COMPARISON OF THE PERFORMANCE OF PRECIPITATION GAUGES DURING SNOWFALL IN WINDY CONDITIONS

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ABSTRACT: One of the main factors contributing to the risk of natural snow avalanches is precipitation. Measuring precipitation is known to be challenging, especially during periods of strong winds which is commonly the case in weather leading to extensive avalanche cycles. The Icelandic Meteorological Office operates different types of precipitation gauges and conducted experiments, comparing their performance last winter (2023/2024). Results show striking differences in measurement between different types of precipitation gauges, where wind speed appears to be the most prominent impact factor.

KEYWORDS: precipitation gauges, weighing bucket gauge, precipitation measurement, solid precipitation.

1. INTRODUCTION

The Icelandic Meteorological Office is responsible for avalanche monitoring in Iceland. Forecasting avalanches is tricky and based on several different factors, one of the most important being precipitation data. Measuring precipitation is known to be challenging, especially during snowfall and strong winds which is typical weather leading to avalanche cycles in Iceland (Sigurðsson, F.H., 1990). Traditionally, precipitation gauges of *Geonor* type have been used for this purpose, but in recent years gauges of *Pluvio* type have been installed at many locations in the IMO's network.

Snow observers and avalanche forecasters have suspected that the *Pluvio* gauges do not measure the precipitation adequately compared with the *Geonor* gauges, especially during strong wind and snowfall.

Figure 1: The weather station with two weighing bucket gauges and precipitation sensor in *Flateyri, Iceland*.

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Therefore, test sites were set up with both types of instruments, and the output data compared.

2. RESEARCH SETUP

Several types of equipment and many sites are used to support the forecasting of avalanche and landslide hazard in Iceland. Most sites have in common, that they rely on a single precipitation gauge at the specific location, which reduces the possibility to verify their reliability and amount of underestimation and makes it hard to detect and quantify systematic weaknesses and errors.

2.1. Measuring sites

There are 37 designated weather stations in Iceland for monitoring avalanche and landslide hazard; most of them located in the Northwest, North and East part of the country. This paper is based on data from the following weather stations:

- *Flateyri* WIGOS 0-352-1-002631
- *Björg í Kinn* WIGOS 0-352-1-003585
- *Reykjavík* WIGOS 0-20000-0-004130

Due to the suspected unreliability of the precipitation measurements, *Flateyri* was equipped with a second precipitation gauge and a precipitation sensor to conduct comparative measurements (see Figure 1).

IMO's main weather station and test field in *Reykjavík*, was also used, due to the availability of reliable manual observation data (using a modified *Hellmann* rain gauge with Icelandic wind screen) as well as data from several precipitation gauges, including data from a heated *Lambrecht rain[e]* tipping bucket precipitation gauge.

2.2. Measuring equipment

Most of the 37 designated avalanche and landslide weather stations use a single weighing bucket precipitation gauge, of either *Geonor T-200B* or *OTT Pluvio² L* type. The precipitation gauges are set up with a single-row windshield from the manufacturer of the gauge, on a pedestal with the opening in 1,5 m height. Some *Pluvio* gauges are equipped with a heated rim, but none of the ones used in this paper. The setup of these stations generally complies with WMO guidelines, and the precipitation measurement setup recommendations for CLASS 1 (WMO, 2008). All buckets are partially filled with anti-freeze for melting snow and a thin layer of hydraulic fluid to prevent evaporation. Both *Geonor* and *Pluvio* claim a weighing accuracy corresponding to 0,1 mm of precipitation (OTT, 2024; Geonor, 2024). All Pluvio gauges have recently passed the accuracy test recommended by OTT and have the latest firmware v1.06 installed.

2.3. Data acquisition

Data is acquired using *Campbell Scientific* dataloggers.

Measurements from *Geonor* gauges are analog signals acquired at 1 s^{-1} (one measurement per second) and averaged over 10 min. The increase in bucket level is interpreted as precipitation.

Measurements from *Pluvio* gauges are digital measurements acquired via SDI-12 at 1 min^{-1}. The gauge's output includes the averaged and filtered accumulated precipitation and the bucket level in close-to real time (5 min delay).

2.4. Impact factors and deviation sources

Precipitation gauges typically have a circular opening of 200 cm^2 or 400 cm^2. For weighing bucket gauges under laboratory conditions, vertical precipitation enters the bucket through the circular opening and increases the weight of the bucket, which is detected and output as a corresponding precipitation in mm.

As soon as natural confounding factors are introduced, the local precipitation (the amount entering the bucket) might deviate from the actual precipitation, due to aerodynamic effects around the opening. Each type of equipment in a certain location might have it's special, often unpredictable characteristics. To reduce the impact of wind, the WMO and manufacturers recommend using natural or artificial windshields around precipitation gauges (WMO, 2008).

Another deviation source is the registration of precipitation. For the *Geonor* gauge with analog input, the signal might be influenced by signal noise and must be analyzed carefully.

Pluvio gauges output digital values, but the precipitation value has been processed by the internal software (including filtering) (OTT, 2024). Comparing the bucket level of the *Pluvio* (equivalent to raw weight data) with the precipitation values can give a good impression of possible deviation created by the software. Communications with *OTT* have revealed that different firmware versions for the *Pluvio* incorporate different "aggressive" filters for accumulated precipitation (Spiegel-Pinzer, 2024).

3. OBSERVATION

The winter season 2023–2024 was used to collect data to get some preliminary evidence whether and in what range the deviation between *Pluvio* and *Geonor* can be expected.

3.1. Comparing Pluvio raw and internally interpreted data

First it is of interest to analyze the relation between the detected bucket level and the reported precipitation measurement of the *Pluvio* precipitation gauge. In Figure 2 these two values are plotted as well as the wind speed in 10m height and ambient temperature for a period of one week at the weather station *Björg í Kinn, Iceland*. It can be seen, that increasing wind speed on the second day, combined with precipitation leads to a strong deviation between bucket level and accumulated precipitation output. The type of precipitation is not known, but can be assumed to be mostly rain and sleet and occasionally wet snowfall. On June 6th the internal underestimation ratio can be quantified as 50% of the bucket level increase and on June 9th as almost 60%.

In other words: More than half of the precipitation, that was collected and weighed by the bucket/load cell during this period, was filtered out by the internal software and disregarded.

3.2. Comparing different gauge types

One of the best sites to compare precipitation gauges is the main station of the IMO in Reykjavík. Each day at 9:00 and 18:00, a manual precipitation measurement is performed which can be used as benchmark for automatic precipitation gauges.

As the goal with this research was to investigate especially solid precipitation under windy conditions, and Reykjavík is not a station where one would expect the most snowfall or highest wind speeds. a second site with more than one precipitation gauge, at *Flateyri*, is also used for studying the behavior of *Pluvio* in comparison to *Geonor*.

We selected precipitation events with snowfall and windy conditions for both sites and show in Figure 3 a 24h period for *Flateyri*, to study the deviation development in higher resolution. There seems to be a cor-

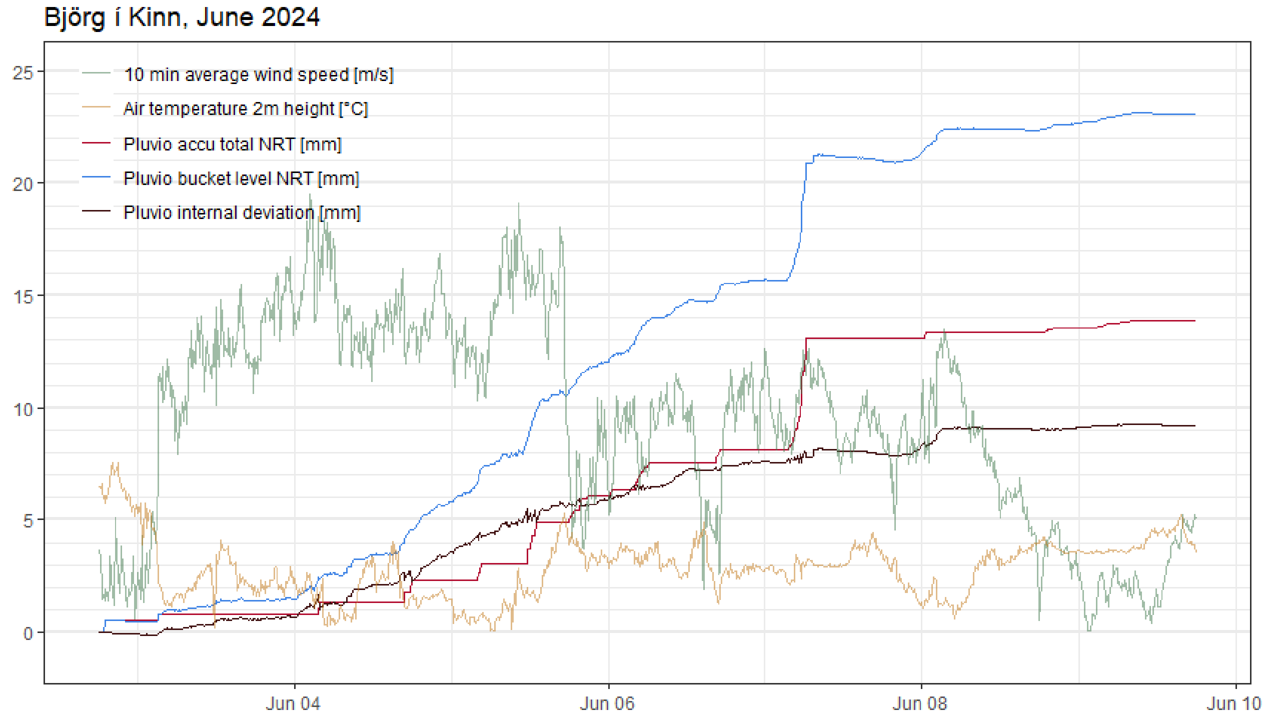

Figure 2: Measurements at *Björg í Kinn, Iceland*, with *Pluvio² L 400* precipitation gauge.

relation between stronger wind and an internal deviation of the accumulated precipitation from the bucket level in the Pluvio. This is the case in the evening of March 18th and early morning of March 19th. However, as the wind speed decreases at around 04:30 AM no further increase in the deviation is noticed. At least four periods can be observed, where the output (*accu total NRT*) is not increasing, despite the bucket level rising and the intensity being well above the threshold of 0,05mm/h (OTT, 2024). After this 24h period an internal deviation of 2mm or 25% has developed.

Another worrying aspect of these data is the obvious deviation between the *Geonor* and the *Pluvio*, when comparing the bucket level. The data show that neither temperature nor wind speed influence the difference between the two gauges. The difference increases steadily and equals to around 50% less bucket filling of the *Pluvio* compared to *Geonor*. It is hard to believe, that very similar shaped gauges and

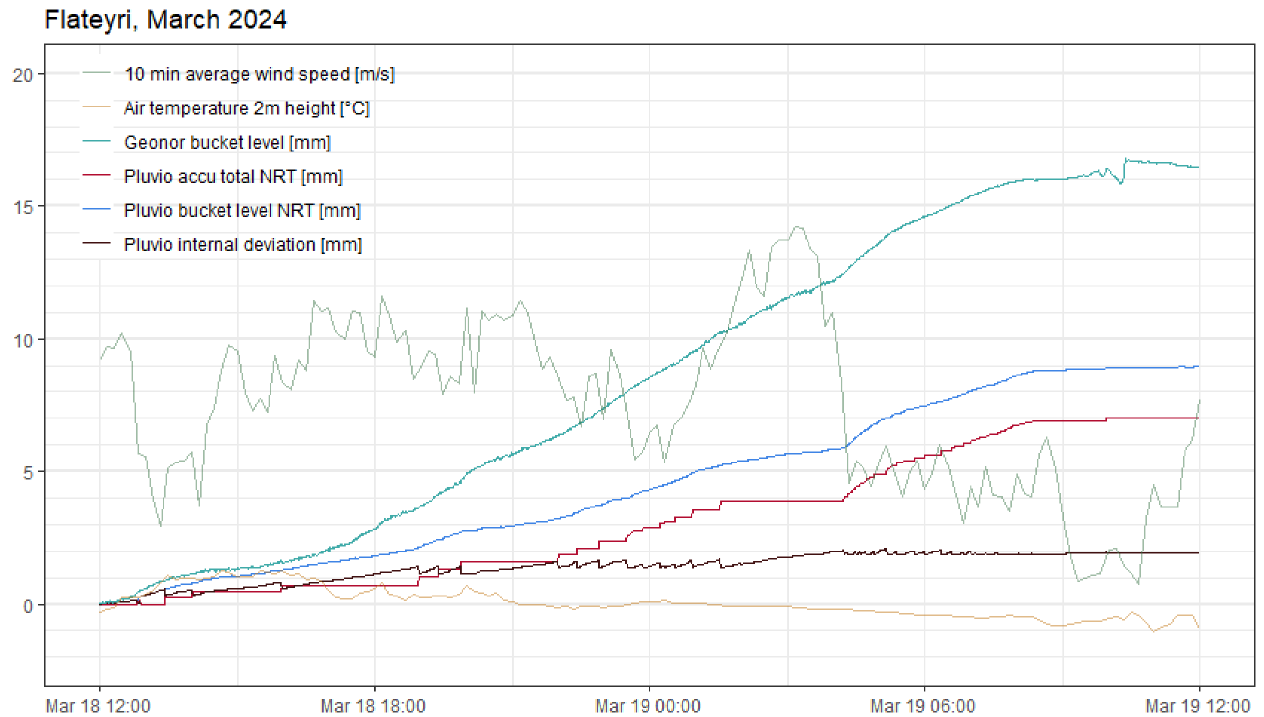

Figure 3: Measurements at *Flateyri, Iceland*, with *Pluvio² L 400* and *Geonor* precipitation gauges.

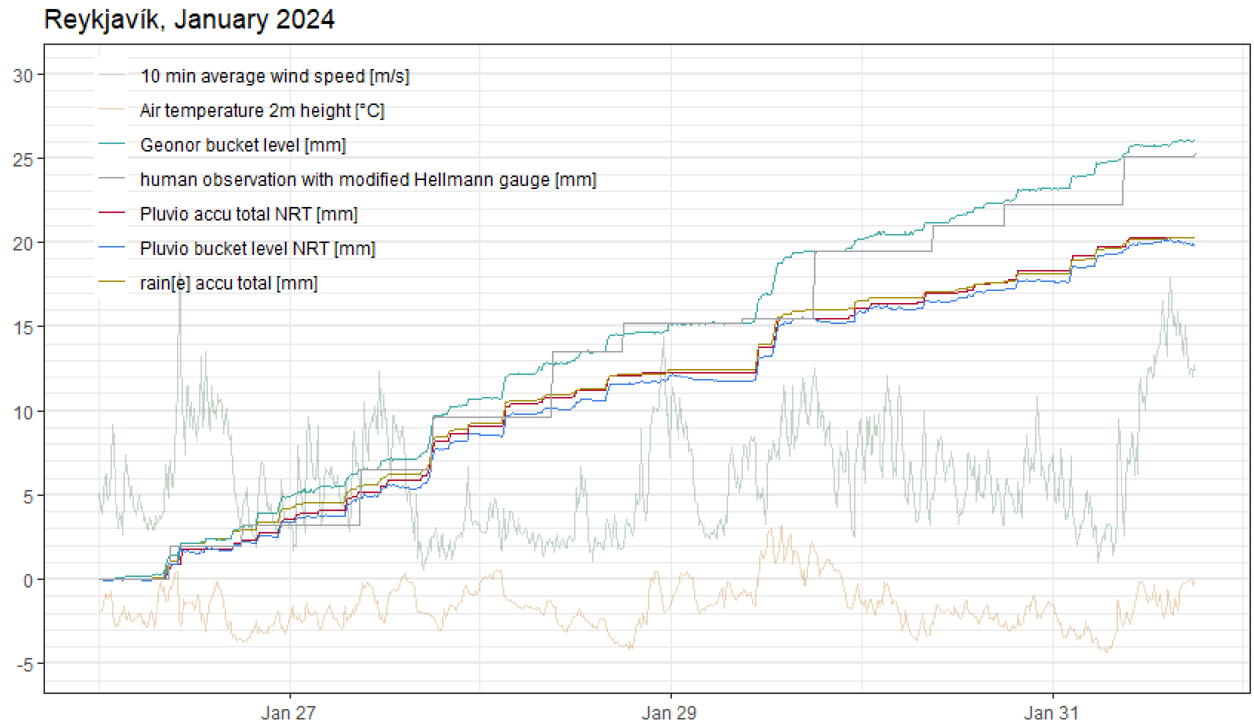

Figure 4: Measurements in *Reykjavík, Iceland*, with automatic and manual observation.

wind shields at the same location can result in such a striking difference in snow capturing capability.

When analyzing the data from IMO's main site in Reykjavík, it wasn't easy to find comparable weather conditions where all data were available. However, it can be seen in Figure 4 that a difference in snow capturing capability is also present there, but to a smaller extent – resulting in around 25% difference. The manual observations (with the modified *Hellmann* gauge) agree very well with the *Geonor* over the whole period. The *Pluvio 200* without rim heater compares on the other hand very well with the also present *Lambrecht rain[e]* heated tipping gauge, which is known to underestimate solid precipitation due to evaporation (Savina et al. 2012).

4. CONCLUSIONS AND LEARNINGS

The preliminary results from this investigation lead to several conclusions regarding possible issues with data filtering of digital weighing gauges, the differences of precipitation capturing capabilities of similar weighing gauges and the compatability with manual observations.

4.1. Performance of Pluvio gauges

With regard to the findings up to the current day, it can be concluded that the accumulated precipitation from the *Pluvio* gauge is not suitable for measuring precipitation (this applies to both liquid and solid form) during strong winds. The internal software seems to be responsible for disregarding increases in bucket weight leading to deviations of more than 50% in severe cases. It might be advantageous to use the raw bucket-level data as a better estimate of the precipitation with less underestimation and to accept the disadvantages of the raw bucket data regarding measurement accuracy.

In addition, the capability of capturing precipitation seems to be significantly higher for the *Geonor* gauge compared with the *Pluvio* in a similar setup with windscreens from the manufacturer.

4.2. Conclusions drawn by the IMO

Due to the importance of reliable precipitation measurements for avalanche monitoring the currently installed *Pluvio* gauges will be replaced with *Geonor* gauges, at least temporarily. The good agreement between the *Geonor* and *Hellmann* gauges further contributes to this decision. Studies of the reliability of precipitation measurements will be continued at the IMO. More evidence will be collected, and statistical analysis carried out to obtain better understanding of the underlying causes for errors in precipitation measurements and deviations between different types of precipitation gauges.

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