Assessment of operational monitoring of snow water equivalent measurements with low-cost GNSS sensors

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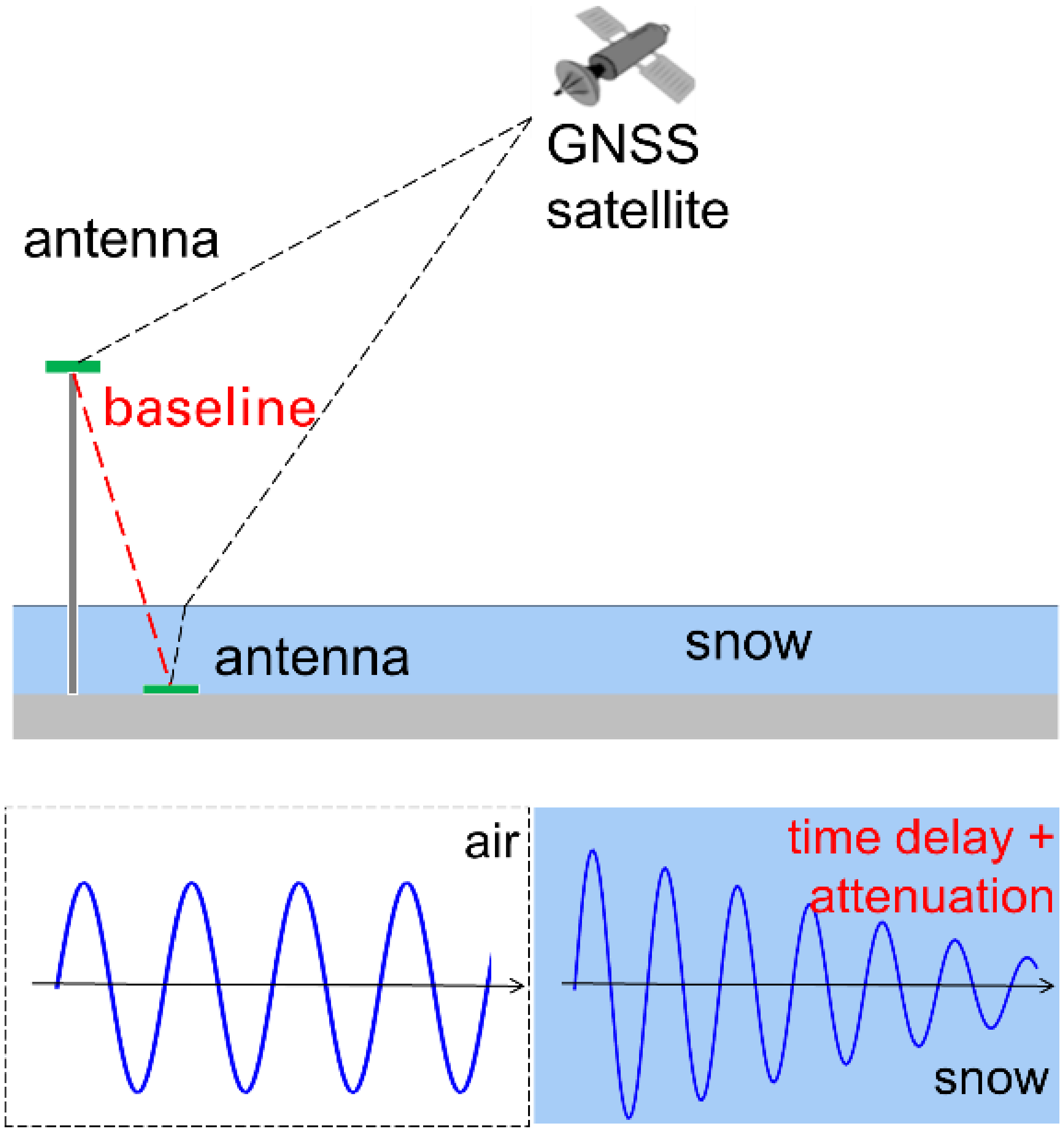
Motivation

Direct measurements of SWE are either scarce and non-continuous (manual) or rather expensive (automatic).

SWE measurements based on GNSS (Global Navigation Satellite System) signals:

- Automatic and continuous measurements, affordable technology
- Very good results at a high-alpine site for several years (Weissfluhjoch (WFJ), 2540 m a.s.l.)
  (Henkel et al. 2018, TGRS; Koch et al. 2019, WRR)
- GNSS algorithm considers different snow characteristics (liquid water content, snow densification), which might change with elevation and climatic conditions.

Measuring principles



- GPS and Galileo L1-Band GNSS signals where used (1.57542 GHz).
- The GNSS signals are recorded by one antenna placed on the ground and another one installed above the snow cover.
- GNSS signals traveling through the snowpack experience time delay and strength attenuation.
- The time delay increases with an increase in SWE and liquid water content.
- The attenuation is significantly higher for wet snow and increases with increasing liquid water content.
- SWE, snow height (HS) and liquid water content (LWC) can be derived for both, dry- and wet-snow conditions.

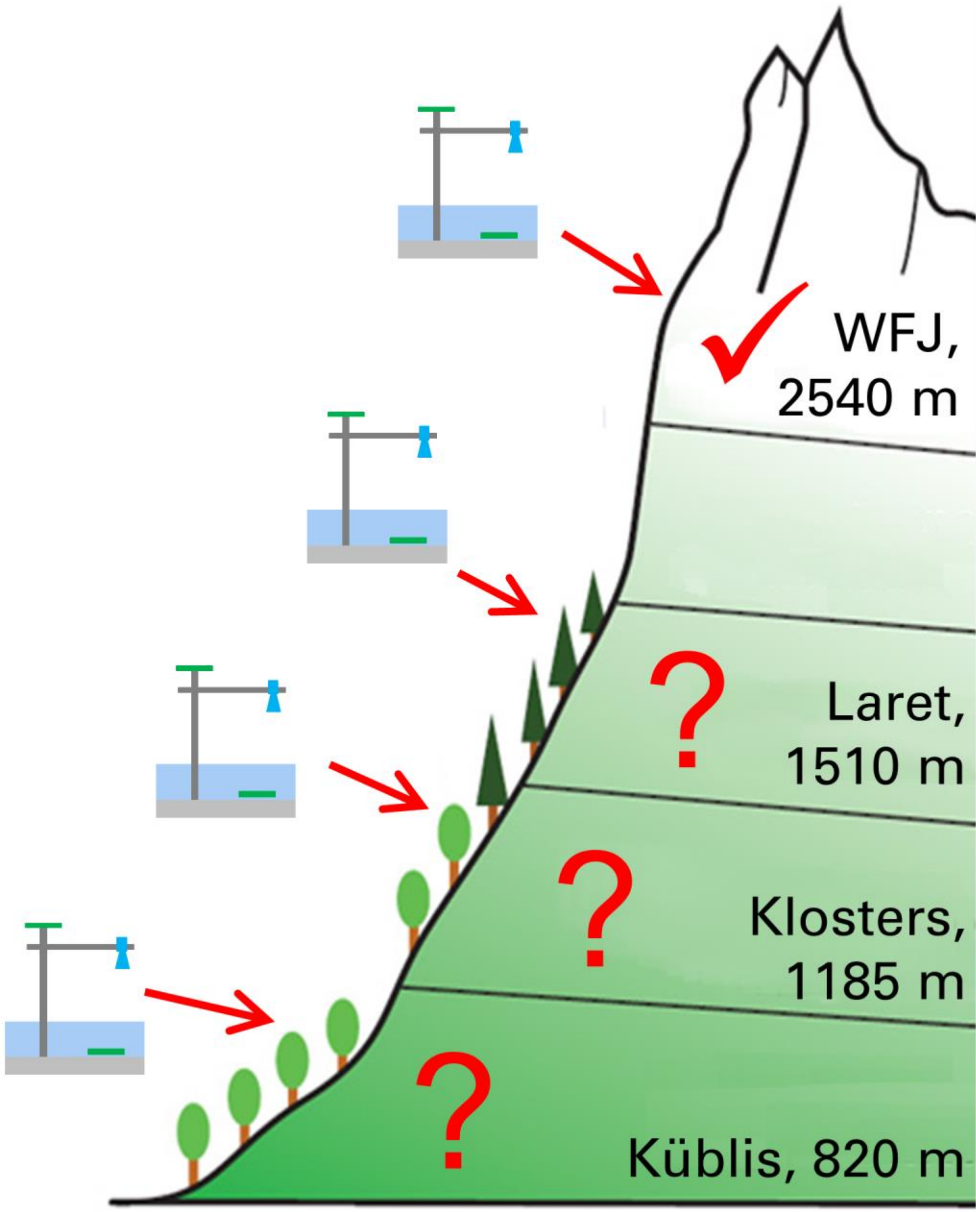
(Henkel et al. 2018, TGRS; Koch et al. 2019, WRR)

Objectives

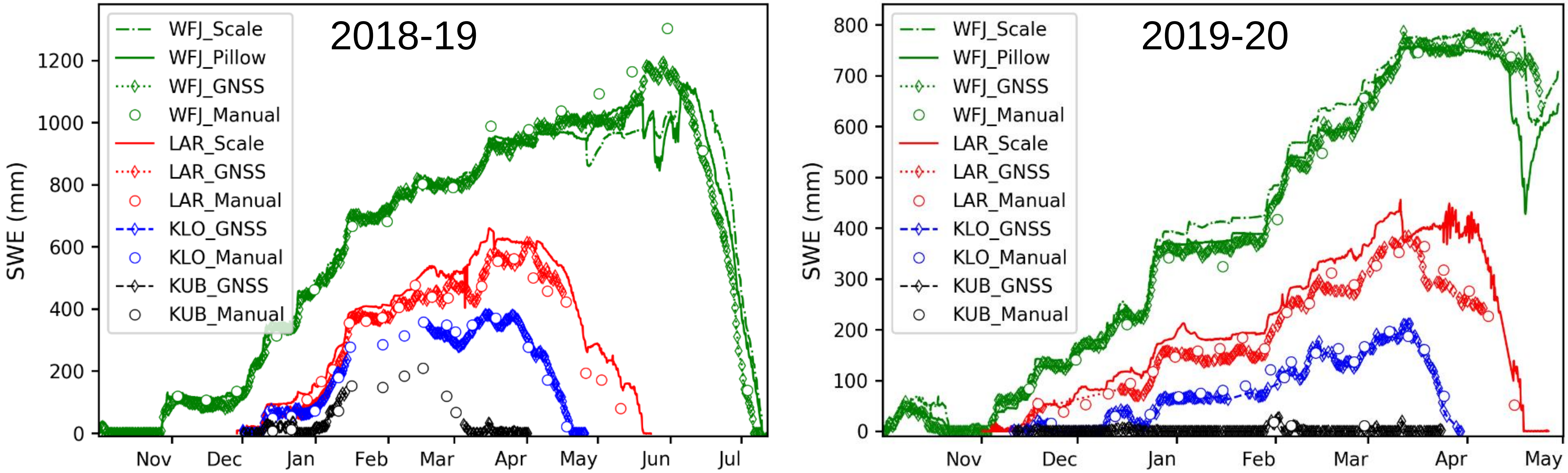
- Determine GNSS-derived SWE at 4 locations along a steep elevation gradient in the Eastern Swiss Alps.
- Validate the GNSS method with regard to snow conditions at different elevations and climatic conditions.
- Assess the accuracy for different meteorological conditions as snowfall events and dry- or wet-snow periods.
- Evaluate whether GNSS-derived SWE is a reliable alternative to existing measuring methods.

SWE validation data at the test sites

- Automatic SWE sensors (scale, snow pillow) at Weissfluhjoch and Laret
- Weekly to biweekly manual measurements at all 4 sites (SWE, density, liquid water content)



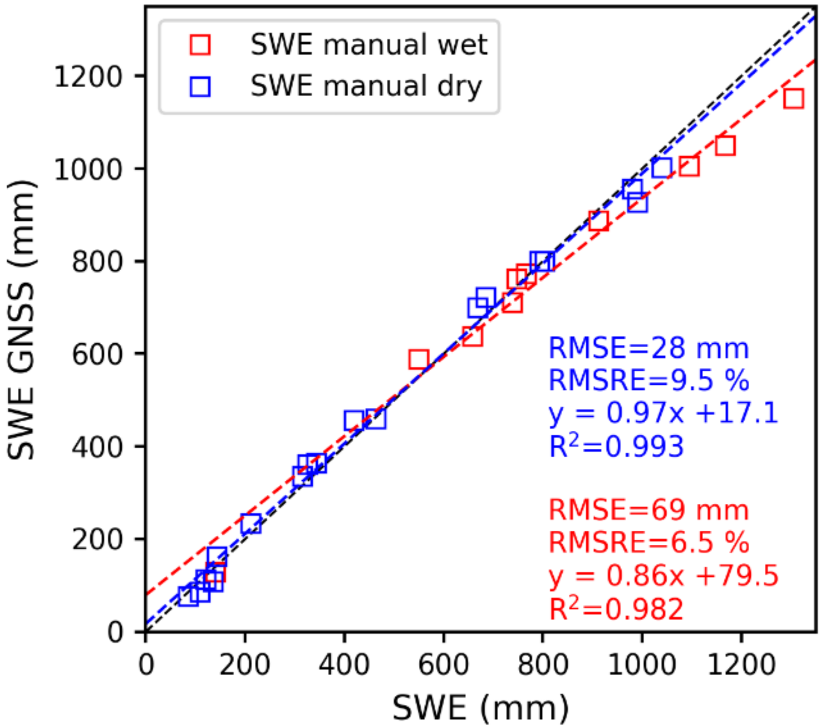
Results



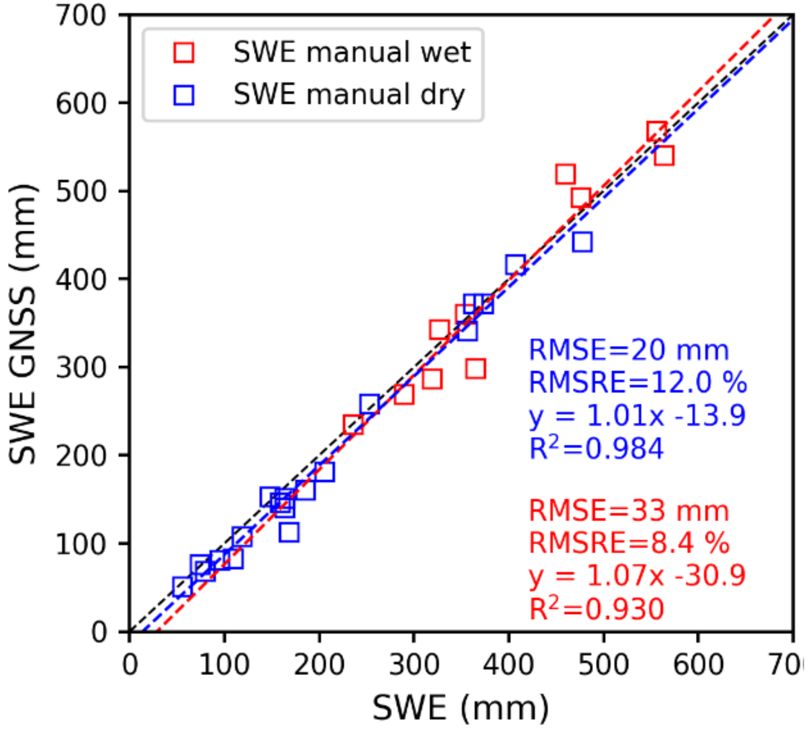
- SWE derived from GNSS signals was estimated for all elevations with good accuracy.
- Especially at the beginning of the melting period in spring, GNSS-derived values of SWE were more accurate than the automatic recordings (which show some unexplainable offsets).
- SWE derivation is robust also in presence of data gaps.
- The GNSS algorithm can discern if snow is lying on the ground or not (>3 mm SWE).

Validation for dry- and wet-snow conditions

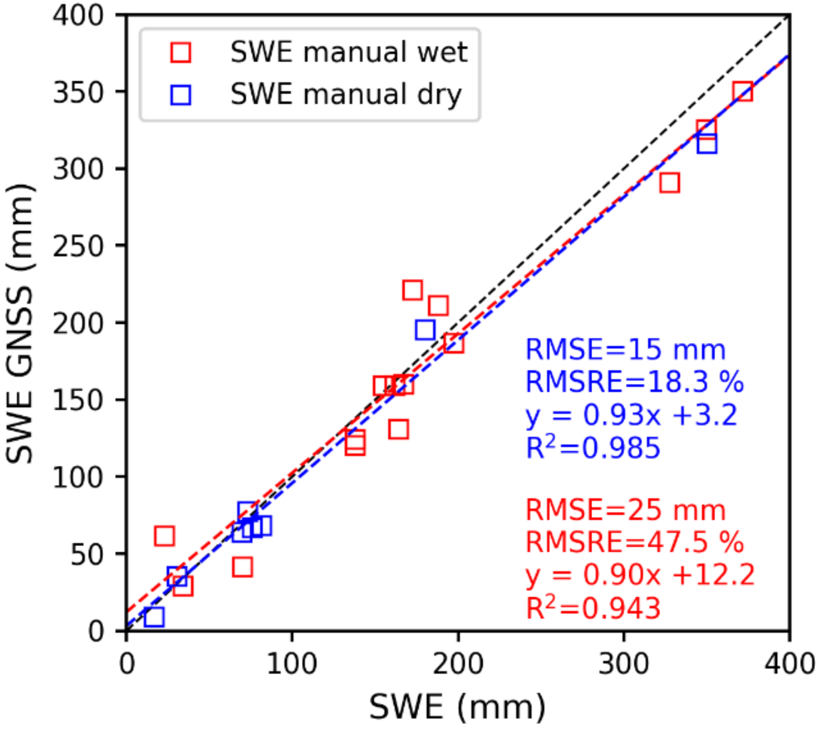
Weissfluhjoch (WFJ), 2540 m asl.



Laret, 1520 m asl.

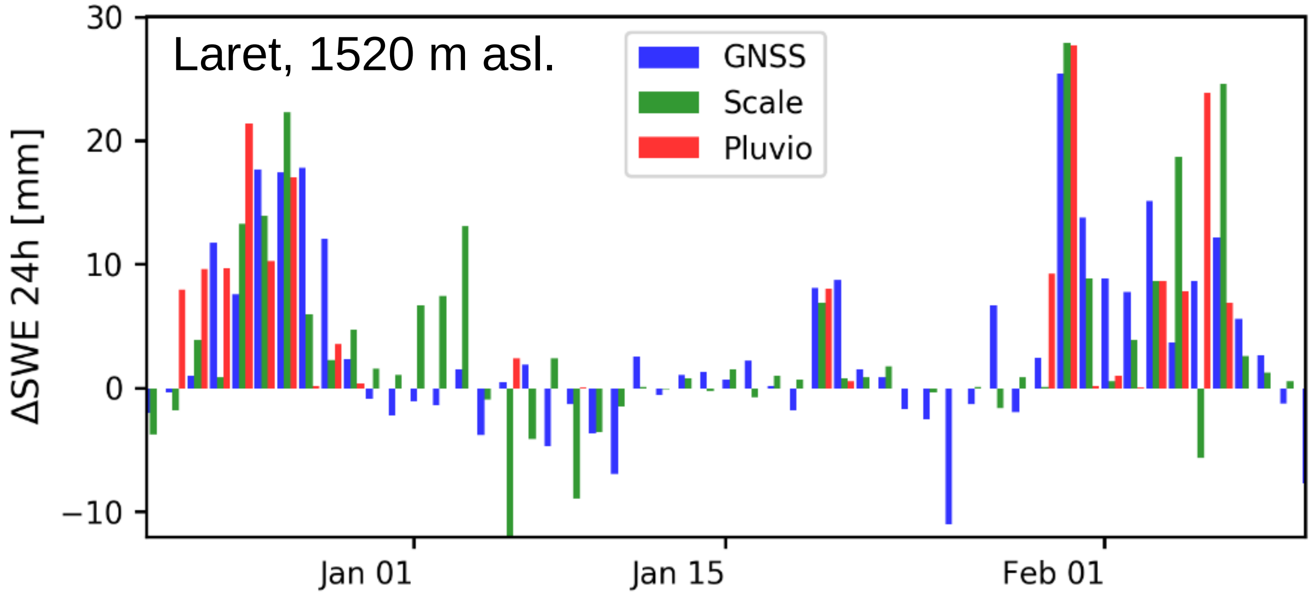


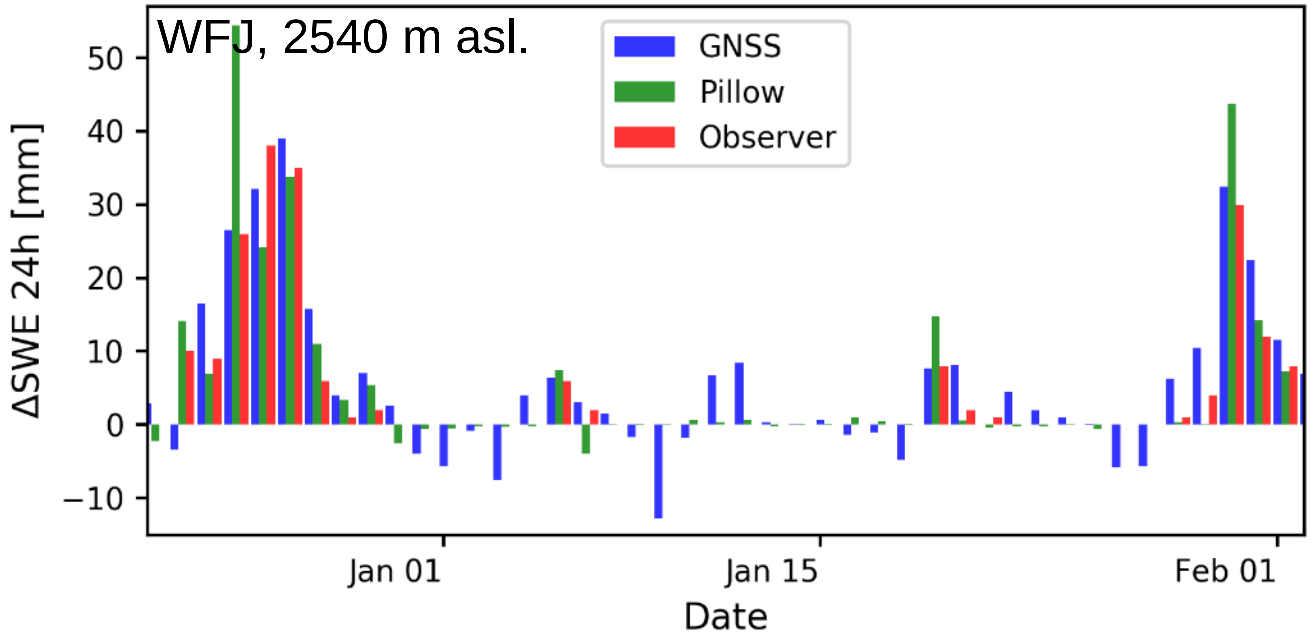
Klosters, 1185 m asl.



- GNSS-derived values of SWE agree well with manual observations of SWE for both, dry and wet conditions.
- Absolute RSME is lower for dry-snow conditions, whereas relative error is lower for wet-snow conditions (due to higher SWE values later in the season).
- The large relative error at Klosters is caused by a single data point with SWE<50 mm for which the error is larger than the reference value.
- For the lowest site (Küblis), only a qualitative evaluation is possible as there was hardly any snow during winter 2019-2020 and a data gap in winter 2018-2019.

Detection of snowfall events





- Snowfall events with more than 10 mm SWE in 24 h are reliably detected by the GNSS snow algorithm.
- Some noise is present in the GNSS-derived SWE (<10 mm SWE) resulting in false snowfall or melting events.
- Thereafter, snowfall or melting events below 10 mm SWE in 24 h cannot reliably be detected.
- Such false events are present also for the snow scale/pillow.
- Further work on the GNSS snow algorithm aims to improve this issue.

Conclusions

- SWE derived from GNSS signals was estimated with good accuracy
  - at all elevations (800 - 2540 m a.s.l.) and
  - for both, dry- and wet-snow conditions.
- During some periods, GNSS-derived SWE was more accurate than alternative measurements of snow load.
- GNSS signal analysis allows to discern if snow is lying on the ground or not (>3 mm SWE).
- SWE derivation is robust also in presence of data gaps.

Outlook:

- A more comprehensive analysis will be published soon (including LWC, rain-on-snow events, comparison to models, …)

References

Henkel, P., Koch, F., Appel, F., Bach, H., Prasch, M., Schmid, L., Schweizer, J., and Mauser, W. (2018). Snow water equivalent of dry snow derived from GNSS carrier phases. *IEEE Transactions on Geoscience and Remote Sensing* 56, 3561-3572. doi: 10.1109/TGRS.2018.2802494

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