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# Impulse radar measurements of snow interception – laboratory tests and field application to a forest stand in northern Sweden

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Snow melt runoff is a dominating water resource in many alpine and high latitude regions. Therefore, hydrological model predictions and information on the amount of snow are important for efficient management of for instance hydropower production. Snow interception and evaporation of snow from forest canopies is known to reduce the snow cover accumulation in forest areas compared to open areas, but there is a need for better process understanding in order to improve the model predictions. The exchange of heat and water between snow cover, canopy, and atmosphere involve many processes that can be difficult to observe at the relevant scales. Particularly, the snow interception storage is difficult to observe on a forest stand level compared with snow cover development and forest evaporation. In this study, a new application of ground penetrating impulse radar (GPR) to measure the total amount, spatial distribution and phase of the interception storage in the forest canopy is presented.

The propagation velocity and frequency dependent attenuation of a broadband impulse radar wave can be used to give a direct estimate of the complex effective dielectric permittivity. The real part of the effective dielectric permittivity, estimated from the propagation velocity alone, can be used to estimate either the mass of liquid water or the mass of dry snow on the canopy if a suitable mixing formula for the effective permittivity is known. However, to separate between liquid and frozen interception additional information that we intend to get from the attenuation is needed. It has been shown for snow that the liquid water content can be estimated from the imaginary component of the effective permittivity alone. Thus, the contribution from liquid water to the real component can be subtracted, and the remaining fraction depended only on the amount of frozen snow.

Laboratory experiments were performed with a GPR system, measuring the propagation velocity and frequency dependent attenuation through a sample of Norway spruce branches loaded with different amount of liquid water and snow. The results were used to establish empirical mixing formulas relating imaginary and real components of the effective dielectric permittivity to the volumetric fraction of liquid and frozen water. The obtained formulas were tested in a field application in northern Sweden, in a homogeneous stand dominated by Norway spruce. The mass of snow stored in the tree canopies were measured in two ways: firstly by measuring the weight of a single tree scaled to a forest stand average and secondly using impulse radar measurements through a small section of the forest. The transmitting and receiving antennas were placed in two small towers, separated horizontally by 15 m. The amount of intercepted snow determined from the radar measurements compared well with the measurements from the single tree weighing lysimeter, especially during cold conditions. Systematic differences were observed in situations with melting snow on the trees, when the estimation of liquid water content was overestimated by the frequency attenuation method. However, this might be due to a combination of uncertainties in the mixing models and inadequate corrections for drift in the measurement system. Overall, the results were promising and showed that impulse radar can be used to study snow interception.