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GNSS signal-based snow water equivalent determination for different snowpack conditions along a steep elevation gradient

by Capelli et al.

This paper completes the evaluation of the GNSS-derived approach for SWE monitoring using the retrieval algorithm already presented by Koch et al. (2019) and validated at the high-alpine site Weissfluhjoch (2540 m a.s.l), with data at 4 altitudes in the Alpes (820, 1185, 1510 and 2540 m a.s.l.). The performance of this approach is thus assessed for shallow to deep snowpack, with more frequent changes between dry- and wet-snow conditions at low altitude, potential differences in densification and a higher influence of rain events compared to the high-alpine site Weissfluhjoch (2540 m a.s.l).

This article first presents the uncertainty results for the Snow Water Equivalent (SWE), the Liquide Water Content (LWC) and the snow depth (HS) estimates derived from SWE and LWC retrieved data for each of the 4 study sites.

The authors then analyzed the potential detection of snow variations over a short period of time (24 h and 72 h) by comparing these with reference precipitation data, and discussed the current limitations in retrieving new snow.

Since the retrieval of HS estimates and LWC parameter are derived using a recursive process from previously retrieved data, the authors assess also the stability of GNSS-derived snow parameters regarding data gaps.

Lastly, outlook on potential improvements are discussed (section 6).

General comments

The results part is well presented based on solid experiments (over 2 winters), with results that confirm the validity of the retrieval algorithm, showing a global relative uncertainty of about 11% compared to manual measurements and other sensors (Snow pillow and Snow scale). These results highlight the problem of certain assumptions used in the inversion (on density for example).
Have you looked at the ice crust effect (melting/freezing, or after a rain-on-snow event) in the snow?

It was foreseeable that the system would not be very efficient for monitoring precipitation events over a short period of time, given that the GNSS signal is integrated over 12 hours of measurements. This is a weak point of the system: 59% of events (Delta SWE>10 mm) was detected, see Table 3, but the exercise is interesting.

For the part of possible improvements of the system, it is clear that the current algorithm needs improvements, which are relatively little discussed in detail, but the authors argue that this was not the purpose of the article. OK

Regarding the improvement of snow height estimation, it is likely that adding GNSS signal analysis by reflectometry would improve the inversion process: but why was this not been done on the SnowSense? Are other specific antennas needed? More expensive? Longer processing time? Please specify.

I thus suggest “minor” correction with suggested clarifications.

Specific comments

- I suggest to use the term GNSS receiver (GNSSr) to name the snow measurement system based on GNSS signals.
- Introduction: I suggest to cite the recent review of SWE sensor (in review process, but probably published soon):
  Royer A., A. Roy, S. Jutras and A. Langlois (2021). Review article: Performance assessment of radiation-based field sensors for monitoring the water equivalent of snow cover (SWE). The Cryosphere Discuss. [preprint], https://doi.org/10.5194/tc-2021-163, in review, 2021.
- In the whole article, it is rather an uncertainty that is evaluated than an accuracy, since manual or other references also have their own, sometimes significant, uncertainties.
  For example, manual SWE measurement is subject to large variations and uncertainties, as studied in the revised version of Royer et al ‘s paper.
  Also, the Denoth system for measuring LWC can have large uncertainties (see the comparison paper:
  Mavrovic* A., J.-B. Madore*, A. Langlois, A. Royer and A. Roy (2020). Snow liquid water content measurement using an open-ended coaxial probe (OECP). Cold Regions Science and Technology. 171, 102958. ）
- What do the red vertical bars in Figure 6 correspond to, for the manual LWC measurements?
- L121 The given speed of signal propagation in dry snow depends upon the density!
- L139 and 141 : what would be the impact in the retrieval of the these assumed limits: (Ro_s,dry,max and Ro_s,0) ?
- L200 Define the acronym LTE
- Table 1 : precise the meaning of height of new snow (HN) and water equivalent of snowfall (HNW).
- L401 The results of this paper for the retrieved wet-snow SWE appears significantly better than those previously presented by Koch et al. (2019) ?
- Figure C1: Very interesting results! I might have put this figure in the results section! How did you differentiate between liquid and solid precipitations. The link between the amount of rain-on-snow and LWC would be original.