



Multi-dimensional GPR full-waveform inversion for small-scale hydrogeophysical soil characterization

Dominik Hoven

Energie & Umwelt / Energy & Environment

Band / Volume 643

ISBN 978-3-95806-781-3

Forschungszentrum Jülich GmbH
Institut für Bio- und Geowissenschaften (IBG)
Agrosphäre (IBG-3)

Multi-dimensional GPR full-waveform inversion for small-scale hydrogeophysical soil characterization

Dominik Hoven

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 643

ISSN 1866-1793

ISBN 978-3-95806-781-3

Contents

1. Introduction	1
1.1. Thesis objective and outline	8
2. Theory	11
2.1. Electromagnetic theory	11
2.2. Numerical modeling of electromagnetic waves	14
2.2.1. Finite-difference time-domain method	15
2.3. Ground-penetrating radar full-waveform inversion	19
2.3.1. Pre-processing	19
2.3.2. Starting model generation	21
2.3.3. 3D-to-2D correction	23
2.3.4. Source wavelet estimation	24
2.3.5. Full-waveform inversion	25
2.3.6. Computational requirements	28
3. Next generation 2.5D GPR FWI including borehole and antenna models	31
3.1. New 2.5D GPR FWI	31
3.2. Realistic synthetic model	34
3.3. GPR full-waveform inversion using different forward model approaches	36
3.3.1. Ray-based inversion	37
3.3.2. Effective source wavelets	39
3.3.3. FWI of the different approaches	41
3.4. Conclusions and outlook	52
4. Benefits of the 2.5D GPR FWI for variably saturated soil-aquifer system	53
4.1. Simulation setup for unsaturated and saturated soil FWI	53
4.2. Synthetic case: Study on the source wavelet estimation with synthetic data	55

Contents

4.3. Experimental case: Source wavelet estimation with measured data	58
4.3.1. Source wavelet estimation using the starting model of the 2D case study	59
4.3.2. Source wavelet estimation using an updated starting model	60
4.4. 2.5D GPR FWI of a variably saturated soil-aquifer system with one source wavelet	63
4.5. Conclusions and outlook	67
5. High-frequency GPR FWI	69
5.1. Synthetic aquifer model	69
5.2. FWI for high-frequency data	73
5.3. Effect of source wavelet variations on high-frequency FWI	81
5.4. Evaluation of starting models using frequency-hopping	88
5.5. Noise in higher-frequency data	92
5.6. Stochastic aquifer model	94
5.7. Conclusions and outlook	96
6. Towards 3D GPR FWI for lysimeter investigation	99
6.1. 3D lysimeter model using 2.5D soil model	100
6.2. Influence of decreasing model complexity	101
6.3. 2.5D FWI of synthetic 3D lysimeter data	104
6.4. Conclusions and outlook	108
7. Conclusions and outlook	111
7.1. Conclusions	111
7.2. Outlook	113
A. Appendix A	117
A.1. Abstract	117
A.2. Introduction	118
A.3. Materials and methods	120
A.3.1. Realistic synthetic lysimeter model setup	120
A.3.2. Expected ray-paths and travel-times for the synthetic case	122
A.3.3. Experimental design of a sand filled lysimeter	123
A.4. Results and discussion	124
A.4.1. Effects of lysimeter casing on wave propagation	124

A.4.2. Antenna effects on wave propagation	128
A.4.3. Experimental data measured data at a sand filled lysimeter	133
A.5. Conclusion	135
A.6. Acknowledgements	137
Tools	139
Acknowledgements	141
List of Figures	143
List of Tables	147
Glossary	150
Bibliography	151

Energie & Umwelt / Energy & Environment
Band / Volume 643
ISBN 978-3-95806-781-3