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Detection of Soil Frost in the Boreal Forest Region with Sentinel-1

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A new approach for monitoring soil frost in the boreal forest region using Sentinel-1 co-polarized synthetic aperture radar (SAR) data is presented. Due to the high sensitivity of the C-band signal to vegetation, estimating the soil Freeze/Thaw (F/T) state directly from the measured backscatter is not feasible over dense vegetation, such as boreal forests. The presented method is based on applying a simple zeroth-order model to estimate the backscatter contribution of the ground and the forest canopy on the observed total backscatter.

The method was tested for various soil types and incidence angles, for a test area near the Sodankylä Arctic Research Station of the Finnish Meteorological Institute. The ground and canopy backscatter values were retrieved by finding the minimum RMSE between the model and the observations. The retrieved backscatter values were then compared with in situ data reflecting the true soil F/T state. The true soil state was determined using soil temperature, soil moisture and air temperature sensors. Based on the ground truth data, the retrieved values were classified to three classes; values representing frozen ground, thawed ground and uncertain soil state. Using the least sum of square errors estimation method, an optimal 2-dimensional linear classification line was calculated to separate between the retrieved backscatter values representing frozen and thawed conditions.

The results show that by retrieving the backscatter beneath the canopy and the backscatter of the canopy itself, the soil F/T state can be successfully estimated. For soil types with higher water holding capacities and lower infiltration rates such as Haplic Podzol and Umbric Gleysol, the estimation accuracy of the F/T state was over 90 %, whereas for dry, well drained soil types such as Haplic Arenosol, it was over 84 %. Estimation accuracy slightly increased with higher incidence angle. The method is not feasible in rocky terrain due to very low water content, or in wet snow conditions due to the low penetration of the C-band SAR signal in wet snow. In previous studies applying a similar method, only the ground backscatter has been used as an indicator for deriving soil properties. Yet, according to the presented results, by adding the retrieved canopy backscatter as an indicator, the ability to separate frozen and thawed soil is considerably improved.

With low ancillary data and computational requirements, the proposed method is applicable for continuous near real-time monitoring of the F/T state. The SAR based F/T detection method can also be combined with existing passive microwave L-band F/T detection methods, which have a better temporal but weaker spatial resolution. As a result, a synergistic product which applies C-band SAR to downscale passive microwave estimates, could be implemented in the future.