Drone-borne GPR measurements for snowpack characterization

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Integration of light air-coupled ground-penetrating radar (GPR) on drones has been booming in the last years. Compared to ground surveys, larger spatial coverage, shorter survey times and better safety for operators are obvious advantages. However, the data quality (signal-to-noise ratio and resolution) as well as the penetration depth are also greatly reduced in most cases. These issues are related to the physics of electromagnetic (EM) wave propagation and mostly because the amount of energy reflected at the interface between the air and the propagation medium (ground, rock, soil, snow, ice…) is large. In many cases, the amount of energy reflected at the air/soil interface is greater than 50 %, making the loss in data quality and penetration depth too large to make drone GPR a viable solution compared to conventional ground surveys. However, in some specific cases, such as surveys in dry sand, ice and even more in snow, the dielectric permittivity contrast between the air and the medium is small enough that a non-negligible part of the EM energy is transmitted in the medium and not reflected at the interface. For snow and ice characterization especially, drone borne GPR is a convenient solution allowing to map large areas of snow and glacier covers in limited time and effort.

In this abstract, we focus on shallow mapping of snow cover. Typical penetration depths are between 1 and 8 meters, and snowpacks are usually dry. Dry snow conductivity is negligible, and dielectric permittivity is very low (between 1 and 5) making the penetration depth very good even with a high frequency antenna. We use a Radsys Zond Aero system with an antenna designed to be centered around 1 GHz, allowing a good compromise between penetration depth and vertical resolution. Even if the antenna central frequency is designed to be around 1 GHz, we observe a central frequency of 700 MHz. The system is mounted on a DJI Matrice 300 and combined with a radar altimeter from SPH Engineering to allow for terrain following. Even if snow is the "best" medium for drone GPR, it is required to have the antenna close to the air/snow interface to minimize energy loss (due to geometrical spreading in the air) and reduce Fresnel zone size.

During winter 2022, we carried out several tests at different locations in Norway. Characterization of the snowpack was the goal of all surveys, but the applications were varied. We were interested in both characterizing snow depth, snow layering and snow properties (density, liquid water content). In some cases, the focus of the survey was to identify the added value of drone GPR for avalanche forecasting, i.e., focusing on detecting fine weak layers and their properties. In other cases, we were focusing on snow depth and snow water equivalent estimation for glacier mass balance. In both cases, we were operating the drone in mountainous areas and steep terrain, with slope gradient up to 35 degrees. The drone terrain following system in such steep terrain showed limitations that we have been tackling by flying at lower speed or higher above the snow surface. Our tests shows that recording data between 2 and 3m above the snow surface is the best compromise in term of data quality and flight safety.

Figure 1 give an example of raw data and processed data recorded at Storlidalen (Norway). The data has been acquired along a moderate slope. Due to wind transport, the snow thickness at the top of the slope is close to zero while we measured 2.5 m thick snow in a snowpit at the middle of the profile. The processing is done with Python and RGPR open-source routines and includes the following steps: resampling, time zero correction, band-pass filter, background removal, amplitude correction for geometrical spreading and deconvolution. The goal of this processing workflow is to preserve true amplitudes in order to carry out a reflectivity analysis. After estimation of reflection coefficients at each interface, a velocity/permittivity model is derived and proper time to depth conversion can be carried out. Snow properties such as density and snow water equivalent can also be derived.

We conclude that drone borne GPR for snow characterization shows promising results even if it requires care for drone flight safety as well as proper quantitative processing to get the most out of the data.

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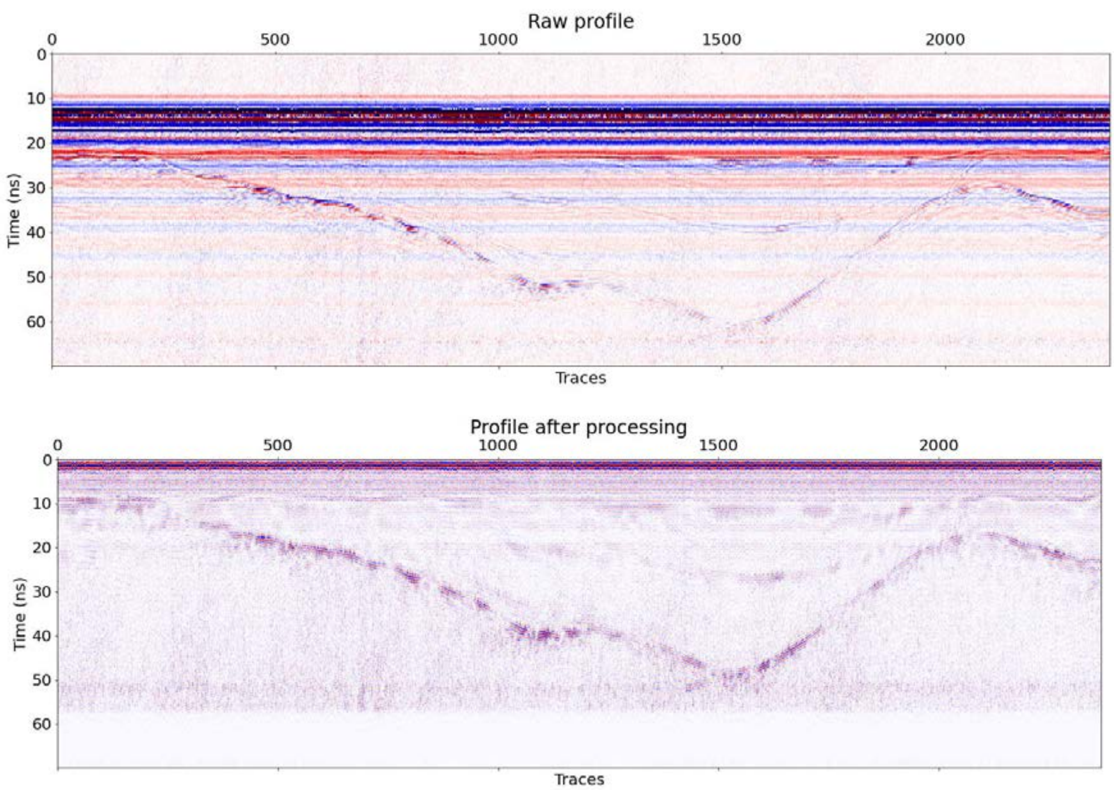

Figure 1: raw GPR profile (top) and profile after processing (bottom). The data is recorded using a drone GPR system flying above the snow surface.