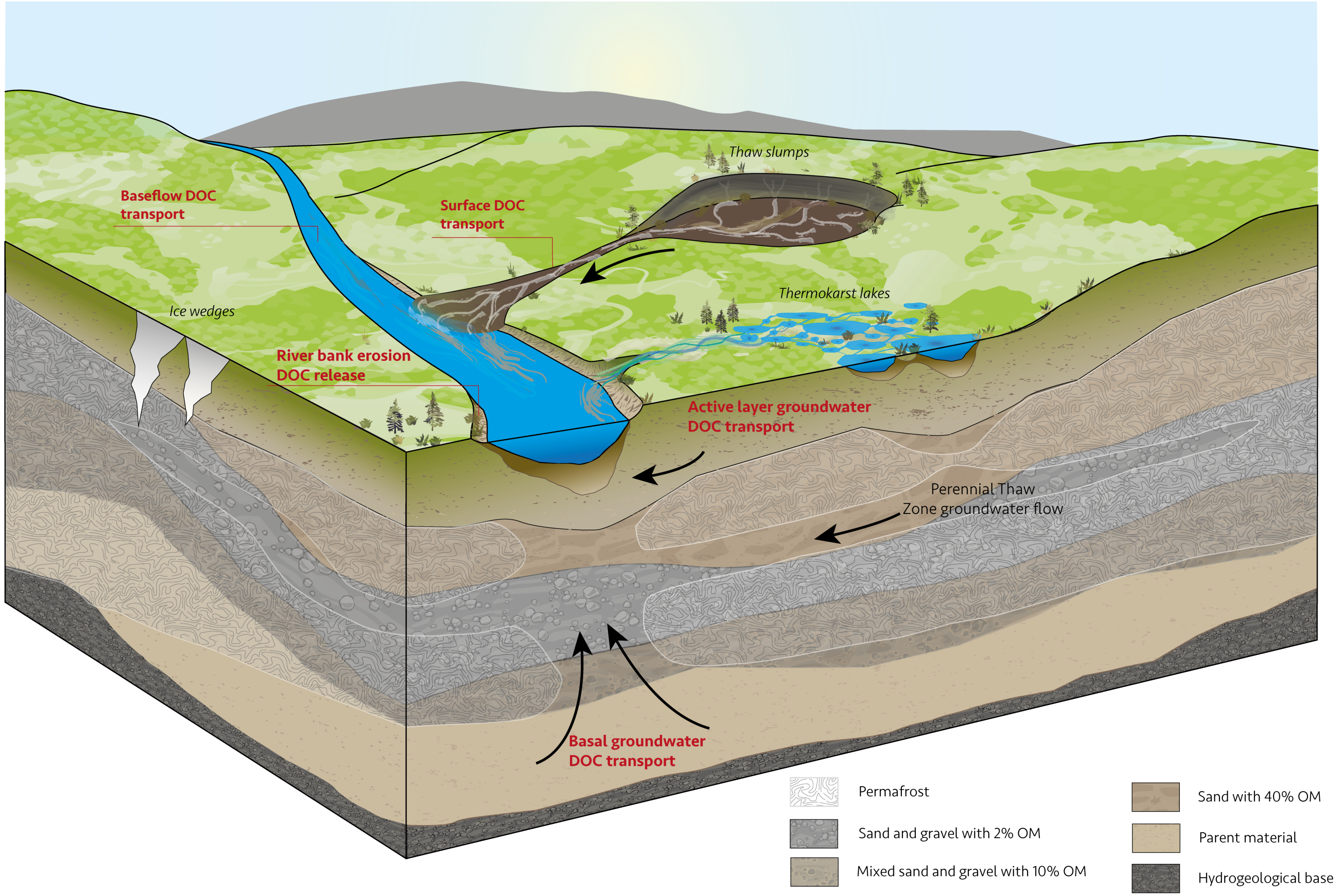
Detecting permafrost freeze-thaw front propagation using time-laps ERT observations in a large column experiment

J.G.H. de Bruin[1], V. F. Bense[1], M van der Ploeg[1], (1) Wageningen University and Research



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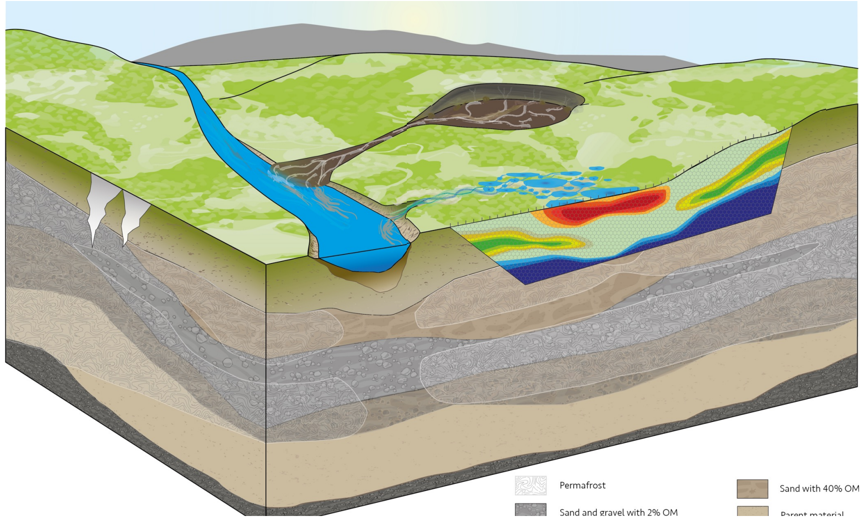
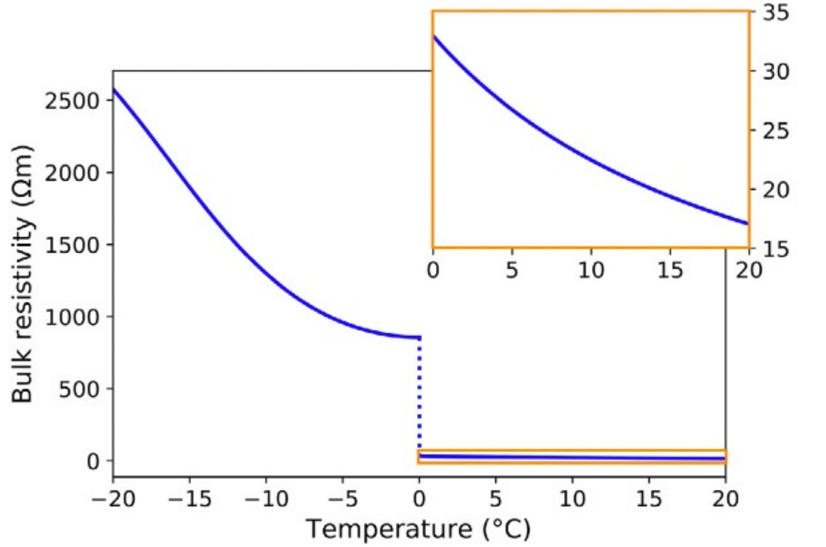
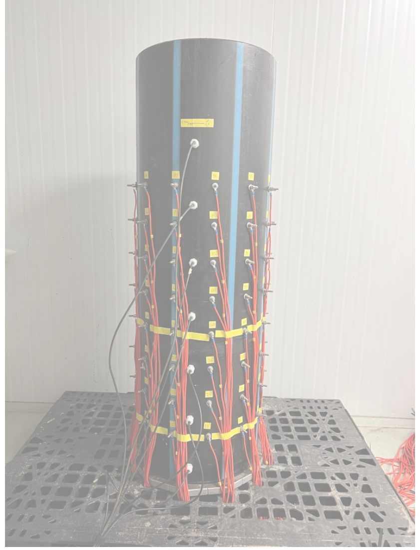


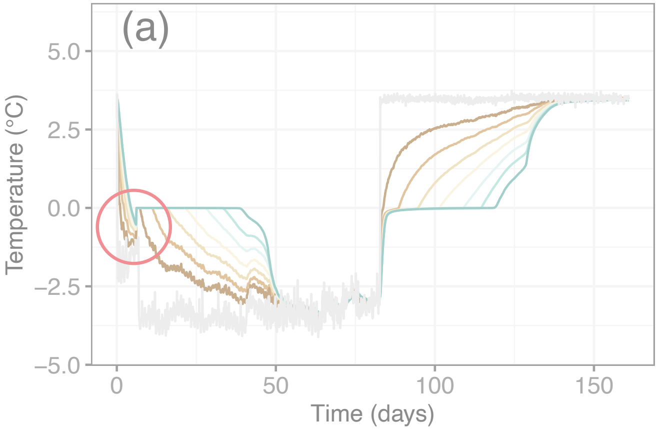
Strong influence of temperature on bulk resistivity

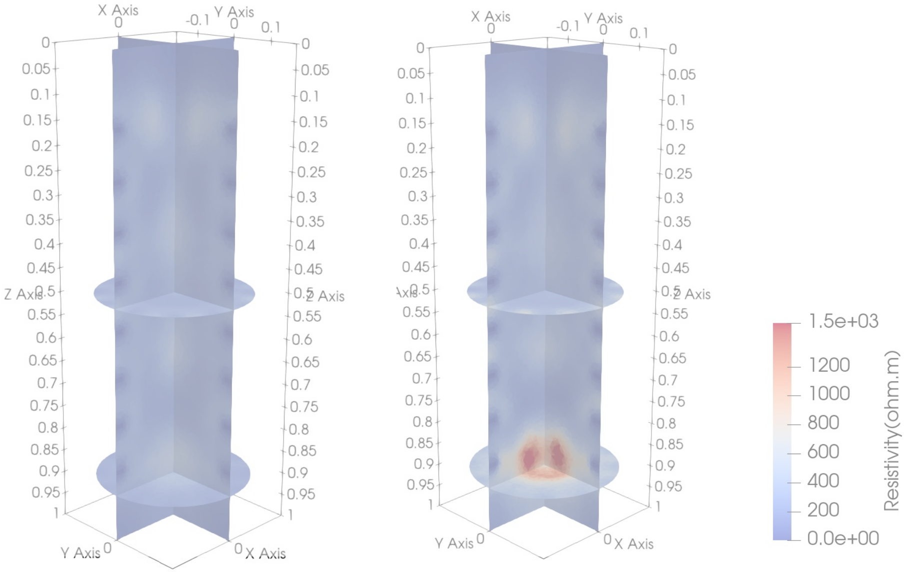




Freeze-thaw cycle

- Temperature
- ERT observations





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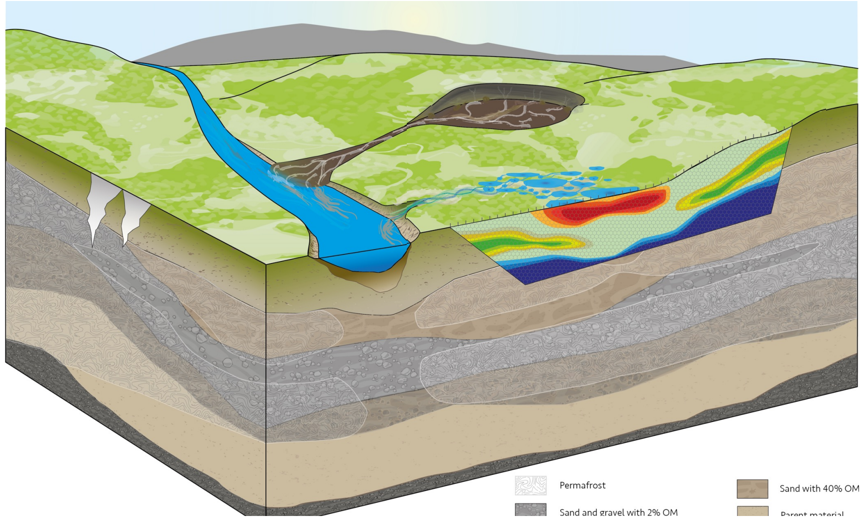

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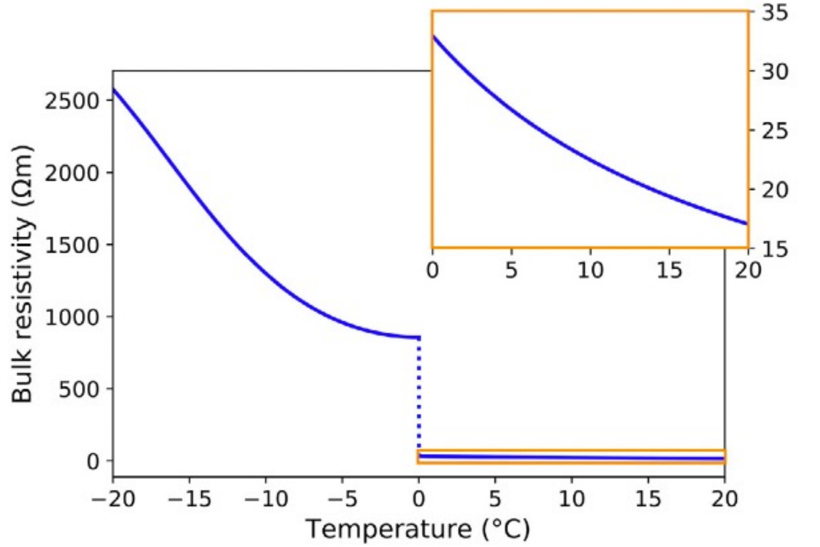

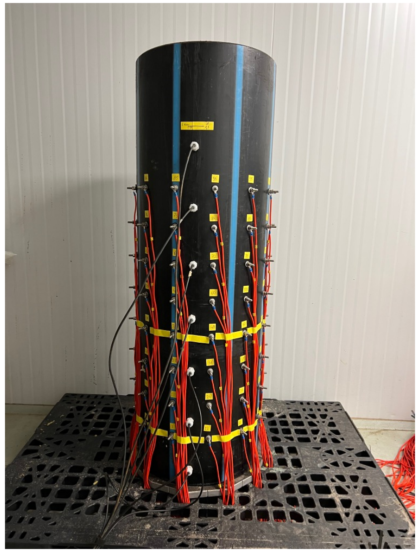

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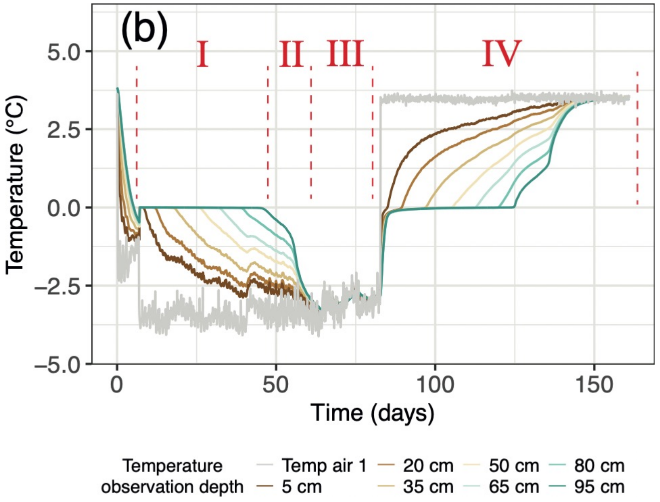

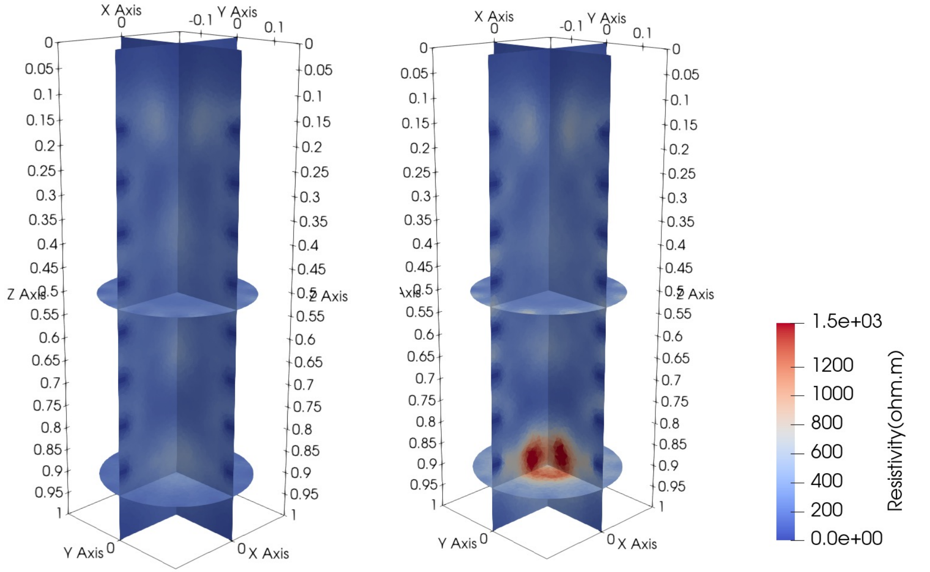

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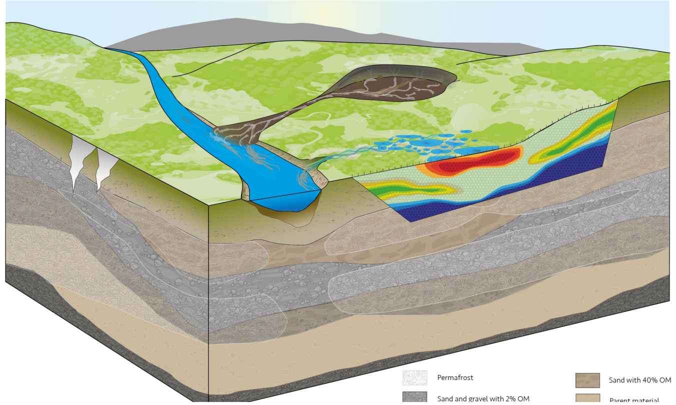
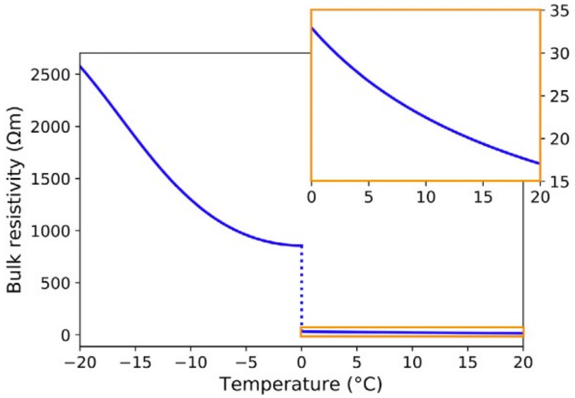




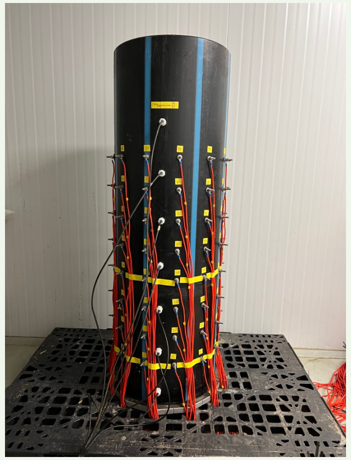
Theoretical temperature- bulk resistivity relation. Figure by: T Herring, E Cay (2021)

Aim & Methodology

Detect freezing and thawing front using ERT, subsequently calibrate numerical heat transfer model to simulate both temperature and bulk resistivity.

1. Design experimental column equipped with temperature sensors and ERT electrodes.
2. Simulate freeze-thaw cycle – collect temperature and ERT observations.
3. Time-laps inversion of ERT observations.
4. Run numerical heat transfer - resistivity model.
5. Compare experimental data with numerical data.
6. Optimize parameterization of numerical model.

Experimental setup

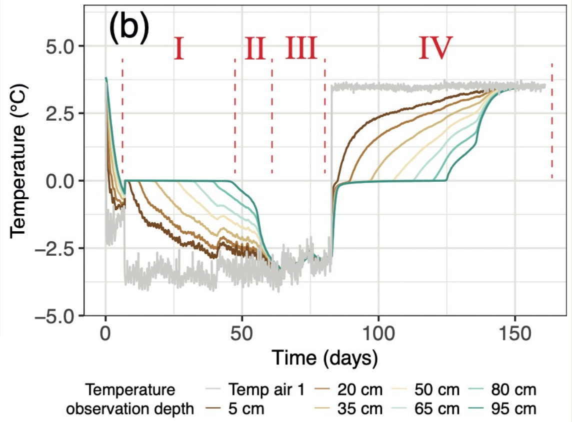


Experimental column

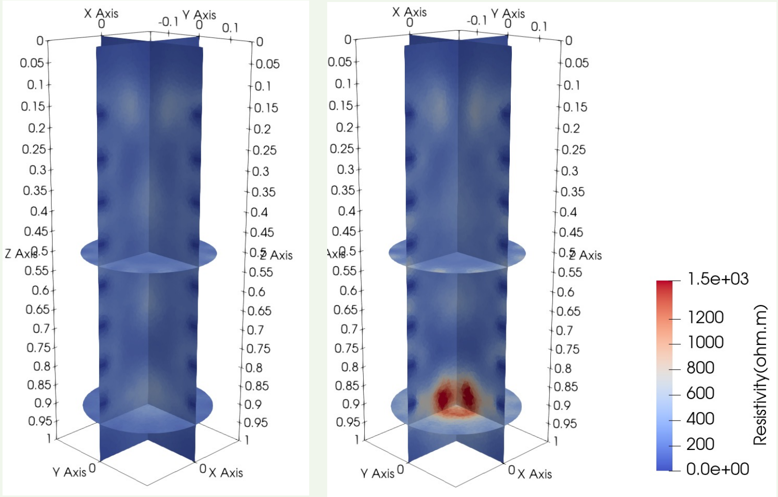
- Temperature observations
- ERT observations

Experimental column, equipped with 96 electrodes placed in 8 rings and 7 temperature sensors

Observations



Temperature observations at different depths within experimental column during freezing and thawing.



Inversed ERT observations collected during freezing, at day 1, and day 14. It shows a sharp increase in bulk resistivity as freezing front moves vertically upward through the column.

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ERT observations

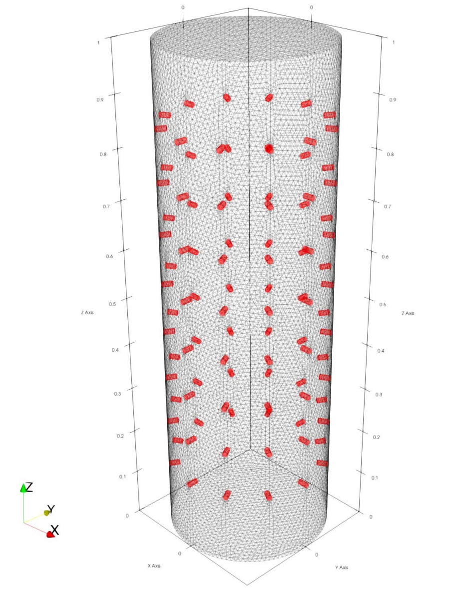


Figure showing the mesh for the ERT inversion, in red the electrodes with a fixed resistivity.

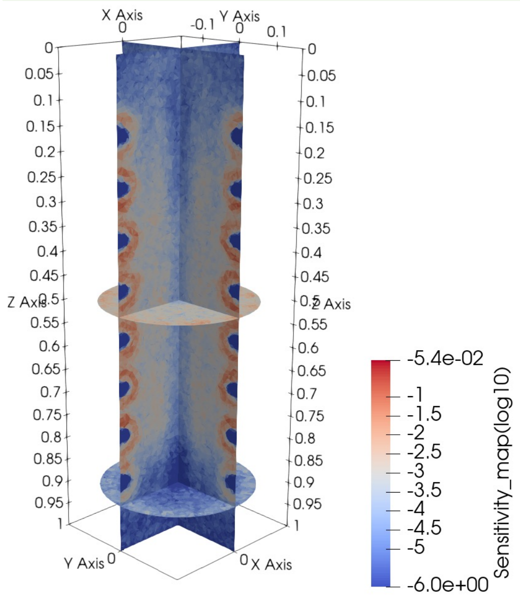
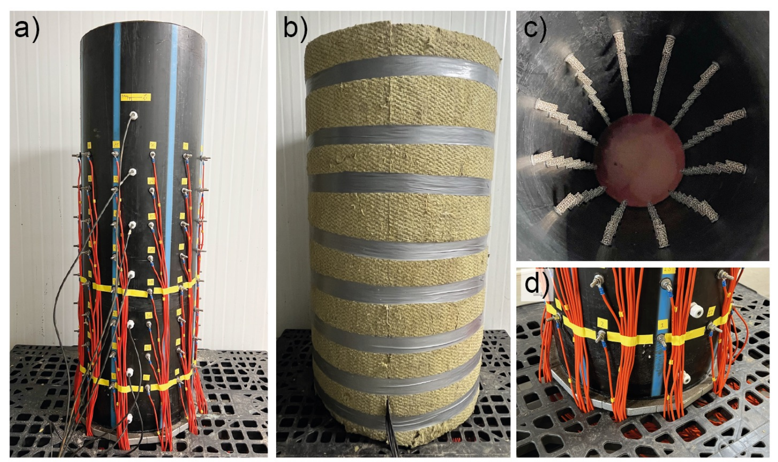


Figure showing the sensitivity of the inversion, with a high sensitivity close to the electrodes.



Numerical model simulations

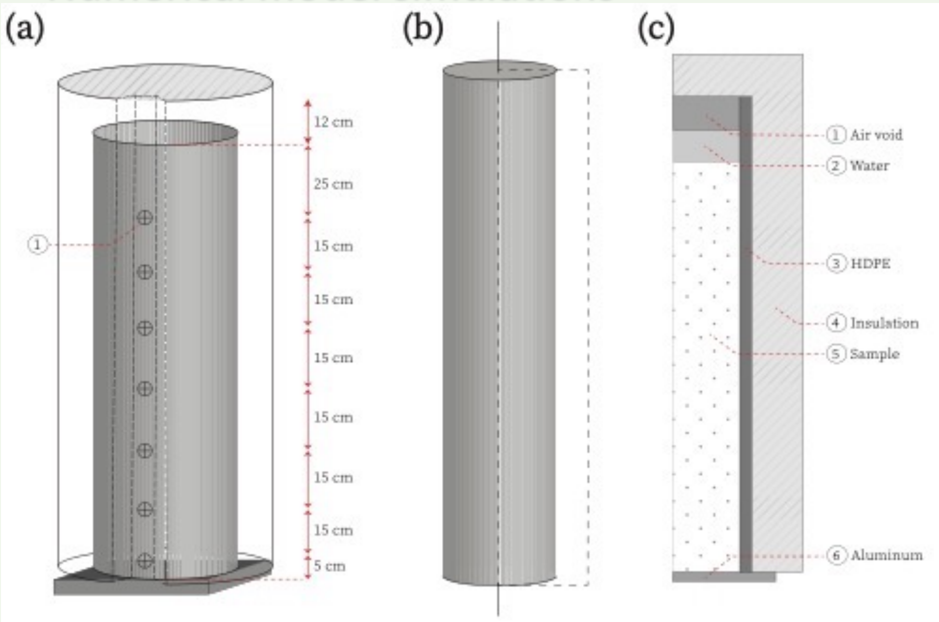


Figure showing a schematic of the experimental setup, and translation to a Y-cylindrical numerical model domain.

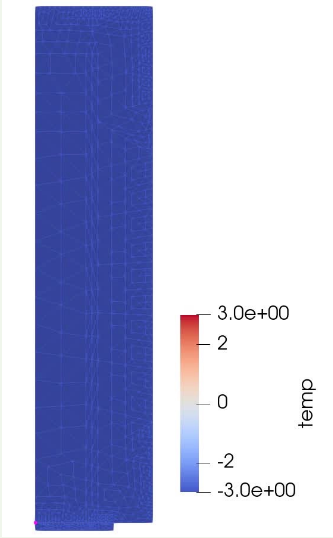
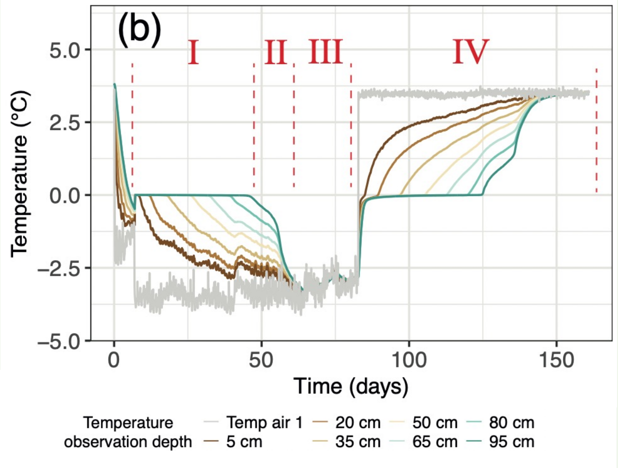


Figure showing temperature simulation of the numerical model over time.



Heat transfer equation

$$\delta z\left(\lambda_t \frac{\delta T}{\delta z}\right) = C_v \frac{\delta T}{\delta t} + \phi \rho_i L \frac{\delta S_w}{\delta t}$$

Temperature dependent bulk resistivity

$$\rho_{\text{bulk}} = \begin{cases} a\phi^{-m} S_{w0}^{-n} \frac{1}{kC_0[d(T-25)+1]} & \text{if } T \geq 0\,°C \\ a\phi^{-m}(S_r S_{w0})^{-n} \frac{S_r}{k\, C_0[d(0-25)+1]} & \text{if } T < 0\,°C \end{cases}$$

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