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Combining low-cost GPS receivers with upGPR to derive continuously liquid water content, snow height and snow water equivalent in Alpine snow covers

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The temporal evolution of Alpine snowpacks is important for assessing water supply, hydropower generation, flood predictions and avalanche forecasts. Especially in high mountain regions with an extremely varying topography, it is until now often difficult to derive continuous and non-destructive information on snow parameters. Since autumn 2012, we are running a new low-cost GPS (Global Positioning System) snow measurement experiment at the high alpine study site Weissfluhjoch (2450 m a.s.l.) in Switzerland. The globally and freely broadcasted GPS L1-band (1.57542 GHz) was continuously recorded with GPS antennas, which are installed at the ground surface underneath the snowpack. GPS raw data, containing carrier-to-noise power density ratio (C/N0) as well as elevation and azimuth angle information for each time step of 1 s, was stored and analyzed for all 32 GPS satellites. Since the dielectric permittivity of an overlying wet snowpack influences microwave radiation, the bulk volumetric liquid water content as well as daily melt-freeze cycles can be derived non-destructively from GPS signal strength losses and external snow height information. This liquid water content information is qualitatively in good accordance with meteorological and snow-hydrological data and quantitatively highly agrees with continuous data derived from an upward-looking ground-penetrating radar (upGPR) working in a similar frequency range. As a promising novelty, we combined the GPS signal strength data with upGPR travel-time information of active impulse radar rays to the snow surface and back from underneath the snow cover. This combination allows determining liquid water content, snow height and snow water equivalent from beneath the snow cover without using any other external information. The snow parameters derived by combining upGPR and GPS data are in good agreement with conventional sensors as e.g. laser distance gauges or snow pillows. As the GPS sensors are cheap, they can easily be installed in parallel with further upGPR systems or as sensor networks to monitor the snowpack evolution in avalanche paths or at a larger scale in an entire hydrological basin to derive distributed melt-water runoff information.