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# Temporal and spatial variability of snow pack at high elevation.

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Knowledge on the temporal and spatial variability of snow pack is important in avalanche control, runoff modeling and climate changes monitoring (e.g., glacier modifications). This needs fast and accurate methods for measuring parameters such as snow cover thickness, snow density and dielectric constant directly connected also to snow water content. In this study we discuss the results of an extensive survey made by using ground probe radar (GPR) and time domain reflectometry (TDR) for the analysis of spatial and temporal macro-physical properties of the snow pack at high elevation (i.e., 3000m high) in the Alps of Northern Italy. Basically, the snow cover consists of layers created by snowfall events which are subject to densification due to thermo-mechanical processes. The properties of each layer differ because of changing meteorological conditions; secondary deposition from wind action may occur. The TDR technique allows for estimating the electromagnetic wave velocity which is essential to obtain detailed density values and to convert GPR travel time images in depth images. The depth converted radar images are calibrated according to the measurements of snow pack thickness. Under dry snow conditions, the conversion of the electromagnetic properties into density values is carried out by the use of simple approaches, such as the Looyenga model which calculates the average densities along each transect from the average wave velocity. Subsequently, the information on snow thickness and density is used to estimate an equivalent snow water value expressed for the area. The accuracy in the density has been estimated of about 10 %.

Testing showed that the georadar-TDR system was particularly suitable for operating under complex logistical conditions with a cost-effective approach to map the thickness variability of the snow pack. The data acquisition system which works at high frequency with simple commercial devices, was found to be capable of estimating the thickness of the snow pack up to 3 meters depth with good accuracy. When combined with a commercialized GPS device, the measuring system becomes a promising tool for short and/or long time monitoring under remote conditions. The device provides a great potential for further investigation into the evolution of temporal and spatial variability of snow pack thickness as a function of meteorological conditions.