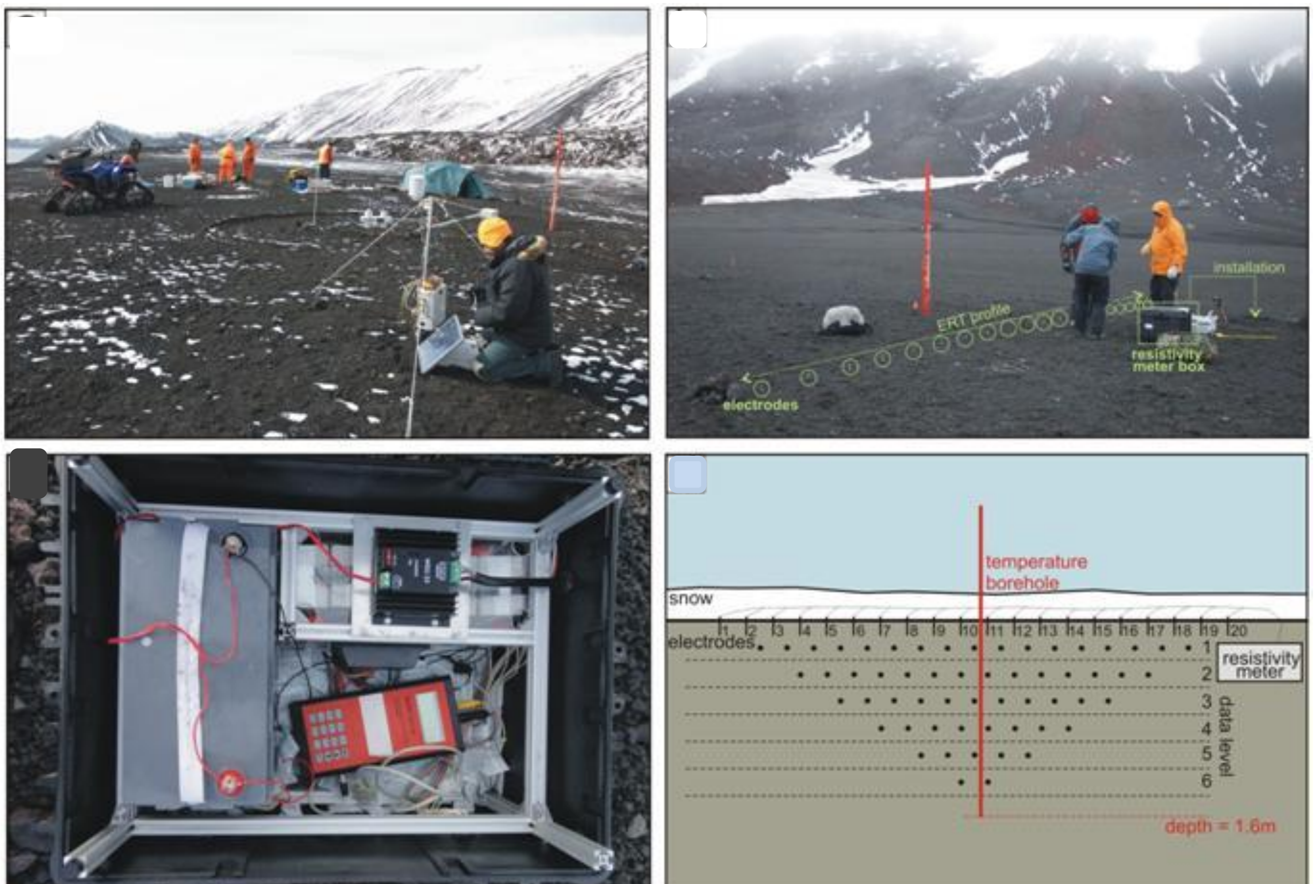
- Air temperature / 160 cm height / 1h
- Borehole temperature / 2.5, 5, 10, 20, 40, 80, 160 cm / 3h
- Snow stakes / 2.5, 5, 10, 20 ,40, 80 cm heights/ 3h
- Snow Pack Analyzing System
- Shallow temperature / Close to the base of the active layer (40 cm) / 20 m interval/ 3h
- Time-lapse camera with daily pictures at 11:00, 12:00 and 13:00 (local solar time)



Environmental monitoring setup (Deception Island)

A-ERT set up

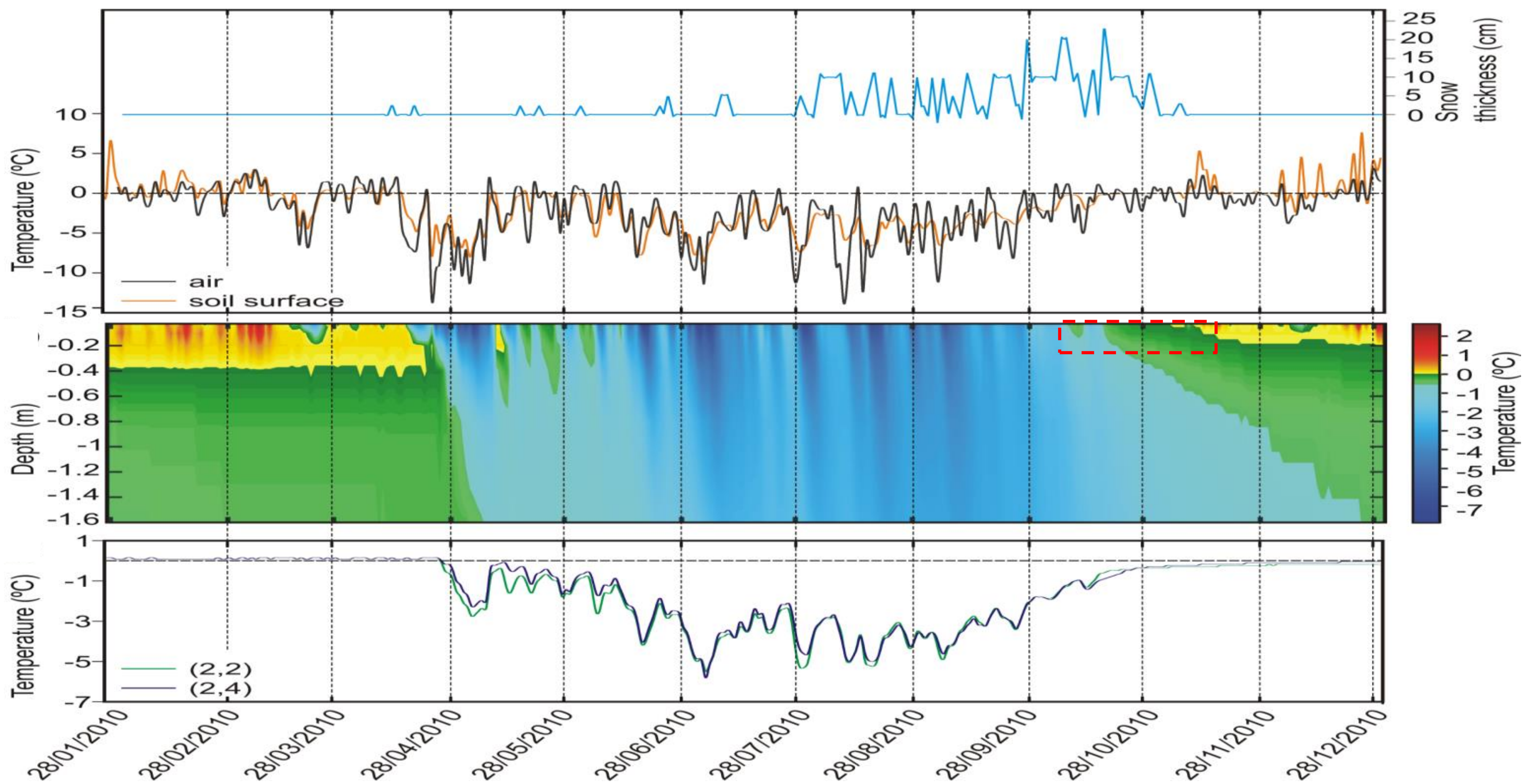
- A robust, water-proof box, casing the 4POINTLIGHT_10W instrument
- Solar panel-driven battery and multi-electrodes connectors
- Wenner electrode configuration, 20 electrodes
- 6h interval / 56 individual data points



Example of observational data

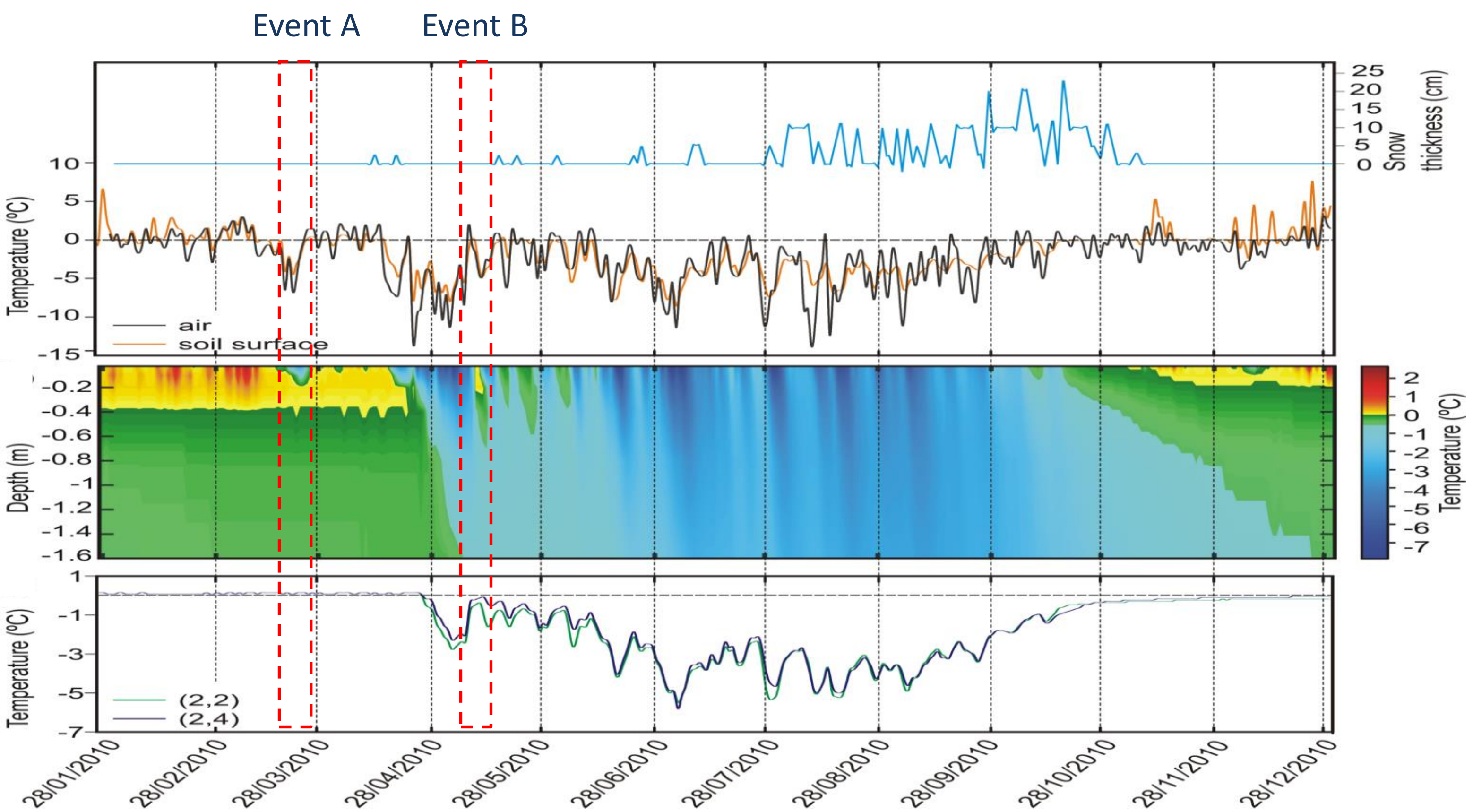
Climate and Borehole data (2010), measured close to the A-ERT system

- The zero-curtain phase in spring is around 1 month, whereas no significant zero-curtain can be seen in autumn due to the low air and soil surface temperatures and the absence of a snow-cover during freezing season.



Example of observational data

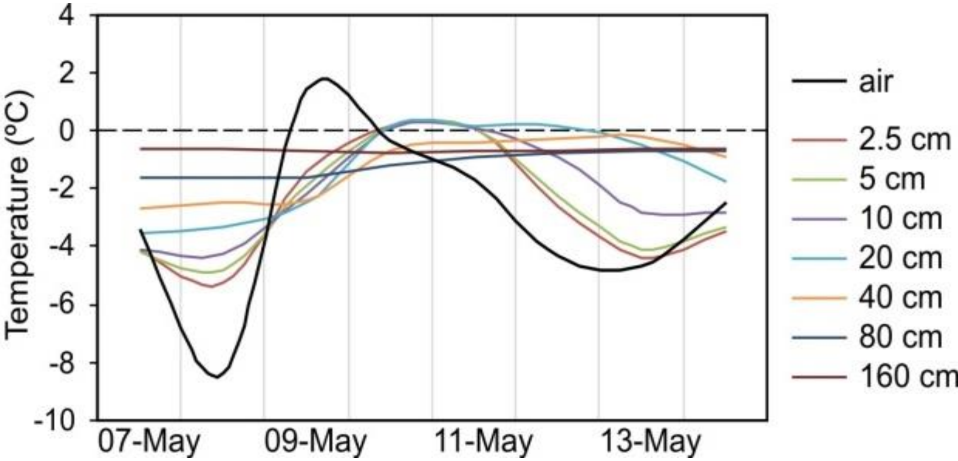
- Short-lived meteorological events with quick and superficial changes of the ground temperature around 0 ºC are quite frequent during the study period. Consequently, brief refreezing (e.g. in March, April, and December- Event A) and thawing of the active layer (May-Event B) can be identified in the summer and winter respectively.



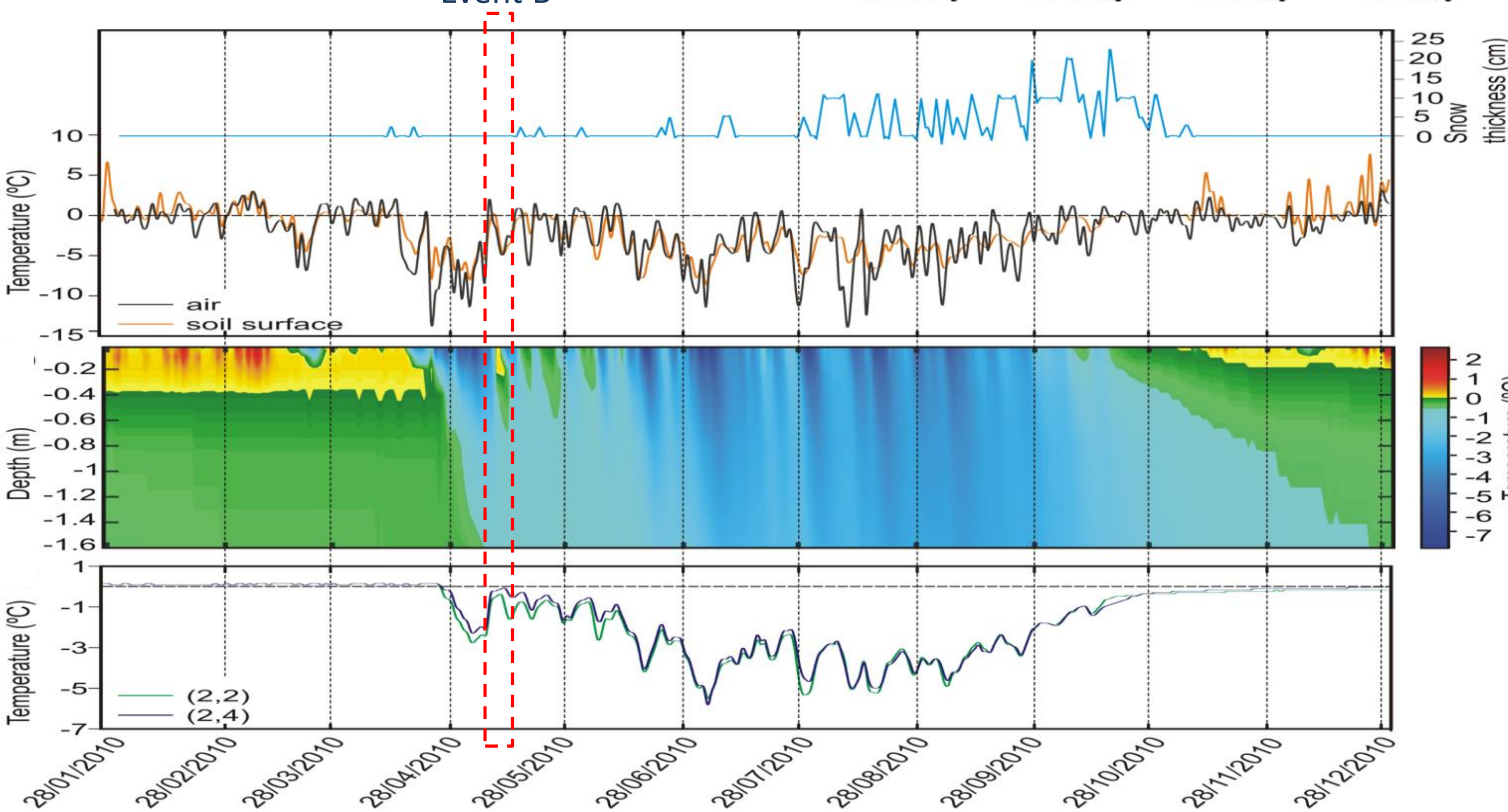
Example of observational data

Example of the short-lived meteorological events and its impact on active-layer dynamic (Event B)

- A drastic rise in the air temperature from -8.4 to 1.4 ºC is evident on May 9.
- The warm air influenced the ground temperature immediately and generated an abrupt phase change in the top 20 cm on May 10.

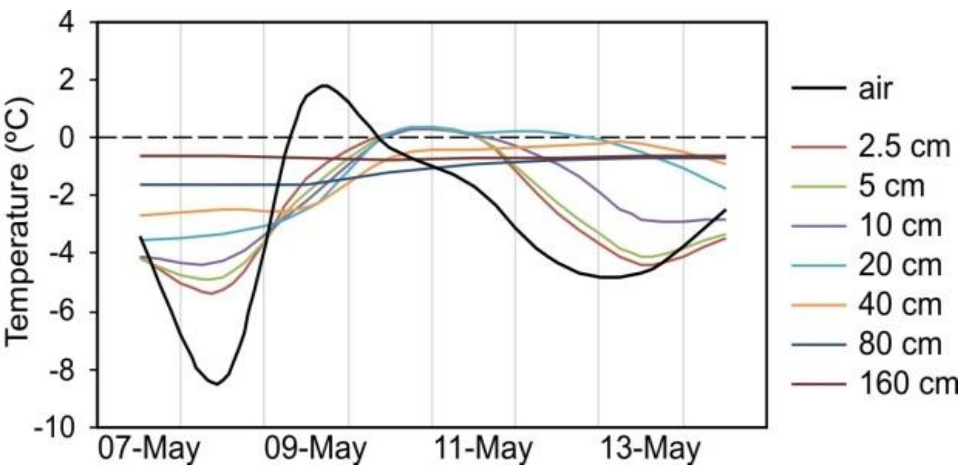


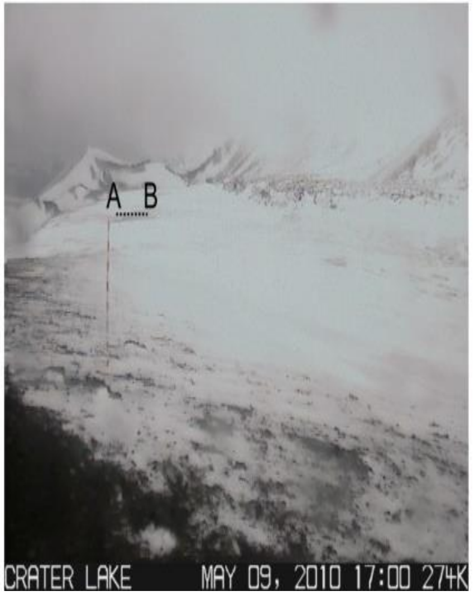
Event B



Example of observational data

- The time-lapse camera photos taken on May 9 show clearly the fast snow melt between 11h00 and 13h00 on this day, which might explain the quick subsurface temperature rise due to the infiltration of the melted snow to the soil subsurface. **Can we detect the impact of this event on active layer from the A-ERT images?**





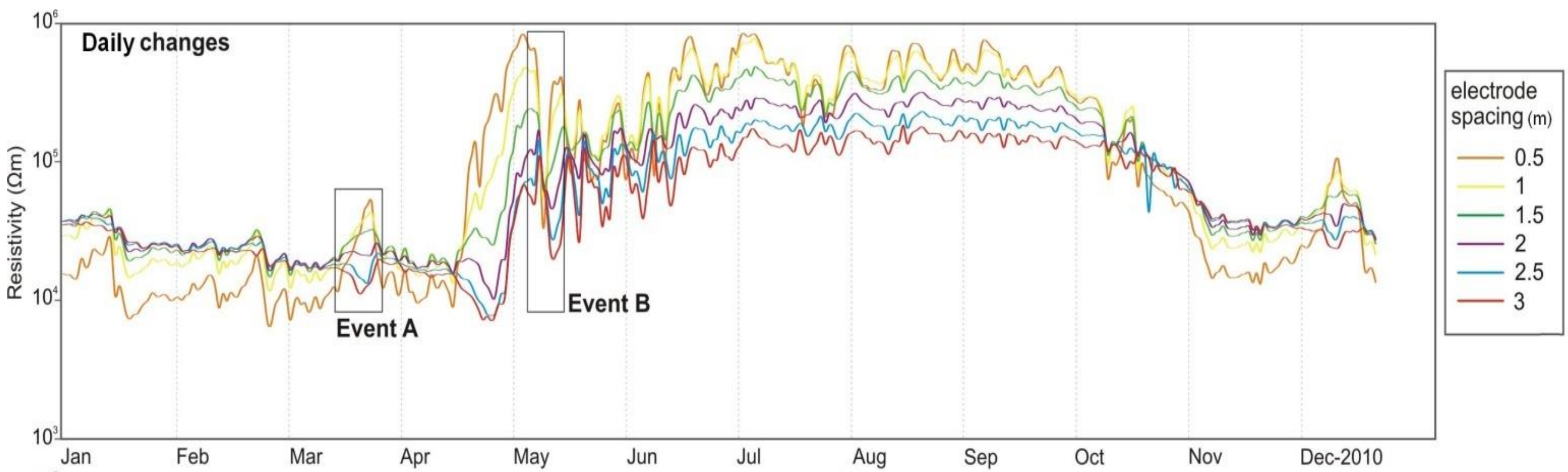
Example of A-ERT results

Mean apparent resistivity data during 2010 for different electrode spacing on a daily scale

➢The data collected at a=0.5 and 1 m levels reveal a sharp resistivity rise on April, 19th suggesting the beginning of the seasonal freezing of the active layer. The delayed response of deeper levels indicates the advancing freezing front and is coincident with the gradual decrease of the active layer temperature with depth.

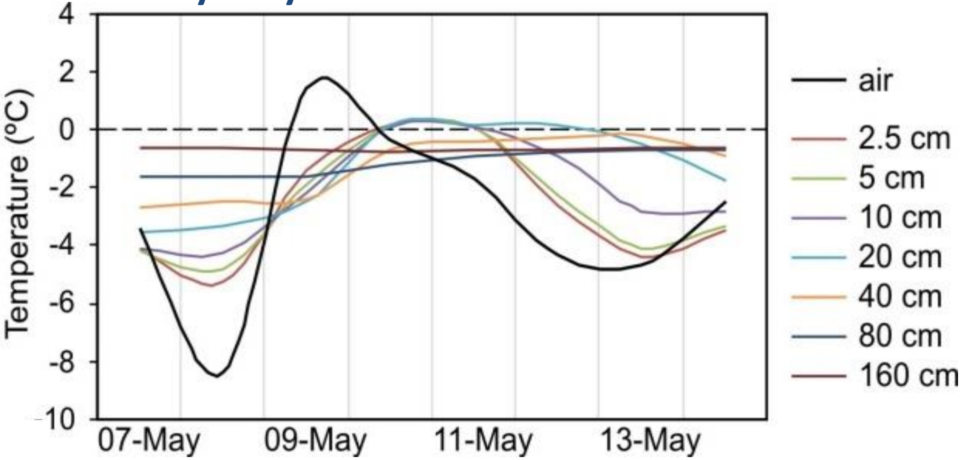
➢The beginning of the seasonal thawing phase is associated with the steady decrease of apparent resistivity, starting on October 4th. During the seasonal thawing of the active layer, the snow cover dampens the thawing effect. This zero-curtain phase was reflected in the steady decrease of apparent resistivity, recorded by the A-ERT system.

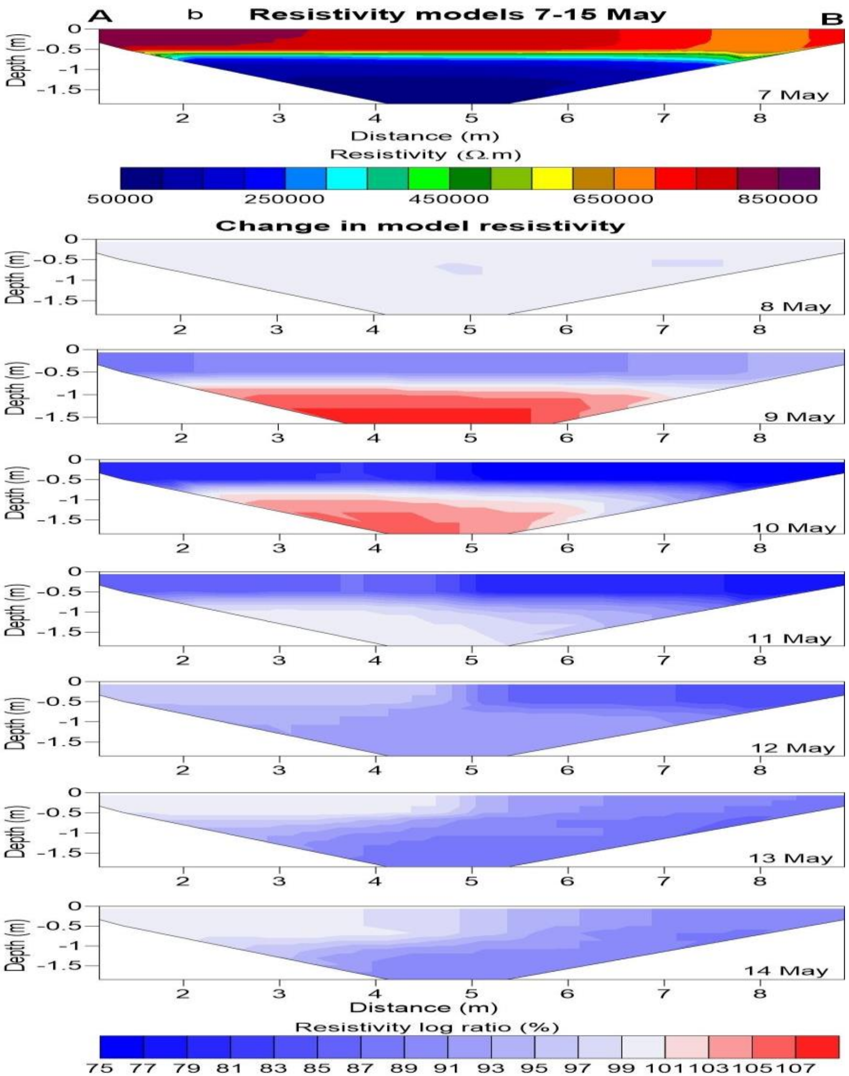
➢The daily apparent resistivity fluctuations are relatively small. However, data reveals several significant resistivity fluctuations during the observation period. These fluctuations are associated with either brief surficial refreezing of near-surface layers in summer, or short thawing periods during winter as a consequence of short-lived meteorological extreme events with quick and superficial changes of the ground temperature around 0 ºC.



Example of A-ERT results

➢ **Does A-ERT data detect the impact of Event B on active layer dynamic?**





Relative resistivity changes of daily spaced A-ERT datasets in the event scale (Event B): brief surficial thawing event from 7–14 May.

• a sharp resistivity decrease on May 9 is evident suggesting an abrupt phase change during this day.

• The resistivity of the active layer reached its minimum on May 10 and 11. We anticipate that this is due to the infiltration of the snow-melt water into the soil subsurface which provides liquid water to the active layer and decreases resistivity.

❖ A-ERT data is able to detect the impact of this event on active layer and also suggest that the infiltration processes from the melting snow cover are the dominating factor provoking the resistivity decrease and temperature increase

Example of A-ERT results

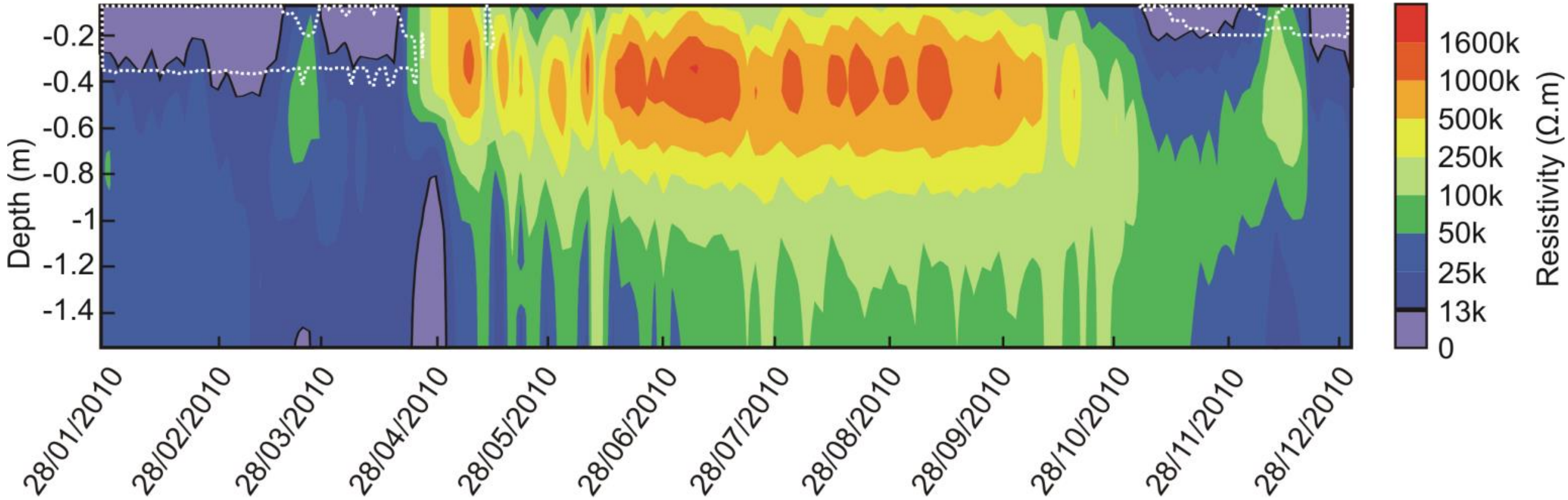
Evaluation of the temporal resistivity variability in the virtual borehole

Here, inverted resistivity values were extracted from the tomogram along a 1-D depth transect, close to the existing borehole S3,3.

➢The largest resistivity changes in the active layer took place at the end of April due to the seasonal active layer freezing. On the contrary, the zero-curtain phase during the seasonal thawing causes a continuous resistivity decrease during several weeks in November.

➢The average of thaw depth at the end of January is about 30 cm with a slight increase in March probably due to the stronger active layer warming at this month.

➢ The resistivity values are greatest in winter and around the permafrost table at depths around 40 cm. We anticipate that this is due to the repeated thawing and refreezing processes of water infiltrating from snow/rain that accumulated on top of the permafrost table.



Conclusion and outlook

- ✓ The process of seasonal active layer freezing in autumn and thawing in spring were well resolved by the A-ERT system. The absence of the snow cover and direct influence of atmospheric processes during the seasonal freezing provoked a drastic resistivity rise in April. On the contrary, the zero-curtain phase during the seasonal thawing causes a continuous resistivity decrease during several weeks in November.

- ✓ Our study clearly shows that without automatic and quasi-continuous measurements, short-time active layer freezing and thawing during the short-lived meteorological events could not be investigated.

- ✓ Since short-lived meteorological events may induce phase change, they are potential generators of geomorphic activity, such as cryoturbation and they may influence soil-forming process and microbial activity. These events are particularly important in regions without a thick or continuous snow cover such as the Deception Island due to the quick response of the active layer to the air temperature signal.

- ✓ The A-ERT results show higher ice-content (higher resistivity values) around the permafrost table (transient layer) suggesting that A-ERT could provide a tool to monitor the transient. The transition zone is ice-enriched, and functions as a buffer between the active layer and long-term permafrost by increasing the latent heat required for thaw.

- ❖ Demonstrate the high potential of remote monitoring in the polar permafrost environments. More info about this project can be found in our recent publication and the ANTERMON website:

- ○ https://antermon.weebly.com/

- ○ Farzamian, M., Vieira, G., Monteiro Santos, F. A., Yaghoobi Tabar, B., Hauck, C., Paz, M. C., Bernando, I., Ramos, M., de Pablo, M. A. 2020. Detailed detection of active layer freeze–thaw dynamics using quasi-continuous electrical resistivity tomography (Deception Island, Antarctica), **The Cryosphere**, 14, 1105–1120, https://doi.org/10.5194/tc-14-1105-2020