Soil ice content determination using heating TDR method

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Frost heaving is a major problem in cold regions. Soil ice content is an important property to understand/predict the frost heaving. However, it has been difficult to measure the soil ice content, in particular, in frozen soils at temperature between 0 and −5 ˚C. Therefore, it is required to develop a method to measure soil ice contents with high accuracy. The objectives of this study are i) to develop heating TDR method for soil ice content measurement, ii) to determine the best heat application i.e., heat intensity and heating stop temperature, and iii) to evaluate the accuracy of the method.
The heating TDR method first measures liquid water content in frozen soil, melts ice around the TDR probe by an embedded heater, and measures total water contents. Soil ice content is determined by subtracting the liquid water content from the total water content. In this study, we used sand and Andisol to test the method. Thermal conductivity of the two soils was measured with dual probe heat pulse technique. Three heat intensities, 15 W m^{-1}, 30 W m^{-1}, 80 W m^{-1}, and three temperatures which the heating stop, 1˚C, 2˚C, and 10˚C, were tested to determine the best heat application. Accuracy of the method was evaluated with the determined best heat application and the soils at various volumetric water contents. The soils were first frozen at -15˚C for 6 hours in a constant temperature chamber and temperature was raised to -2˚C when the measurement was performed. The liquid water content, total water content, and ice content determined with the heating TDR method were compared to those determined by the gravimetric method or a model to evaluate the accuracy.
Thermal conductivity of the sand wassix times larger than that of Andisol when volumetric water content is 0.30 m^3 m^{-3}. It indicates that larger heat amount is required to melt sufficient volume of Andisol than that for sand. The best heat application was 30 W m^{-1} heat intensity and 1˚C heating stop temperature for sand, and 15 W m^{-1} heat intensity and 2˚C heating stop temperature for Andisol. The accuracies of the method with the best heat application were ±0.07 m^3 m^{-3} for sand and ±0.05 m^3 m^{-3} for Andisol, respectively. The accuracy decreased when the measurement was repeated because of water transfer due to heat application. However, the accuracies of the first measurements were better than that reported for other methods and there has been no method which efficiently determines soil ice content at temperature between 0 and −5 ˚C. Therefore, the heating TDR method is a beneficial for many studies related to frozen soils at temperature close to 0 ˚C which soil ice content dynamically changes.

Keywords: soil ice content, Time Domain Reflectometry, Frost heaving

