POTENTIAL AND CHALLENGES OF AN EXTENSIVE OPERATIONAL USE OF HIGH ACCURACY OPTICAL SNOW DEPTH SENSORS TO MINIMIZE SOLID PRECIPITATION UNDERCATCH

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ABSTRACT: Within the pluSnow project we analyse snow depth measurements using the SHM30 optical sensor with the objective to minimize the error of solid precipitation undercatch of operational rain gauge measurements. The study is based on snow depth data from more than 50 automatic weather stations with installed SHM30 operated by the Austrian Zentralanstalt für Meteorologie und Geodynamik (ZAMG). The high accurate sensor returns snow depth measurements with reasonable snow depth variations during snowfall events and a moderate correlation to gauged precipitation using sub-hourly temporal resolution. In general, there is a high correlation between snow depth changes and precipitation sums using 60-minute intervals, where the snow depth measurements on the mm-resolution surpass the cm-resolution. Nevertheless, additional analysis on new snow densities is required to compare gauged precipitation and the water equivalent of snowfall directly.

KEYWORDS: new snow, snow density, solid precipitation, undercatch, snow water equivalent

1. INTRODUCTION

In mountain regions there is an increasing demand for high-quality analysis, nowcast and short-range forecasts of the spatial distribution of snowfall. Operational services, such as for avalanche warning, road maintenance and hydrology, but also hydropower companies and ski resorts need reliable information on the depth (HN) and the water equivalent (HNW) of snowfall.

However, producing accurate precipitation maps for complex mountain regions is a difficult task, especially in cold and windy conditions, when conventional rain gauge measurements are prone to large errors (e.g. Goodison et al. 1998). Recent studies of the Solid Precipitation Intercomparison Experiment (SPICE, Nitu et al. 2012) reveal that these errors still exist in standard meteorological measurements (e.g. Buisan et al. 2016, Pan et al. 2016).

Precipitation radar can provide information on intensity and extent of observed precipitation for spatially distributed weather analysis (e.g. Joss and Lee 1995), but topographic shading in mountain regions and low level clouds remain challenging, especially in winter. Precipitation radar data and rain gauge measurements are combined to form precipitation data sets for specific model regions (e.g. Haiden et al., 2010), which thus contain the errors from the gauge measurements.

From the early 1980s onwards, ultrasonic sensors were used to monitor snow depths (Goodison et al. 1984, Lundberg et al. 2010). They have the advantage of a high temporal resolution and are a more objective method compared to subjective manual measurements (Ryan et al. 2008). In general, the uncertainty of ultrasonic ranging is about 1% of the distance between the device and the snow surface, but the signal velocity strongly depends on meteorological conditions. Additionally, erroneous measurements are reported during snowfall (e.g. Lundberg et al. 2010).

In contrast, no data outages were observed during heavy precipitation events using the SHM30 laser snow depth gauge (Mair and Baumgartner 2010). The measurement accuracy of the SHM30 (http://www.lufft.com/en/products/optical-sensors/snow-depth-sensor-shm-30-836510/) is potentially larger by about one order of magnitude compared to ultrasonic sensors, and there is negligible temperature dependence and no wind influence on the laser signal (Lanzinger and Theel 2010).

The pluSnow project investigates the value of automatic snow depth measurements using the

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SHM30 for minimizing the error in winter precipitation data at conventional rain gauges in the Austrian Alps. It aims to correct precipitation undercatch in the operational use of the high accuracy snow depth data on the hourly to sub-hourly time scale.

To this end, high-accuracy snow depth measurements and gauged precipitation data are extensively analysed in combination with contemporaneous meteorological data.

2. DATA AND METHODS

The study is based on snow depth data from SHM30 devices at 53 automatic weather stations (TAWES) operated by the Austrian weather service (Zentralanstalt für Meteorologie und Geodynamik ZAMG).

Meteorological data of the time period 1 Jan 2014 to 31 May 2015 were analysed within this study.

In a first analysis we considered the relevance of potential precipitation correction at the TAWES locations for the total year and for the winter season from 1st of January to 31st of March (JFM). Catch ratios were calculated according to Goodison (1998, p. 34, Eq. 4.5.7+8) using the correction scheme for unshielded Hellmann type rain gauges. The catch ratio (CR) is defined as ratio between gauged precipitation (P_g) and corrected precipitation (P_{cor}):

$$CR = P_g / P_{cor}. \qquad (1)$$

The correlations between gauged precipitation and HN in cm- and mm-resolution of 10-minute and 60-minute intervals were calculated for each observed precipitation event with HNW > 0 mm and a wet bulb temperature $T_w <= -1$ °C

Finally, all snowfall events of the entire period were considered and converted into HNW, using the empirical density parametrisations developed by Jordan et al. (1999), Hedstrom and Pomeroy (1998) and Diamond and Lowry (1954), as well as a constant density of 100 kgm^{-3} to calculate catch ratios (CR_c) from HN and gauged precipitation (P_g):

$$CR_c = P_g / HN. \qquad (2)$$

3. RESULTS

The mean annual CR of all stations is 89%, and 78% in winter (JFM). These values are well represented at the 15 stations in the elevation zone between 1000 and 1500 m a.s.l. (Fig. 1). At 10 stations located higher than 1500m a.s.l., mean CR decreases to 62%, because of lower temperatures and higher wind speeds (Fig. 1, Tab. 1). The relationship between CR, temperature and wind at each TAWES station is given in Figure 1 for mean annual values and for winter season separately.

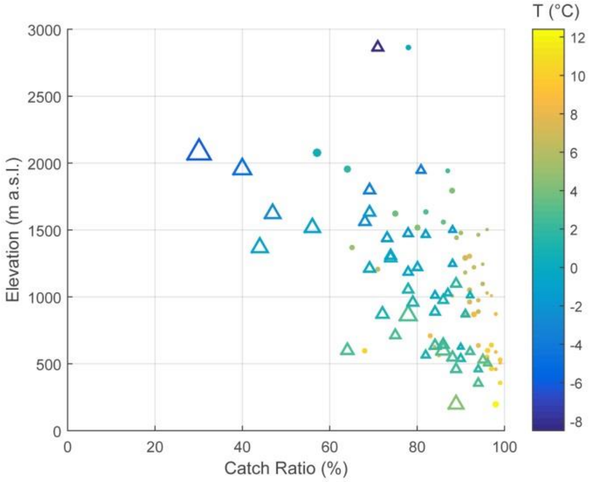

Fig. 1: Catch ratios (CR, Eq. 1) for TAWES stations for the time periods 1 Jan 2014 to 31 Dec 2014 (dots) and 1 Jan 2014 to 31 March 2014 (JFM, triangles). Size of the markers is scaled according to wind speed. The color of the markers shows the mean air temperature at time of precipitation events.

Tbl. 1: Mean values of wind speed (ff), air temperature (T) and calculated catch ratios (CR) for precipitation events at all TAWES stations and subsets of stations regarding to their elevation in the period periods 1 Jan 2014 to 31 Dec 2014 (annual) and 1 Jan 2014 to 31 March 2014 (winter).

stations		*all*	*H<1000 m*	*1000<=H<=1500 m*	*H>1500 m*
annual	ff (ms^{-1})	2.0	1.8	1.6	3.2
	T (°C)	6.7	8.8	6.3	2.8
	CR (%)	89	93	89	79
winter	ff (ms^{-1})	1.9	1.7	1.5	3.0
	T (°C)	0.1	2.1	-0.3	-3.6
	CR (%)	78	86	78	62

The impact of higher wind speeds and decreasing temperatures on potential CR at higher elevated stations is obvious. Generally, there is a larger range between seasonal CRs (JFM) and annual

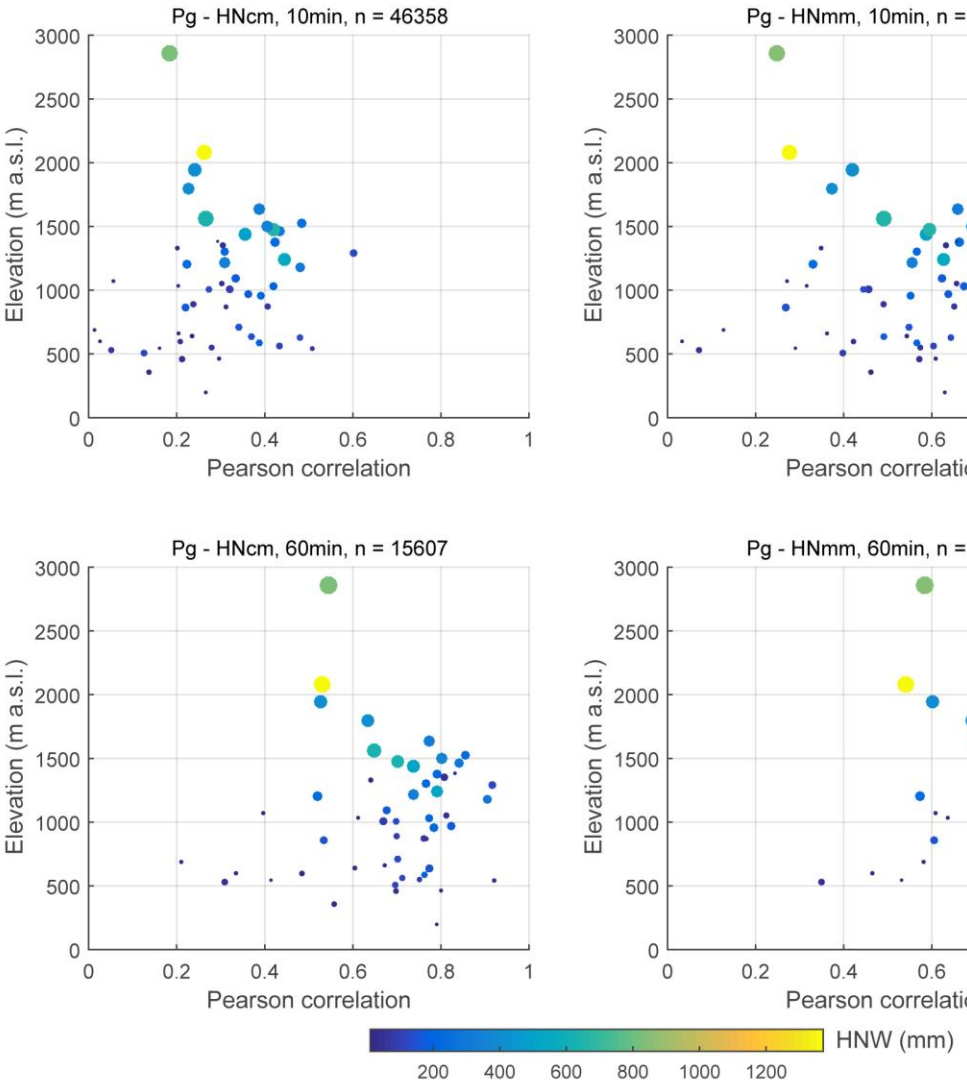

Fig. 2: Pearson Correlation coefficients between gauged precipitation (P_g) and the depth of snowfall (HN) calculated on the centimeter (HNcm) and millimeter resolution (HNmm) for all precipitation events with HNW > 0mm and Tw <= -1 °C at 53 automatic weather stations in the period 01/2014-05/2015 for 10min and 60min intervals. The size of the dots presents the number of events relative to the total event number (n, subtitle). The color of the dots represents the corresponding cumulative HNW sum of all events assuming a mean snow density of 100 kgm^{-3}.

CRs for higher elevated stations compared to stations in the flatlands. Pearson correlation is low for 10min values with a cm-resolution of snow depth measurement (Fig. 2, Tbl. 2). Using the mm-values of SHM30 measurements in 10 min intervals results in a moderate correlation of 0.5. A distinct increase of the correlation is achieved by comparing 60 min-values of precipitation sums and HN. Again the mm-resolution in snow depth measurement surpasses the cm-resolution. A large spread in the correlation is evident at low elevated stations, where less precipitation falls as snow (Fig. 1) due to the Tw threshold chosen. A better correlation is achieved at mid-elevation stations around 1500 m a.s.l.. At stations elevated higher than 1500 m a.s.l., the total amount of accumulated HNW increases, but the correlation decreases.

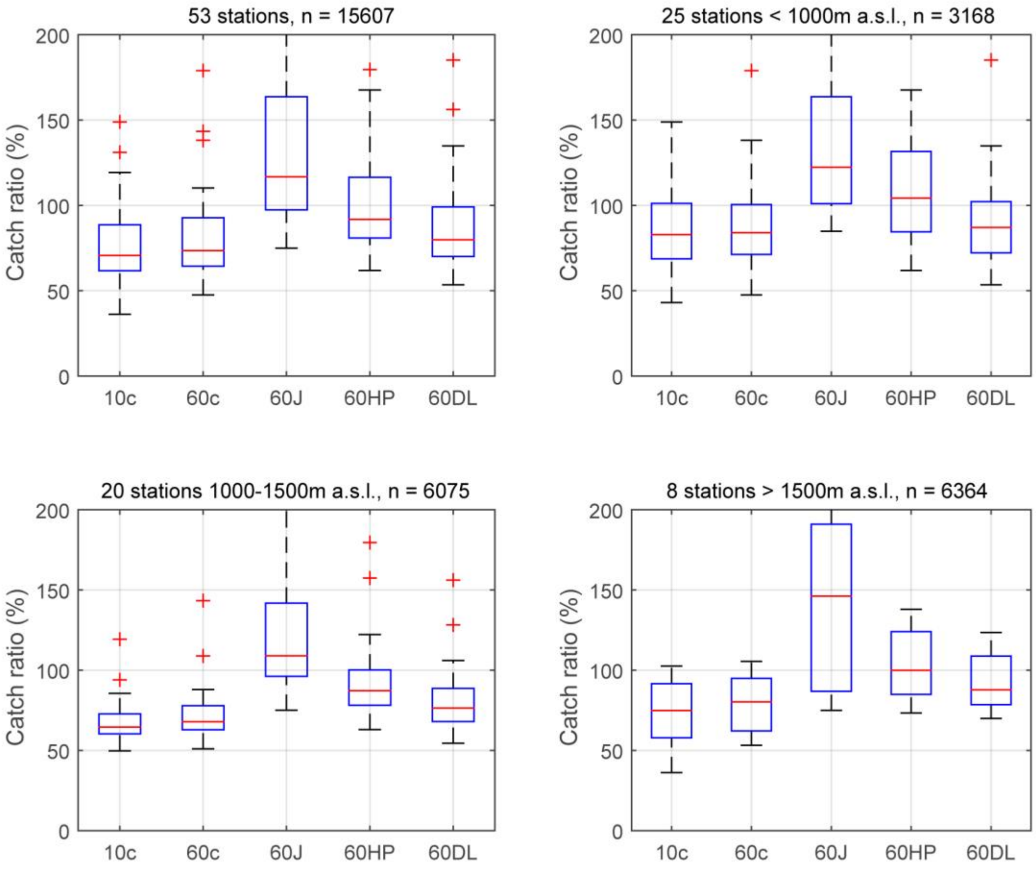

Fig. 3: Boxplots (Median, 25th/75th percentile,1.5 interquartile range, outliers) of calculated catch ratios (CRc, Eq. 2) based on gauged precipitation and SHM30 data for all precipitation events with HNW > 0 mm and Tw <= -1 °C at 53 automatic weather stations in the period 1 Jan 2014 to 31 May 2015. Results are shown using constant density of 100 kgm-3 for 10min temporal resolution (10c) and hourly resolution (60c), and for calculations of new snow densities according to Jordan et al. (1999, 60J), Hedstrom and Pomeroy (1998, 60HP) and Diamond and Lowry (1954, 60DL). The upper left panel shows results for all stations, the other three for stations located in particular elevation zones. The corresponding total number of events (n) of the hourly values is given in the subtitles.

However, differences in the mean correlation at all stations are minor compared to the mean correlation considering the number of events at each station (Tbl. 2). The CR_c using observed precipitation and HNW with a constant snow density of 100 kgm^{-3} are similar for 10 min and 60 min temporal resolution (Fig. 3). However, applying new snow density approximation formulas from literature results in higher CR_c caused by lower new snow densities. Particularly the approximation of Jordan et al. (1998) calculates lower snow densities. Using the new snow density approximation of Hedstrom and Pomeroy (1999) results in almost

Tbl. 2: Mean Pearson correlation coefficients between gauged precipitation and HN in cm and mm resolution for 10 min and 60 min intervals based on the simple station mean and weighted with the total number of events at each station.

	cm		*mm*	
Time step	*station*	*event*	*station*	*event*
10min	0.30	0.32	0.51	0.52
60min	0.68	0.68	0.77	0.74

no undercatch. The higher new snow densities of Diamond et al. (1954) result in lower CR_c compared to the approximations mentioned before, but still higher CR_c compared to HNW with a constant density of 100 kgm^{-3}.

4. DISCUSSION AND CONCLUSIONS

This study demonstrates from calculations applying a standard precipitation correction formula according to Goodison et al. (1998), that a mean undercatch of solid precipitation by 20% can be expected at automatic weather stations in the Austrian Alps. CRs lower than 50% were calculated at stations elevated higher than 1500 m a.s.l. for winter season.

High accuracy snow depth measurements using the SHM30 optical sensor were analysed with the objective of an operational correction of solid precipitation undercatch based on HN values. On average, the mm-resolution of the SHM30 surpasses the cm-resolution when comparing snow depth changes to gauged precipitation. This shows the potential of the high accuracy SHM30 data to be used operationally for HN calculation even using hourly or sub-hourly intervals.

Highest correlations between HN and precipitation can be expected at mid-elevations in mountain valleys. At low-altitude stations, melt caused by ground heat, the generally lower precipitation rates and higher fraction of mixed precipitation influence the results of this analysis. Increased exposure to wind and thus lateral snow erosion/deposition processes, in combination with increased snow compaction caused by higher snow loads affect the uncertainty of HN measurements at high elevated stations (> 1500 m a.s.l.). This is evident in the low correlations between HN and gauged precipitation at those weather stations.

Calculating the HNW strongly depends on the used snow density approximation. However, the transferability of snow density approximations gained at particular elevation zones in particular regions to different locations remains a challenge. This again influences the analysis of the CR_c from HN measurements.

To calculate more realistic CR_c values, upcoming work in the pluSnow project targets to improve fresh snow density parameterizations on a local scale using in-situ data of measured snow depth, snow water equivalent and precipitation in a high temporal resolution.

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