Calculation of new snow densities from sub-daily automated snow measurements

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Motivation

In mountain regions there is an increasing demand for high-quality analysis, nowcasting and short-range forecasts of the spatial distribution of new snow (HN) and the corresponding water equivalent (HNW), and thus the density of new snow for conversion from one to the other. In the past, attempts were made to calculate new snow densities from meteorological parameters mainly using daily values of temperature and wind. However, only a few long-term in-situ measurements of new snow density exist for sub-daily time intervals. Within the scope of the pluSnow project, data of several automatic weather stations with simultaneous measurements of precipitation (pluviometers), snow water equivalent (SWE) using snow pillows and snow depth (HS) measurements using ultrasonic rangers were analysed.

Data & Filtering

New snow densities (NSD_{obs}) were calculated for a set of hourly data of changes in HS and SWE from 4 different snow stations: Weissfluhjoch (2540 m a.s.l., Fig. 1A), Kühtai (1970 m a.s.l., Fig 1B), Wattener Lizum (2041 m a.s.l., Fig1C) and Kühroint (1420 m a.s.l., Fig 1D). Data were filtered using the following meteorological thresholds:

- precipitation signal rain gauge: yes
- snow depth change (HN) > 1.5 cm
- water equivalent of snowfall (HNW) > 0.1 mm
- wet bulb temperature (Tw) < 0° C
- wind speed (U) < 5 ms^{-1}

The filtered data (Fig. 2 red points) are analysed for the period 01 Oct 2013 to 20 May 2015. A first correction of snow settling was applied using the approach of Anderson (1976).

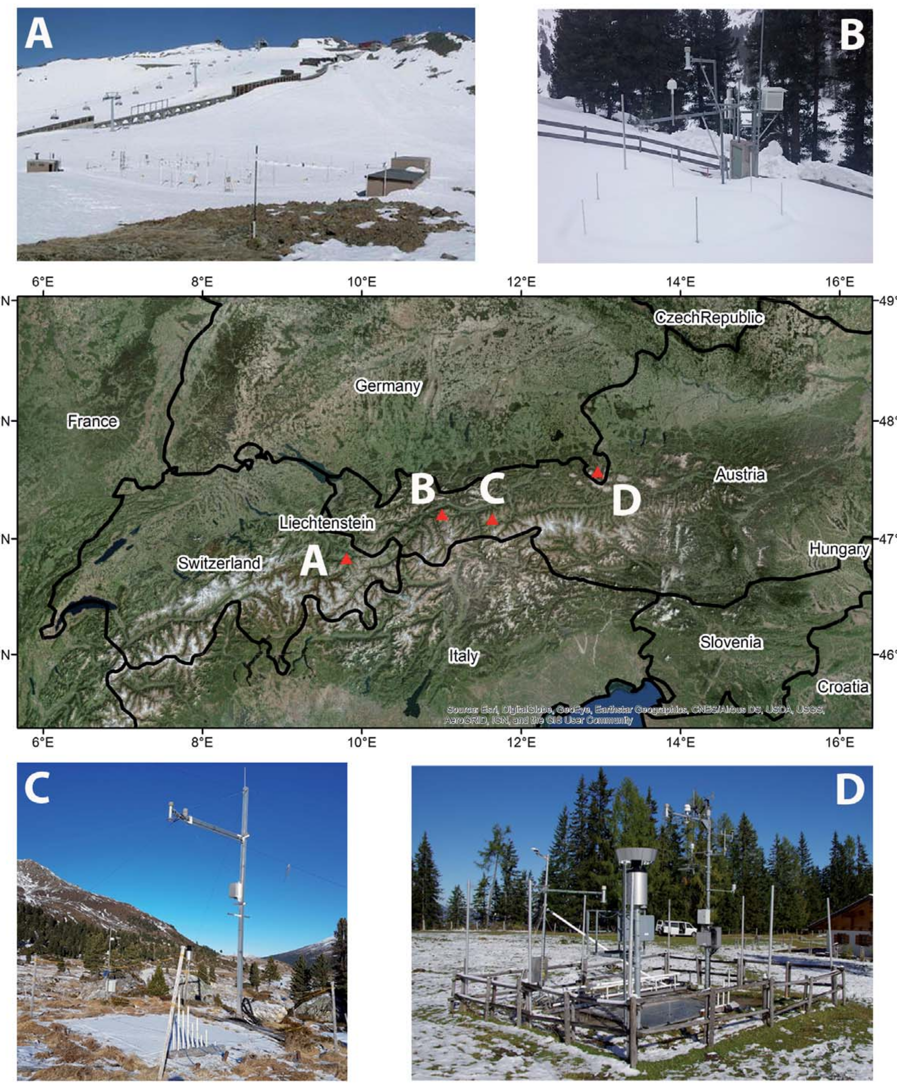
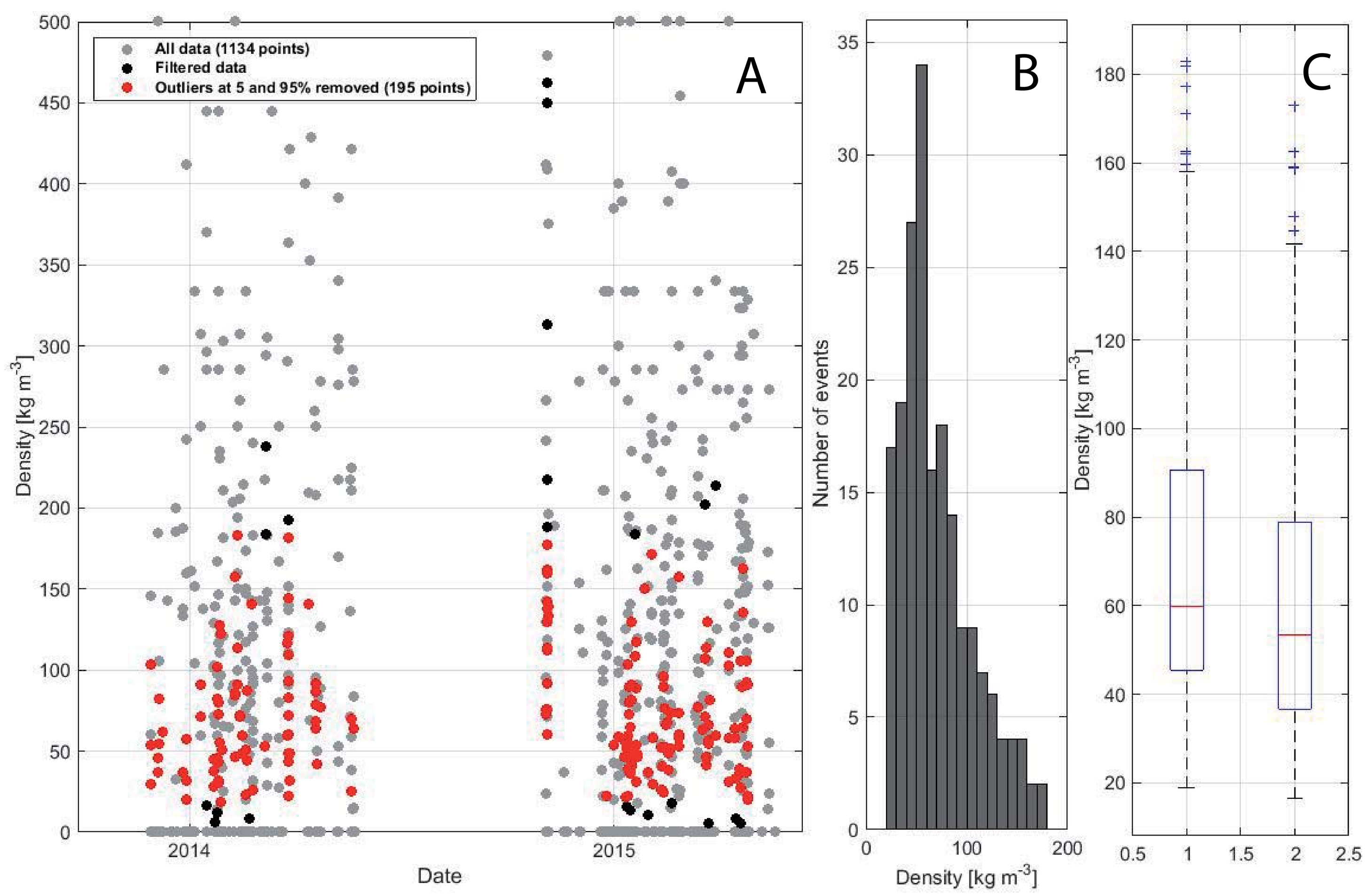


Fig 1: Location of the four snow stations A) Weissfluhjoch, B) Kühtai, C) Wattener Lizum and D) Kühroint.



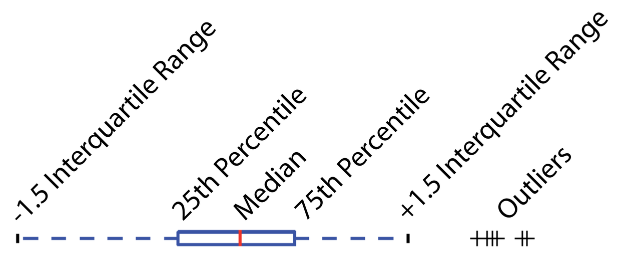


Fig 2: A) Filtered and unfiltered calculated densities at Kühroint station, B) the histogramm of all filtered data and C) the corresponding box plot for filtered data with and without settling correction. This figure is exemplarily for filtering of data from all 4 stations.

Density Calculations

New snow densities from measurements (NSD_{obs}) were compared to NSD calculations using the following existing equations:

$\rho_{HP} = 67.92 + 51.25 \cdot \exp(T / 2.59)$ (Hedstrom and Pomeroy 1998)

$\rho_{D} = 119 + 6.48 \cdot T$ (Diamond and Lowry 1954)

$\rho_{LC} = 50 + 1.7 \cdot (T+15)^{1.5}$ (LaChapelle 1962)

$\rho_{C} = 109 + 6 \cdot (T - Tf) + 26 \cdot U \cdot 0.5$ (Vionnet et al. 2012)

$\rho_{J} = 500 \cdot (1 - 0.951 \cdot \exp(-1.4 \cdot (278.15 - (T + 273.15))^{-1.15})) - 0.008 \cdot u^{1.7}$ [-13< T>= 2.5°C]
$\rho_{J} = 500 \cdot (1 - 0.904 \cdot \exp(-0.008 \cdot U^{1.7}))$ [T <= -13°C]
(Jordan et al.1999)

$\rho_{S} = 10^\wedge(3.28 + 0.03 \cdot T - 0.36 - 0.75 \cdot \arcsin(\sqrt{(rH / 100)} + 0.3 \cdot \log_{10}(U))$ [T >= -14 °C]
$\rho_{S} = 10^\wedge(3.28 + 0.03 \cdot T - 0.75 \cdot \arcsin(\sqrt{(rH / 100)}) + 0.3 \cdot \log_{10}(U))$ [T < -14°C]
(Schmucki et al. 2015)

$\rho_{L} = 70 + 6.5 \cdot T + 7.5 \cdot Ts + 0.26 \cdot rh + 13 \cdot U - 4.5 \cdot T \cdot Ts - 0.65 \cdot T \cdot U - 0.17 \cdot rh \cdot U + 0.06 \cdot T \cdot Ts \cdot rh$
(Lehning et al. 2002)

Results (Fig. 3)

NSD_{obs} from hourly automated snow measurements:
- are lower than calculations using approaches based on daily NSD data ($\rho_{HP, D, LC, J}$).
- are on average in a good match with equations developed for SNOWPACK model ($\rho_{S, L}$).
- show high variability which cannot be explained by near surface meteorological parameters so far.

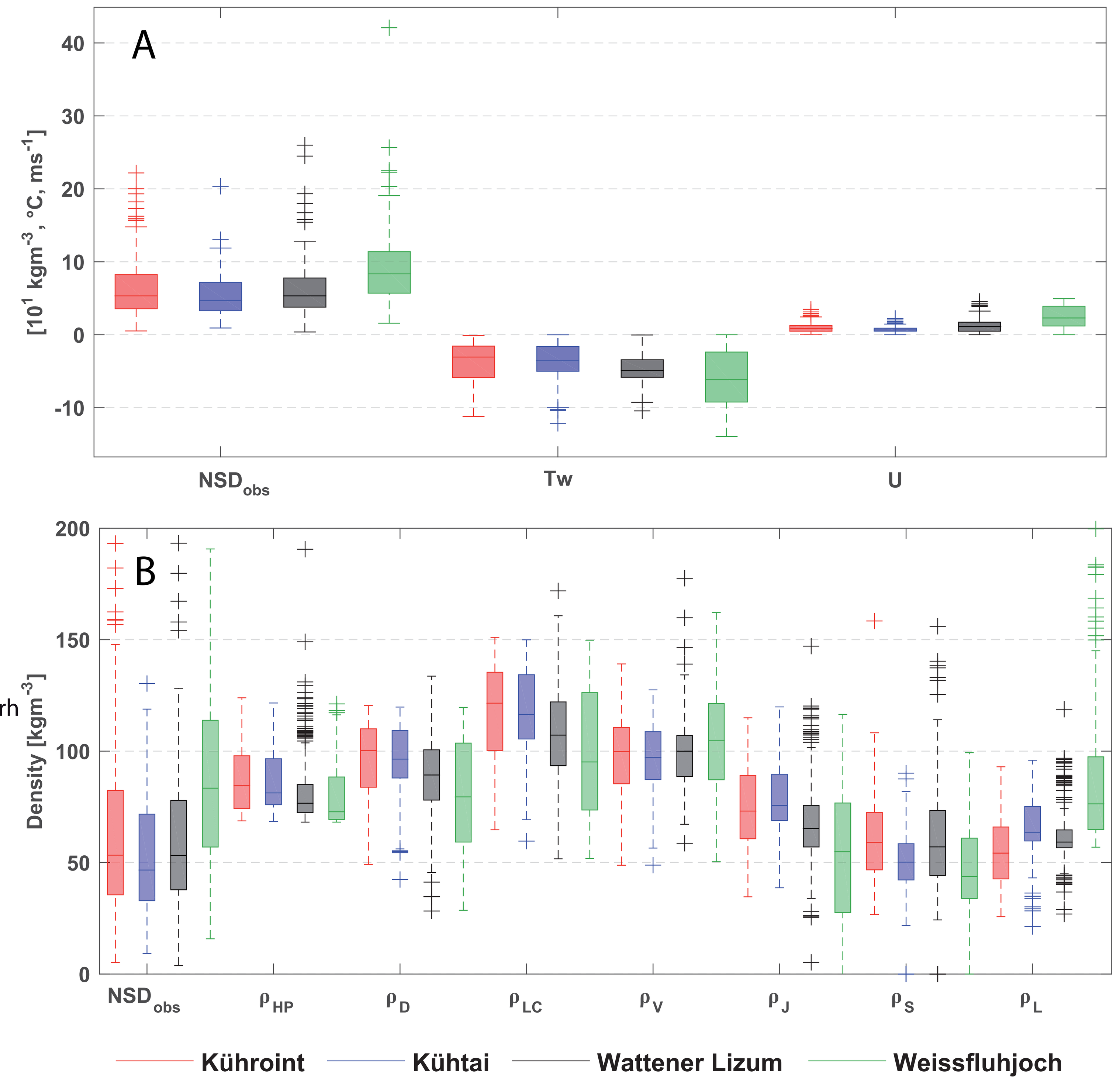


Fig 3: Statistical distribution of the calculated NSD in comparison to A) the wet bulb temperature (Tw) and wind speed (U) at time of snowfall and B) results using NSD parametrizations.

Settling

The influence of settling both of the new and the old snow was calculated. With respect to data restrictions we applied the approach of Anderson (1976) to the presented data. In comparison the multi-layer SNOWPACK model calculates higher relative contribution (Fig. 4), which, however, would result in higher actual HN and thus lower densities. In general, settling has to be considered calculating HN from snow depth changes on subdaily time-scales.

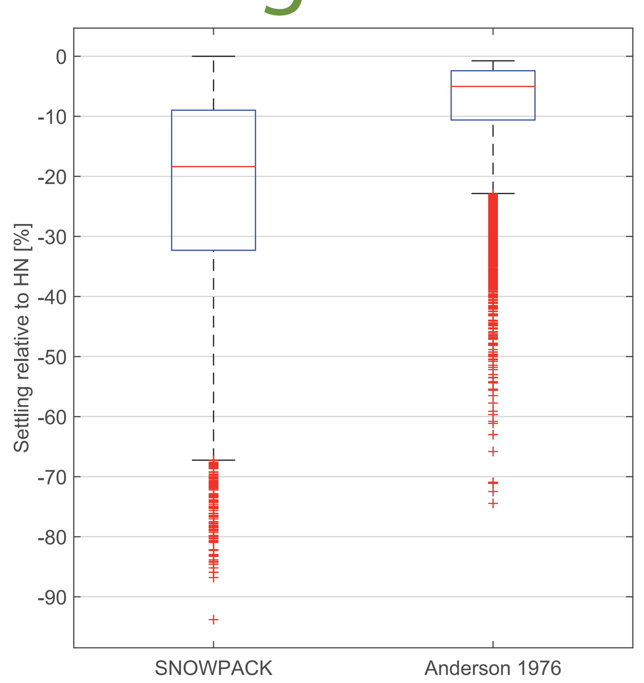


Fig 4: The relative contribution of settling calculated using two approaches for the Weissfluhjoch data set from 1 Sep 1999 to 31 Dec 2015 (WSL Institute for Snow and Avalanche Research SLF doi:10.16904/1.)

Prospect

The reasonable NSD mean values encourage calculating NSD from operational hydro-meteorological measurements using more precise observation devices such as optical snow depth sensors and more sensitive scales.

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