Characterizing the Complex Dielectric Properties of Permafrost Across Freeze-Thaw Cycles

*M.M. Rahman, A. Hossain, S.E. Perini, and M.T. Lanagan

Abstract: Remote sensing in the Arctic regions is an essential tool for tracking the changing landscapes due to climate change, employing a wide range of frequencies in the electromagnetic spectrum to assess the condition of permafrost. Permafrost is a complex material of solid, liquid, gas, organic, and inorganic phases with each constituent contributing to the broadband dielectric response. The dielectric properties, coupled with the physical structure of permafrost, yield distinct electromagnetic signatures that are detectable through remote sensing. In this study, permafrost was synthesized from clay, sand, and silt mixed with various amounts of water. Various weight fractions of permafrost/water mixtures were prepared by mixing clay, sand, and silt with different amounts of water. Microwave characterization and IR spectroscopy were subsequently performed on these mixtures to analyze their properties.

The dielectric permittivity and loss of individual permafrost constituents in the dry and wet states were measured from radio frequency to infrared, using various reflection and transmission techniques. A coax reflection method was developed to provide complex dielectric data between 200 MHz and 26 GHz over a temperature range from 25 to -20^{o} C. Dry constituents had low permittivity ($\varepsilon_r < 5$) and low dielectric loss ($\tan\delta < 0.02$). The experimental dielectric properties were compared with models based on effective medium theories to assess the contributions of porosity to the composite permittivity. Wet constituents had high permittivity ($10 < \varepsilon_r < 40$) and there was a significant dielectric relaxation in the GHz frequency due to the dipolar state of water. Dielectric relaxation was observed well below 0^{o}C, which indicates the presence of liquid below the bulk freezing temperature. The temperature-dependent dielectric data will be correlated with differential scanning calorimetry to determine the temperature of the water-ice transition. Linking broadband dielectric and thermodynamic responses of water-organic and water-inorganic interfaces in permafrost will provide critical insight on the dipolar mechanisms governing permittivity and loss during the freeze-thaw cycle.