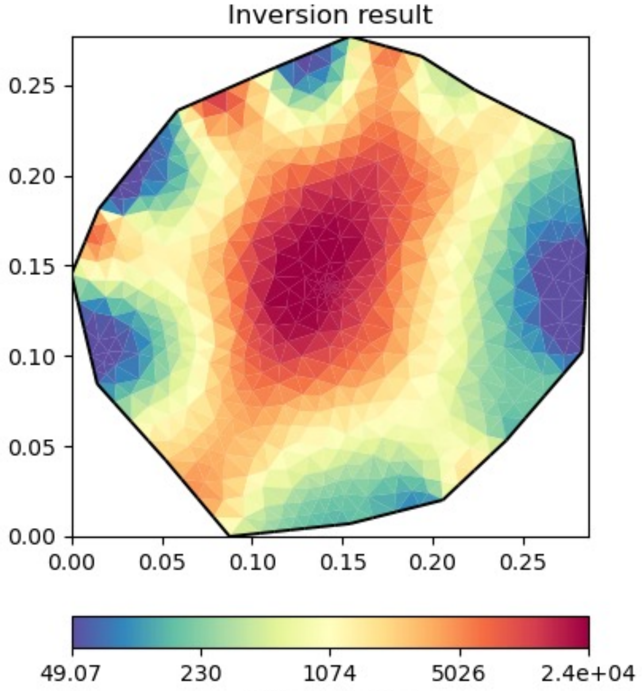
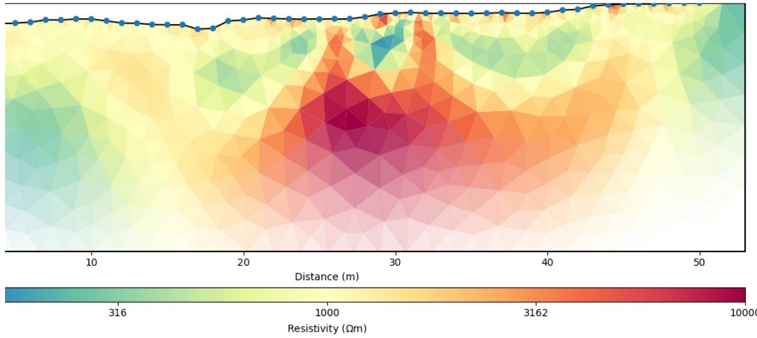
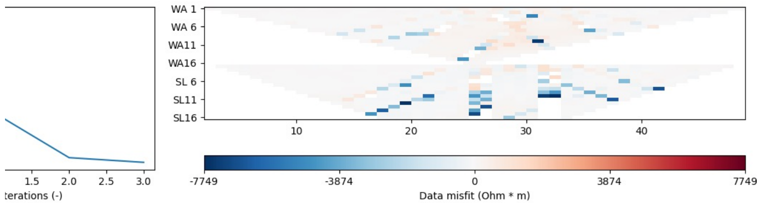
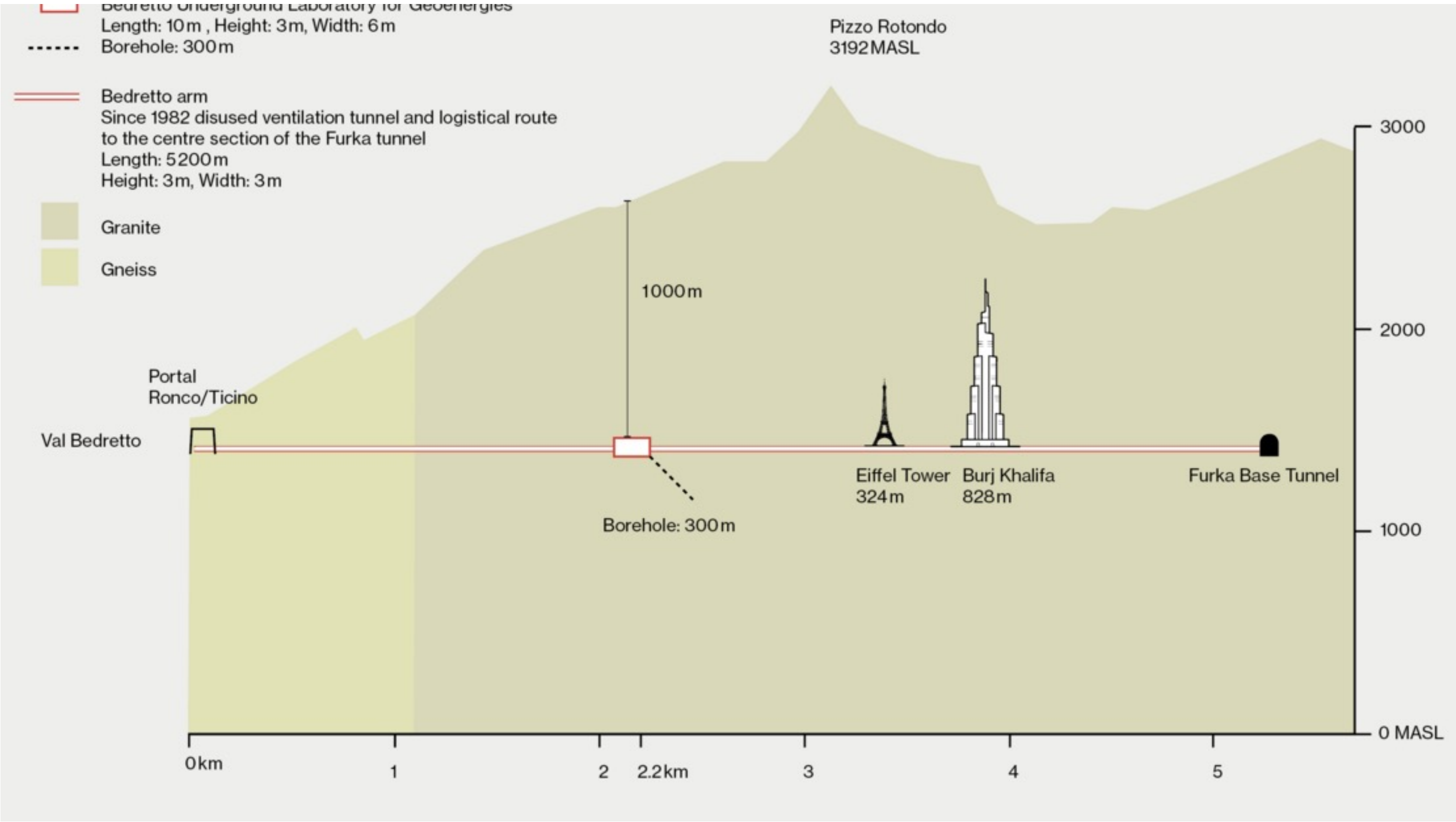
Insights from Geophysical Imaging of the Below Ground and Tree Trunks in Pfynwald

Alexis Shakas, Exploration and Environmental Geophysics, ETH Zurich









- About myself: Lecturer in geophysics (ETH Zurich)
- Mainly involved in projects about deep geothermal energy (Bedretto Lab)
- Fascinated by the use of geophysics in forests (need more sunlight)
- Collaborating with Katrin Meusburger since 2021

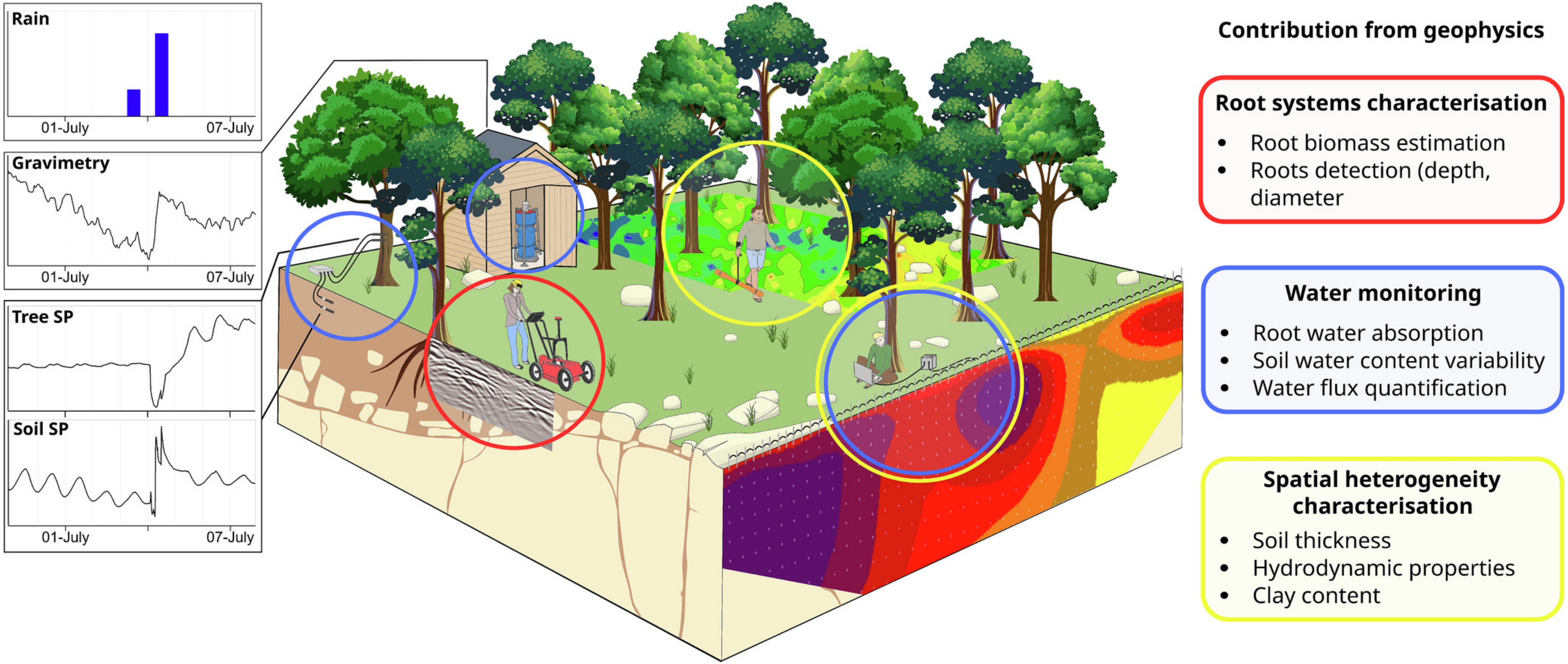
Alexis Shakas [1], Katrin Meusburger[2], Roman Hediger[3], Isabelle Pfister[3], Justine Bouchard[1], Petra D'Odorico[2], Arthur Gessler[2], Kamini Singha [4], Giulia de Pasquale [5], Hansruedi Maurer [1], Cedric Schelzbach[1], Florian Wagner [6], and Georg von Arx[2]

[1]ETH Zürich
[2]Swiss Federal Institute for Forest, Snow and Landscape Research WSL
[3]external companies
[4]Colorado School of Mines
[5]Centro de Estudios Avanzados en Zonas Áridas
[6]RWTH Aachen

Outline of the talk

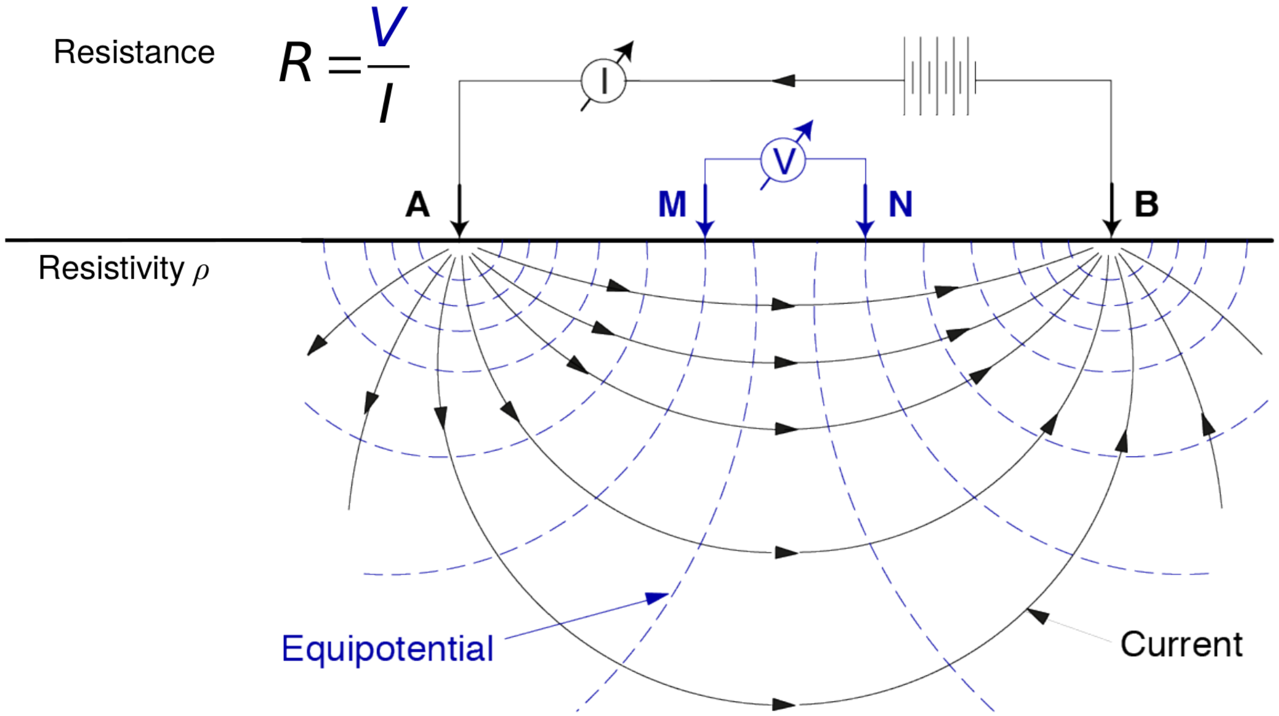
- Motivation for using geophysics
- Primer on electrical resistivity
- Results from past projects
    - o Monitoring uptake depth from irrigation experiments (Roman)
    - o Modeling and prior knowledge for tree-trunk resistivity (Isabelle)
- Running project (Justine)
- Outlook

Geophysics in forest ecosystems



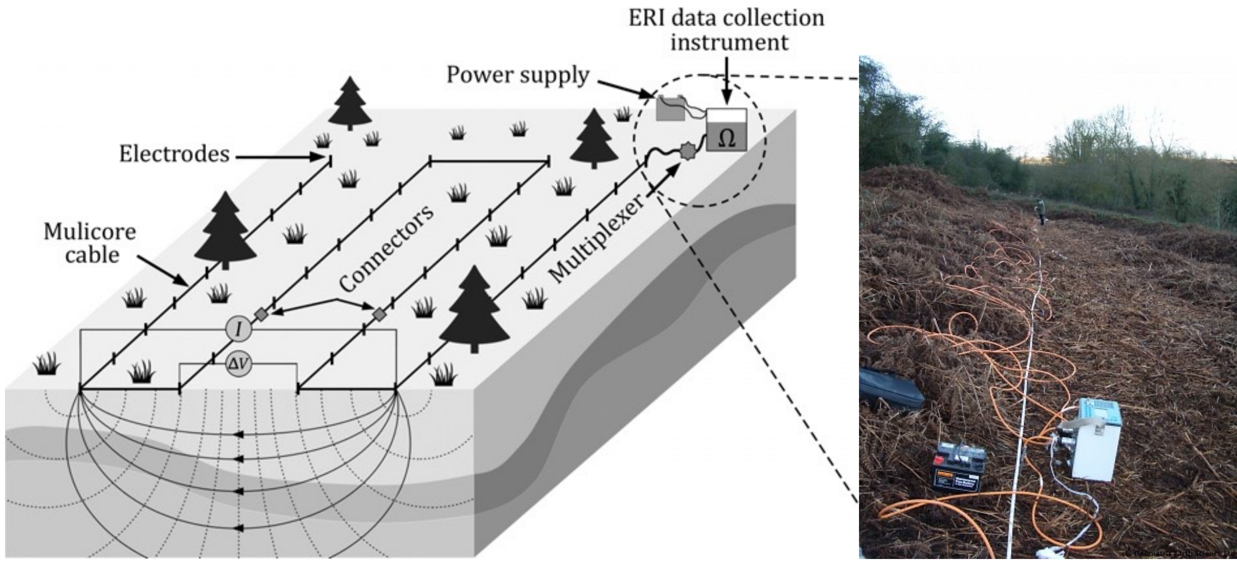
Loiseau et al., 2023: The geophysical toolbox applied to forest ecosystems – A review, Science of the Total Environment

Electrical resistivity: A short introduction

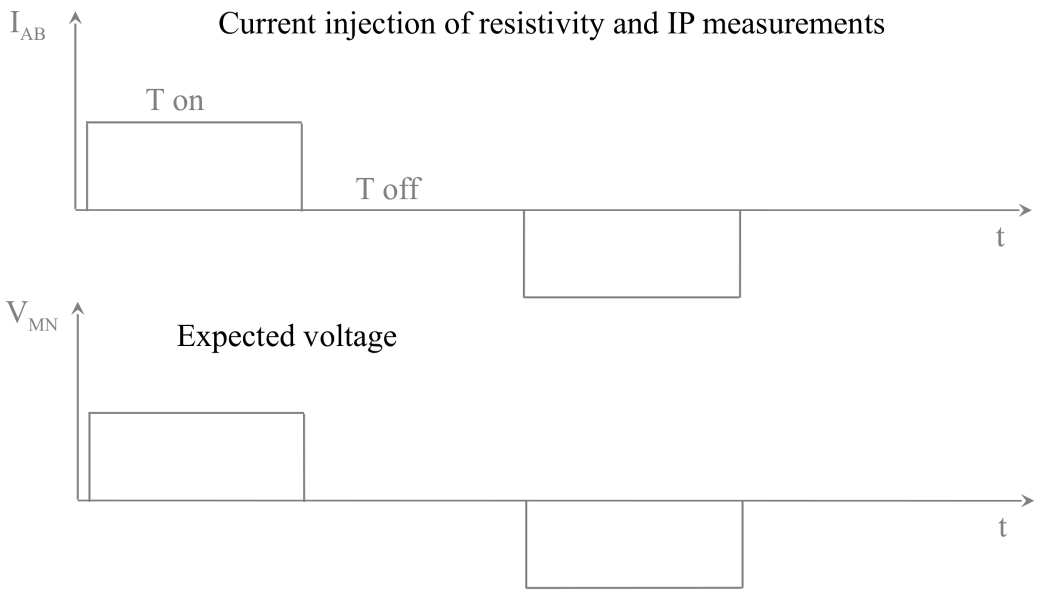


In the field, the setup consists of placing electrodes in the soil (or nails on tree barks) and turning on/off selections of these electrodes through a multiplexer (one input, several outputs). *Figure below from Slater and Binley, 2020: Resistivity and Induced Polarization.*

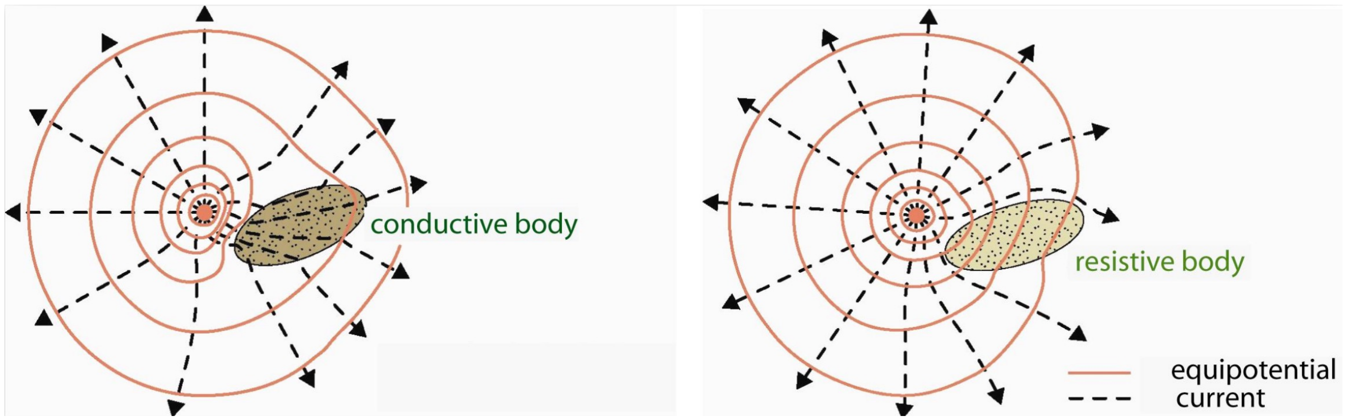
Electrical resistivity (often called electrical resistivity tomography, or ERT) relies on the process of injecting a current through 2 electrodes and measuring the potential difference through another 2 electrodes.



Direct Current (DC) vs Induced Polarization (IP)

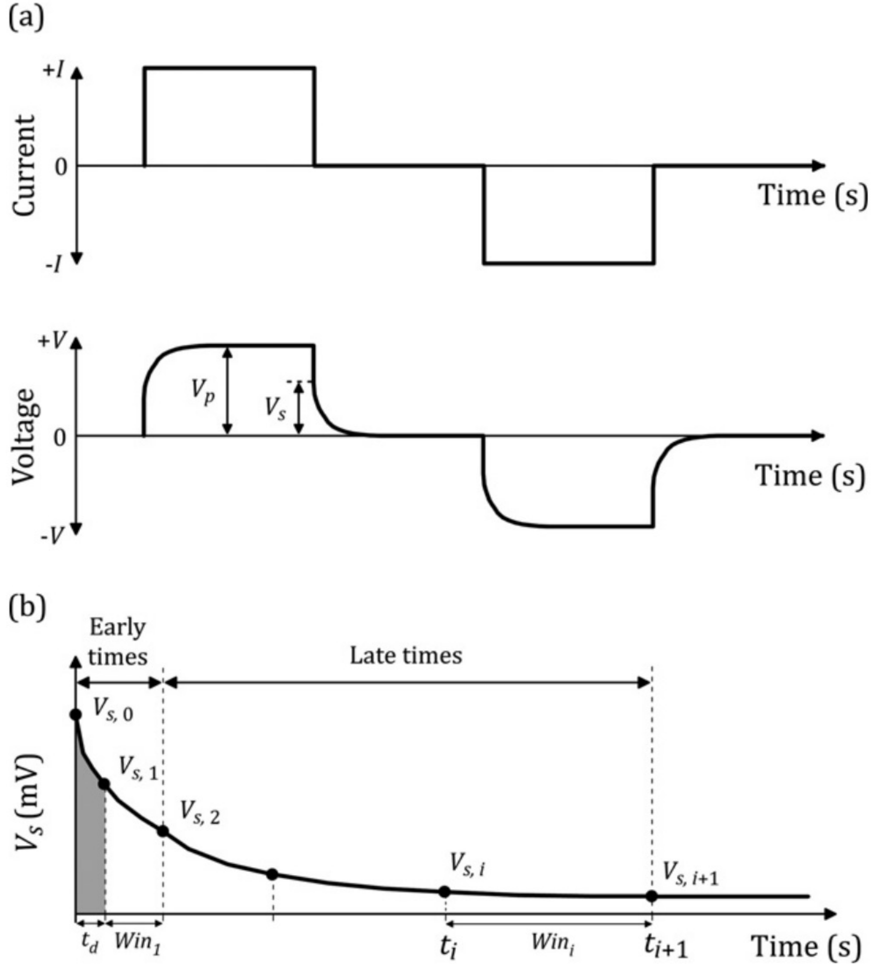


Current preferentially flows through conductors and this affects the measured potential difference (voltage) along the remaining electrodes. A dense dataset allows us to reconstruct the subsoil (tree trunk) processes if they affect the electrical conductivity.

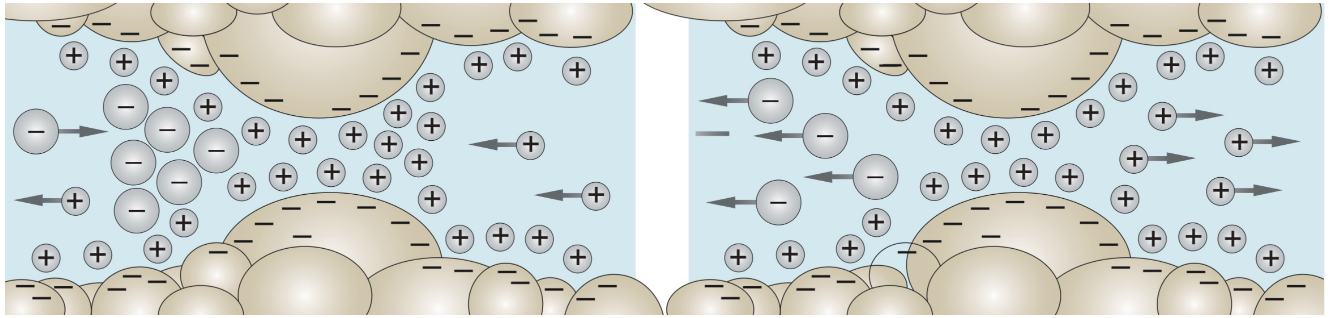


In DC resistivity, a current is induced in the ground (tree) and the voltage is measured for steady conditions. Often, measurements are repeated by flowing current in the opposite direction (reciprocal).

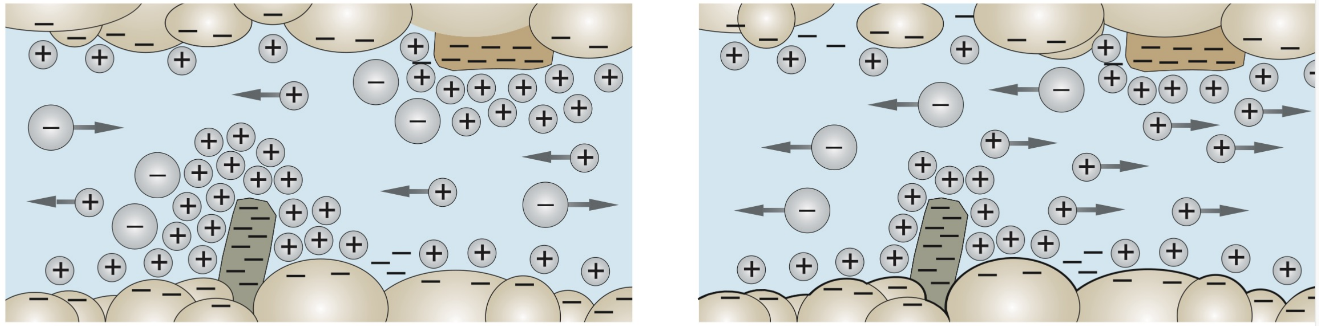
Direct Current (DC) vs **Induced Polarization (IP)**



Figures above from Slater and Binley (2020)



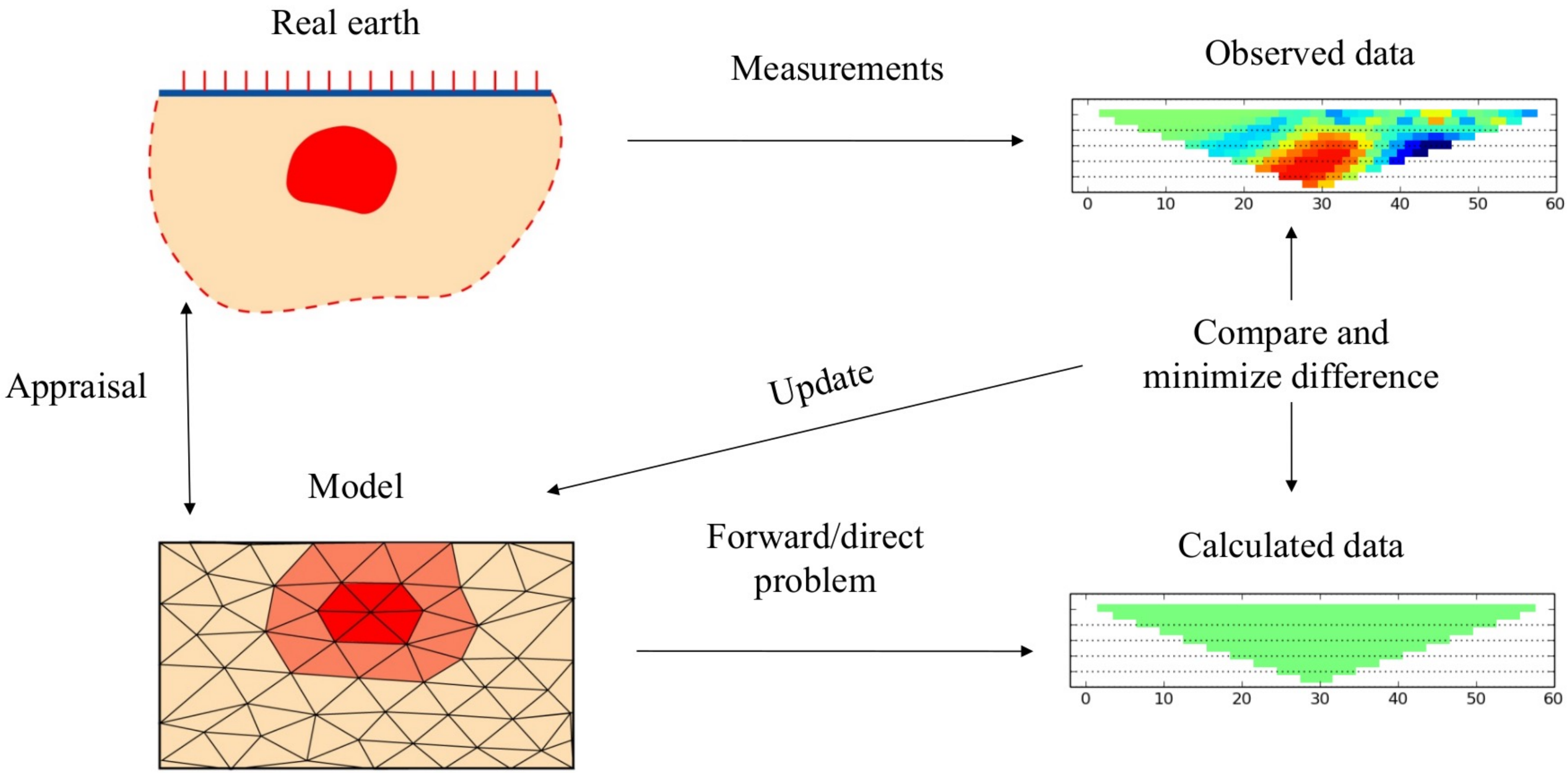
Polarization effects from pore structure in the soil that blocks the free flow of ions in water.



Polarization effects from grains in the soil that may have different electric charge (e.g., clay).

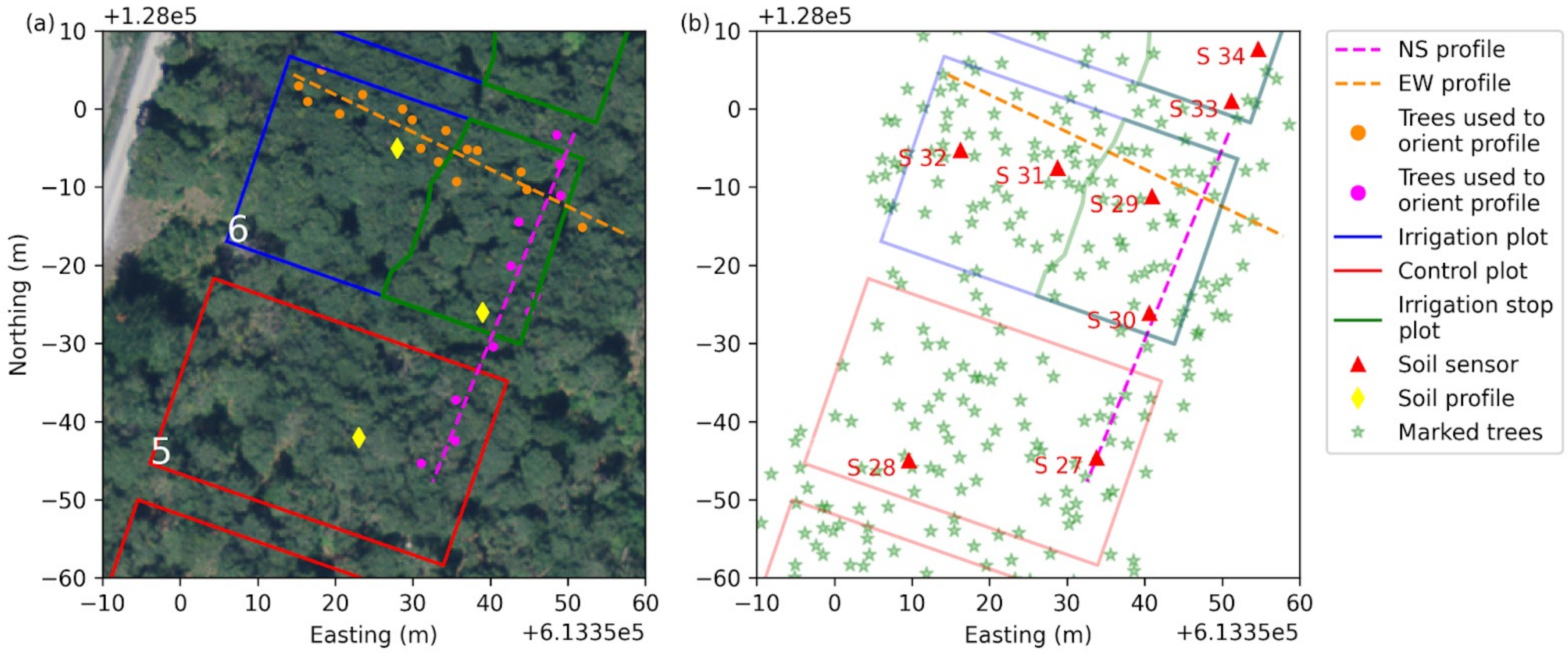
Figures above from Dentith and Mudge (2014) Geophysics for the Mineral Exploration Geoscientist

Interpretation through geophysical inversion

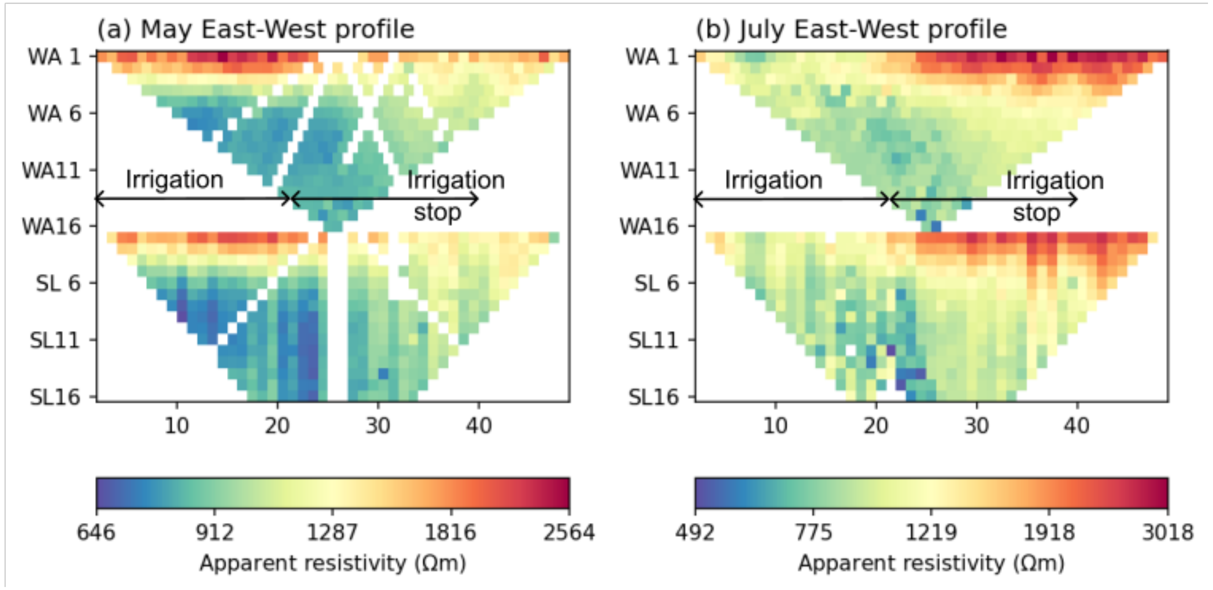


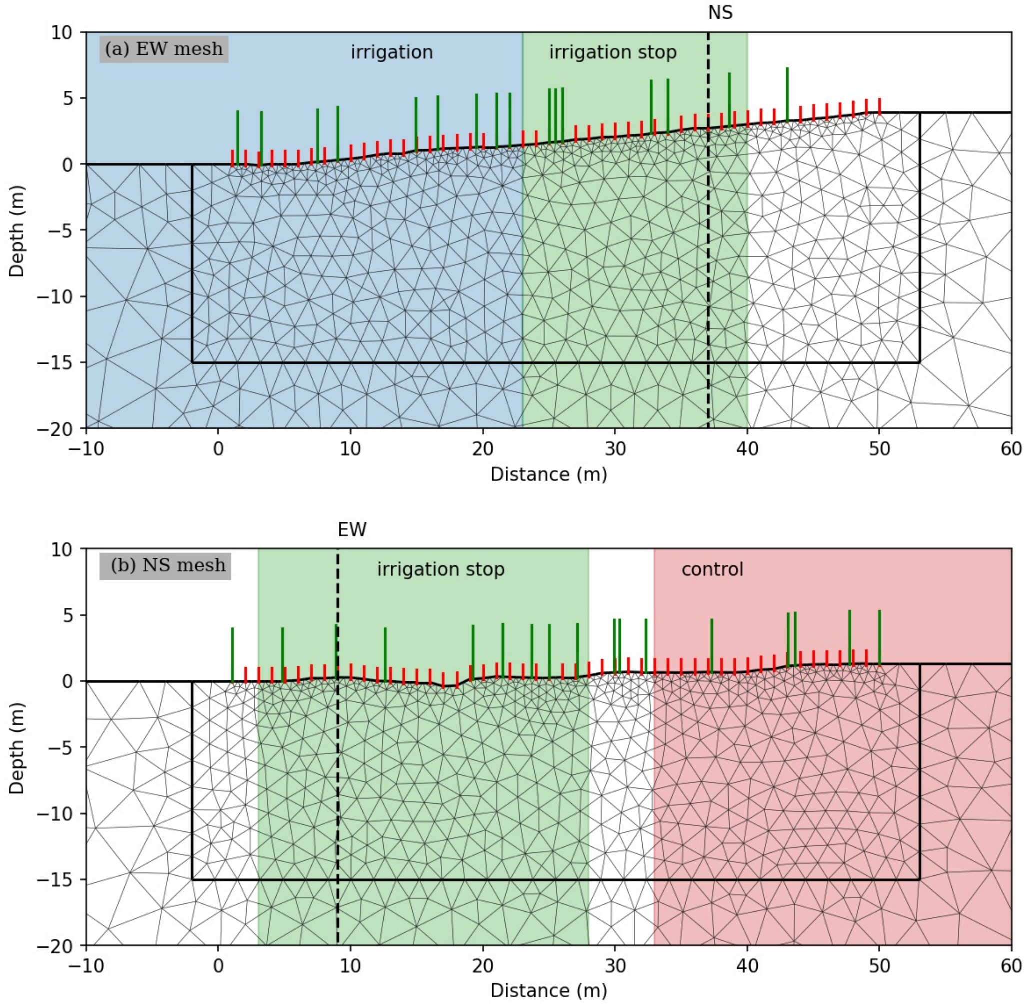
Results from past projects (2022)

Root uptake depth for the various treatments



Data analysis and forward modeling

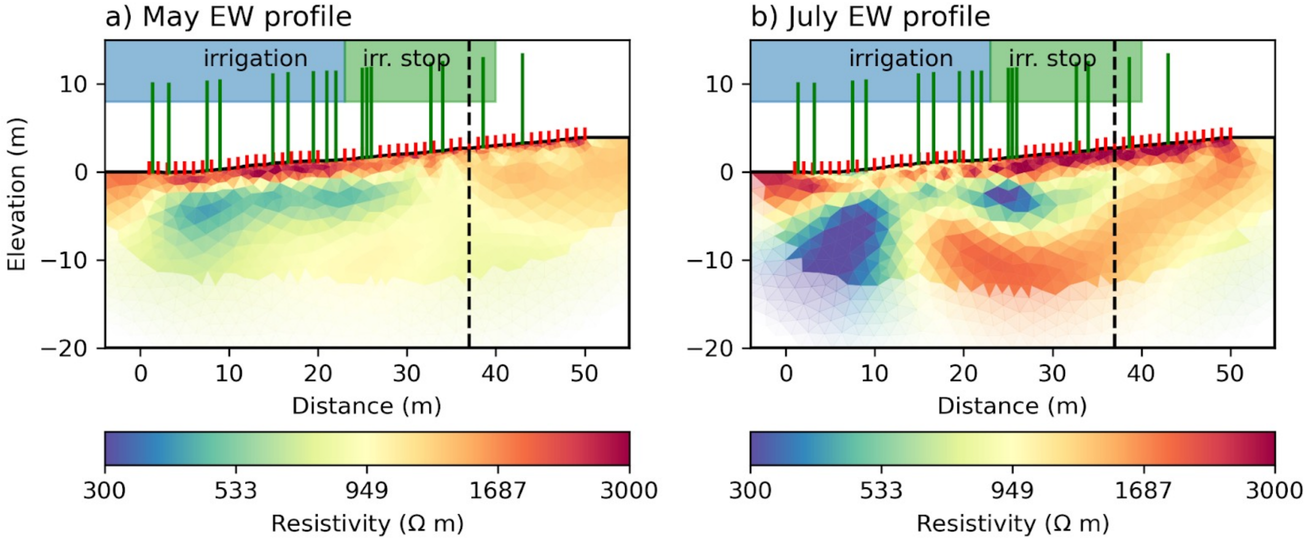




Above: Comparison of raw data before and after irrigation for the East-West profile. Changes are clearly visible even before inversion.

Right: Meshes used to invert for the subsoil resistivity.

Inversion results



The irrigation stop trees dry up the deep soil, up to 10 m, considerably more than the other plots during the summer drought.

The irrigation trees show a reverse pattern, where the resistivity in the deep layers is reduced (suggesting water stored at these depths).

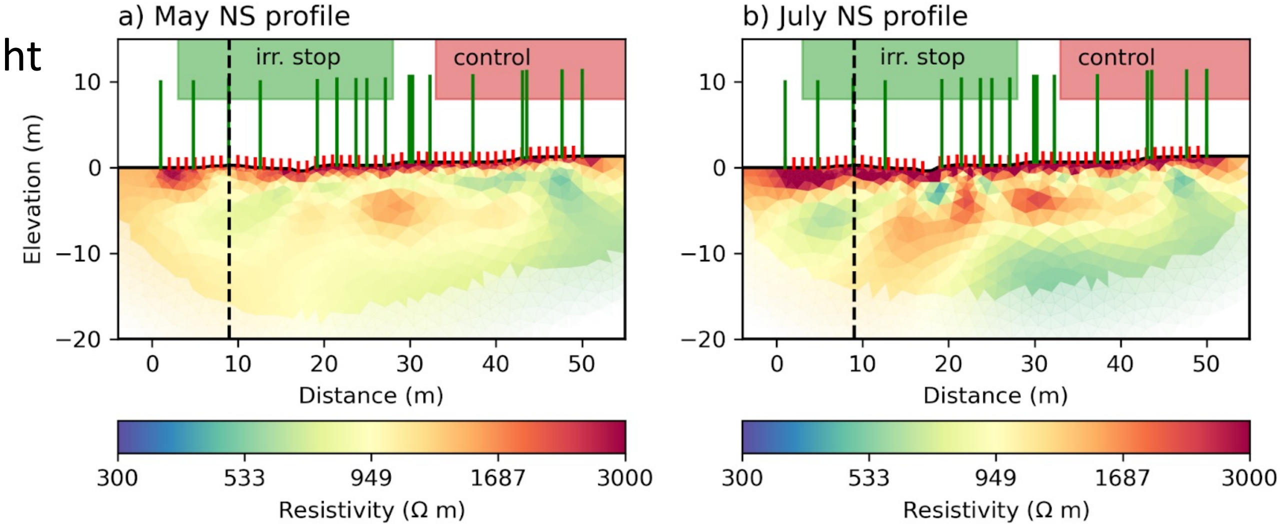
The control trees do not change the conditions much compared to the rest.

Note: Irrigation water has a resistivity of about 20 Ohm m.

Inversion results for East-West (top) and North-South (right side) profiles comparing the May and July campaigns.

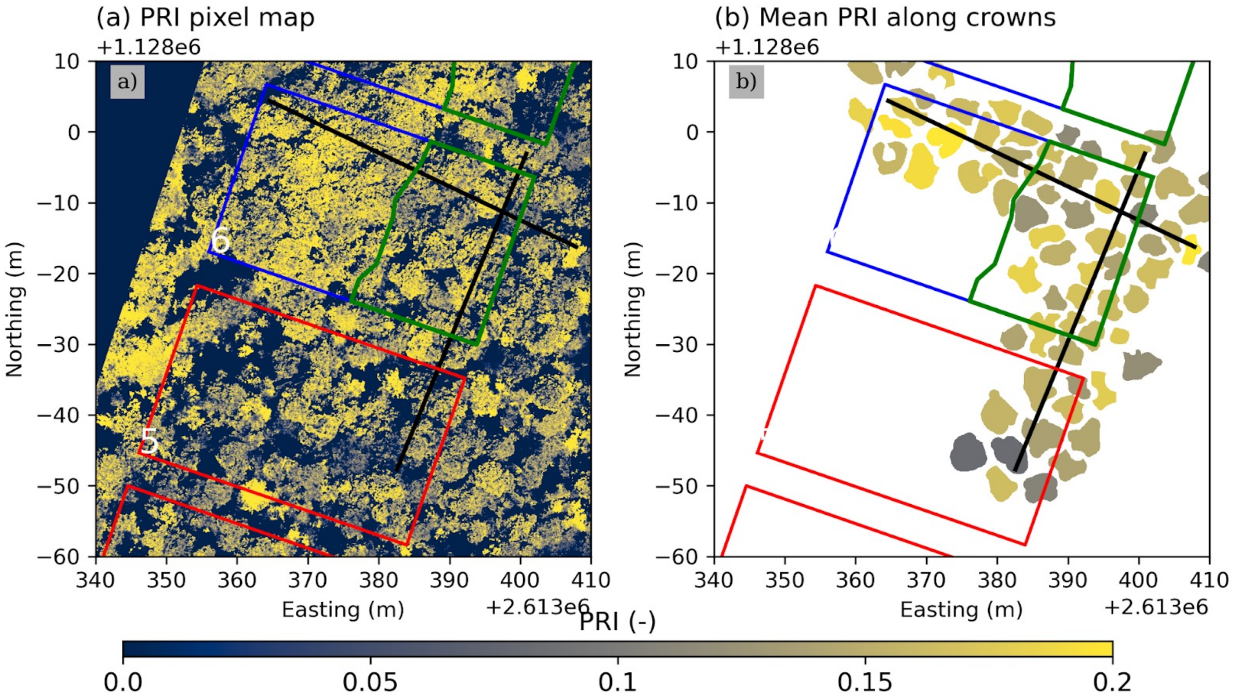
The intersection between the profile is indicated with a dashed vertical line.

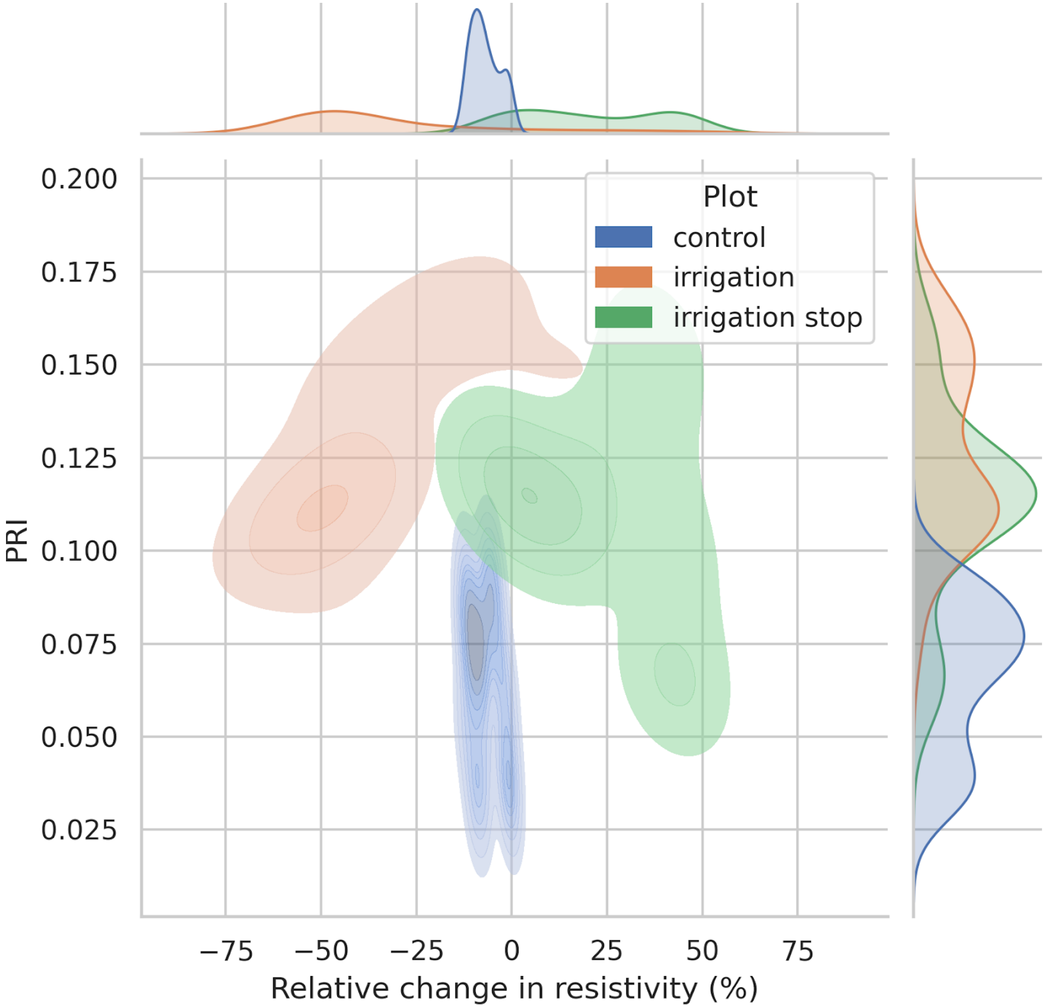
The electrodes are shown as short red vertical lines and nearby trees (<2 m) with long green vertical lines.



Combined analysis of PRI and ER

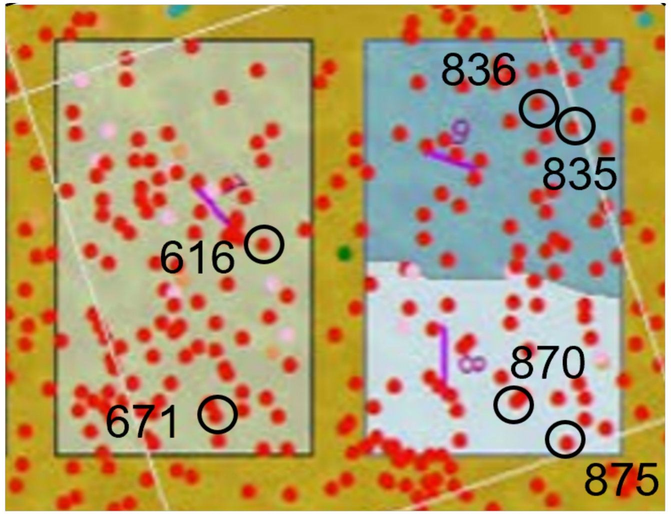
We further compared the relative changes in resistivity along with photochemical reflectance index (PRI) obtained during the July campaign, both with a pixel-based and crown-based approach.





Electrical resistivity on trees

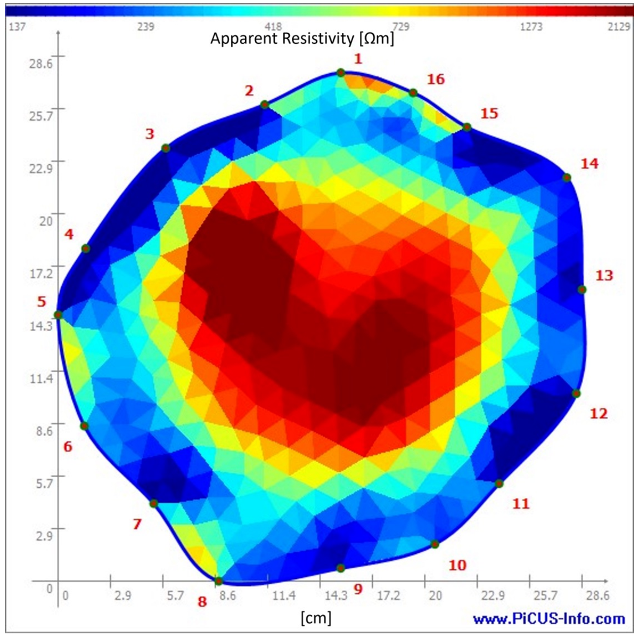
control irrigation



Irrigation stop

ABEM Terrameter LS

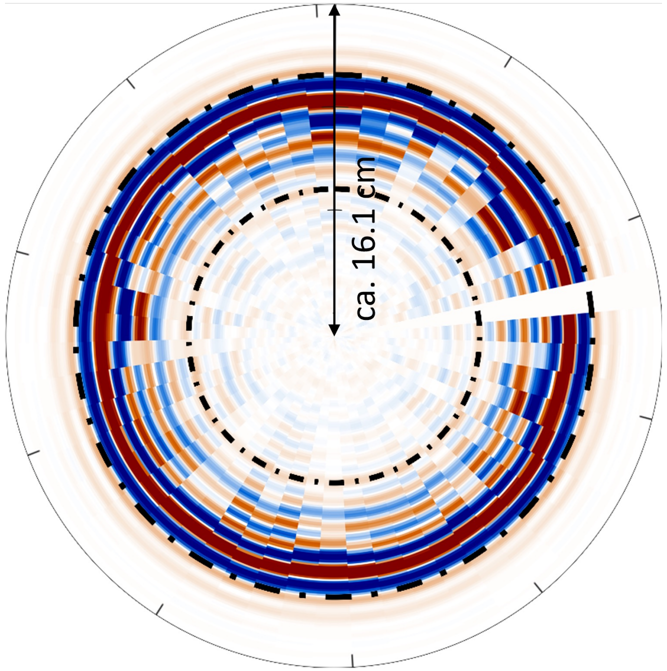
PiCUS TreeTronic



Data collection:
Measurements repeated 3 times per tree (~10 min) and **both** in early morning and afternoon, over several days. Result ~8 k datapoints per tree. Tested both PiCUS and ABEM systems.

Including the heartwood as a prior constraint

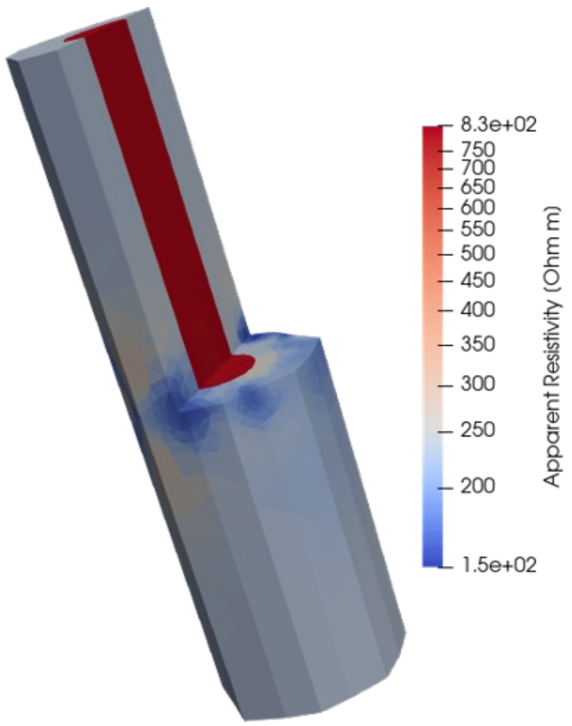
Including the heartwood / sapwood boundary as a prior constraint in the inversion requires knowledge of the heartwood extent. With ground penetrating radar (Proceq GP 8800, left figure) we were able to collect reflections of the three layers, bark, sapwood and heartwood (middle). Using velocities obtained from dielectric measurements on freshly cut trees, we could obtain realistic estimates of these boundaries (right table).

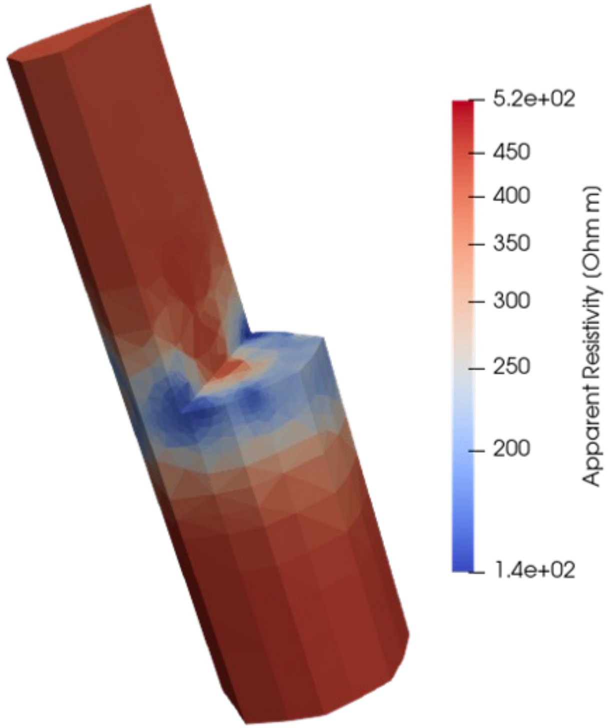


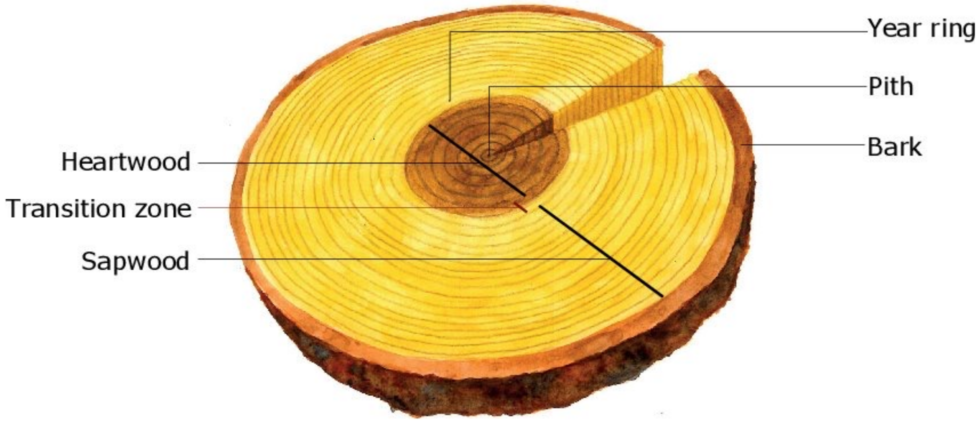
	Tree Nr. 753 (Core data, WSL)	Tree Nr. 835
Bark width [cm]	3.34	3.4
Sapwood width [cm]	4.70	5.67
Hardwood width [cm]	8.03	9.49
Circumference at h= 130 cm [cm]	101	108.5

3D inversion with heartwood

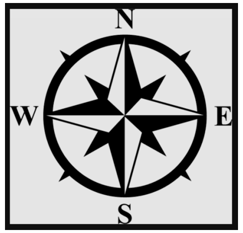
In addition to the internal structure of trees, the inclusion of the actual 3D geometry (extent) completely redistributes the current flow and strongly changes the inversion result.







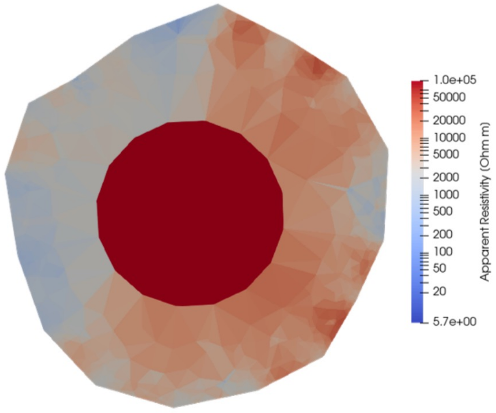
Back to the field data (some results)



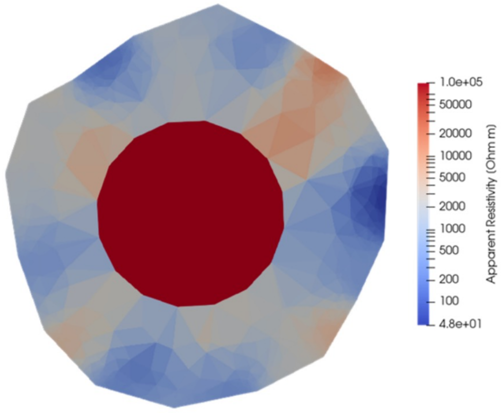
With the 3D geometry and heterogeneous internal structure that honors the sapwood/heartwood boundary, we compared the dynamics of each plot (irrigation, control, irrigation-stop).

A comparison of tree 836 in the irrigation plot:

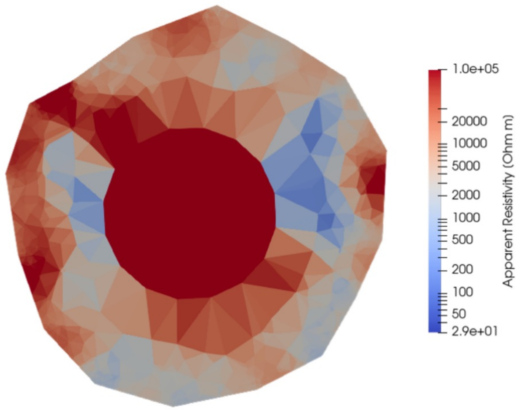
- March: resistivities are high and mainly on the East of the trunk
- May (irrigation starts): the overall resistivity is low, with likely increased water movement but still low temperatures
- July: resistivities are high all around the trunk



(a) 18.03.2022: heterogeneous 3D inversion.



(b) 12.05.2022: heterogeneous 3D inversion.



(c) 21.07.2022 afternoon: heterogeneous 3D inversion.

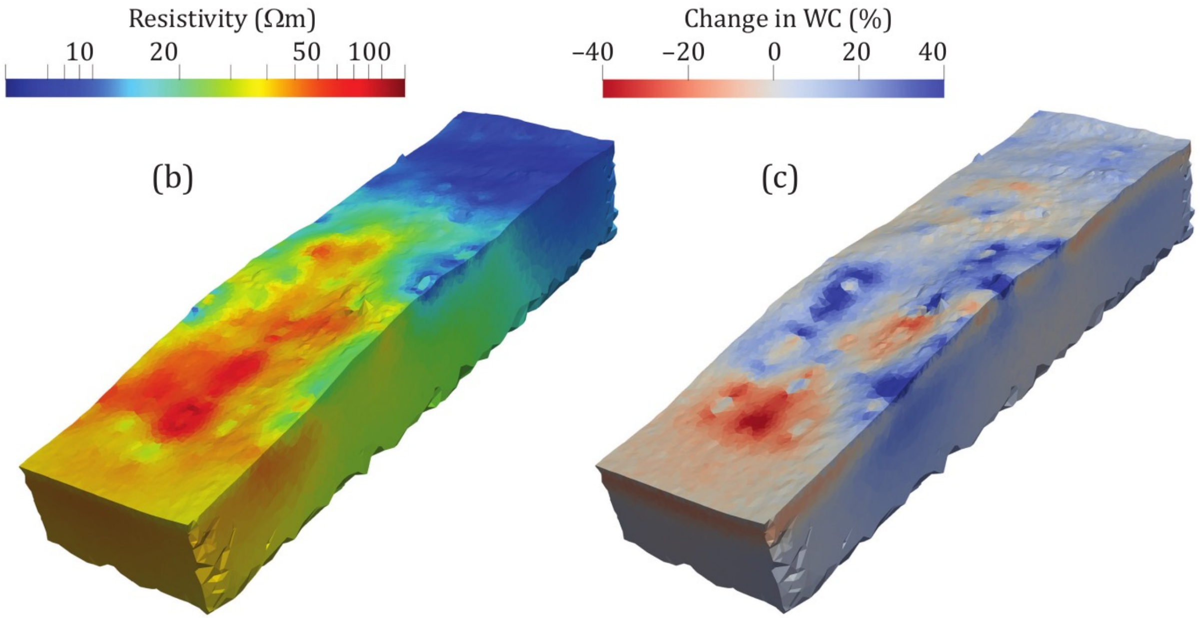
Ongoing project

4D monitoring of VPDrought experiment

For this project we will install 3D electrode configurations to span the various VPD treatments and perform a time-lapse (4D) monitoring of the experiment using both DC and IP.

Above: A 3D survey carried out in Zurichberg in January to test remote monitoring.

Below: Results from a 3D survey (Slater and Binely, 2020) where the time-lapse monitoring allows to convert resistivity to relative change in water content.



Summary and conclusions

- We were able to monitor changes up to depths of 10 m between the different irrigation plots. These changes agree well with the observations from PRI data. Publication in preparation.
- We applied novel modeling and inversion techniques to interpret resistivity data from tree trunks, using prior information and 3D geometries. Results are still compiled.
- We are planning new 4D resistivity, both DC and IP, for the upcoming VPDrought experiment. We also will perform repeated GPR.
- We have tried using active seismics (travel-time tomography) in Pfynwald but with limited success.

Geophysical methods can be a great addition to the existing monitoring network of Pfynwald, and provide information on below-ground processes at high spatial and temporal resolution.