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Dispersion inversion of GPR data recorded across freezing and thawing induced waveguides

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Soil frost zones are an important component in spring runoff and ground water recharge studies. The depth and distribution of seasonal frost zones influence the dynamics of spring infiltration. Therefore, knowledge of the temporal and spatial distribution of soil frost zones is an important component in modeling groundwater/surface water recharge. High frequency GPR is particularly well suited for monitoring the freezing process within the shallow subsurface due to its non-invasive nature and ability to measure the liquid water component in frozen soil. The freezing wet sand and the thawing frozen sand induce waveguides which results in the occurrence of dispersed GPR waves. In these cases, the use of standard travel-time analysis is not possible. In the case of frozen wet sand overlying wet sand, the underlying layer has a much higher permittivity and thus provides a strong reflection, but still a certain amount of energy is transmitted. This waveguide is referred to as a leaky waveguide. Total internal reflection occurs at the upper interface beyond the critical angle. In the case of thawing of the frozen sand resulting in wet sand overlying frozen sand, the underlying layer has a relatively lower permittivity and total internal reflection occurs in this low-velocity waveguide when the angle of incidence at both interfaces is larger than the critical angle. This waveguide is referred to as a low-velocity waveguide.

For dispersed GPR data, the waveguide properties can be obtained by calculating phase-velocity spectra, followed by picking dispersion curves from the maxima in the spectra. The picked dispersion curve is then inverted for a single-layer subsurface model; inversion involves adjusting the model parameters until the difference between the picked dispersion curve and the model-predicted dispersion curve is minimized.

Common mid-point gathers using high-frequency 900 MHz antennas were collected on a test site in Waterloo, Ontario, Canada. Surveys were conducted during the development of a seasonal frost layer and subsequent seasonal thaw. For the leaky waveguide, constituted by frozen sand overlying wet sand, several higher order modes could be identified and were used to invert for the thickness and medium properties. The low velocity waveguide, which was caused by thawing of the shallow part of the frozen ground, shows clear dispersion of the fundamental TE and TM modes for the broadside and endfire antenna configurations, respectively. Here, a joint inversion was carried out to invert for the medium properties.