

Measurement of Precipitation at AWS in Canada: Configuration, Challenges and Alternative Approaches

Kai Wong, Alexandre Fischer, Rodica Nitu
Meteorological Service of Canada, 4905 Dufferin Street, Toronto, Ontario, Canada
Phone: (416) 739-4139, Fax: (416) 739-5721, kai.wong@ec.gc.ca

Abstract

The variability of climate and weather conditions in Canada and the vastness of its territory require special attention when configuring and maintaining its atmospheric monitoring networks. One of the challenges is to maintain the automatic stations in these networks to ensure that they are fully functional and that the data reported are accurate, and across such a vast country the cost of this effort is considerable. In a plan for modernizing the networks, it is proposed that weather (i.e., precipitation type) be included in the new configuration. In response, two present weather sensors (PWS) in the market are currently being assessed. Since in addition to precipitation types a PWS also reports precipitation amount and rate, it is suggested that if a PWS is used in the new configuration it could also possibly replace the precipitation gauge in some of the stations, providing that the precipitation measurement reported by the PWS is sufficiently accurate. This would simplify the configuration and thus reduce the maintenance burden. This study assesses performance of PWSs as precipitation gauges.

Introduction

Environment Canada (EC), with other agencies, operates about 900 weather observing stations across the country, the majority of which are automated. These stations serve different purposes such as weather forecast, aviation and climatology, and they can be broadly classified into two networks: Surface Weather Station (SWX) network and Reference Climate Station (RCS) network. The SWX stations are further classified into four categories, with the first category (SWX 1) consisting of stations that are critical for EC forecasts and warnings, and other categories consisting of stations that are jointly managed with other agencies such as NAV Canada. There are about 630 SWX stations, with about 230 of them as SWX 1 stations. The RCS stations are designed to provide long-term, high-quality observation for meeting the need of the climate science community. There are about 300 RCS stations across the country. The RCS and SWX 1 stations share the same configuration which consists of the following parameters: temperature, humidity, pressure, precipitation amount, rainfall rate, surface wind and snow on the ground, with solar radiation on some selected stations. These stations are inspected and maintained twice yearly to ensure that they are fully functional and that the data reported are accurate, in accordance with the RCS inspection and maintenance procedure [3]. The cost to maintain these networks across a vast country as Canada is considerable.

In a plan for upgrading the networks, it is proposed that weather (i.e., precipitation type) be included in the new configuration. In response to this, Test and Evaluation (T&E) in EC has been assessing some PWSs in the market. The PWSs that has been assessed so far are the OTT Parsivel and Vaisala PWD22. Since in addition to precipitation types these PWSs also report precipitation amount and rate, if a PWS is used in the new configuration, it is suggested that it can also possibly replace the precipitation gauge in some of the stations providing that the precipitation amount measured by the PWS is sufficiently accurate. If this approach proves feasible, it would simplify the configuration and thus would reduce the maintenance burden. Furthermore, in contrast with precipitation gauges a PWS generally has a higher sensitivity in the detection of precipitation, and thus has the potential of reporting precipitation rates over a shorter time intervals and is able to detect very light precipitation events which the traditional precipitation gauges might not detect ([1] and [6]).

In this poster, we present an initial assessment of the performance of the OTT Parsivel and Vaisala PWD22 as precipitation gauges. The amount from the PWSs accumulated over a day is compared to a reference daily amount computed from four collocated precipitation gauges.

This study is the first step in our effort to quantify the performance of the OTT Parsivel and Vaisala PWD22 PWSs as precipitation gauges in field conditions.

Present Weather Sensors as Precipitation Gauges

There are two previous studies ([1] and [6]) on the use of present weather sensors as precipitation gauges. In [1] the ability of the Laser Precipitation Monitor (LPM) in measuring rainfall amount and intensity is assessed. The LPM is a present weather sensor based on an optical laser disdrometer, which measures the size and vertical velocity of the hydrometers falling through a 1 mm thick laser light sheet. The size of the measurement area is approximately 46 cm². The daily rainfall amount measured by the LPM is compared with that of a pit gauge. All three LPMs in the test measure significantly higher rainfall amount than the pit gauge, with mean deviation ranging from + 5.3% to +20.2%. The rain intensity from the LPMs is compared to the rate calculated from the raw measurement of an OTT Pluvio precipitation gauge, using an algorithm developed by the authors. The intensity measured by the LPMs ranges from +19.2% to +37.2% higher than that of the reference. The LPM has a tendency to overshoot at the intensity peak.

In [6] the Precipitation Occurrence Sensor System (POSS) is evaluated as a gauge for measuring rain and snow amounts. POSS is a bistatic, continuous wave, X-band radar. The rate is integrated over a period of 6 hours or more, and the accumulated amount is then compared to a reference amount. The pit gauge or type B rain gauge is used as a reference for liquid and the Double Fence Intercomparison Reference (DFIR) or Nipher snow gauge is used as a reference for snow. For liquid precipitation the median of the catch ratio distribution is 82% and the interquartile range (IQR) is -12% to +19% about the median when the pit gauge is used as the reference. For solid precipitation the median

of the catch ratio distribution is 90% and the IQR is -17% to +24% about the median when DFIR is used as the reference.

OTT Parsivel

OTT Parsivel is a laser-based optical disdrometer for simultaneously measuring the size and velocity of all types of hydrometeors during precipitation ([4] and [2]). The transmitter generates a 1 mm thick, horizontal light sheet of 30 mm wide and 180 mm long, resulting in a measurement area of 45 cm². The sensor determines the size and velocity of a hydrometeor by measuring the light extinction caused by the hydrometeor falling through the light sheet. The amount of this reduction in light is used to estimate the size of the particle, and the fall velocity of the particle is derived from the duration of the reduction. The hydrometeor is then classified into 32 classes of sizes and velocity. From the size and velocity distribution information over the measurement period, the rain rate is calculated, with an accuracy of +/- 5%.

Vaisala PWD22

Vaisala Present Weather Detector PWD22 is an optical sensor that measures visibility, precipitation intensity, and precipitation type [7]. The visibility is measured by measuring the forward optical scattering by the particles in the measurement volume which is about 100 cm³. The sensor calculates the precipitation intensity by analyzing the rapid signal changes caused by the precipitation droplets. This intensity estimate is proportional to the volume of the precipitation droplets. For precipitation type identification, PWD22 also estimates the water content of the precipitation using a rain sensor. The intensity obtained from the optical measurement and the intensity from the rain sensor measurement together with an air temperature measurement allow for the identification of precipitation types. The precipitation intensity reported by the sensor is calculated from both optical and rain sensor intensity estimates.

Reference Precipitation Gauges

There are four precipitation gauges, two Vaisala VRG 101 gauges and two OTT Pluvio gauges, collocated with the PWSs. The reference is computed from these four gauges if the majority of them agree with each other. That is, if the pair-wise differences between the daily accumulations from the four, or any three, gauges are all less than 0.4 mm, then a reference daily amount is calculated as the average of the daily amounts from the gauges which are within 0.4 mm of each other.

Test Site

All the measurements used for this assessment were taken from the T&E test site at the Centre for Atmospheric Research Experiments (CARE) at Egbert, Ontario, Canada. Two Parsivel PWSs, and one PWD22 PWS, were installed in the Egbert test site in late 2006 and in middle of 2007, respectively. These PWSs are arranged in a line running east-west. The distance between the two Parsivel PWSs is 10 m, and the distance between the

PWD22 PWS and the nearest Parsivel PWS is 5 m. Two OTT Pluvio gauges and two Vaisala VRG gauges are about 25 m to the west the PWSs. The Pluvios and VRGs are installed in a line running north-south. The VRGs are shielded with a double Alter shield, and the Pluvios are in a Tretyakov type shield. The VRG and Pluvio gauges are heated. The relative locations of the PWSs and precipitation gauges are shown in Figure 1. Data from the T&E sensors is logged minutely. There is an RCS station about 75 m to the west of the PWSs, with a Geonor precipitation gauge in an Alter shield for measuring precipitation amount, which is reported daily.

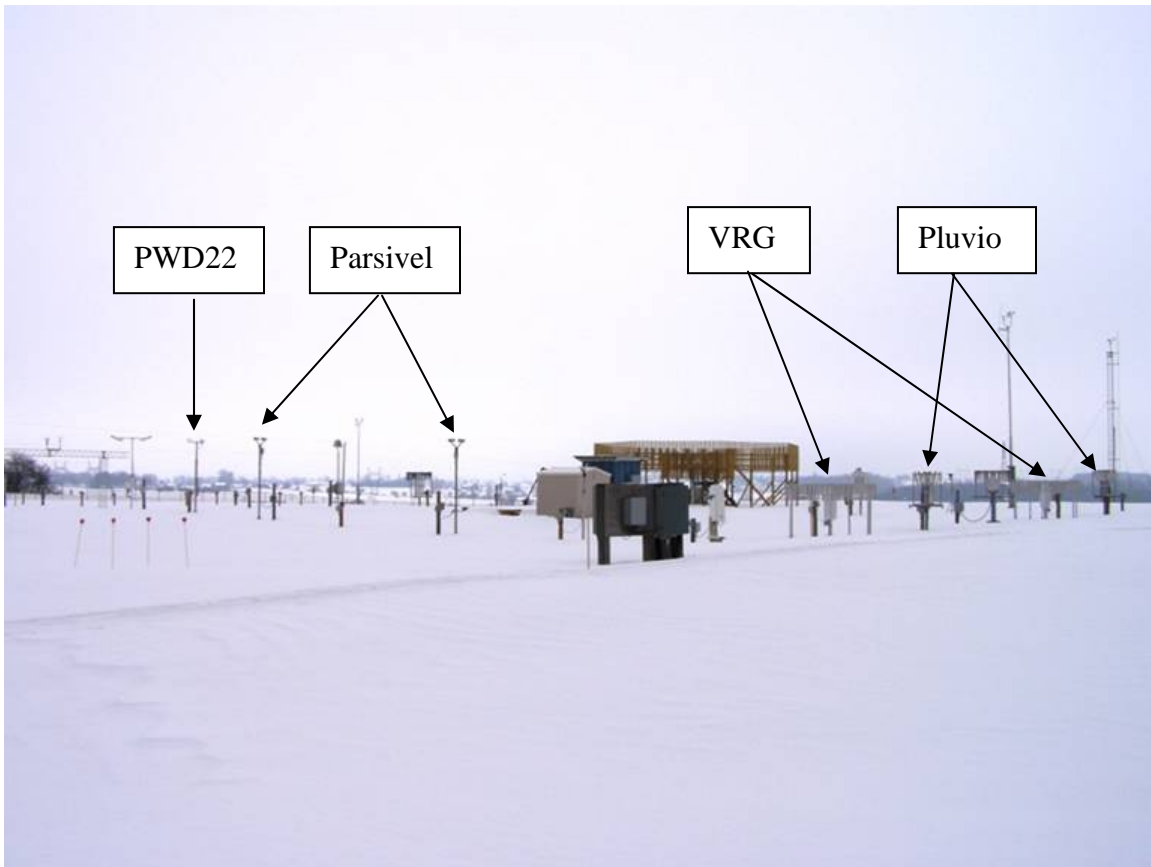


Figure 1 - Parsivel and PWD22 PWSs, and VRG and Pluvio gauges in Egbert test site, looking towards South-East.

Data Analysis

The performance of the precipitation amount measurement by the PWSs is described as the “catch ratio” of the sensor estimate to the reference amount. The quartile statistics are used describe the distribution of these catch ratios ([6]). The median catch ratio (Q2 or 50th percentile) is an indicator of the bias. The interquartile range (IQR) is the difference of the third (Q3 or 75th percentile) and the first (Q1 or 25th percentile) quartile, and is a measure of the dispersion of the distribution. Quartile statistics are less influenced by outliers than statistics such as mean and standard deviation [8]. A box plot is used to display the comparison, in which the lower and upper edges of the box located at Q1 and Q3, respectively, and the bar through the box at Q2. The vertical lines are drawn from the

box to the most extreme point within 1.5 interquartile ranges. That is, the end of the lower line is at the minimum value that is greater than $(Q1 - 1.5 IQR)$, and the end of the upper line is at the maximum value that is less than $(Q3 + 1.5 IQR)$. Any data points outside this range are considered outliers and marked with crosses. The distribution is said to be positively skewed if $(Q3 - Q2) > (Q2 - Q1)$, and is negatively skewed if $(Q2 - Q1) > (Q3 - Q2)$.

Results

The following results are based on the data from August 13, 2007 to March 30, 2008. The daily accumulations from the Parsivel and PWD22 PWSs are compared to the reference daily amount when the reference is greater than 1 mm. The result quartile statistics and outliers are presented in Figure 2 and in Table 1. Figure 3 is a zoom-in version of Figure 2, displaying the main catch ratio distributions. The RCS station is also included for comparison.

Egbert 2007 Aug 13 to 2008 Mar 31: Box Plots of Catch Ratio Distributions

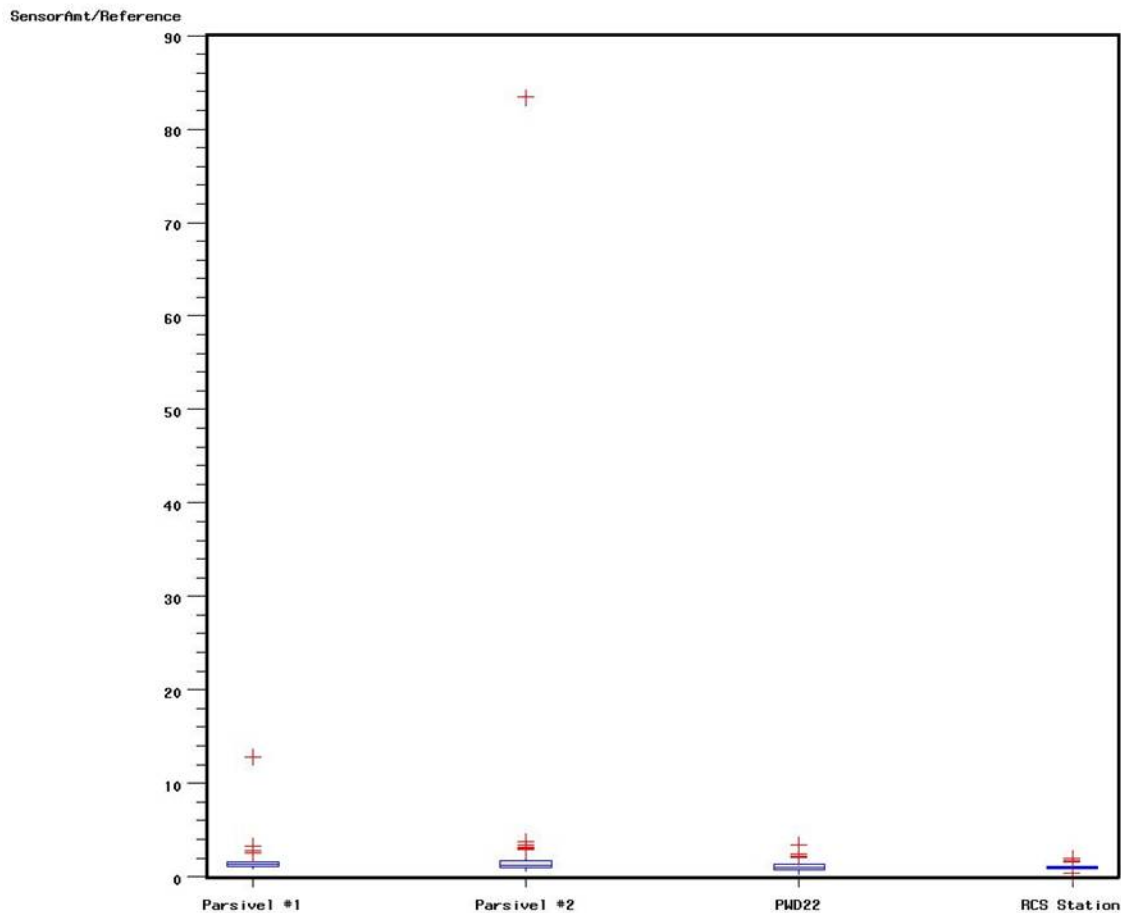


Figure 2 - Box plot comparing the quartile statistics of the distribution of catch ratios.

Quartile Statistics of the Catch Ratio Distributions For Parsivel and PWD22 PWSs At Egbert From August 13, 2007 to March 31, 2008					
	No. of Obs.	Q1	Q2	Q3	IQR
Parsivel #1	55	1.12	1.29	1.59	0.47
Parsivel #2	55	1.04	1.24	1.71	0.67
PWD22	55	0.79	0.98	1.29	0.5
RCS Station	47	0.81	0.98	1.06	0.25

Table 1 - The quartile statistics of the catch ratio distributions.

Egbert 2007 Aug 13 to 2008 Mar 31: Box Plots of Catch Ratio Distributions

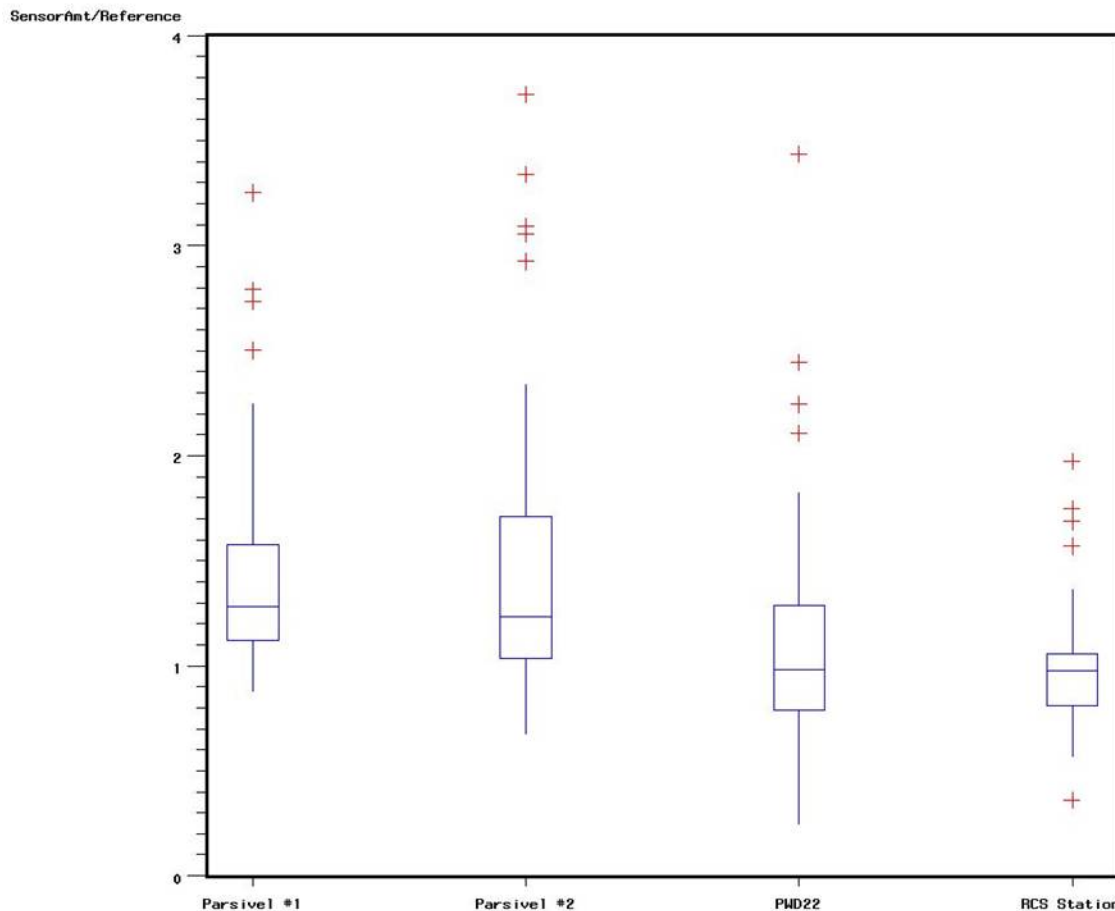


Figure 3 – Box plot comparing the quartile statistics of the distribution of catch ratios, not displaying the two large outliers.

We note the two large outliers for Parsivel #1 and Parsivel #2. These come from the 4th of December 2007, on which both Parsivel PWSs reported significantly higher daily amount than that of the other devices. Over the day Parsivel #1 and #2 reported 80.08

mm and 521.78 mm respectively, while PWD 22 reported 14.05 mm accumulation, the RCS station 5 mm, the two VRG gauges 6.27 mm and 6.46 mm, and the two Pluvio gauges 6.2 mm and 6.1 mm. The precipitation over the day is snow. Upon a closer examination of the Parsivel messages, we found that, when the precipitation accumulation of the Parsivel PWSs increases significantly above that of the others, a signal in the Parsivel output message called “signal amplitude of the laser strip” drops well below 5000, as seen in Figure 4. This “signal amplitude” indicates the received energy of the laser, and ranges from 0 to 15000 (K. Nemeth of OTT, personal communication). The meaning of the values of this signal is as follows. From 0 to 5000, the sensor is non-operating; from 5000 to 7500, immediate maintenance or cleaning is required; from 7500 to 10000, maintenance should be in the next 3 months; and from 10000 to 15000, the sensor is operating normally.

One speculation of the cause of this significant overestimation and its apparent connection to signal amplitude is that snow accumulates on the window of the receiver and/or transmitter, thus affecting the strength of laser. The axis of the transmitter and receiver is oriented to be perpendicular to the prevailing wind which is westerly, as recommended by the operation manual [5], with the receiver facing north. The wind over the day is from north to north-west, with an average of 4.5 m/s over the day. It seems possible that snow was blown on to the window of the receiver. Even though there is heating, if there is sufficient snow, there might still be some snow, water or a mixture of both left on the window. As the snow lessened, the snow or water on the window gradually evaporated and the signal amplitude recovered back to the normal region.

Another day on which the signal amplitudes of both Parsivel drop below 5000 is the 9th of January 2008. The precipitation accumulations and signal amplitudes for this day are shown in Figure 5. The precipitation type over the day is rain. We see that the signal amplitude of Parsivel #1 dropped below 7500 when the precipitation started and returned to the normal region at the end of the precipitation, whereas the signal amplitude of Parsivel #2 hovered above 8000 throughout the precipitation period. Around 11:00 both signal amplitude dropped sharply to well below 5000, then recovered to the normal region few hours later. The average wind direction for the day is 118° (almost south-east), and at about 8:00 the wind speed picked up from about 5 m/s to about 10 m/s, and remained at the higher speed for the rest of the day. The temperature was above 8°C before 11:00, and it dropped quickly to around 3°C within an hour. This sudden drop in temperature seems to correspond with the sudden drop in signal amplitude. What causes the drop in the signal amplitudes of both Parsivel PWSs requires further investigation. In this case the drop in signal amplitude does not seem to affect the precipitation estimation.

The medians of the catch ratio distributions for the Parsivel #1 and #2 are 129% and 124%, respectively. The IQR for Parsivel #1 is from -17% to +30% about the median, and the IQR for Parsivel #2 is from -20% to +47% about the median. The median of the PWD22 catch ratio distribution is at 98%, thus there is essentially no bias in the PWD22 estimate. The interquartile range is between -19% to +31% about the median. The Parsivel and PWD22 PWSs are positively skewed. The dispersion of Parsivel #2 is larger than that of the other PWSs. The RCS station is also included for comparison, and it has

the smallest dispersion and is negatively skewed. Of these 55 days, 18 of them have precipitation type as rain, 19 as mixed, and 18 as snow. The precipitation type is determined based on the weather typing reports of the PWSs.

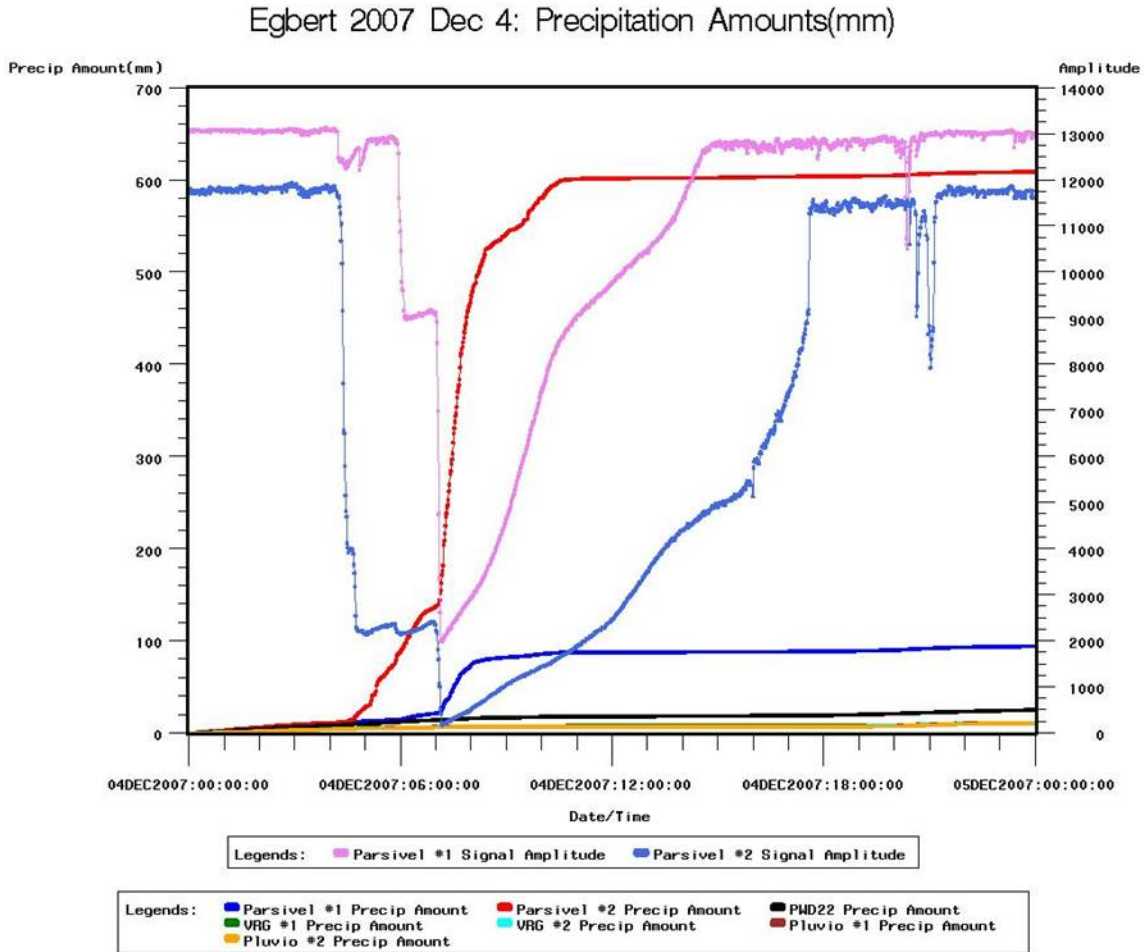


Figure 4 – Precipitation accumulations and Parsivel signal amplitudes for December 5, 2007.

To see if there is any possible connection between the signal amplitude and the performance of the Parsivel PWS in measuring precipitation amounts. We compute the quartile statistics for the catch ratio distributions for the days on which both Parsivel PWSs have signal amplitudes below 7500 (i.e., immediate cleaning of the window is required.), and they are given in Table 2.

The median of catch ratio distribution for Parsivel #1 is 133%, and for Parsivel #2 is 134%. The IQR for Parsivel #1 is from -7% to +27% about the median, and for Parsivel #2 is from -14% to 17% about the median. The medians of the catch ratio distributions for PWD22 and the RCS station remain more or less the same as that of Table 1. This seems to suggest that the signal amplitude dropping below 7500 could lead to a greater overestimation on the precipitation amount. We note that the sample size of the current study is relative small. More data is needed before any firm conclusion can be drawn.

Egbert 2008 Jan 9: Precipitation Amounts(mm)

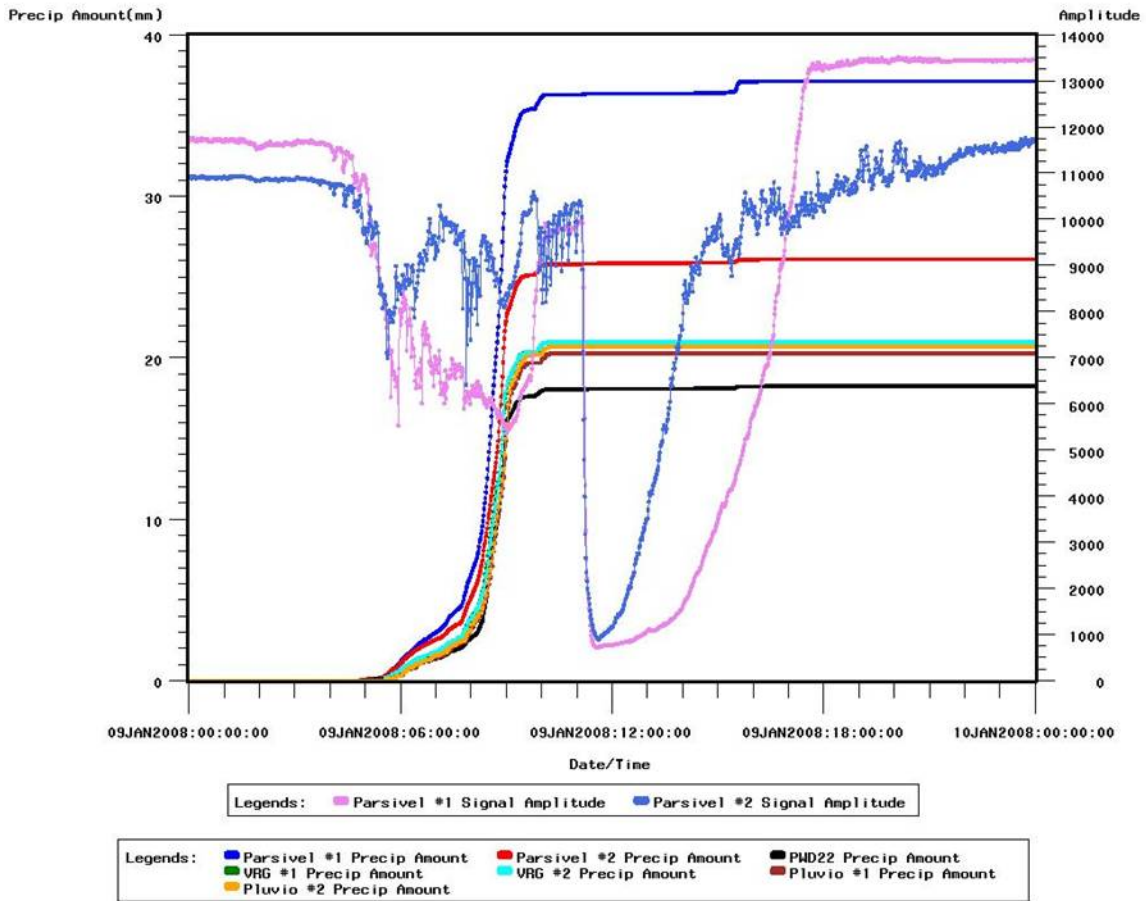


Figure 5 - Precipitation accumulations and Parsivel signal amplitudes for January 10, 2008.

Quartile Statistics of the Catch Ratio Distributions For Parsivel and PWD22 PWSs At Egbert From August 13, 2007 to March 31, 2008 For Data in which both Parsivel PWSs have signal amplitude below 7500 (i.e., immediate cleaning is required.)					
	No. of Obs.	Q1	Q2	Q3	IQR
Parsivel #1	12	1.26	1.33	1.60	0.34
Parsivel #2	12	1.20	1.34	1.51	0.31
PWD22	12	0.66	0.99	1.11	0.45
RCS Station	12	0.83	0.97	1.00	0.17

Table 2 - The quartile statistics of the catch ratio distributions for days on which both Parsivel PWS have signal amplitude below 7500.

Conclusions

In this poster, we present some initial results of assessing the performance of two present weather sensors, the OTT Parsivel and the Vaisala PWD22, as precipitation gauges.

Using a reference computed from four collocated precipitation gauges, the medians of the catch ratio distributions for Parsivel #1 and #2 are 129% and 124%, respectively. The IQR for Parsivel #1 is from -17% to +30% about the median, and the IQR for Parsivel #2 is from -20% to +47% about the median. The median of the PWD22 catch ratio distribution is at 98%, and the interquartile range is between -19% to +31% about the median. Thus relative to our reference Parsivel #1 and #2 overestimate by 29% and 24% respectively, while PWD22 is essentially unbiased. We note that the results have to be viewed in the light that the reference used is not an international standard, and that the sample size is relatively small.

It seems that the Parsivel PWS performance can be, sometimes quite strongly, affected by some degradation of the laser strength, due possibly to precipitation on the transmitter and/or receiver windows.

Acknowledgments

Sorin Pinzariu and Jule Michard of T&E have provided expert engineering and software support in the installation and operation of the PWSs, precipitation gauges and data logger in the Egbert test site. We are also indebted to Debra Allsopp of EC for providing valuable information on the RCS and SWX networks.

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