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Monitoring of permafrost dynamics using Electrical Resistivity tomography (ERT) at the Aiguille Du Midi in the French Alps

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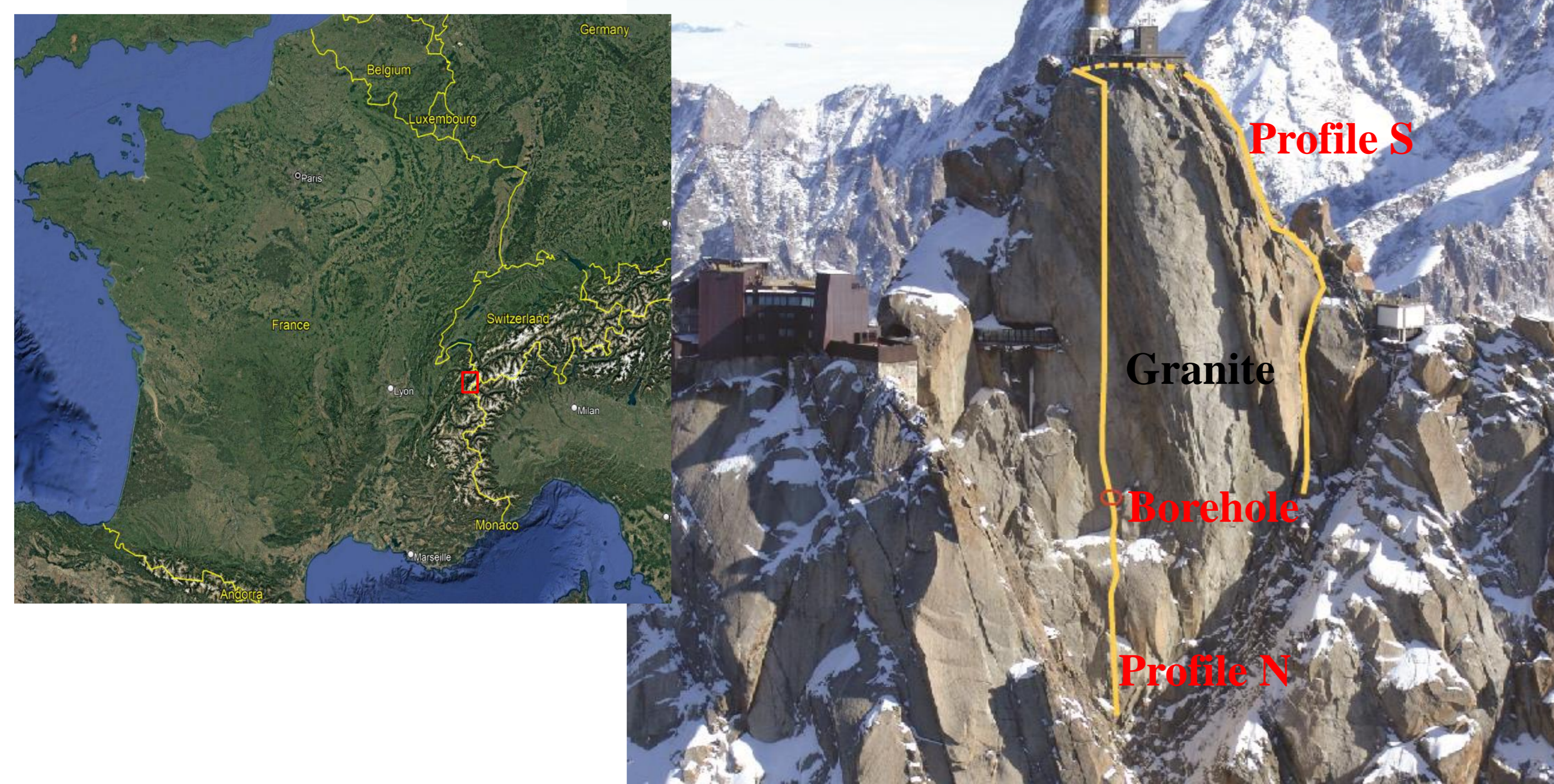
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1- Introduction: Permafrost degradation significantly affects the stability of rockwalls in high altitude regions. Subsurface monitoring of permafrost is essential for assessing potential geohazards related to its degradation. In this study, we present part of the data collected during ERT monitoring carried out over four years at the Aiguille du Midi (3840 m a.s.l) in the French Alps. The aim is to assess permafrost dynamics from seasonal to pluriannual timescales, analyze the hydrogeological processes (desiccation, water flux, drainage in fractures), in order to anticipate potential geohazards on the site. We took advantage of the existence of temperature measurements in a borehole located along the geophysical profile, and lab measurement on sample from the site to calibrate resistivity interpretation and evaluate the temperature distribution over the site.

2- Study Site

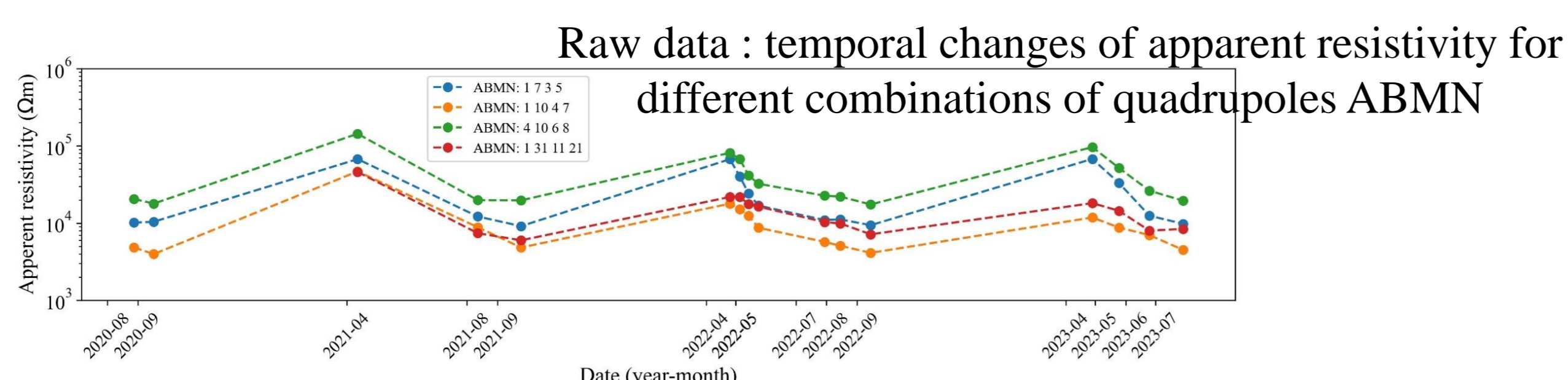
The Aiguille Du Midi (ADM)



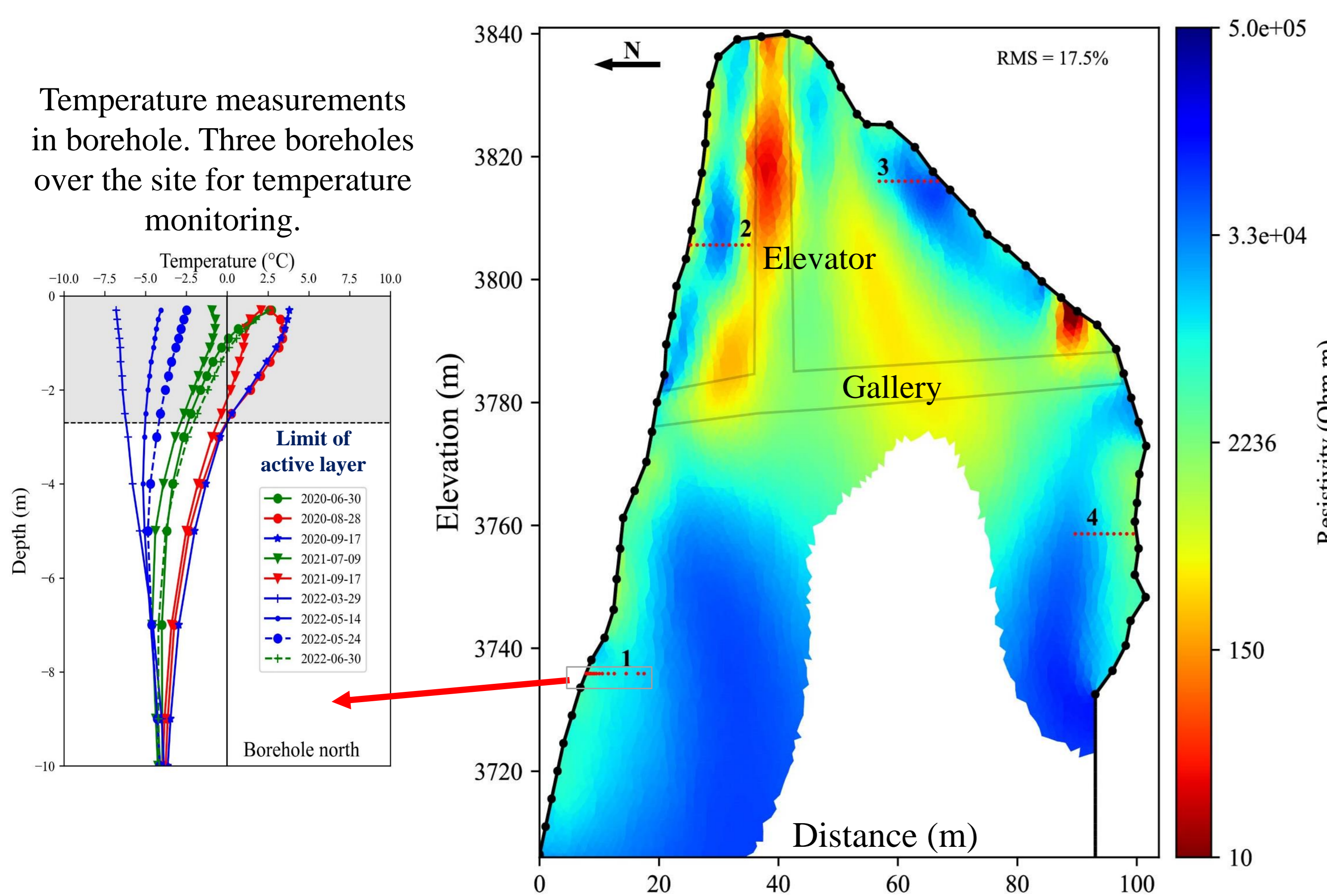
3- Field measurements and inversion



- 3 ERT profiles of 32 electrodes spaced at 5 m, deployed from the summit in three directions: N, S and E.
- Wenner dispositive.
- Permanent monitoring and remote data acquisition (from June 2020 to July 2023).
- ERT data processing :
 - 1- Remove electrodes with high Contact Resistance,
 - 2- check N° of connected electrodes,
 - 3- Remove outliers,
 - 4- check pseudo-section quality (N of filtered data/).



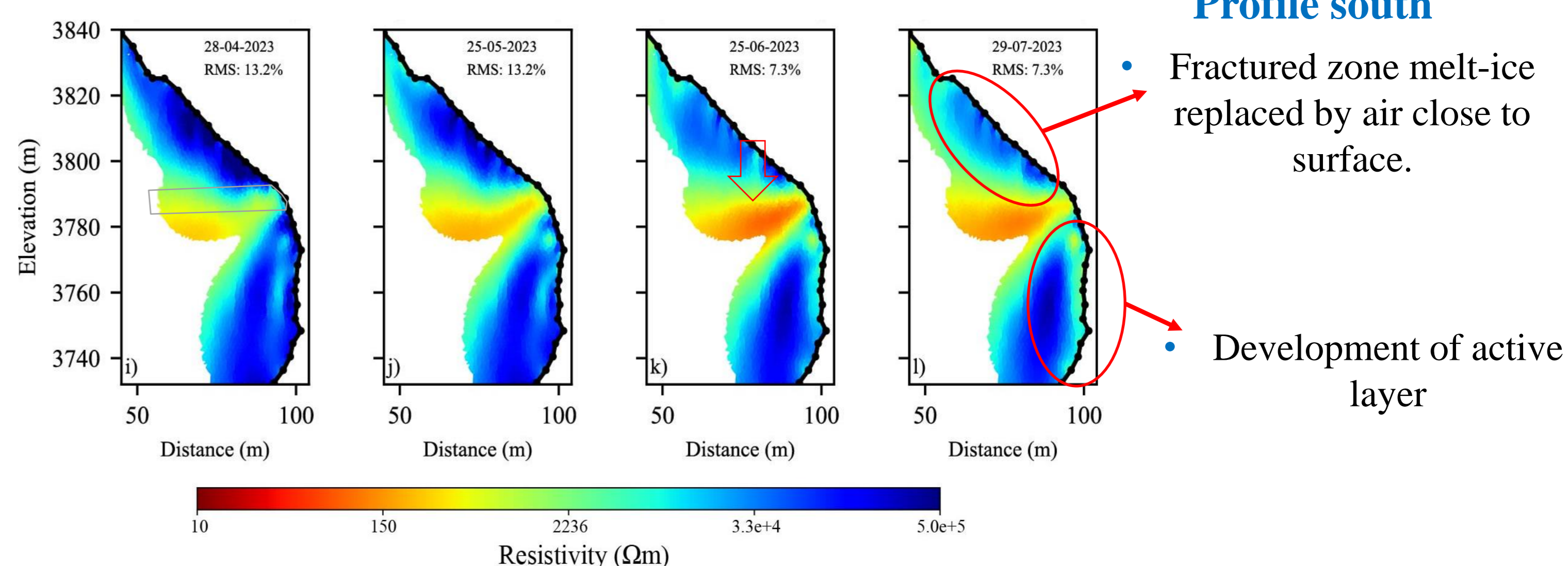
ERT data inversion using pyGIMLI inversion packages (Rücker et al., 2017)



Example of resistivity distribution in August, 28 2020, profile north-south. Gray lines show the anthropogenic structure

4- Results and interpretation

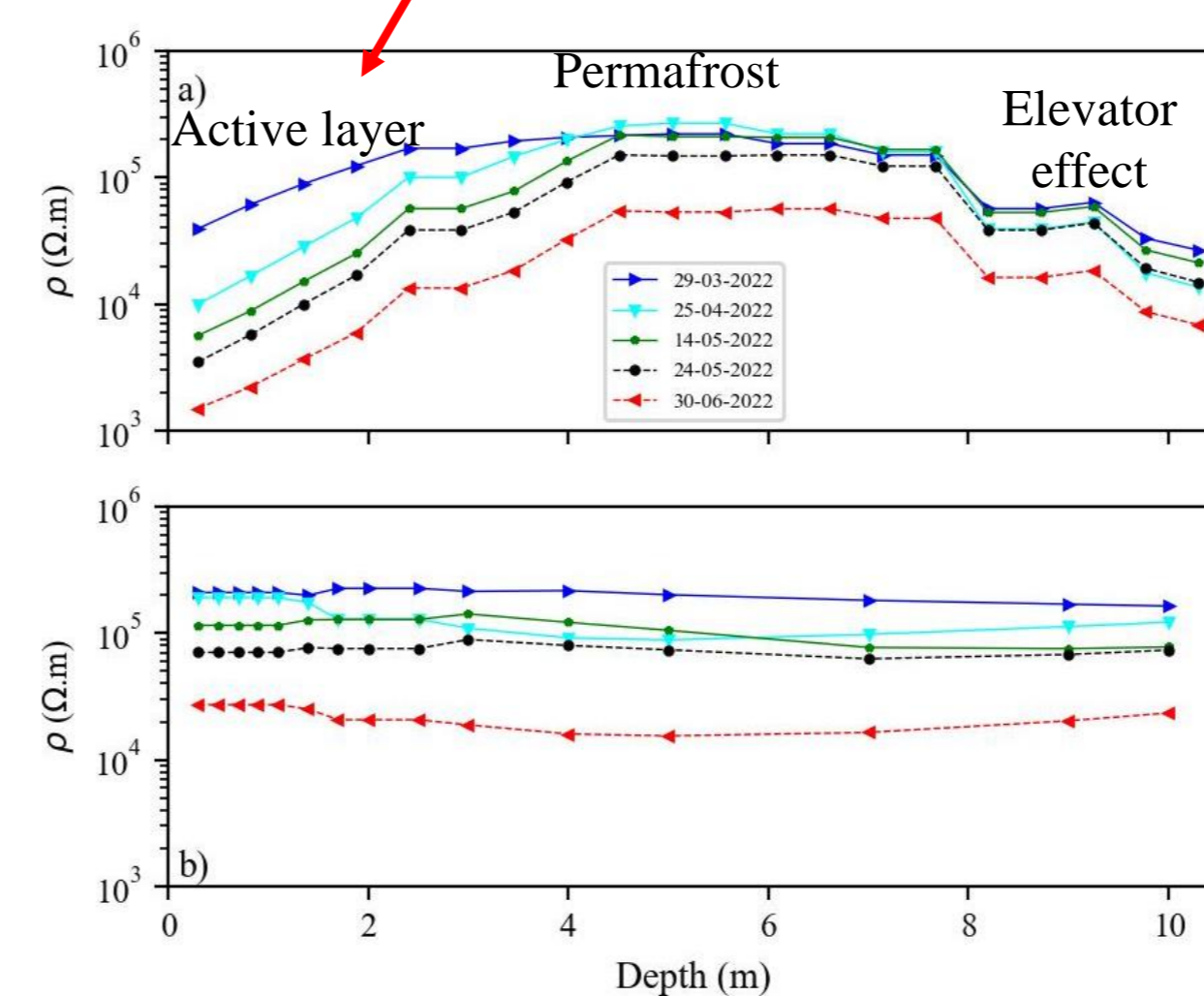
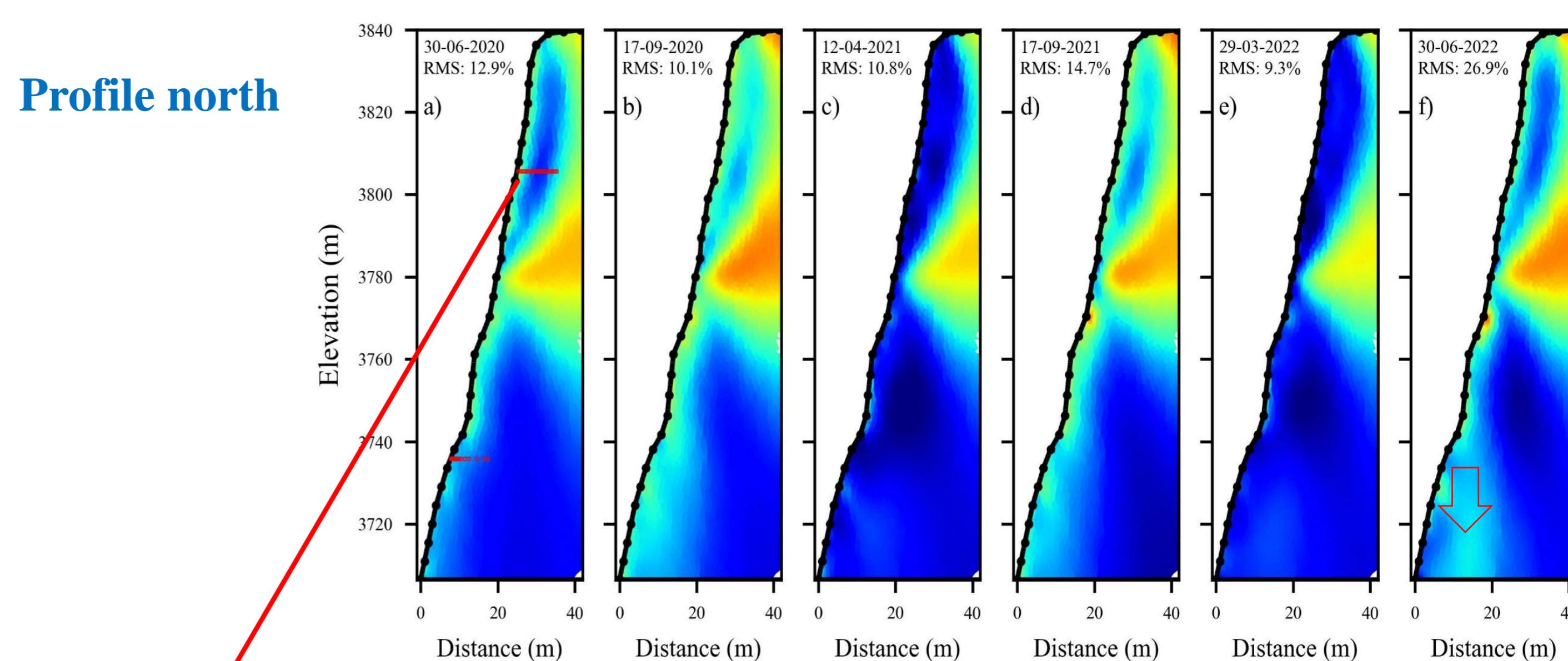
1. Permafrost dynamics



Profile south

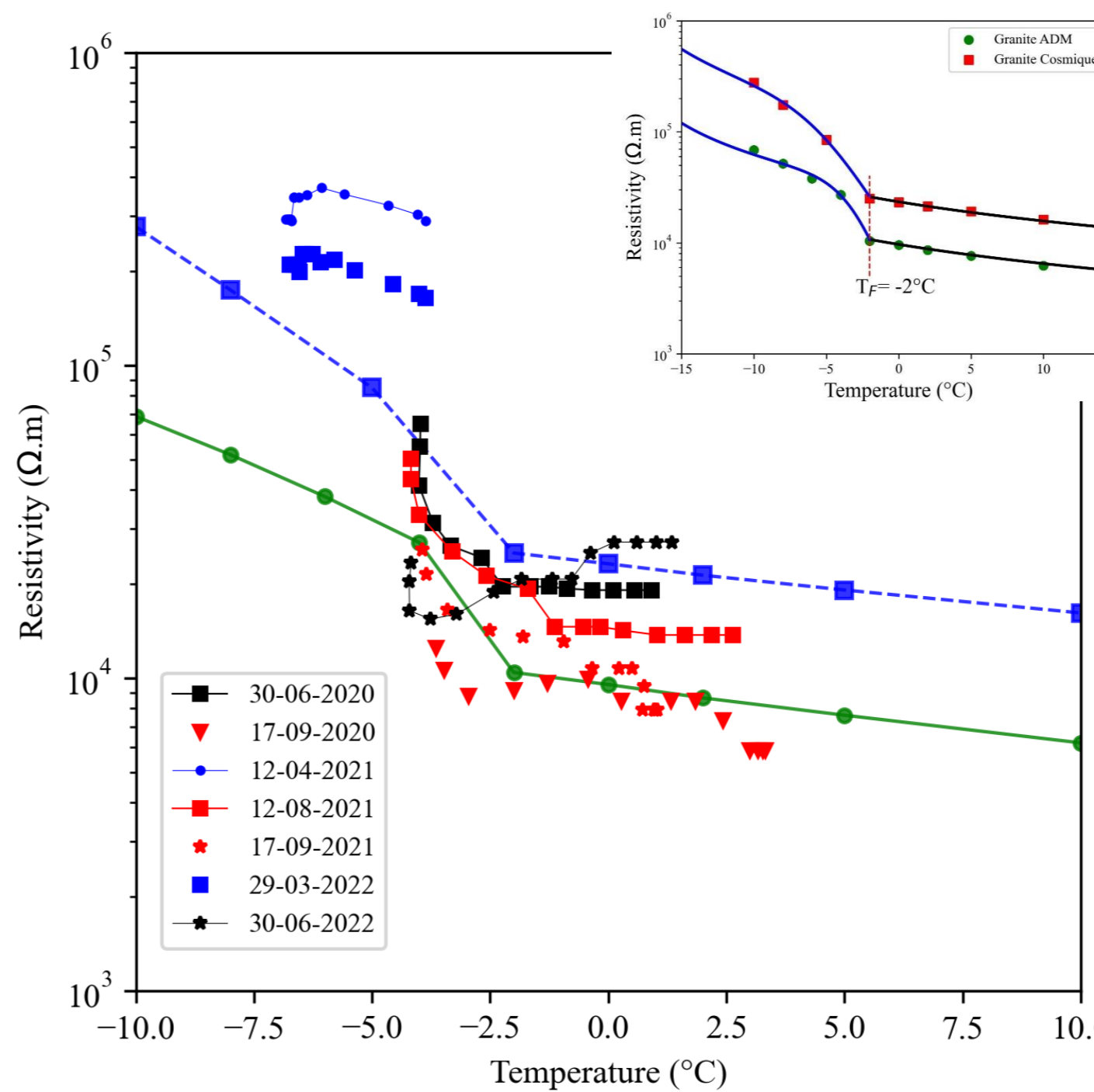
- Fractured zone melt-ice replaced by air close to surface.
- Development of active layer

Profile north



- Temporal evolution of resistivity extracted at two positions (1, 2):
 - The active layer is more pronounced above the gallery,
 - Permafrost in middle (high resistivity).
 - Slight increase in resistivity with depth,
 - In two cases, decreases in resistivity maybe related to water infiltration.

2. Resistivity (ρ) – temperature (T) relationship



Lab measurements on granite samples.

Solid lines is a fit of data with a petrophysical model from Duvillard et al. (2021) : in frozen condition and unfrozen conditions

T vs ρ at field scale

The relation T vs ρ is less pronounced at field scale. Freezing temperature ? (heterogeneity, data quality, anthropogenic effects, 3D effect)

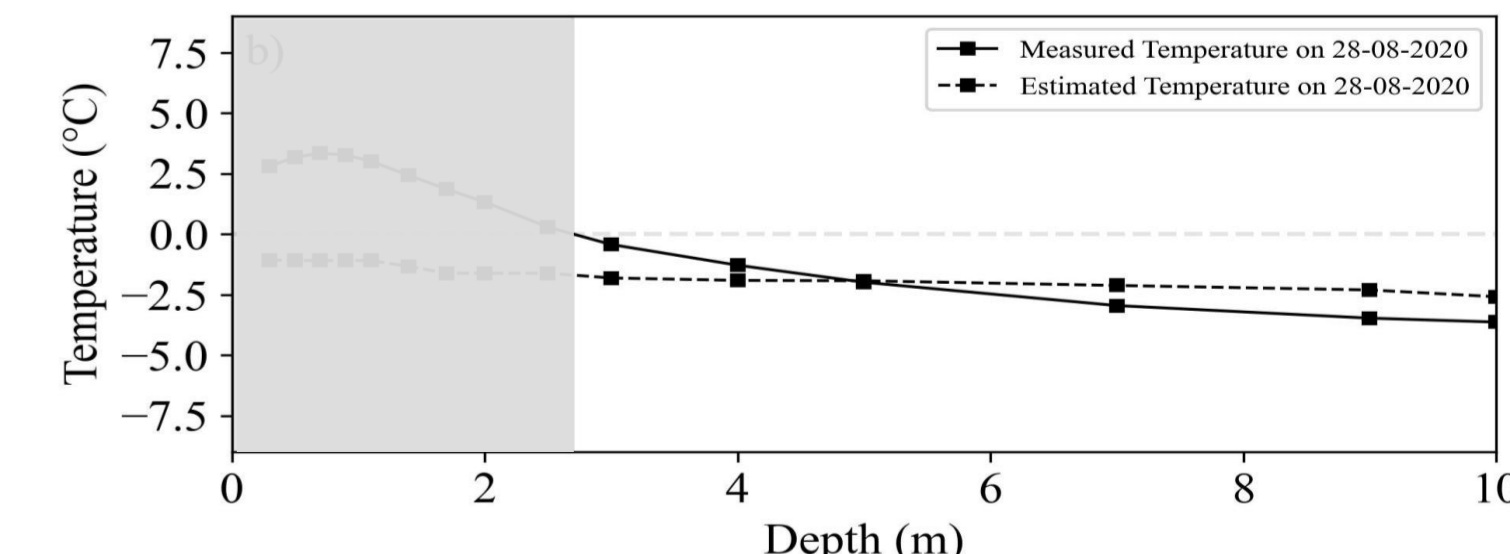
Evaluate the temperature from resistivity measurements using the petrophysical model From Duvillard et al., (2021) ?

Under frozen conditions : $\sigma(T)$: conductivity at temperature T

$$\sigma(T) \approx \left[(\phi - \theta_r) \exp\left(-\frac{T - T_F}{T_C}\right) + \theta_r \right] \frac{\sigma(T_0)}{\phi} [1 + \alpha_T (T - T_0)]$$

ϕ : the (connected) porosity, T_F : freezing temperature, $T_0 = 25^\circ\text{C}$, T_C : characteristic temperature controlling the transition (frozen -unfrozen state), and θ_r is the residual water content.

Good correlation in case of data measured in summer



5- Conclusion

ERT monitoring at high altitude and in rockwalls presents significant challenges. The quality of the data is impacted by the high contact resistance. Nevertheless, ERT data can provide valuable insights into permafrost dynamics and the results are consistent with temperature measurements (Magnin et al., 2024). The assessment of temperature from resistivity measurements using petrophysical model is good for summer data. The relation T versus ρ at field scale is not evident as in laboratory measurements. An inversion 3D could improve the results by taking the real 3D geometry of the site.

6- References

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