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Accounting for data error and model correlation in hydrogeophysical cross-borehole GPR tomography studies

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Cross-borehole GPR data have been widely used in integrated geophysical-hydrogeological studies of the upper approx. 20 m of the unsaturated zone in permeable environments. Tomographic algorithms are used for estimating the radar wave velocities between the boreholes from picked first arrival travel times. The estimated velocity values are then converted to values of water saturation. The inversion results are strongly influenced by the assumptions that are made regarding model and data error correlation. We analyse and quantify key characteristics of model and data error correlation using different independent sources of information, and we account for these characteristics during inversion. Different sources of correlated data errors exist. Examples are: cavities around the borehole walls; unknown small-scale anomalies close to the borehole walls; incorrect positioning of the receiver and/or the transmitter antenna during data acquisition; time jumps due to instrument mis-calibration. If standard inversion techniques are used, such data errors may give rise to significant artefacts in the tomographic images. We account for the correlated data errors by specification of data error covariance matrices which are included in the inverse operator used for obtaining the velocity distribution from the picked travel times. We demonstrate that accounting for the correlated data errors results in more optimal inverse estimates and more realistic model resolution estimates. Normal-incidence reflected radar data sections acquired along profile lines on the surface constrain the approximate correlation properties of the geological structures. These properties are used as a priori information in the tomographic inversion process. Thereby, models capturing realistic heterogeneity of the subsurface are estimated.