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Identifying dispersive GPR signals and inverting for surface waveguide properties

Jan van der Kruk (1), Rob Jacob (2), Colby Steelman (3), Tony Endres (3), and Harry Vereecken (1)

(1) Forschungszentrum Juelich, Agrosphere, Juelich, Germany (j.van.der.kruk@fz-juelich.de), (2) Brown University, Brown, U.S.A., (3) University of Waterloo, Waterloo, Canada

At locations where a thin surface layer overlies a substrate medium that has a lower permittivity, or a much larger permittivity/conductivity than the surface layer, pronounced dispersion of GPR waves can be observed and the surface layer acts as a waveguide. A low velocity waveguide is present when the substrate has a lower permittivity and total reflection occurs beyond the critical angle on the upper and lower interfaces. A leaky waveguide is present when the substrate medium has a much larger permittivity and/or conductivity. Although the lower interface is a strong reflector, some energy is still transmitted across the interface and total reflection only occurs at the upper waveguide-air interface. In both cases, electromagnetic waves are trapped within the waveguide and the radar energy is internally reflected, resulting in a series of interfering multiples that manifest themselves as shingling reflections that exhibit different phase and group velocities. Normalizing the data on the maximum amplitude for each trace shows that most of the energy is contained within the dispersive waves which propagate over large distances.

Phase-velocity spectra calculated from these dispersed GPR data clearly indicate the presence of a frequency-dependent phase velocity that decreases with increasing frequency. The dispersion characteristics depend on the type of waveguide and the source-receiver antenna orientations. For low-velocity waveguides, the transverse electric (TE) modes propagate at lower frequencies compared to transverse magnetic (TM) modes, whereas only uneven TE and even TM modes can propagate through leaky waveguides. The waveguide properties can be obtained by picking dispersion curves from the maxima in the phase-velocity spectra and inverting for a single-layer waveguide model by adjusting the model parameters using a combined global and local minimization algorithm until the difference between the picked dispersion curve and the model-predicted dispersion curve is minimized. Single-mode inversions enable the reconstruction of single-layer waveguides. The inclusion of higher order modes (i.e., if they are present) in the inversion permits the reconstruction of two-layer waveguide properties.

Recently, an increasing number of data sets are being identified as containing dispersive waves due to the presence of a low-velocity or leaky waveguide. The following common midpoint data sets were identified as being strongly dispersive due to a low-velocity waveguide: a layer of wet, organic silty to gravelly soil overlying a drier layer of sand and gravel, an organic-rich sandy silt overlying gravel units, a mountain slope with a 1-m soil cover, thawing of a frozen soil layer and a concrete slab present in air. The following CMP data sets were identified as being strongly dispersive due to leaky waveguides: frozen saturated sand overlying moist sand, an ice layer overlying salt or fresh water, the freezing of wet soil and a concrete slab overlying a conductive aluminium sheet.