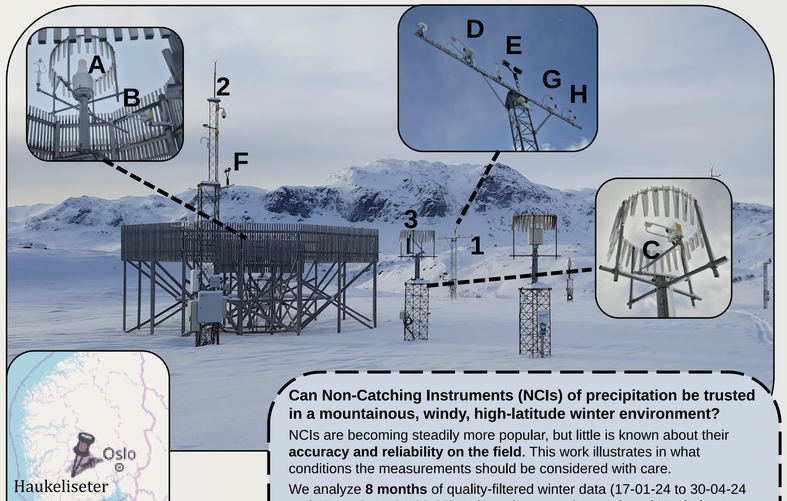
An evaluation of the uncertainty of precipitation measurements from optical sensors at a Norwegian mountainous site

Renaud Gaban[1,2], Mareile Wolff[1,2], Bikas Chandra Bhattarai[2]

[1]Department of Physics, Faculty of Science and Technology, Norwegian University of Life Sciences,

[2] Observation and Climate Department, Norwegian Meteorological Institute



Can Non-Catching Instruments (NCIs) of precipitation be trusted in a mountainous, windy, high-latitude winter environment?

NCIs are becoming steadily more popular, but little is known about their **accuracy and reliability on the field**. This work illustrates in what conditions the measurements should be considered with care.

We analyze **8 months** of quality-filtered winter data (17-01-24 to 30-04-24 and 15–11-24 to 31-03-25) at the unique weather station of **Haukeiseter, Norway**.We look at **7 instruments** measuring **Precipitation Occurrence** (PO), **Precipitation Rate** (PR) and **Precipitation Type** (PT) at 1-min resolution. Figure 1 shows the accumulation curves from both winters and how they diverge significantly.

Wind speed data is taken from a Gill WindObserver at 10m height and is classified as **low** (< 3m/s), **mid** (3 to 6m/s) or **high** (> 9m/s).

Agreements between categorical measurements are evaluated using the **Heidke Skill Score** (HSS) [2]; HSS = 1 (0) represents perfect (no) agreement.

- ✓ Haukeliseter weather station
- ✓ Norway, 59.8°N - 7.2°E
- ✓ 991m above sea-level
- ✓ Operated by MET Norway since 2012
- ✓ Former WMO-SPICE site [1]

	Instrument model	Platform (shield)	Code	Group Code
A	Geonor	0 (DFAR	*Geonor*	*Geonor*
B	Thies Clima LPM	0 (DFAR)	*Thies_DF*	*Thies*
C	Thies Clima LPM	3 (SA)	*Thies_SA*	*Thies*
D	Thies Clima LPM	1 (UN)	*Thies_UN*	*Thies*
E	OTT Parsivel²	1 (UN)	*Parsi_1*	*Parsivel*
F	OTT Parsivel²	2 (UN)	*Parsi_2*	*Parsivel*
G	Vaisala PWD12	1 (UN)	*PWD12*	*PWD*
H	Vaisala PWD22	1 (UN)	*PWD22*	*PWD*

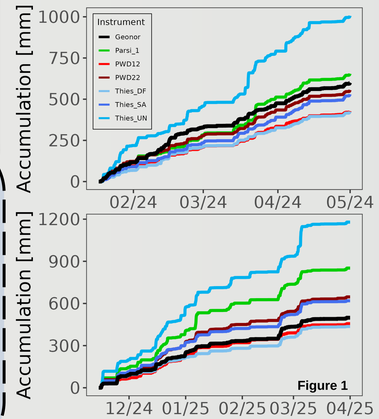


Figure 1

Precipitation Type (PT)

Figure 4: Instruments from the same group **agree** with each other **80-87%** of the time, more than with any other instrument.
The Best Guess is closer to Thies and PWD than to Parsivel.

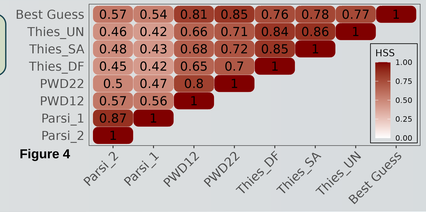


Figure 4

Methodology

- 1-min PT is **SOL** (snow, snow grains), **MIX** (rain&snow, ice pellets), **LIQ** (rain, drizzle), or **NO**
- 10-min aggregation from a majority principle (MP): NO if ≥ 9 1-min observations are NO ; SOL, MIX or LIQ if > 66% of the YES are SOL, MIX or LIQ; if no such majority, it is MIX.
- Group observation is the MP applied to individual observations among the group.
- **Best Guess** is the MP applied to the group observations

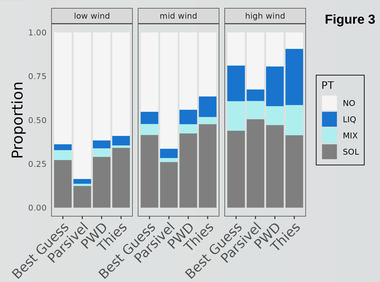


Figure 3

Figure 3: The distribution of PT is **correlated with the wind speed** in each group. This could be either a bias, or a climatological observation. Under high wind, Thies instruments might report too much LIQ, while Parsivel reports more SOL.

Case study (5 Feb 2025)

- 9-hours-long episode of intermittent precipitation observed on the field.
- PT reported every 10min.
- Very windy, T < 0°C.
- **Evidence of blowing snow in PWD and Thies.**
- HSS scores are very low (< 0.18) and **the Best Guess is not better against the reference.**

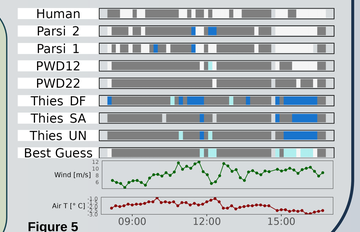


Figure 5

Precipitation Rate (PR)

10min / 1h	Parsi_1	PWD12	PWD22	Thies_DF	Thies_SA	Thies_UN
Corr	0.29 / 0.38	0.40 / 0.42	0.45 / 0.48	0.48 / 0.51	0.50 / 0.52	0.37 / 0.41
Bias (mm/h)	0.09 / 0.07	-0.05 / -0.05	0.02 / 0.01	-0.05 / -0.05	0.01 / 0.00	0.24 / 0.20
RMSE (mm/h)	1.39 / 0.95	0.73 / 0.58	0.74 / 0.59	0.67 / 0.53	0.74 / 0.59	1.70 / 1.34

Table 1

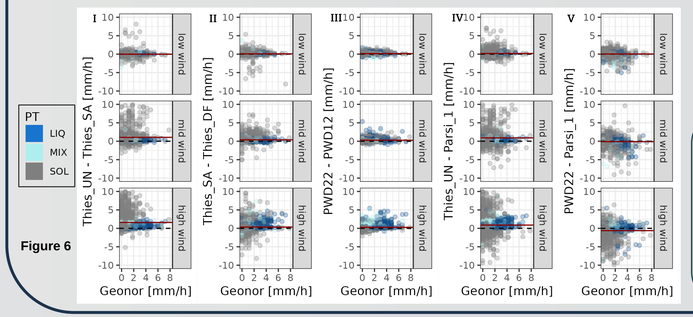


Figure 6

Methodology

- Geonor DFAR is an official reference for PR. [1]
- Figure 6 shows PR differences between selected pairs against the «real» magnitude taken fron Geonor PR, with mean bias in red.
- PT is taken from the Best Guess (cf. Section Precipitation Type).

Note! The method doesn't allow to compare PR estimations to the reference (figure 7). Another reference value would be required on the x-axis.

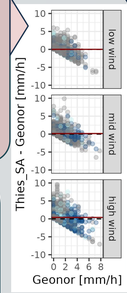


Figure 7

Key observations

- Shielded instruments are in closer agreement with Geonor (**Table 1**).
- All instruments **agree better at 1h resolution** than 10min (**Table 1**).
- **Low spread** and negligible bias (< 0.2mm/h) in **low wind** regime (**I** to **V**).
- The spread is larger in 3 cases : 1) Mid/high wind speed 2) SOL type 3) Low-intensity precipitation (according to the reference) (**I** to **V**).
- Shielding Thies instruments appears to reduce a positive bias (**I** & **II**).
- At **mid/high wind speeds**, unshielded **Thies > Parsivel > PWD in terms of PR estimations** (**IV** & **V**).

Precipitation Occurrence (PO)

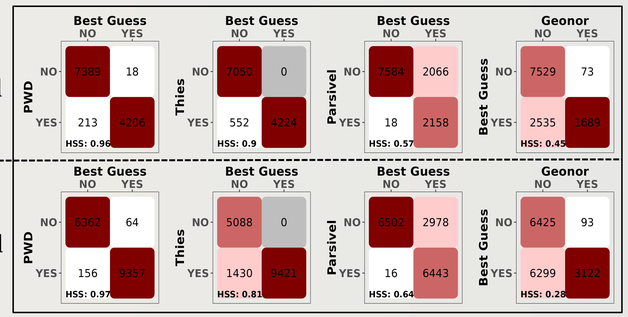


Figure 2

Methodology

- 1-min observation is **YES** or **NO.**
- 10-min aggregation is NO if ≥ 9 of the 1-min observations are NO.
- Group observation is YES only if >= 50% of the members say YES.
- **Best Guess** is YES only if >=50% of the groups say YES.

Key observations

- Low wind speed: Thies and PWD agree well, Parsivel reports significantly less.
- High wind speed: Thies reports much more than PWD.
- **The Best Guess reports more than Geonor at low wind, and even more with stronger wind.**

Conclusions

Precipitation measurements from NCIs on the field show **significant discrepancy**, amplifying **under strong wind conditions**. These instruments also **struggle** at reporting accurately **trace precipitation**, **and blowing snow** has been found to be **falsely reported** as precipitation.
Under mid/high wind conditions (> 3 m/s), **Geonor DFAR and the NCIs show very little agreement of PO**; the former suffers from undercatch, the latter are affected by blowing snow.
Treating Geonor DFAR as a reference for PR**, the RMSE of each NCI is of the order of 0.7-1.7 mm/h** and the **correlations are low**. However, Geonor DFAR is thought to underestimate low-intensity precipitation and to not perform well in windy conditions.
A new reference («Best Guess») for PT has been defined, but as it is not independent from the NCIs, it does not allow to derive scores in a meaningful way. Overall, instruments from different manufacturers show **meaningful agreement** (**40-70%** in terms of HSS) **of PT**, but their reliability can drop significantly under windy conditions and light precipitation.

References:
- Nitu, Rodica, et al. "WMO solid precipitation intercomparison experiment (SPICE)(2012-2015)." (2019).
- Pickering, B. S., et al. (2021). Evaluation of multiple precipitation sensor designs for precipitation rate and depth, drop size and velocity distribution, and precipitation type. Journal of Hydrometeorology, 22(3):703–720.

Contact: renaud.gaban@nmbu.no

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