Ground-penetrating radar (GPR) for characterizing near-surface environments: Some recent advancements in data modeling and interpretation

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Within the past decades, ground-penetrating radar (GPR) reflection imaging has evolved as one of the key geophysical techniques to explore the shallow subsurface. In various fields of application, 2D and 3D GPR data are routinely used to image and characterize subsurface features such as soil horizons, sedimentary layers, faults and fractures, or buried anthropogenic targets including human infrastructure and archaeologically relevant objects. The success and popularity of the GPR technique is largely based on its outstanding spatial resolution capabilities; i.e., to resolve subsurface structures in the decimeter range while concurrently providing investigation depths in the order of several meters to tens of meters. Today, methodological research focuses on the development of sophisticated forward modeling tools, efficient large-scale surveying strategies, advanced processing tools, as well as reproducible interpretation approaches.

Here, I start with briefly reviewing the basics of 2D/3D GPR reflection imaging. This includes the physical basics, today's data acquisition and processing strategies, and typical fields of application. With a focus on geological applications, I also discuss the most common approaches for interpreting processed 2D/3D images (horizon tracking and facies analysis) including their shortcomings (limited objectivity and reproducibility). After that, because synthetic data represent a prerequisite to develop and evaluate more advanced interpretation approaches, I present some recent advances in modeling synthetic GPR data comprising characteristics as typically observed in field data; for example, related to system and environmental noise or electrical property variations at multiple spatial scales. Using such realistic synthetic data examples, I then introduce attribute-based GPR interpretation mainly based on texture and structure attributes calculated from the gray-level cooccurrence matrix (GLCM) and the gradient-structure tensor (GST), respectively. Relying on these attributes, I present recently developed workflows to generate line drawings (images of tracked horizons) and facies models (comprising classes of similar reflection characteristics). As also demonstrated by various field data examples, these innovative interpretation strategies allow for generating meaningful and reproducible interpretation results in a largely automated fashion. This can be considered as major step to raise the usefulness and reputation of the GPR method in various fields of application.