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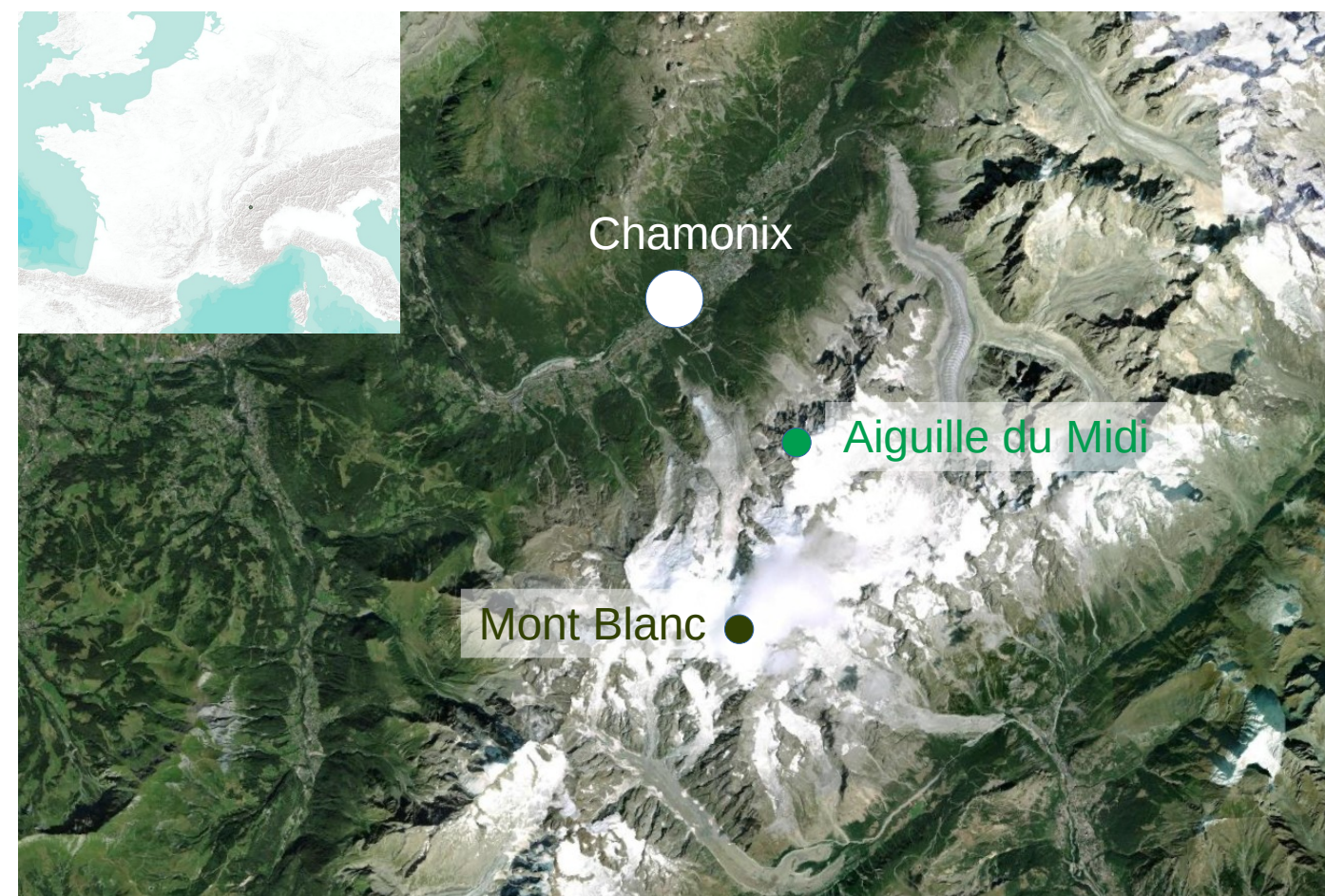
Monitoring steep rock wall permafrost using electrical resistivity and induced polarisation

Part 1: installation, instrumentation

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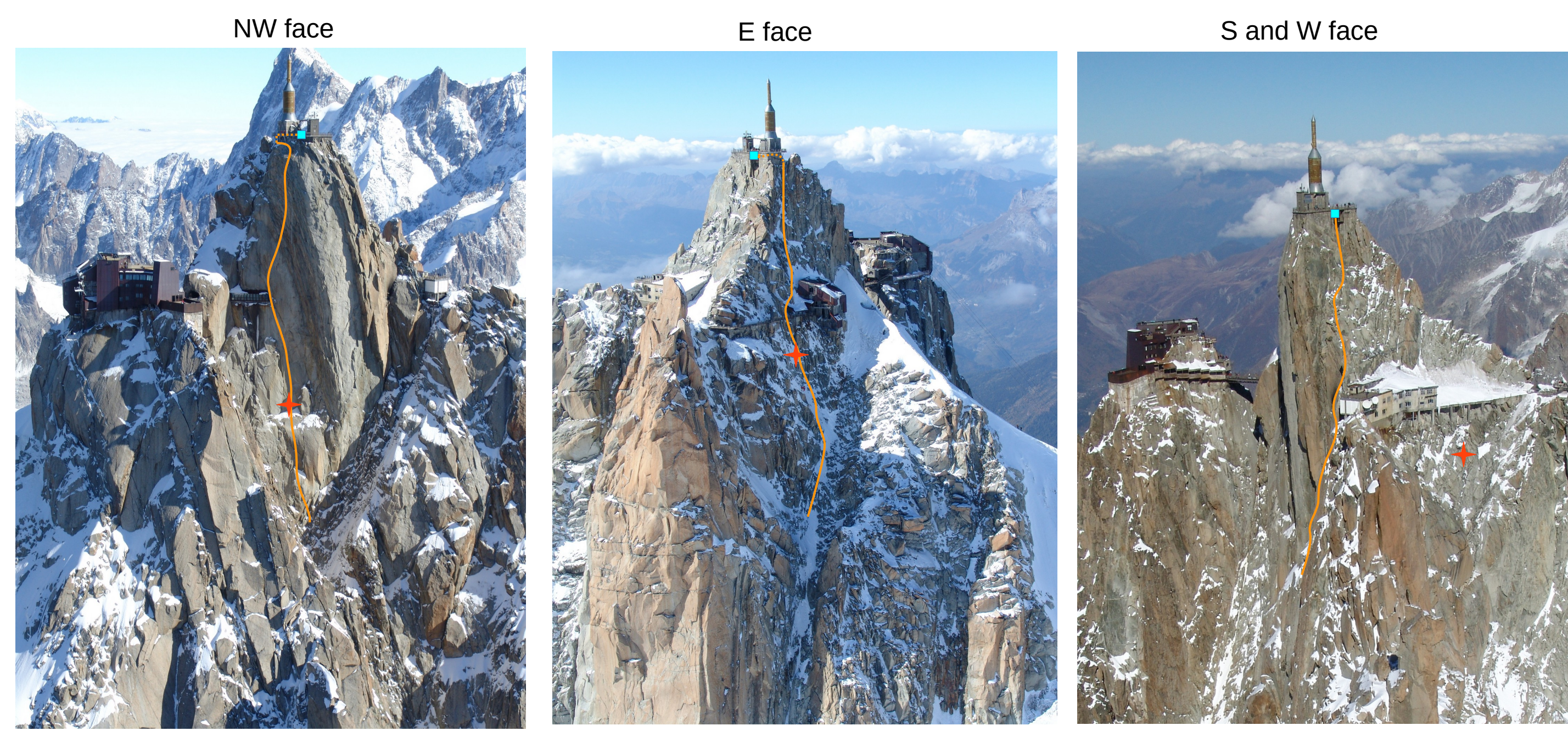
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Location



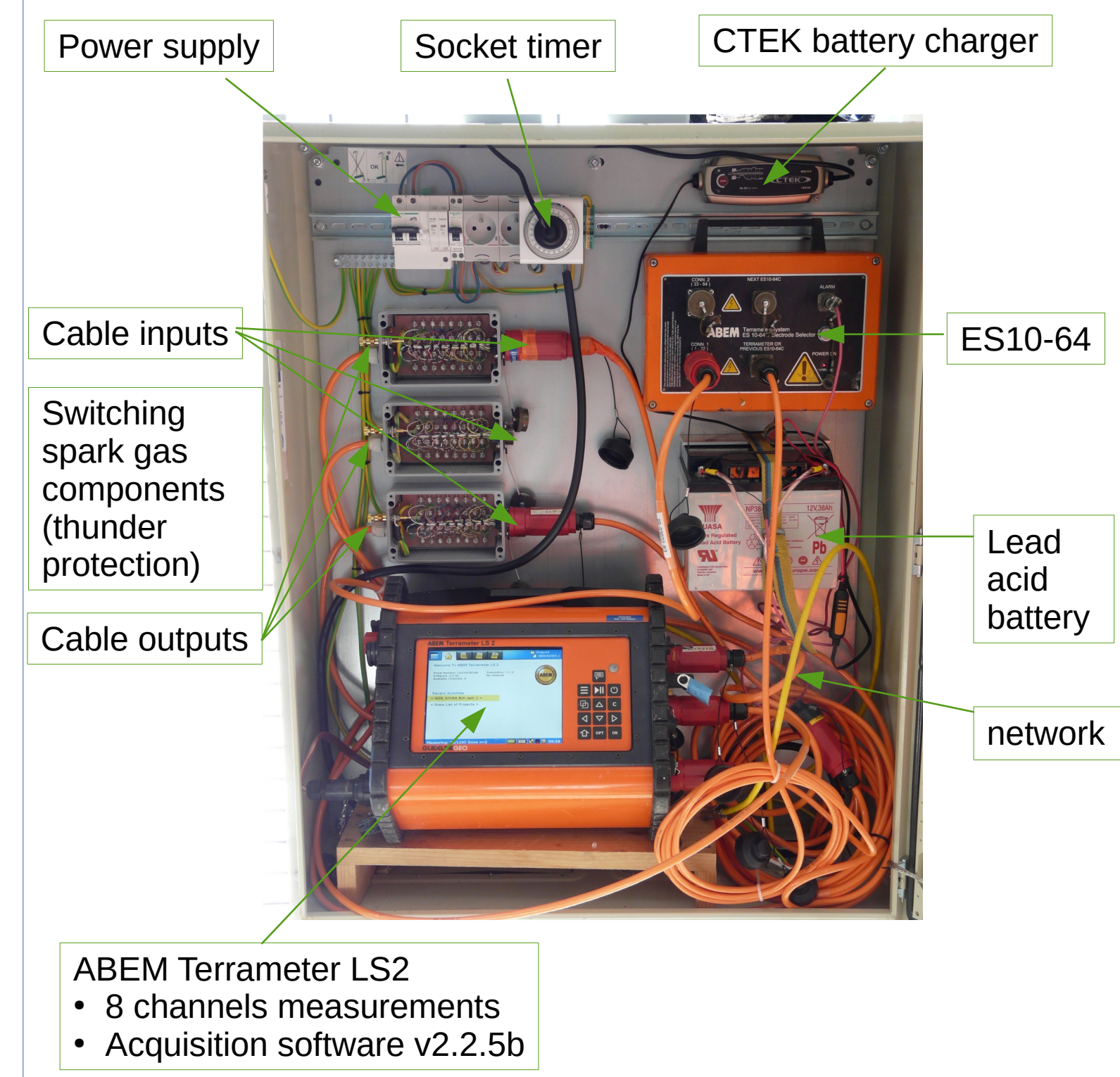
- Mont Blanc massif (Western European Alps)
- Aiguille du Midi central peak (3842 m)
- Granitic rock

Cables setup



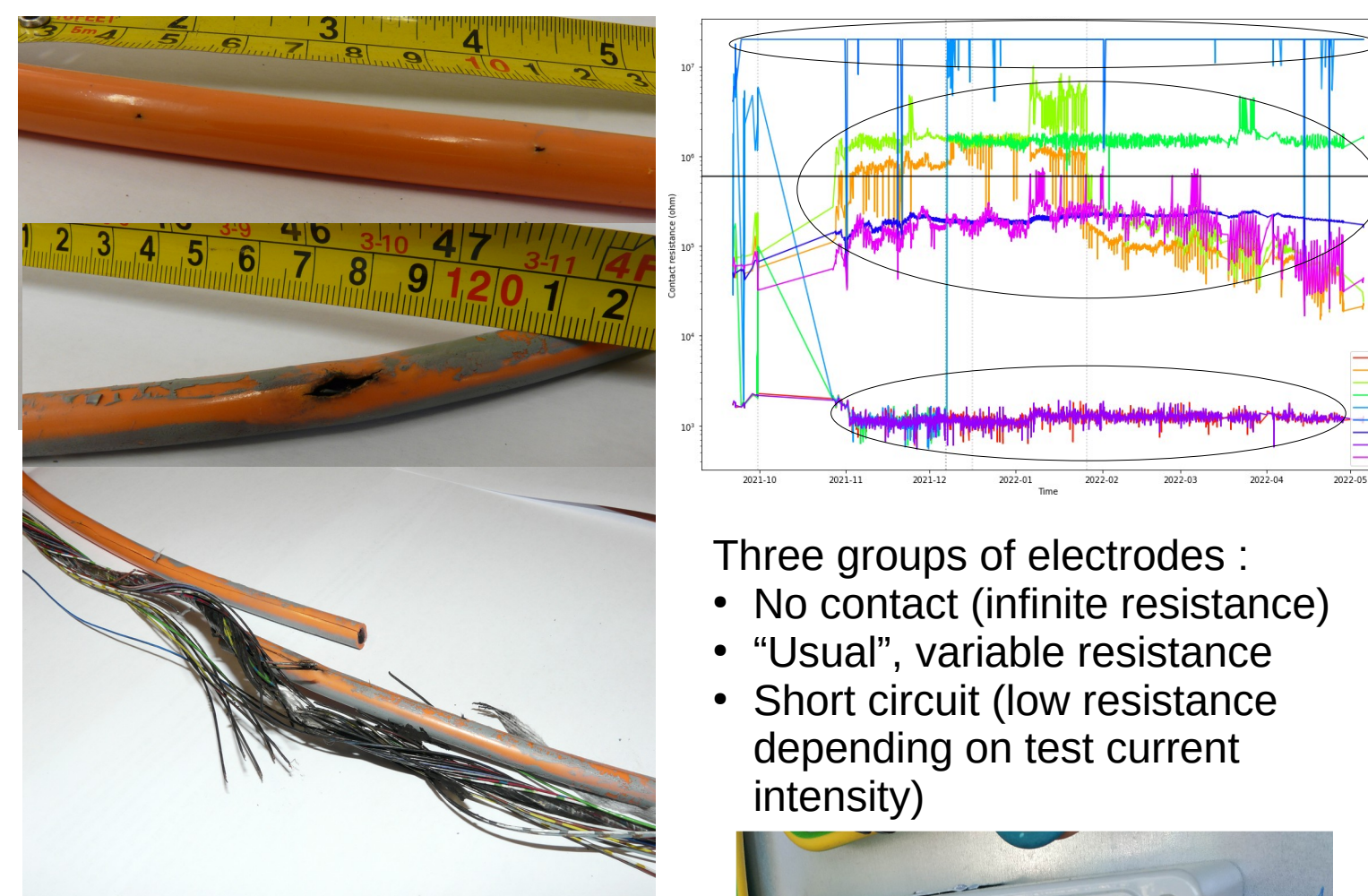
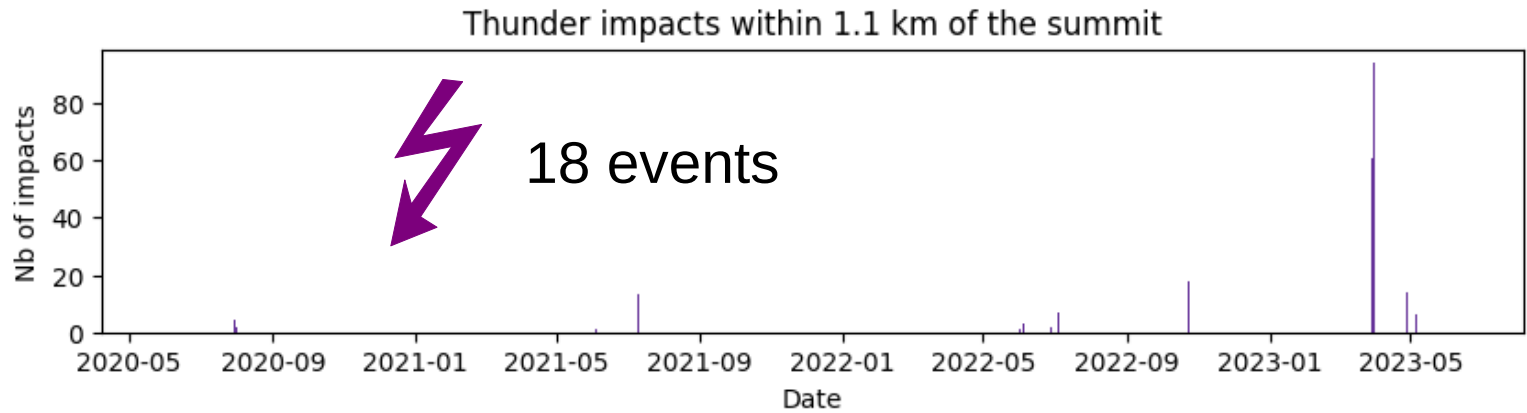
- 32 electrodes, 5 m spacing (160m long)
 - Average slope 78°
 - 10 m deep borehole
 - Installed in June-July 2020
 - Malfunction in August 2022 (probably mechanically damaged by a cable)
- 32 electrodes, 5 m spacing (160m long)
 - Average slope 50°
 - 10 m deep borehole
 - Installed from August 2020 to March 2021
 - Malfunction in Summer 2021 (evidence of thunder impact discovered in 2023)
 - Damaged by rockfall in July 2022
- 2x16 electrodes, 5 m spacing (160m long)
 - Average slope 54° (44° upper half, 64° lower half)
 - 10 m deep borehole apart
 - Installed July-August 2020
 - Still working!

Device



- ABEM Terrameter LS2
- 8 channels measurements
- Acquisition software v2.2.5b

Thunder issue(s)



- No contact (infinite resistance)
- "Usual", variable resistance
- Short circuit (low resistance depending on test current intensity)

Evidences of electrical component damage :
• Box of switching spark gas with a lot of dust

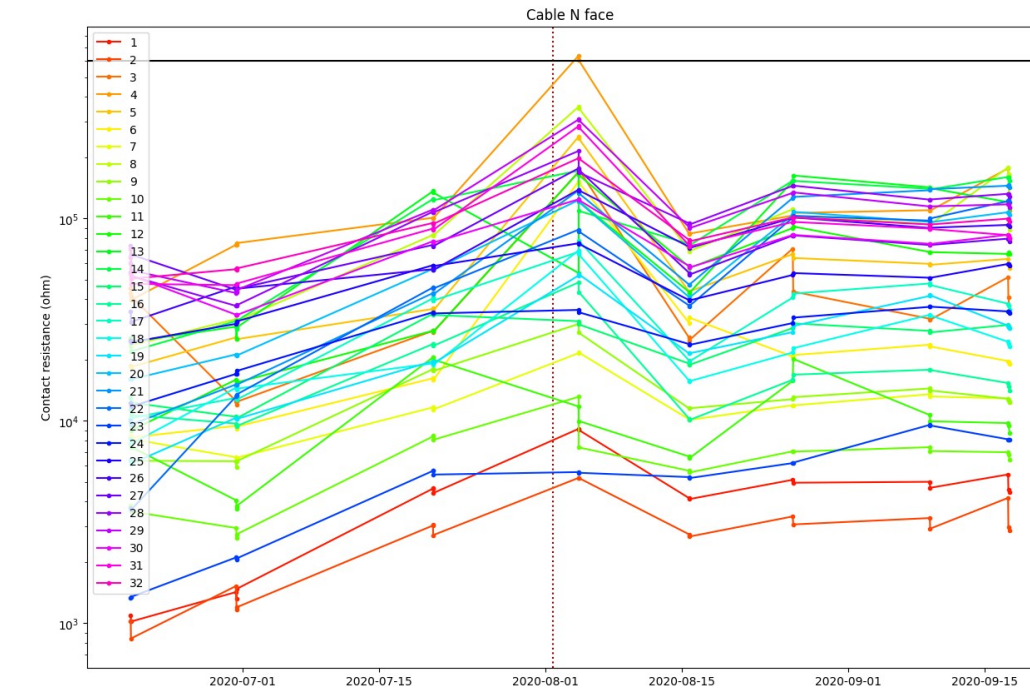
Major difficulty : no access to a safe grounding connector (thunder impacts can come from the grounding wire)

Tremendous efforts to plan daily measurement as a function of weather forecast

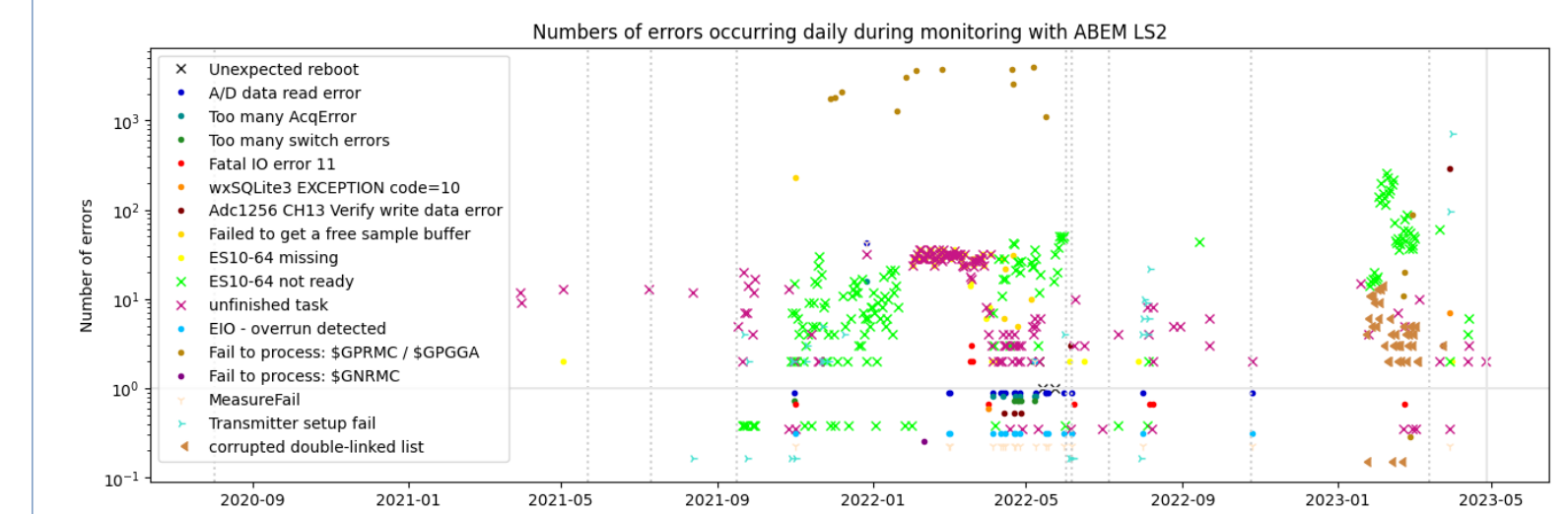
Electrode / takeout setup



- Stainless steel (A4/316) climbing bolts (Fischer 10x126) poured in salty bentonite
- Specially designed jumper to attach the takeout onto the bolt with maximum contact
- Initial contact resistance range from a few kΩ to a few tens of kΩ ...
- ... but readily (~1 month and a half) reached hundreds of kΩ



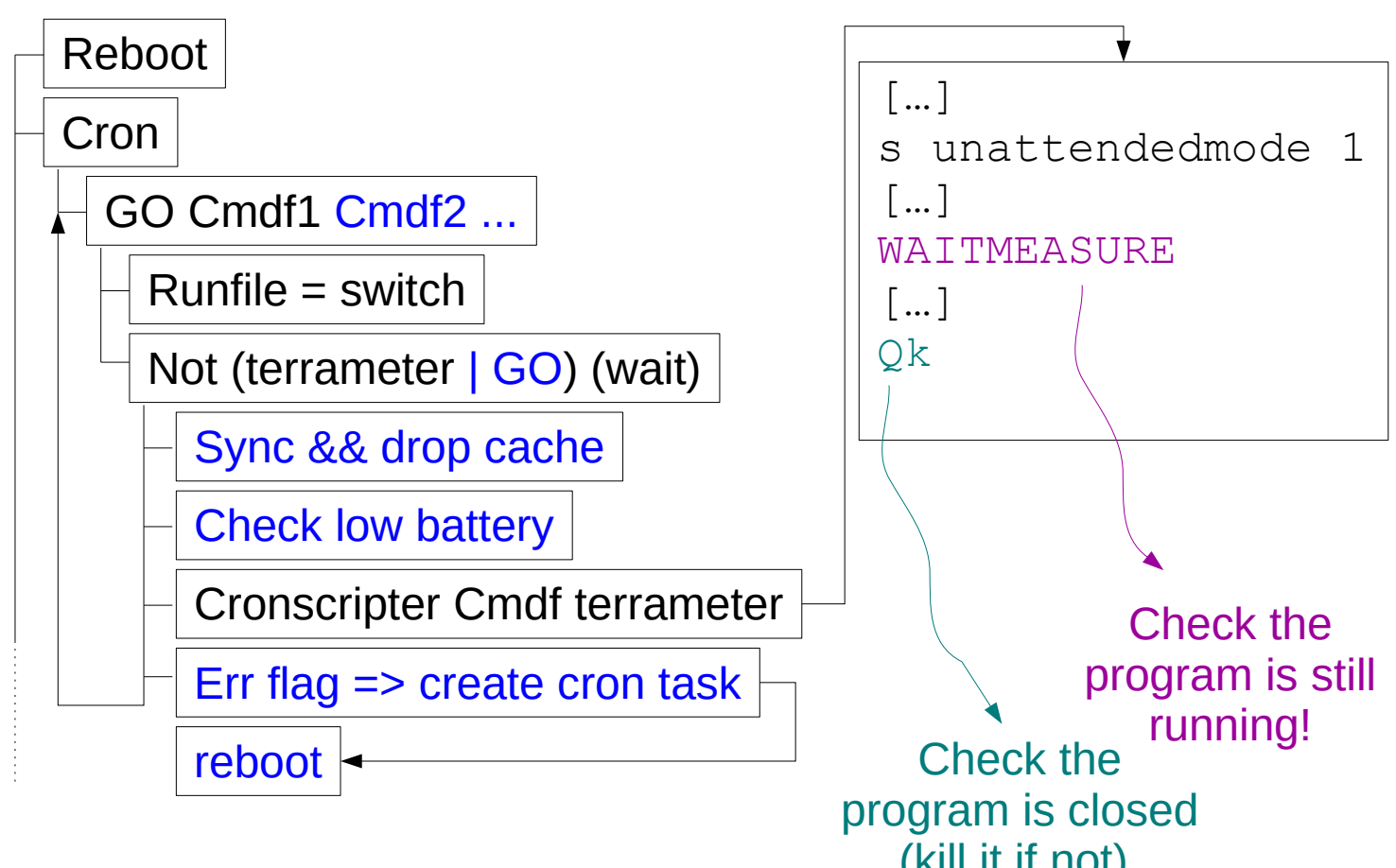
Terrameter LS2 malfunction



- High number of software and hardware errors
- Device under repair or fix for months
- Software updates (v2.6.2, v2.7.1) no longer work with ES10-64
- RAM memory issue
- Little reliability of the device

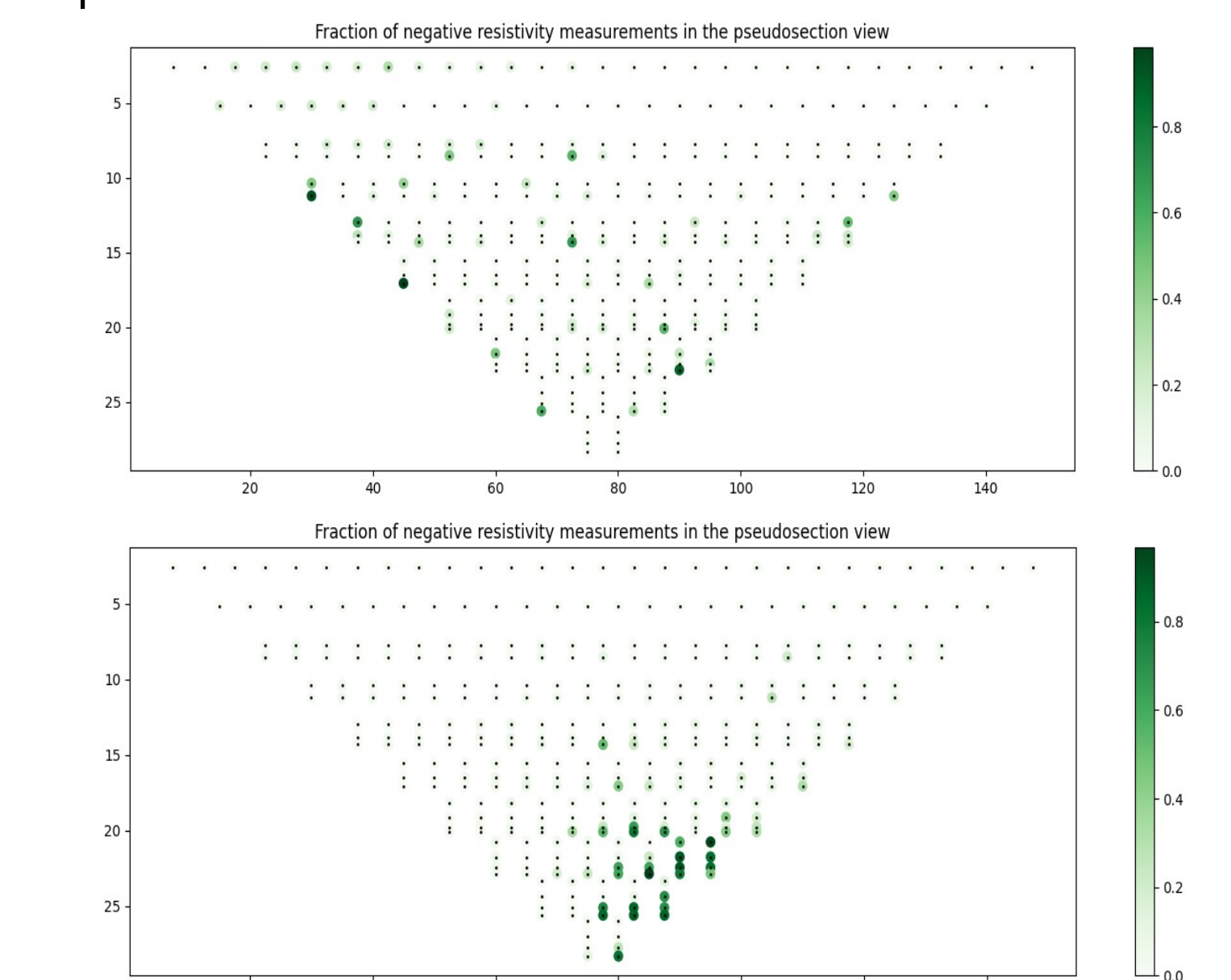
Monitoring with Terrameter LS2

Improvements to help auto-recovery after measurement errors:

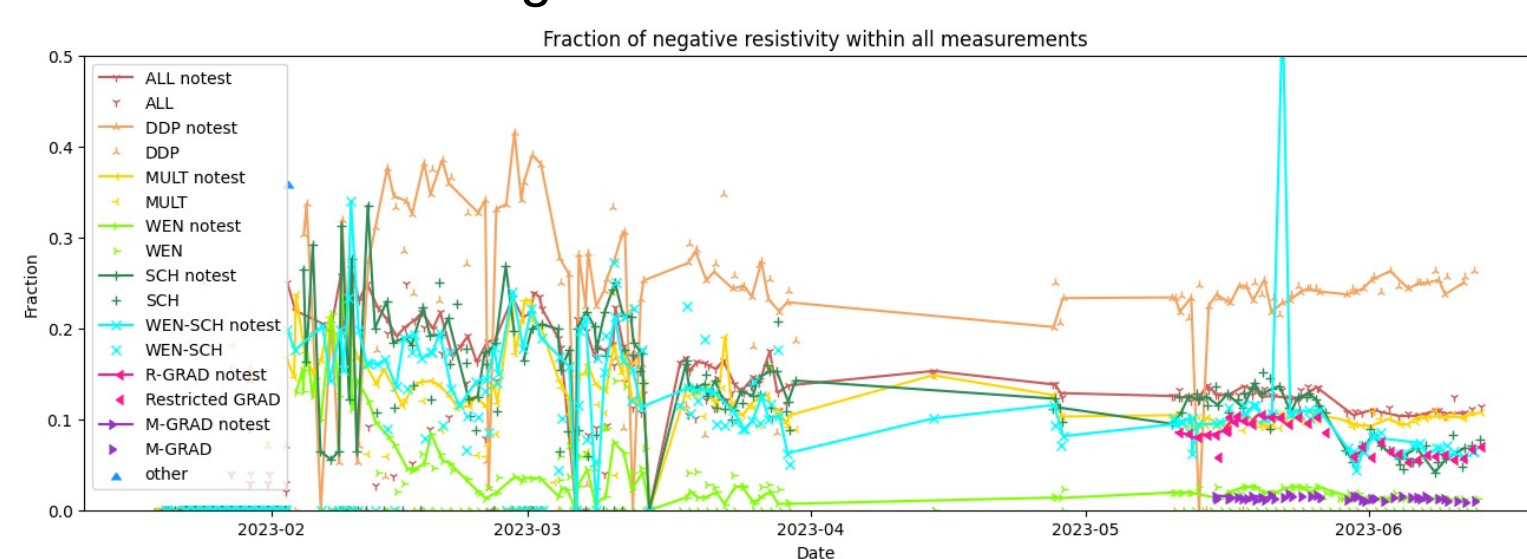


Negative resistivity

- Significant amount (up to 40 %) of negative resistivity measurements in datasets
- Several reasons under investigation :
 - presence of metal structures



- high contact resistance
- low measured signal



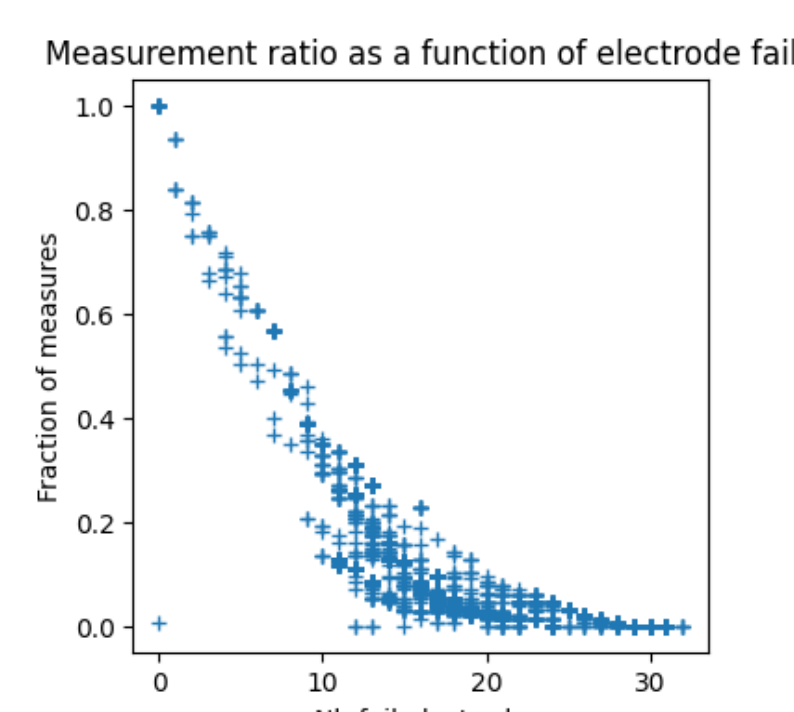
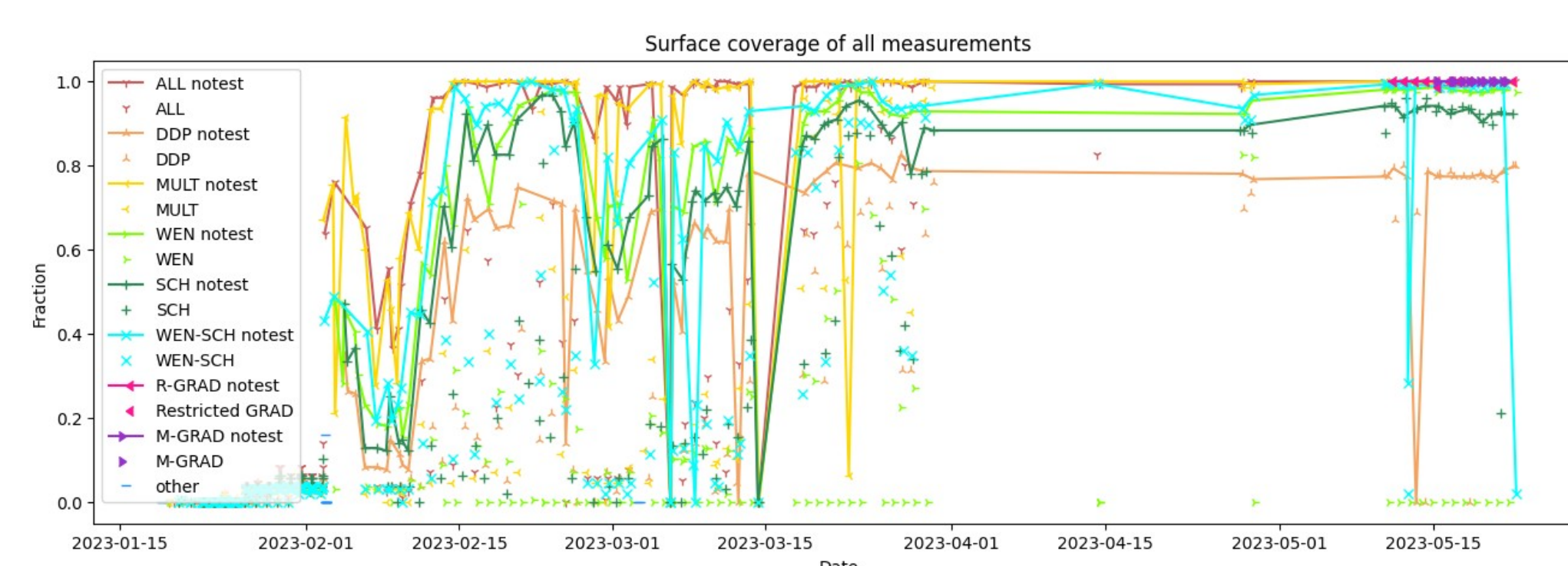
Efforts to improve the contact resistance

Duplicating electrodes	Using copper tubes	Using stainless steel tubes	Pouring hot salty water
<ul style="list-style-type: none"> ✓ Long lasting improvement ✓ Moderate fieldwork ✓ Limited improvement of ECR 	<ul style="list-style-type: none"> ✓ Long lasting (oxidation?) ✓ Soft, conductive metal ✓ Expensive ✓ Important fieldwork 	<ul style="list-style-type: none"> ✓ Long lasting (if A4/316) ✓ Enables to pour salty water ✓ Hard metal, difficult to insert ✓ Important fieldwork 	<ul style="list-style-type: none"> ✓ Easiest fieldwork ✓ Lasts a few weeks to months ✓ Limited impact, only on high resistances ✓ Not possible for snow-covered electrodes

Measurement protocols

High contact resistance hinders measurement. The number of measured quadrupoles, and thus the dataset relevance (Wenner-α) rapidly drops if one or a few electrodes have high contact resistance.

Performing measurements without initial electrode contact test slightly improves the surface coverage, though it leads to numerous measurement errors.

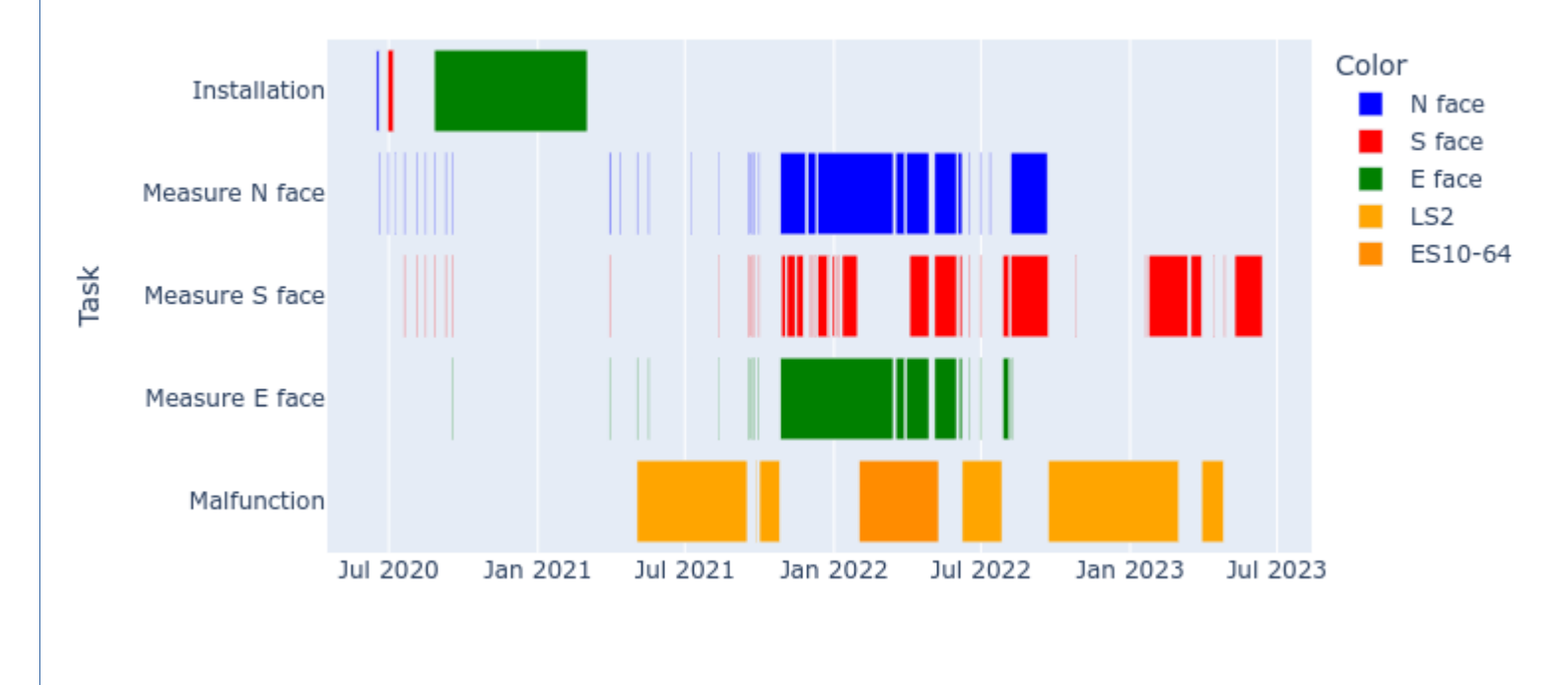


Using multichannel capability improve the surface coverage

(but ES10-64 is actually limited to 7 channels using 8 electrodes)

Collected datasets

- Spanning 3 years (discontinuous)
- 410 days of data
- 4 Gb of data (excluding full wave form data)
- 9740 measurement tasks
- Major filtering requirement



Acknowledgements

- The Compagnie du Mont-Blanc (CMB) for giving us access to the Aiguille du Midi and providing help.
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- Stephan Gruber for taking pictures of Aiguille du Midi during a helicopter flight in 2005.
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- Simon Alésina, Michel Piquand, Ibai Rico for their help to instal the ERT cables during several days on the field.