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SVD inversion of cross-borehole GPR data obtained from an infiltration experiment in the vadose zone

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Cross-borehole ground-penetrating radar (GPR) has been widely used to characterize the shallow subsurface. To monitor an infiltration process in the vadose zone, an artificial groundwater infiltration experiment was conducted in Nagaoka, Japan. Time-lapse cross-borehole GPR data were collected using zero-offset profiling (ZOP) mode. The infiltration process was observed as a variation of GPR traveltimes, which can be transformed into dielectric constant and further converted to volumetric water content. Although ZOPs provide only a one-dimensional integrated profile of volumetric water content estimates, the ZOP mode is useful for detecting the variation of water content if rapid water migration is expected in the vadose zone during the infiltration process. However, the standard ZOP analysis for which all first arrivals are assumed to be direct waves results in a significant underestimation of dielectric constant mainly due to the existence of critically refracted waves. This paper presents an effective approach to extract accurate information about the hydrogeologic process in the vadose zone from ZOP data. This approach is based on a least-squares inversion method using singular value decomposition (SVD), in which a finite-difference time-domain forward modeling is used for computing electromagnetic wave fields on two-dimensional cylindrical coordinates. The SVD inversion method is validated using a synthetic example and the field data. The SVD inversion method was effective to reduce the underestimation of dielectric constant estimates derived from the conventional ZOP analysis. We can successfully estimate the variation of soil water content during infiltration in the Nagaoka site from the reconstructed dielectric constant models. The soil water content varied from 16 – 19% in the initial state to 23 – 27% after fully saturated. The shape of the water content profile shows an opposite characteristics between the unsaturated and fully saturated states. The inversion results show that the saturation information is useful to assess the hydrogeologic properties of the test soil zone.