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LIAG Leibniz Institute for Applied Geophysics

A Forward Modeling Study for the Investigation of the Vertical Water-Content Distribution Using Guided GPR Waves

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RESEARCH OBJECTIVE

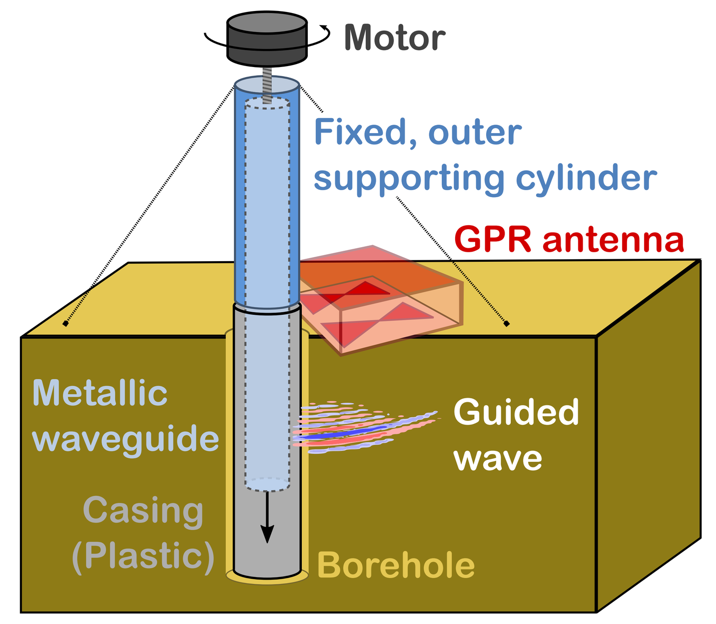
Using a 400 MHz GPR antenna with the guided-waves method, numerical FDTD studies are performed with the software gprMax [2] to investigate:

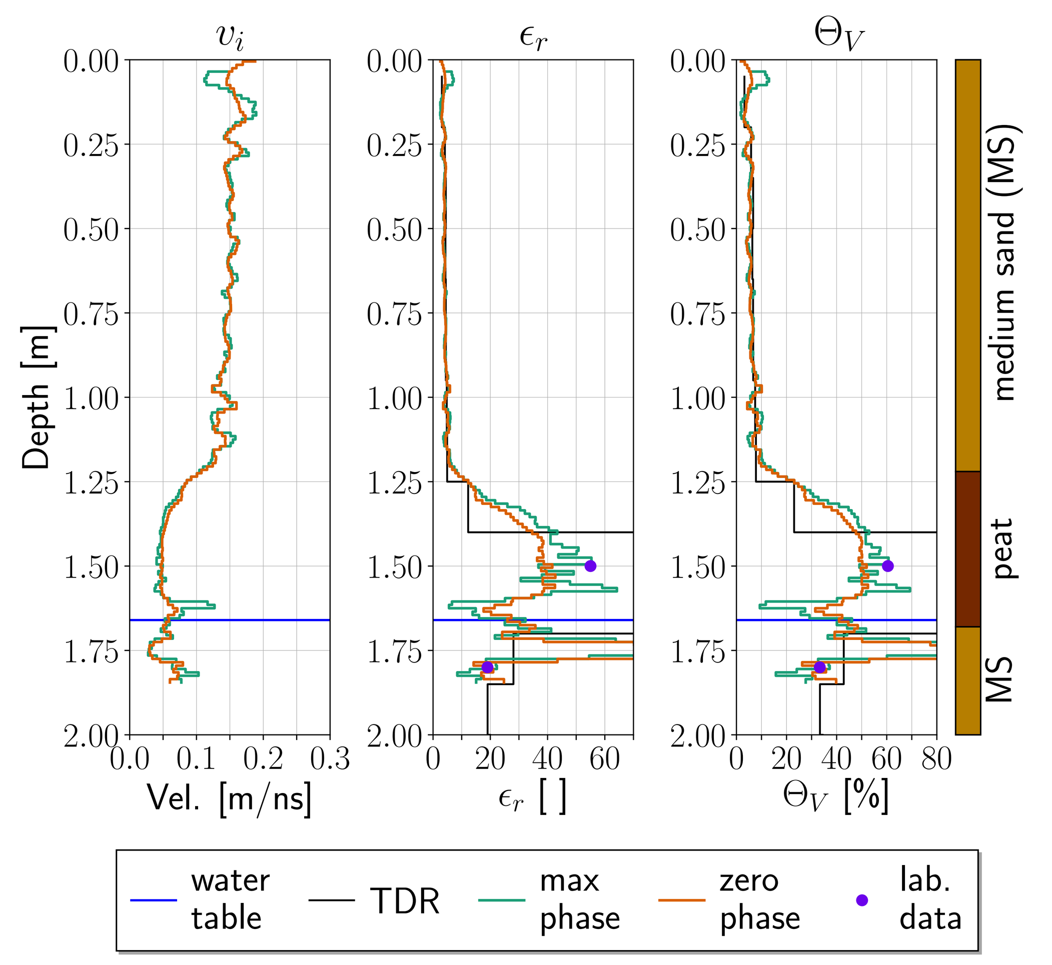
- the electromagnetic field around a metallic waveguide to assess a sensible volume of the method,
- the phase velocity in the vicinity of the antenna,
- the accuracy of the guided-waves method with and without a plastic borehole casing

Background

The guided-waves method can yield highly resolved velocity-, permittivity- and water-content distributions of soils. A metal waveguide is sequentially lowered in a borehole and produces a reflection of the GPR pulse, which is coupled to the waveguide, at its lower end [1].

Guided GPR Waves: Setup & Field Measurements

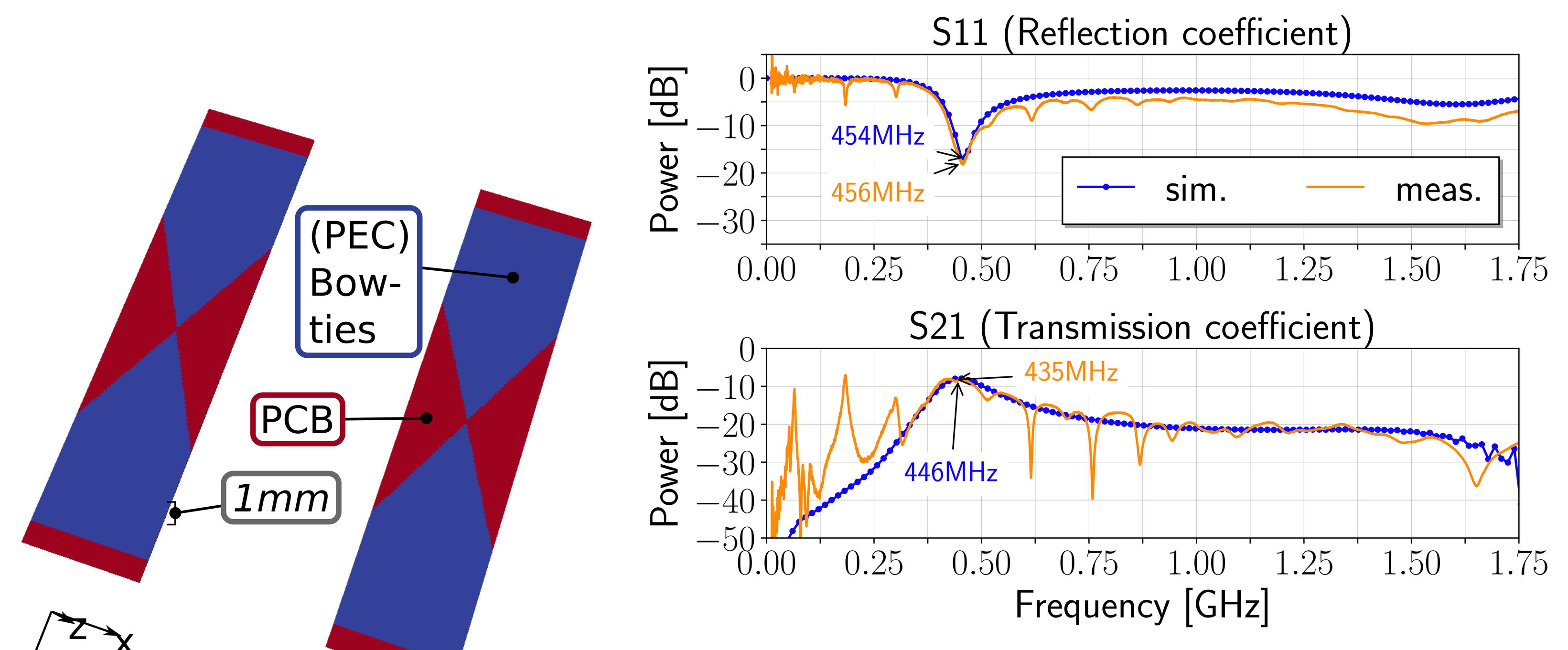




▲ Experimental setup ► Interval velocity v_i, relative permittivity ϵ_r and volumetric water-content Θ_V calculated over a 2 cm interval. The data stems from the LIAG test-site at Schillerslage, near Hannover.

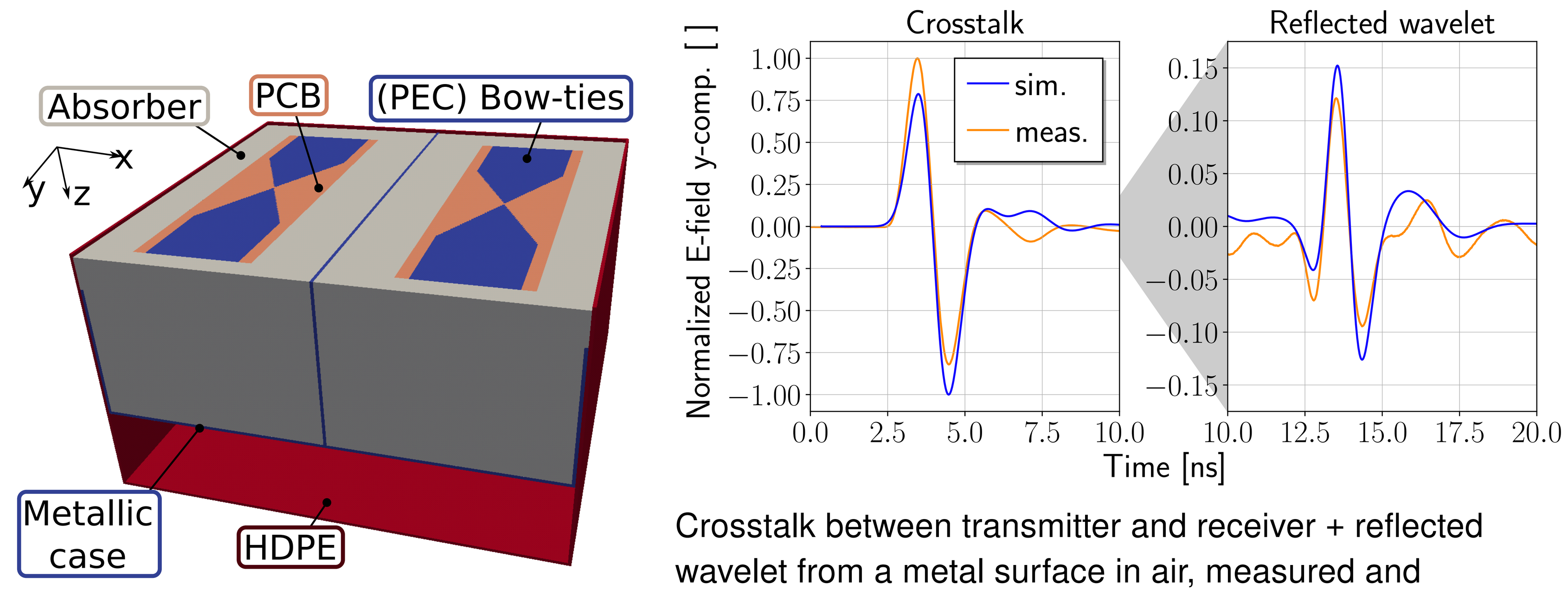
Building & Validating a 3D Antenna Model

An unshielded 400 MHz antenna model



Reflection (S11) and Transmission (S21) Coefficient, measured and simulated.

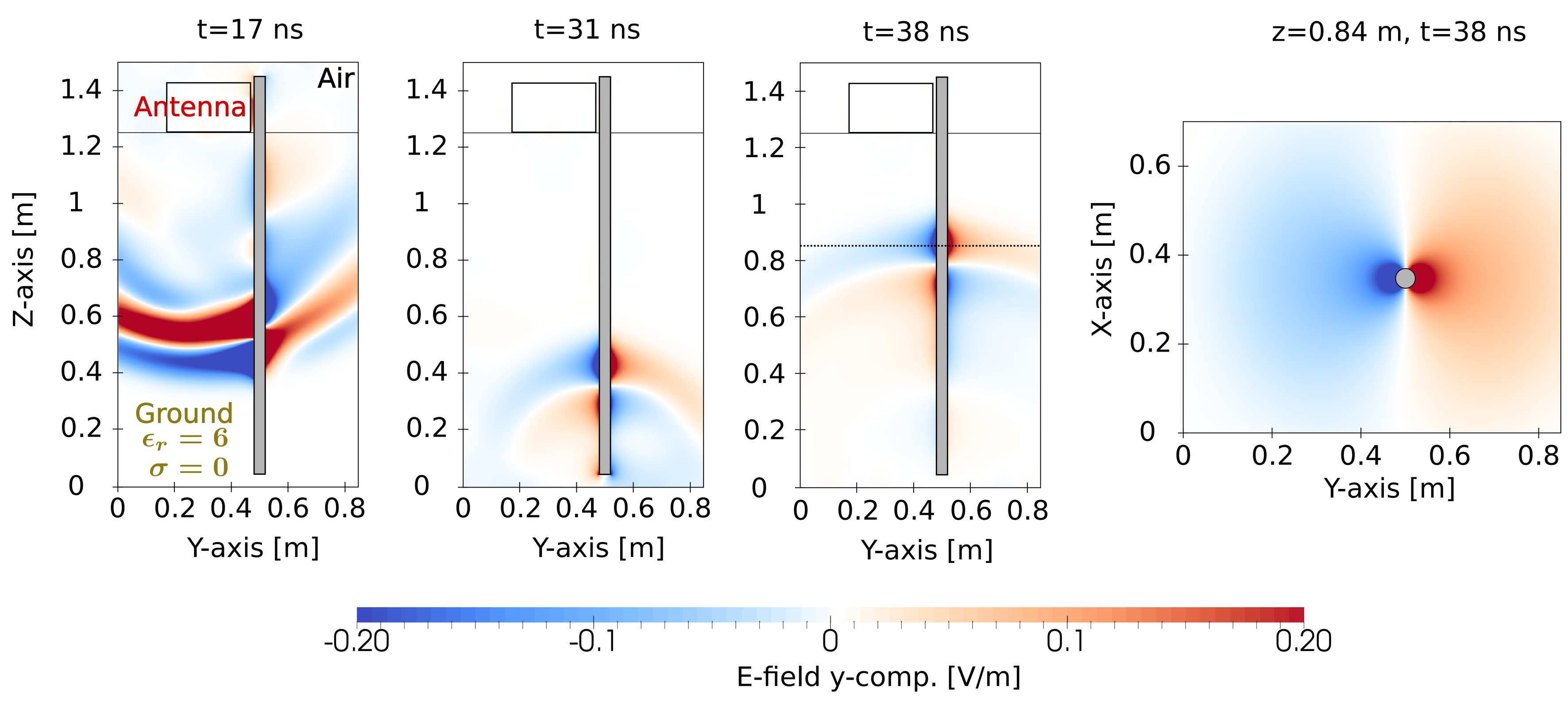
A complex, shielded, 3D 400 MHz antenna model



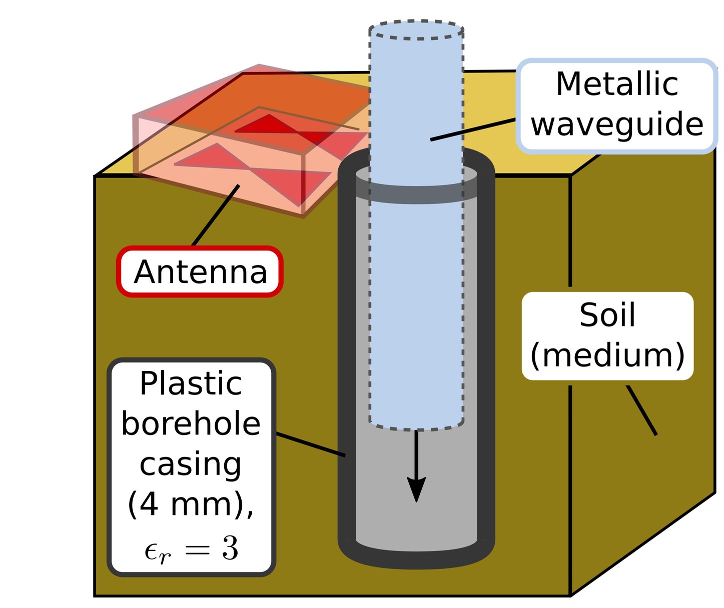
Crosstalk between transmitter and receiver + reflected wavelet from a metal surface in air, measured and simulated.

Numerical Studies

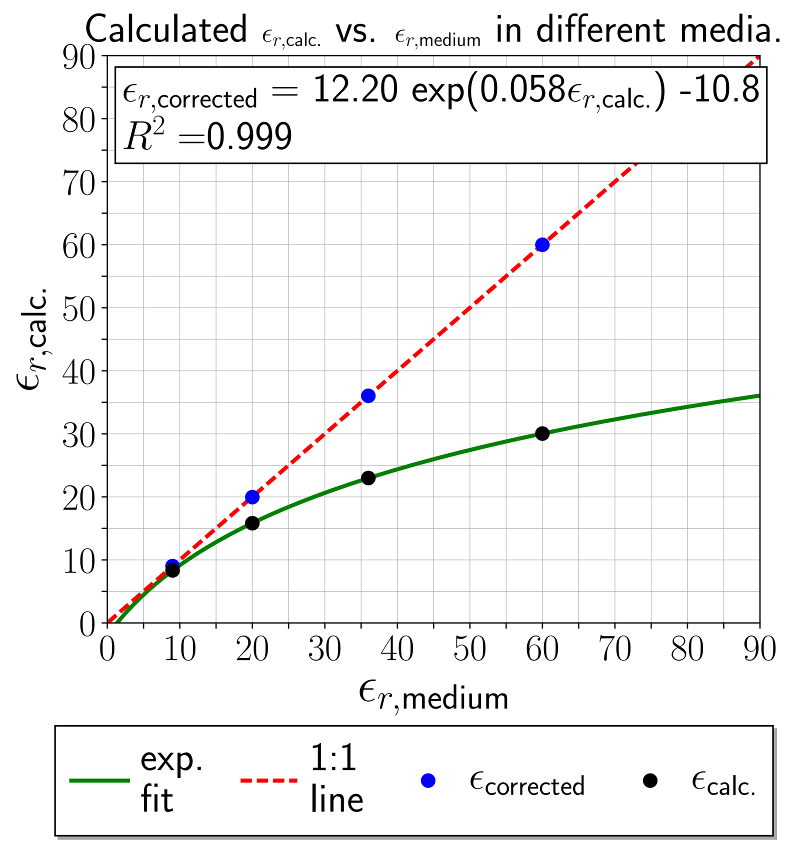
Field Distribution around the waveguide



Influence of plastic borehole casing on ϵ_r measurements

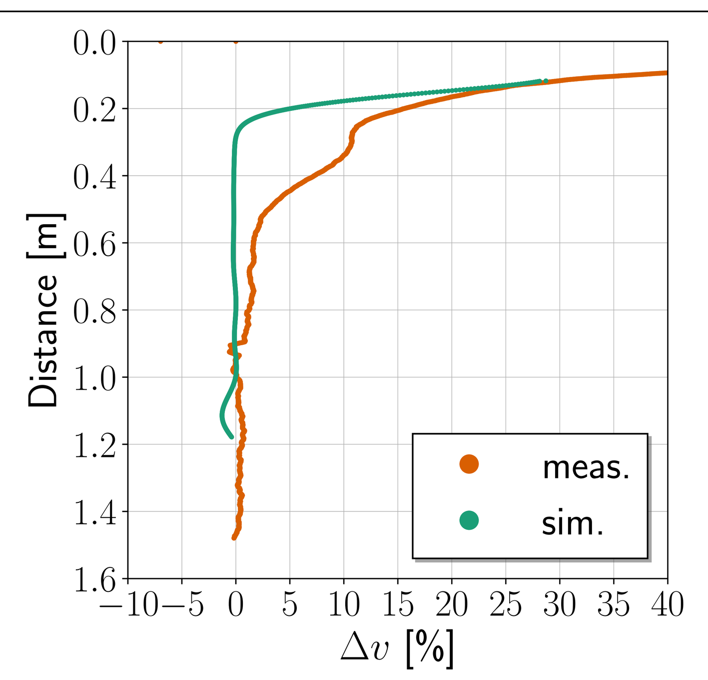


▲ Modeling setup ► Calculated and corrected ϵ_r values for media with different $\epsilon_{r,\text{medium}}$



Velocity in the Vicinity of the Antenna

Guided waves measurements were performed in air and compared to simulations thereof. The interval-velocity difference $\Delta v_i = v_i - v_{\text{air}}$ is plotted vs. the distance to the antenna whereby v_i is filtered with a running average over a 1 cm.



CONCLUSION

- The EM field is distributed anti-symmetrically around the metallic waveguide. The sensible volume of the method can be estimated with the radial skin-depth of the EM field of ≈ 5 cm.
- A 4 mm-thick plastic borehole casing causes a considerable reduction in calculated ϵ_r. This can be corrected with an exponential function.
- When picking travel-times in air with the waveguide ≤ 60 cm away from the antenna, phase velocities will appear to be superluminal ($v_p \geq c_0$), leading to a reduced calculated ϵ_r.

[1] J. Igel, S. Stadler, and T. Günther. "High-Resolution Investigation of the Capillary Transition Zone and its Influence on GPR Signatures". In: *Proceedings of the 16th International Conference of Ground Penetrating Radar.* 2016.
[2] C. Warren, A. Giannopoulos, and G. Iraklis. "gprMax: Open source software to simulate electromagnetic wave propagation for Ground Penetrating Radar". In: *Computer Physics Communications* (2016).

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