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Long-Wavelength Radar Scattering Model of Vegetated Permafrost Soils

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Arctic and boreal landscapes are believed to be among the most vulnerable regions to the effects of climate variability trends. One way in which these regions may be manifesting climate impacts is the gradual loss of permafrost. Permafrost is soil that remains frozen for two or more years in a row. The layer of soil that freezes and thaws annually is called the active layer. Ground-based observations in the past several years have shown that as temperatures have risen in the arctic and boreal zones, the depth of the active layer has increased, which is to say that the permanently frozen soil, or permafrost, has receded. Ground observations are inherently limited in their spatial coverage.

To provide a more synoptic and spatially extensive observation of permafrost dynamics, we have hypothesized that long-wavelength synthetic aperture radar (SAR), in particular in the P-band frequency range, can be used to probe beneath the surface to estimate the depth of thaw of soils above permafrost and to provide insight into the seasonal and inter-annual dynamics of permafrost active layer. We have therefore collected multiple data sets with the polarimetric P-band Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS), spanning a period of 3 years, over a number of sites in northern Alaska. Successful retrieval of permafrost soil properties depends on an accurate radar scattering model that takes into account not only the subsurface structure of permafrost soils (including organic and mineral soil layers as well as the frozen soil), but also the numerous types of vegetation cover present in the boreal and arctic regions. In this paper, we present a coherent scattering model of vegetated permafrost soils, using a previously developed vegetation scattering module based on the distorted Born approximation, but with new provisions for coherent interactions between vegetation and the permafrost soil layered profiles. The types of vegetation in the regions under consideration include both taiga (woody vegetation and primarily conifer forests) and tundra (low to medium height shrubs). The vegetation-ground interaction effects include (1) the vegetation attenuation of direct ground scattering by considering the vegetation forward scattering amplitude, and (2) multi-bounce coherent scattering between vegetation and layered ground. We will present the model derivation, with focus on the above two items, and show the tradeoff between the effects of attenuation and multi-bounce scattering enhancement. Simulation results will be presented to demonstrate the expected sensitivity of radar backscattering cross section to vegetation and permafrost soil properties. Comparison between model predictions and AirMOSS measurements will also be shown for sites where ground-truth data are available.