JÜLICH
FORSCHUNGSZENTRUM

Hydrogeophysical Imaging and Characterisation Group

Jan van der Kruk, Anja Klotzsche, Nils Gueting, Christian von Hebel, Sebastian Busch, Tao Liu, ..., ..., ..., Jan Vanderborght, Harry Vereecken

Research Center Jülich, Germany

j.van.der.kruk@fz-juelich.de

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Inversion methods

Ray-based methods

Input data:

- First arrival times
- First cycle amplitudes

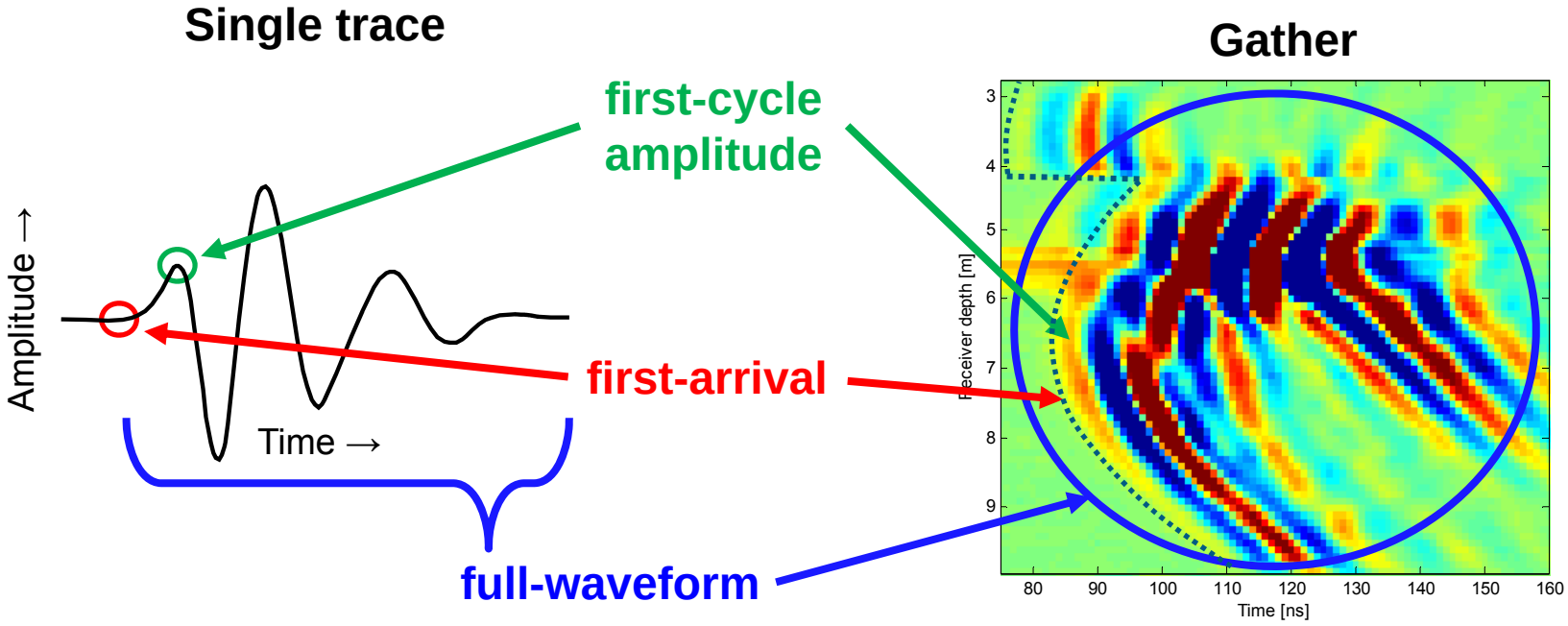
➢ Inexpensive
➢ Coarse structures

Waveform methods

Input data:

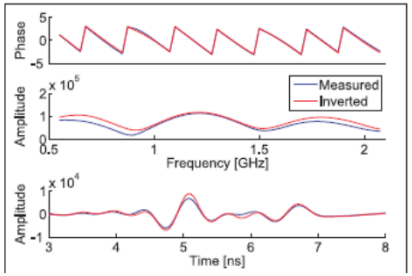
- Significant parts of wavefields
- Inversion based on Maxwell's Eq.

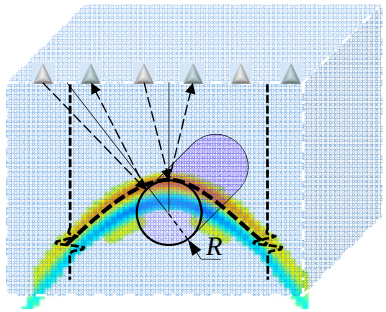
➢ Expensive
➢ Sub-wavelength structures



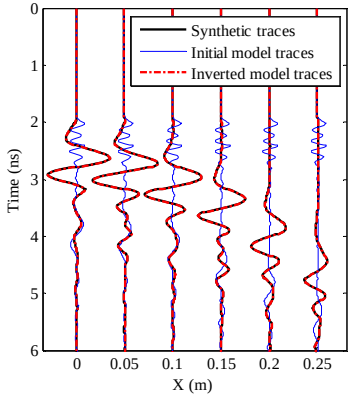
Selected Research Projects on Full-Waveform Inversion (FWI)

GPR full waveform inversion for quantitative chlorides and moisture detection in concrete Kalogeropoulos et al., 2011, 2013, EMPA, EPFL)

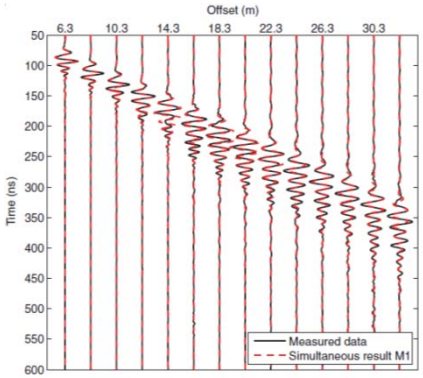




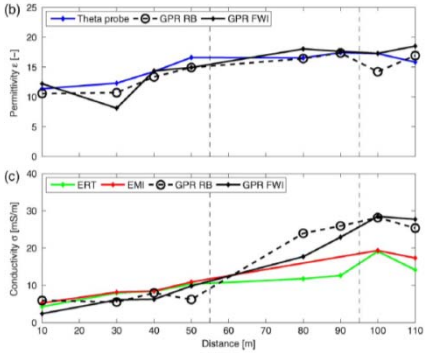
Radius estimation of cylindrical objects using a parameterized 3D FDTD modeling tool gprMax (Liu et al., 2017)



Selected Research Projects
Full-Waveform Inversion

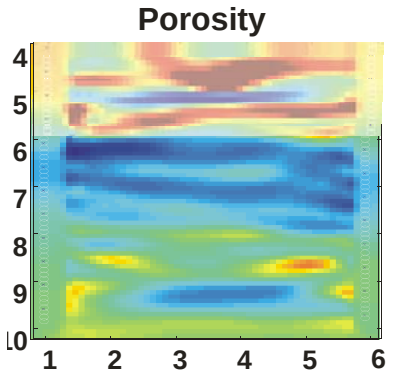


Full-waveform inversion of on-ground GPR assuming a horizontally layered model (Busch et al., 2012, 2014)



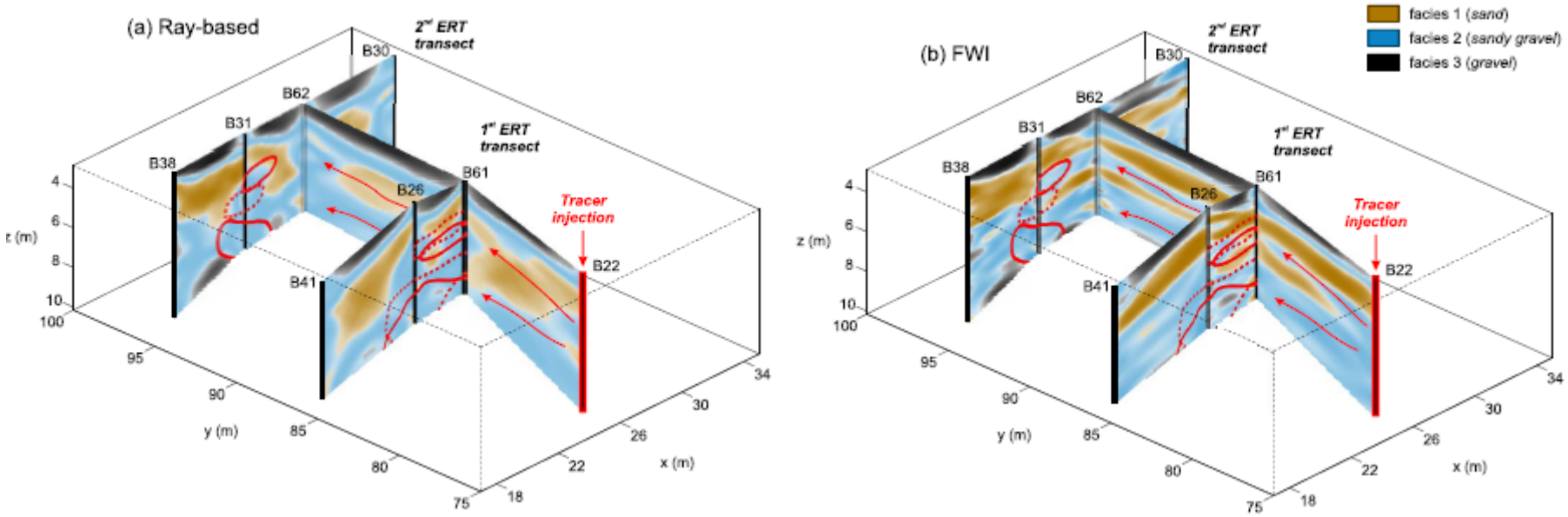
Full-waveform inversion of combined cross-hole GPR data

Widen Switzerland, Boise USA, Krauthausen, Germany



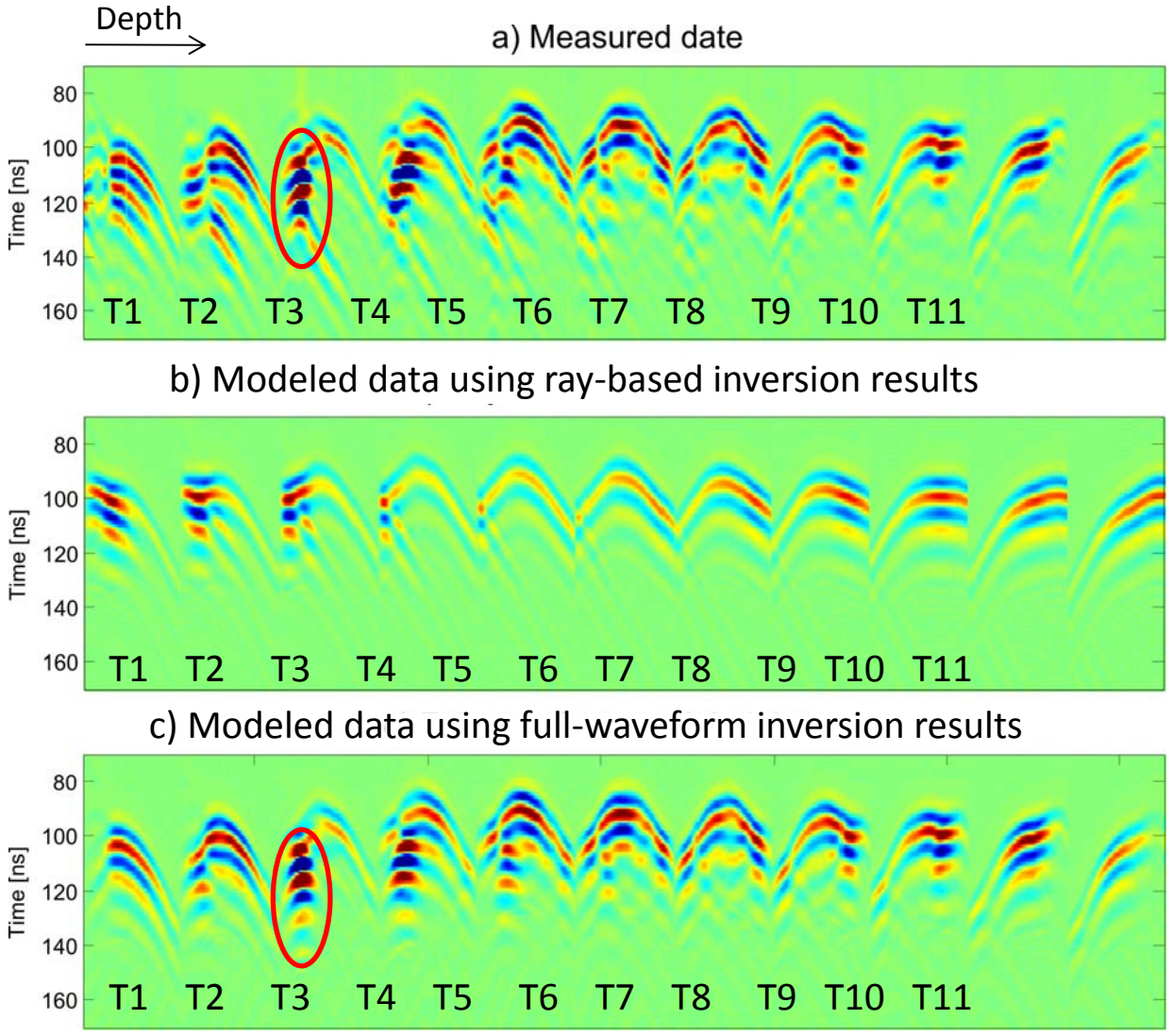
(Klotzsche et al., 2010, 2012, 2013, 2014, Oberrohrmann, 2013, van der Kruk et al., 2015 Gueting et al. 2015, 2017, Keskinen et al., 2017

Crosshole GPR Full-waveform inversion at Krauthausen, Germany



Observed Plume splitting explained by facies determined
by crosshole GPR Full-waveform inversion (Gueting et al., WRR 2017)

Comparison of measured & modeled data B3-C3

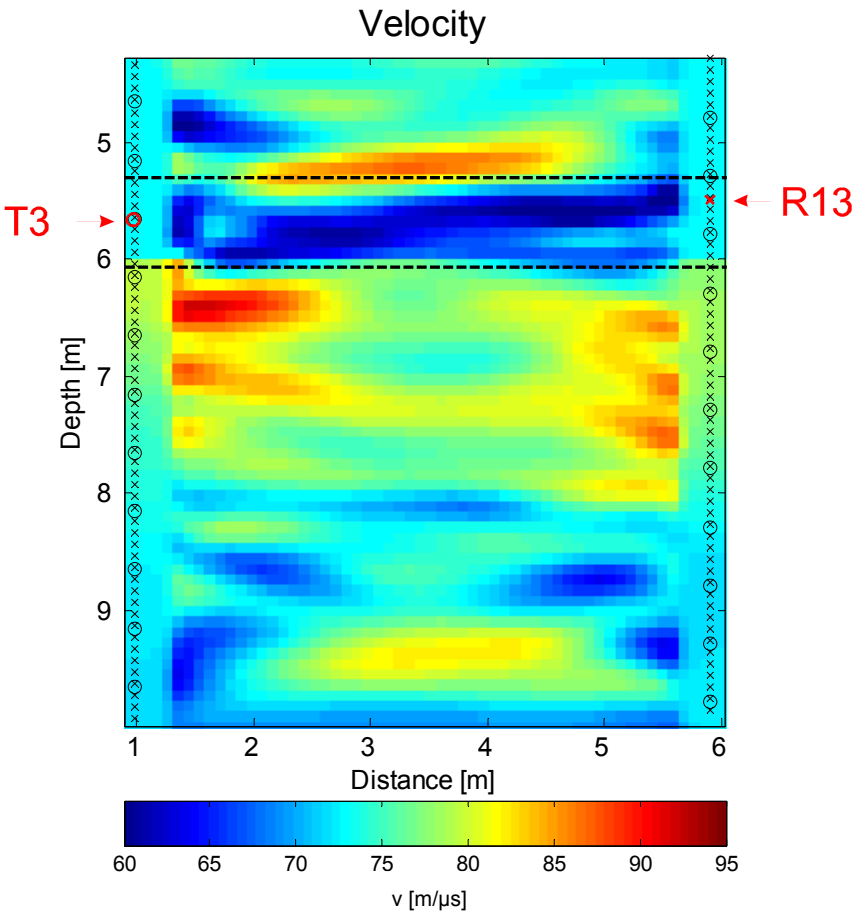


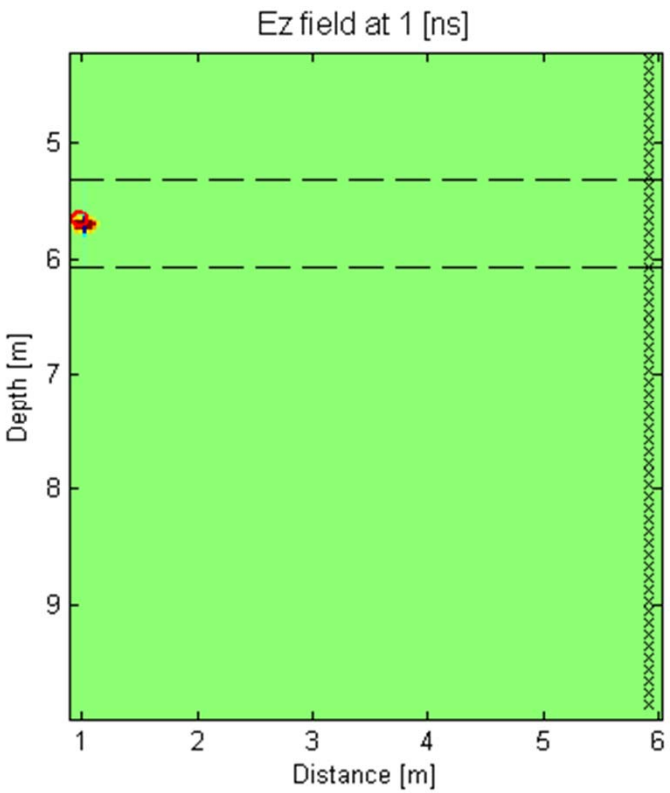
RMS= $4.08 \cdot 10^{-6}$ (100%)

RMS= $1.81 \cdot 10^{-6}$ (44%)

(Klotzsche et al., 2013)

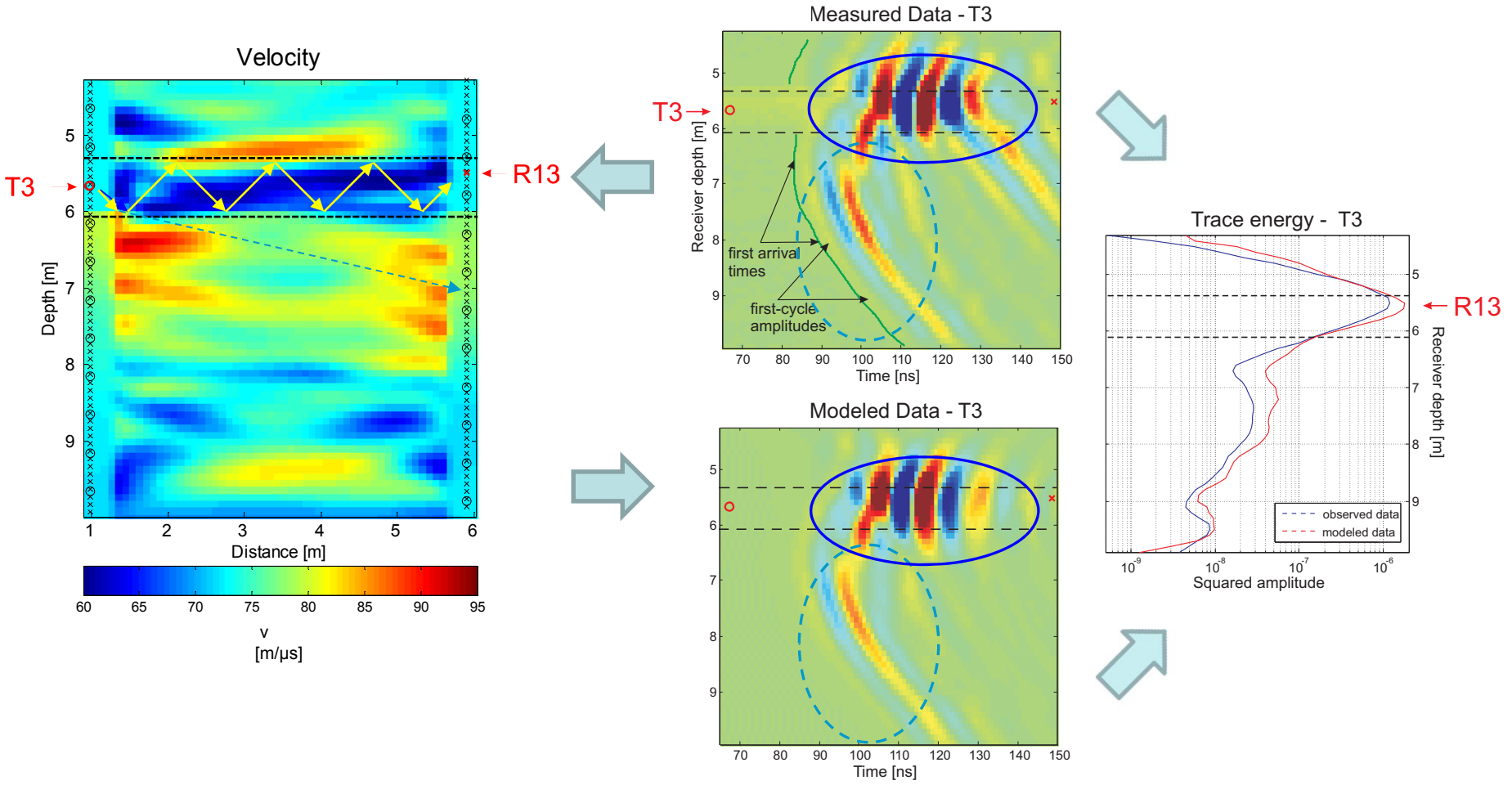
Propagation of the E_z-field – Transmitter 3



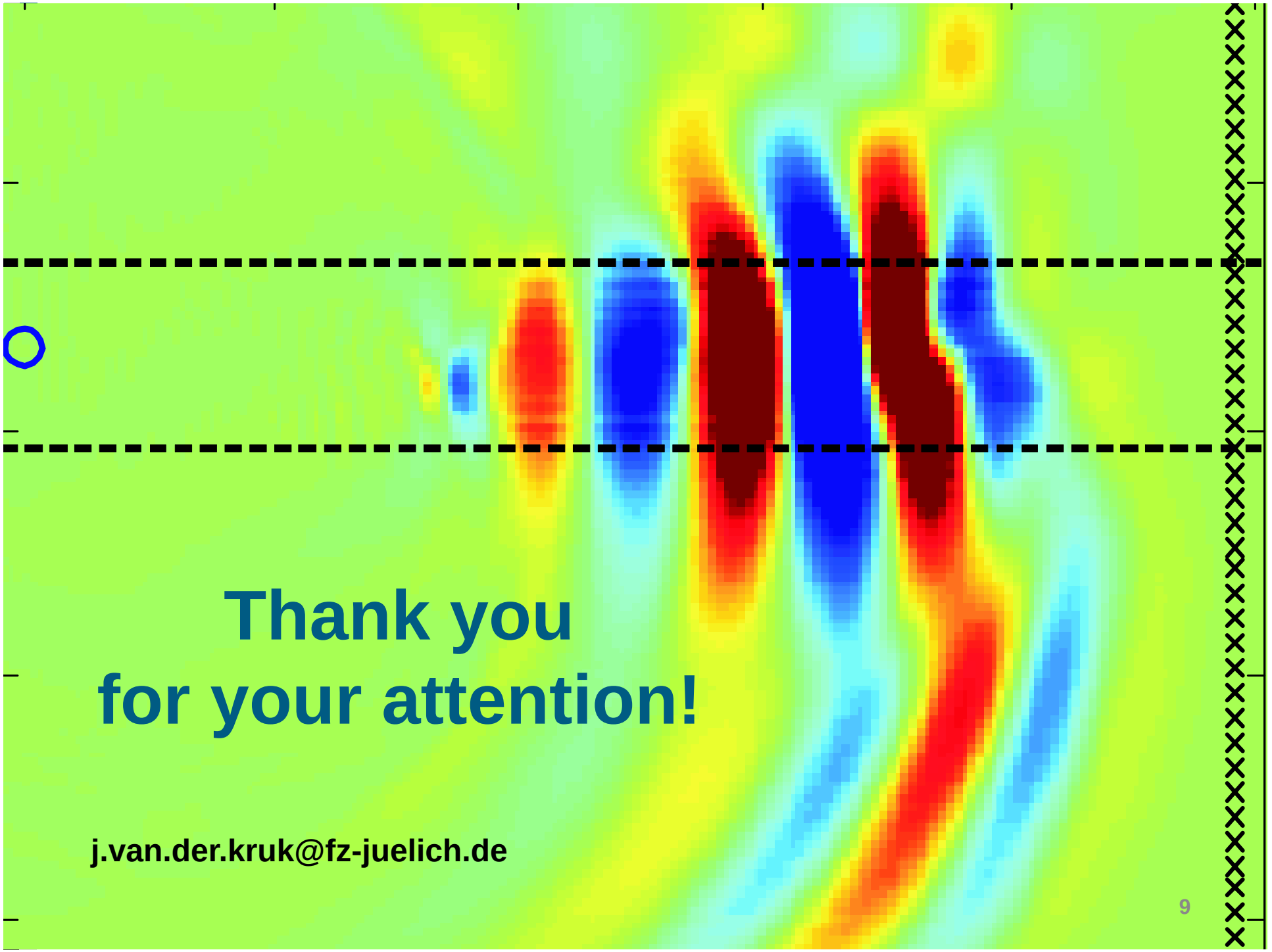


(Klotzsche et al., 2013)

Analyzing the low velocity layer: transmitter 3



(Klotzsche et al., 2013)



Thank you for your attention!

j.van.der.kruk@fz-juelich.de

Cited references:

- S. Busch, J. van der Kruk, J. Bikowski, H. Vereecken, 2012, Quantitative conductivity and permittivity estimation using full-waveform inversion of on-ground GPR data, Geophysics, 77, H79-H91.
- S. Busch, J. van der Kruk, H. Vereecken, 2014, Improved characterization of fine texture soils using on-ground GPR full-waveform inversion, IEEE, Transactions in Geoscience and Remote Sensing, 52, 3947-3958.
- A. Kalogeropoulos, J. van der Kruk, J. Hugenschmidt, S. Busch, K. Merz, 2011, Chlorides and moisture assessment in concrete by GPR full waveform inversion Near Surf. Geoph. 2011, 9, 277-285.
- A. Kalogeropoulos, J. van der Kruk, J. Hugenschmidt, J. Bikowski, E. Bruhwiler, 2013,
  Full-waveform GPR inversion to assess chloride gradients in concrete,
  NDT&E International, 57, 74-84, DOI:10.1016/j.ndteint.2013.03.003
- J. Keskinen, A. Klotzsche, M. C. Looms, J. Moreau, J. van der Kruk, K. Holliger, L. Stemmerik, L. Nielsen, 2017, Full-waveforminversion of Crosshole GPR data: Implications for porosity estimation in chalk, Journal of Applied Geophysics 140, 102–116
- A. Klotzsche, J. van der Kruk, G. A. Meles, H. Vereecken, 2012, Crosshole GPR full-waveform inversion of waveguides acting as preferential flow paths within aquifer systems, Geophysics, 77, H57-H62.

Cited references:

- A. Klotzsche, J. van der Kruk, N. Linde, J. Doetsch, H. Vereecken, 2013, 3D characterization of high-permeability zones in a gravel aquifer using 2D crosshole GPR full-waveform inversion and waveguide detection, Geophysical Journal International, 195, 932-944.
- A. Klotzsche, J. van der Kruk, J.H. Bradford, H. Vereecken, 2014, Detection of spatially limited high porosity layers using crosshole GPR signal analysis and full-waveform inversion, Water Resources Research50, 6966-6985.
- J. van der Kruk, Gueting, N., Klotzsche, A., He, G., Rudolph, S., von Hebel, C., Yang, X. Weihermller, L., Mester, A., Vereecken, H., 2015, Quantitative multi-layer electromagnetic induction inversion and full-waveform inversion of crosshole ground penetrating radar data, Journal of Earth Science, 26, 844850 doi:10.1007/s12583-015-0610-3.
- M. Oberröhrmann, A. Klotzsche, H. Vereecken, J. van der Kruk, 2013, Optimization of acquisition setup for cross-hole GPR full-waveform inversion using checkerboard analysis, Near Surface Geophysics, 11, 197-209,
- N. Gueting, Klotzsche, A., van der Kruk, J., Vanderborght, J., Vereecken, H., Englert, A., 2015, Imaging and characterization of facies heterogeneity in an alluvial aquifer using GPR full-waveform inversion and cone penetration tests, Journal of Hydrology, 524, 680695, doi:10.1016/j.jhydrol.2015.03.030.
- N. Gueting, Vienken, T. Klotzsche, A., van der Kruk, J., Vanderborght, J., Caers, J., Vereecken, H., Englert, A., 2017, High resolution aquifer characterization using crosshole GPR full-waveform tomography: Comparison with direct-push and tracer test data, Water Resources Research, 53, doi:10.1002/2016WR019498.