Monitoring of snow height and snow water equivalent with GPS

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SLF WSL

1. Introduction

- Goal: Investigation of the potential of GPS techniques for the observation of snow heights and snow water equivalent (SWE).
- 5 GPS stations installed at the Weissfluhjoch test site of the Institute for Snow and Avalanche Research SLF near Davos, Switzerland (Fig. 1).
- Use of low-cost GPS receivers and antennas.
- First feasibility study carried out in March 2012.
- Permanent GPS monitoring system operated since October 2012
- The availability of reference data for snow heights and SWE from state-of-the-art sensors operated by SLF allows for a validation and calibration of the results from GPS monitoring.

Fig. 1: Weissfluhjoch test site of the Institute for Snow and Avalanche Research SLF near Davos, Switzerland

2. Snow height from GPS

The determination of snow heights is based on the multipath effects caused by the reflection of the GPS signals at the surface of the snow cover. The influence of the reflected signal on the signal strength depends on the path extension with respect to the direct signal. The overlay of the direct and the reflected signal yields an oscillation of the signal strengths (Fig 2). The oscillation frequency depends on the distance between the GPS antenna and the surface where the signal is reflected, hence on the snow height. The frequency is determined with a frequency analysis of the detrended signal strength observations.

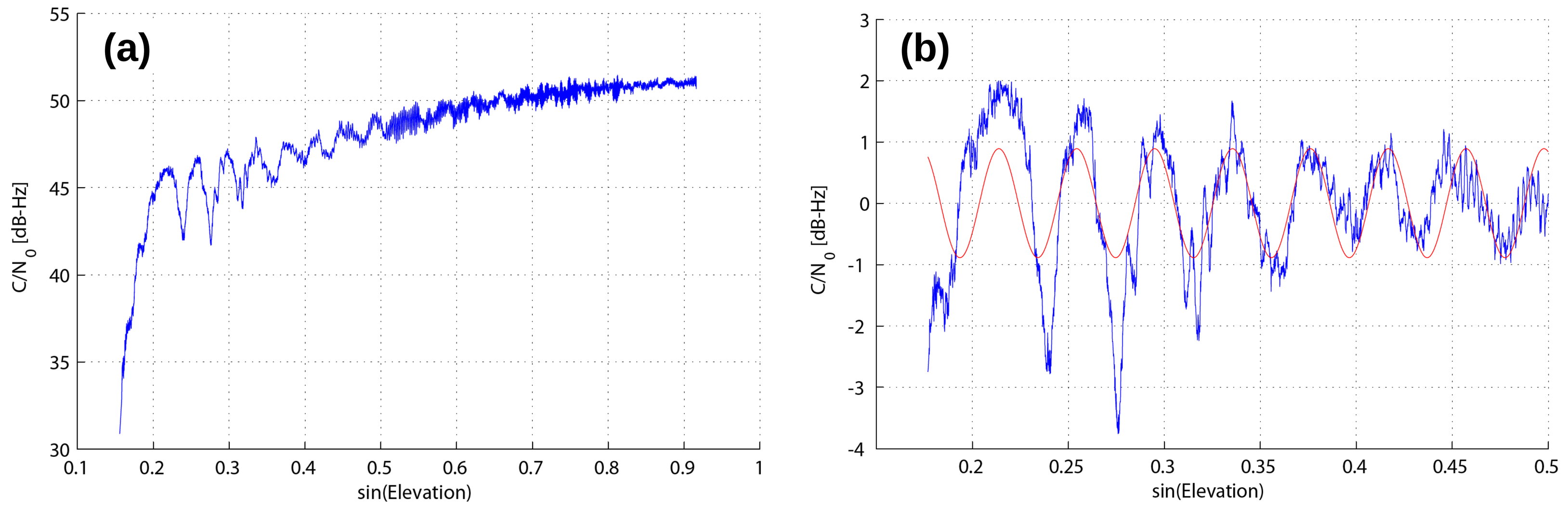

Fig. 2: GPS signal strength of a track of PRN 22 as a function of the sine of the elevation angle. **(a)** Observed signal strength. **(b)** Signal strength after subtraction of elevation-depending trend. Red line: cosine function with estimated oscillation frequency.

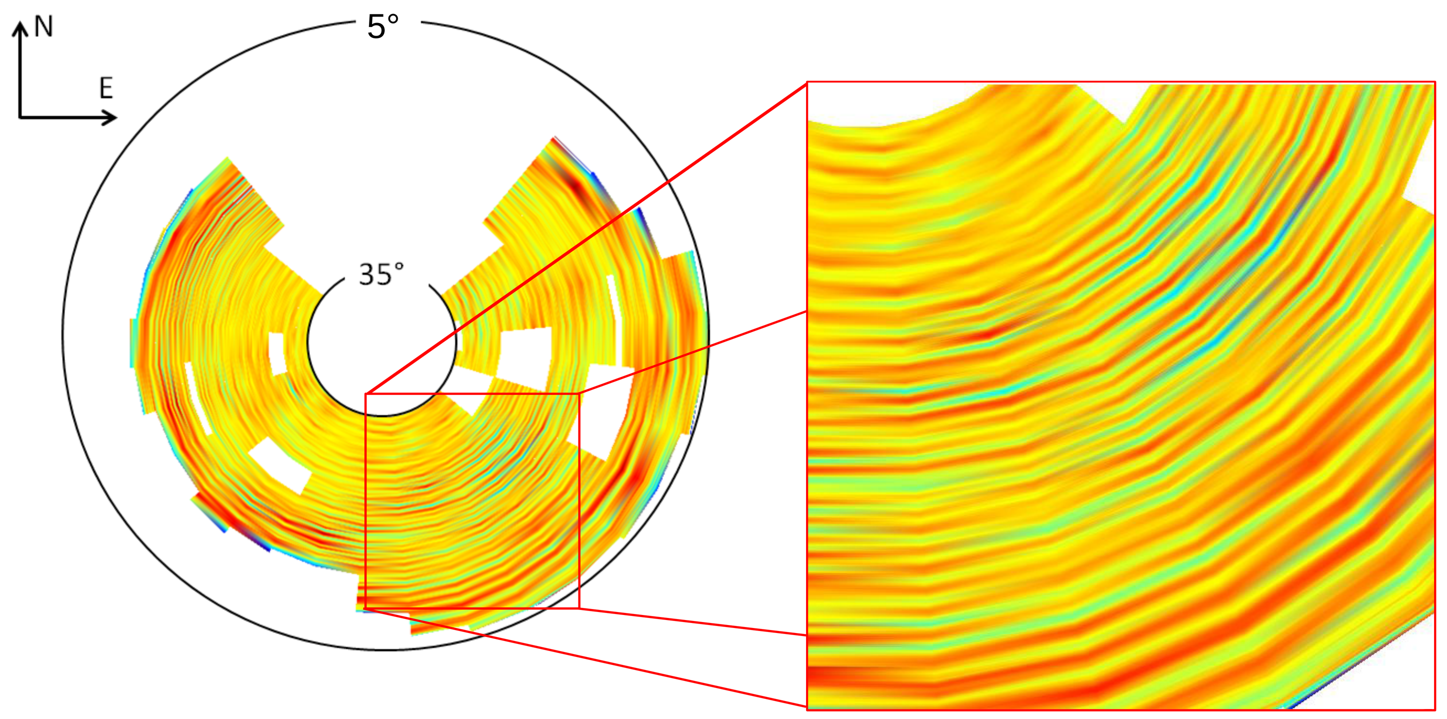

Fig. 3: Polar view (azimuth/elevation) of interpolation of detrended signal strengths of all GPS satellites tracked during 24h. The signal strengths are color-coded (red: neagitve values, yellow/green: positive values). The considered elevations range from 5° to 35°. The white areas are locations with no available GPS signal.

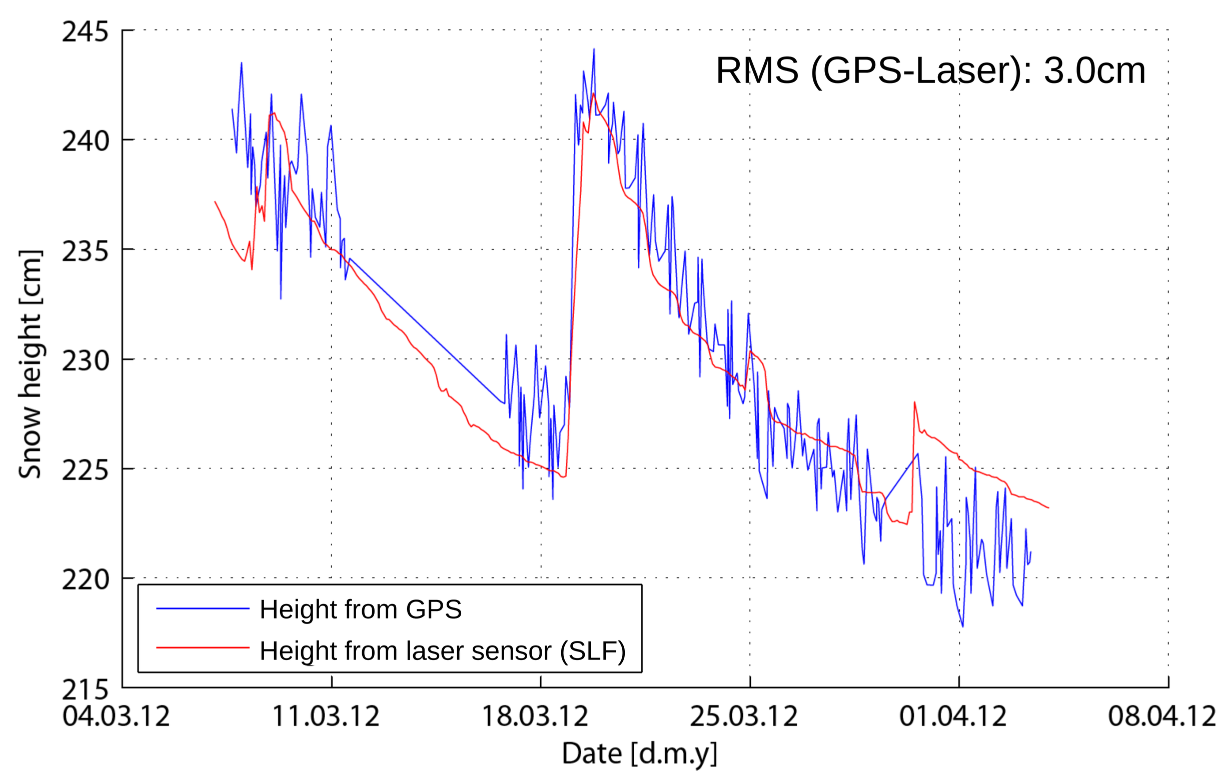

Fig. 4: Snow heights computed from GPS signal strengths (blue line) and snow heights observed with a laser distance sensor (red line). The GPS snow heights are a superposition of the results from 11 satellite tracks.

3. Snow water equivalent from GPS

The determination of snow water equivalents (SWE) is based on the refraction of the GPS signals during their propagation through the snow pack. The refraction strongly depends on the amount of snow that the signal has to travel through. Similar to atmospheric refraction, the GPS signals received by an antenna under a snow pack are delayed by refraction, causing errors on the GPS position, especially in the vertical component. The obtained results are calibrated using the SWE observed with state-of-the-art sensors (Snowscale, Snowpillow).

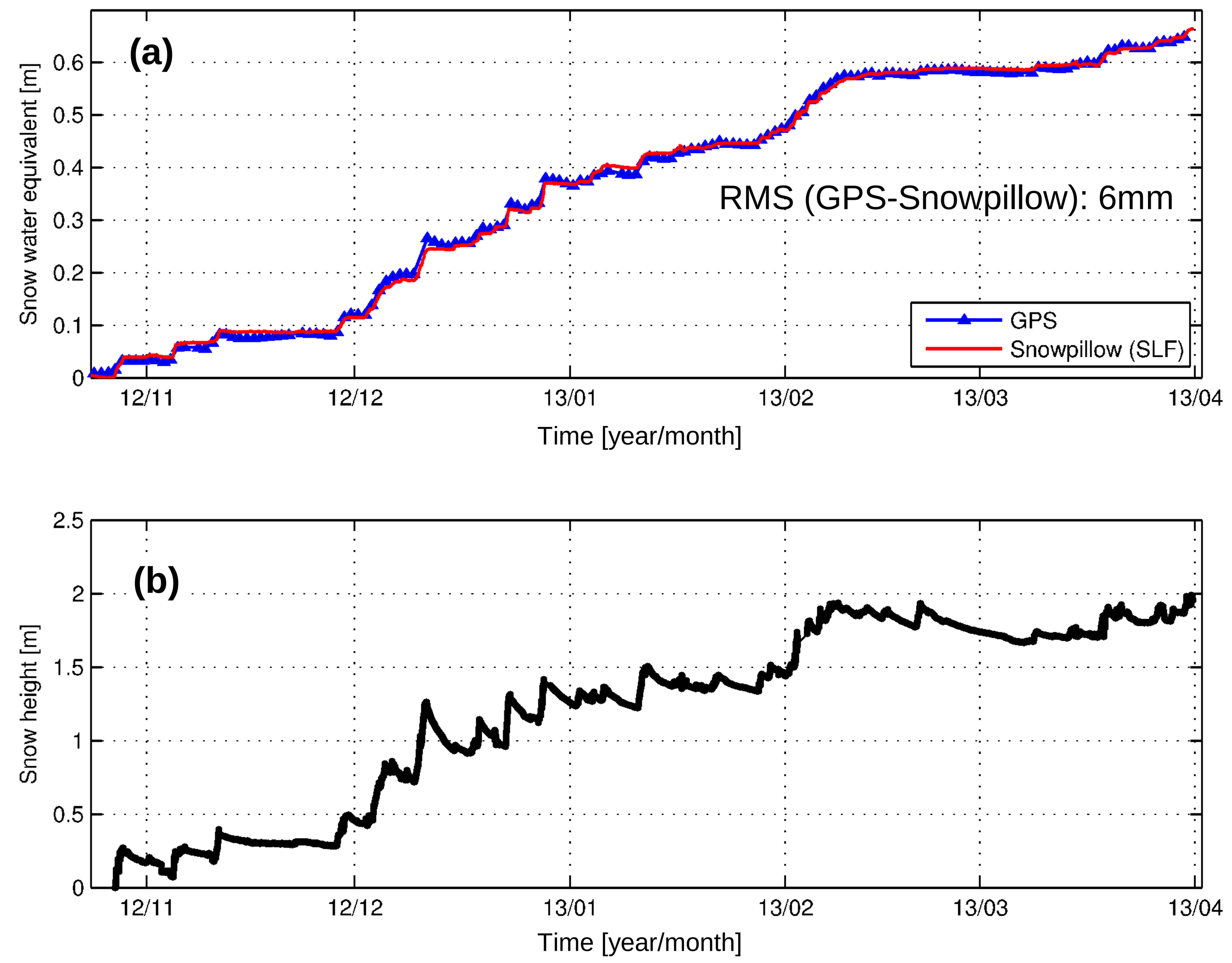

Fig. 5: (a) Snow water equivalent (SWE) computed from GPS data (blue line) and SWE from the Snowpillow sensor (red line). **(b)** Snow heights observed with a laser distance sensor.

4. Conclusions

- The determination of snow heights by analyzing GPS signal strengths yields promising results (Fig. 4), but also reveals certain difficulties. Especially the data interpretation in non-flat terrain remains challenging.
- The determination of snow water equivalent by analyzing the refraction of GPS signals in the snowpack shows a very good agreement with the reference data (Fig. 5). The obtained accuracy is similar to the accuracy of differential GPS positioning.