A TEST OF THE PRECIPITATION AMOUNT AND INTENSITY MEASUREMENTS WITH THE OTT PLUVIO

Wiel M.F. Wauben,

Instrumental Department, Royal Netherlands Meteorological Institute (KNMI)

P.O. Box 201, 3730 AE De Bilt, The Netherlands

Tel. +31-30-2206-482, Fax +31-30-2210 407, e-mail: Wiel.Wauben@knmi.nl

ABSTRACT

The Pluvio precipitation sensor of Ott has been tested at KNMI in order to find out whether it is a suitable candidate for replacing the current operational KNMI precipitation gauge. Tests performed at the calibration facilities of KNMI showed that the accuracy of the Pluvio is within the WMO requirements and proved stable after the field tests. The 1-year field test in De Bilt showed good agreement between the KNMI precipitation gauge in a pit and the Pluvio placed on the measurement field within a windscreen. The differences between Pluvio and KNMI gauge showed no evidence of a wind effect, but a dependency on precipitation intensity, ambient temperature, and the temperature gradient has been observed. A Vaisala FD12P present weather sensor showed generally the same behaviour for the differences as the Pluvio. The Pluvio did hardly report any faulty precipitation events that were not detected by the KNMI gauge or the FD12P. The Pluvio results obtained during a 1-year field test at the coastal station of De Kooy are not fully satisfactory. The observed differences for the Pluvio are generally not corroborated by the FD12P. Furthermore, the Pluvio reported isolated precipitation events that were not confirmed by the KNMI gauge or the FD12P. These faulty precipitation reports show a dependency on wind speed. It is unclear why these faulty reports were not observed at De Bilt in the same the wind speed range. The Pluvio is not suitable for operational use at KNMI due to the faulty precipitation reports observed in De Kooy although their effect on total amounts is small. Ott has currently an updated version of the Pluvio that should overcome the faulty reports. KNMI now considers an upgrade of the KNMI gauge in combination with the usage of a precipitation detector.

1. INTRODUCTION

The Royal Netherlands Meteorological Institute (KNMI) measures precipitation amount with an electronic precipitation gauge that has been developed indoors. The design of this sensor originates from 1991 and since then it has undergone no significant changes. The sensor is of the so-called float type and determines the precipitation intensity by the change of the water level in a reservoir as measured by a potentiometer every 12 seconds. A more detailed description of the KNMI precipitation gauge is given in Wauben (2004). The KNMI gauge has some shortcomings namely: (i) isolated faulty precipitation events up to about 3μm=0.018mm/h sometimes occur during sunny days and are reported because the users require a high sensitivity since the sensor is also used for precipitation detection; (ii) a relatively high level of maintenance is required as a result of the sensitivity to contamination and the potentiometer is susceptible to failures: (iii) the large delay both at onset and cessation of solid precipitation that can occur since solid precipitation falling into the funnel has to be melted before the gauge can register it. The Pluvio precipitation sensor from Ott Hydrometrie is of the weighing type and hence will be less susceptible to contamination and will detect solid precipitation directly. Furthermore, tests with the Pluvio performed in other countries looked promising suggesting that the sensor could be a good alternative for the KNMI precipitation gauge. Therefore KNMI decided to test the new Pluvio precipitation sensor and to compare the results with that of the KNMI precipitation gauge. The tests are performed in the laboratory as well as during 1-year field trails performed at the KNMI test site in De Bilt and the coastal station at De Kooy. The aim of the tests was to investigate how the precipitation amount and intensity measurements of the Pluvio and the KNMI precipitation gauge compare in order to determine whether the Pluvio is suitable for being considered for operational use by KNMI.

Details of this study are reported in a KNMI technical report (Wauben 2005).

2. OVERVIEW OF THE PRECIPITATION SENSORS

An overview of the main sensor characteristics of both precipitation sensors is given in Table 1. The reported specifications for both sensors meet the criteria of WMO. Comparison of the main characteristics of the Pluvio precipitation sensor (Ott Hydrometrie, 2000 and 2002) and the KNMI precipitation gauge already point out some interesting differences. The Pluvio precipitation sensor will measure solid precipitation without delay since the precipitation that has passed the orifice will directly fall into the collector bucket and will be measured. This could overcome the delays and possible evaporation losses the KNMI gauge might experience during solid precipitation. However, the filtering algorithm of the Pluvio can give a delay up to maximally 90 seconds. A further advantage of the Pluvio precipitation sensor is that the sensor is less sensitive to contamination. In case any contamination by insects, leaves, dust, bird excrements, etc. falls in the collector, it could result in a faulty precipitation event -although the sensor filters out the very low (less than 0.03mm in 20minutes) and very high (more than 50mm per minute) contributions- but it will not lead to sensor failures. Another advantage of the Pluvio is that it can easily be calibrated by using a set of reference weights whereas the KNMI precipitation gauge of the float type involves the use off fixed (weighed) amounts of water. Drawbacks of the Pluvio sensor are the lesser sensitivity compared to the KNMI precipitation gauge and the additional maintenance required for emptying the bucket and the required application of a saline solution to the collector at the start of the winter season in order to prevent deformation or damage of the collector. The reduced sensitivity of the Pluvio makes the sensor less suitable for precipitation detection and the determination of precipitation duration.

Table 1: An overview of the general characteristics of the Pluvio precipitation sensor and the KNMI precipitation gauge.

Parameter	***Pluvio***	***KNMI gauge***
Range	0 … 10mm/min	0 …10mm
Accuracy	±0.04mm@10mm	±2% full scale
Reproducibility	±0.04mm@10mm	within ±1% full scale
Long-term stability (1yr)	±0.06mm@10mm	within ±2% full scale
Resolution	0.01mm/h	0.006mm/h
Sensitivity	0.03mm/20min	0.001mm/10min
Maximum intensity	600mm/h	300mm/h
Averaging time	30-90sec[1]	12sec
Collector content	0-200mm	1-11mm
Temperature range	–30 … +45°C	–25 … +40°C
MTBF	3500h	26500h
Calibration interval	+1year	36months
Maintenance	1 p.a. antifreeze 2-3 p.a. emptying	Covering of orifice during mowing
Collector area	$200cm^2$±0.5%	$400cm^2$±0.5%
Diameter sensor	210mm	226-284mm
Height sensor	570mm	610mm
Weight	6kg	19kg
Voltage sensor	12VDC	24VAC
Power usage sensor	<1.8W	3.6W
Voltage heater	24VAC	24VAC
Power usage heater	70W	115W
Communication interface	RS232/RS485	Frequency output

3. INDOOR TESTS

The Pluvio precipitation sensor was first subjected to some indoor tests. The Pluvio sensor that was considered at that time did not include the data logger but used a pulse output. Furthermore the sensor was equipped with the automatic emptying mechanism. Tests were performed with an adjustable pump and a balance so that the amount of water pumped into the collector of the Pluvio could be regulated and determined. The results of these tests will not be discussed here because since then changes were made to the sensor/software that resolved the problems or overcame them, whereas other findings could be explained in terms of the processing performed by the sensor. The results described in this paper are based on the Pluvio precipitation sensor without the automatic emptying mechanism, since tests showed that the emptying occurred only when the collector was almost full. Furthermore, a sensor equipped with a serial interface and a data logger was considered. A software upgrade (release 2.13) was performed in end of January 2001, after preliminary field test results indicated faulty precipitation events caused by wind effects. During the software upgrade the 2 sensors tested at KNMI were calibrated. Checks of the calibration were performed again in October 2003 after the field tests were completed. These tests showed that the addition of 1 and 2.5mm at five levels of the collector contents is accurate within ±0.01mm, i.e. the resolution of the Pluvio. The contents measurements of 0, 50, 100, 150 and 150mm give differences of about 0.00, +0.03,

[1] Depending on the variability of the raw weight measurements the averaging time can be as high as 400sec.

0.00, –0.05 and –0.08mm, respectively. All these differences are within the stated long-term accuracy of ±0.06mm when adding 10mm, and the accuracy required by WMO (1996), i.e. ±0.1mm for precipitation sums less than 5mm and ±2% for larger amounts.

4. FIELD TEST DE BILT

The field tests with the Pluvio precipitation sensor have been performed between February 1, 2001 and May 16, 2002 in De Bilt and between May 25, 2002 and August 11, 2003 in De Kooy. At both locations the Pluvio was placed on the measurement field in a windscreen, whereas the KNMI precipitation gauge was installed in the so-called English set-up. The data used in this study is the 10-minute averaged precipitation intensity of the KNMI gauge, the precipitation duration, and some additional parameters like the 10meter wind speed and direction, ambient temperature and humidity. Furthermore, precipitation intensity data from a Vaisala FD12P present weather sensor is used. The validated hourly KLIM data of the climatological department was used as a reference. Monthly sums of the precipitation amounts obtained by all 3 sensors are given in Table 2 and compared to the hourly KLIM data. Here, only those hours are considered where all 10-minute intervals of all 3 sensors have valid readings. The monthly results show that the sums for KNMI gauge and the KLIM data are quite close, i.e. within ±1mm or in the range –1 to 2%, as could be expected, since the KLIM data are mainly based on the sensor reading from the KNMI gauge. The large differences between the KNMI gauge and KLIM for June and July 2001 could both be ascribed to faulty sensor readings on a particular day that lasted several hours and returned to normal without any intervention. More suspicious events can be found in the raw sensor data by scanning the daily plot. The differences between Pluvio and KLIM are generally larger than those for the KNMI gauge, and range between –3 and 2mm or –4 and 3%. This could be expected when comparing the results for 2 different types of precipitation sensors during a field test. The monthly precipitation amounts for the present weather sensor show larger differences. However, KNMI does not use the PWS for the determination of precipitation amounts, but only for precipitation detection, and for the determination of precipitation type and visibility.

Table 2: Monthly sums and differences between the precipitation amounts reported by the Vaisala PWS, the KNMI gauge, the Ott Pluvio, and the validated climatological sum for the field test in De Bilt. All hours are considered where valid precipitation data of all three sensors is available.

Month	***Sum (mm)***				***# valid hours***	***Difference (mm)***		***Difference (%)***	
	PWS	***Gauge***	***Pluvio***	***Klim***		***Ga–Kl***	***Pl–Kl***	***Ga–Kl***	***Pl–Kl***
0201	89.4	87.7	84.8	88.1	592	–0.41	–3.35	–0.47	–3.80
0301	84.0	74.0	72.4	74.2	735	–0.22	–1.81	–0.29	–2.44
0401	97.2	83.7	82.3	84.3	675	–0.55	–2.05	–0.66	–2.43
0501	33.2	29.2	29.6	29.1	739	0.14	0.49	0.49	1.68
0601	53.4	61.7	56.5	52.8	705	8.87	3.66	16.80	6.93
0701	76.3	74.3	85.0	86.6	737	–12.34	–1.63	–14.25	–1.88
0801	105.6	99.0	99.8	99.2	723	–0.20	0.61	–0.20	0.61
0901	188.9	190.3	187.4	190.3	704	–0.04	–2.90	–0.02	–1.52
1001	36.5	34.8	35.3	34.3	704	0.54	0.98	1.58	2.86
1101	68.3	60.7	61.0	59.7	655	0.99	1.29	1.66	2.16
1201	109.5	93.0	95.9	93.9	743	–0.95	1.96	–1.01	2.09
0102	61.1	57.6	58.3	57.8	719	–0.15	0.53	–0.26	0.92
0202	131.8	136.8	135.7	137.2	663	–0.40	–1.46	–0.29	–1.06
0302	34.7	29.7	28.1	29.3	718	0.38	–1.18	1.29	–4.03
0402	46.6	39.8	39.0	39.5	700	0.34	–0.55	0.85	–1.39
0502	24.7	21.2	21.4	21.4	360	–0.21	0.02	–0.98	0.09
Total	**1241.0**	**1173.5**	**1172.3**	**1177.7**	**10872**	**–4.22**	**–5.38**	**–0.36**	**–0.46**

The differences are studied in more detail by comparing of the 10-minute precipitation data of the 3 sensors directly. A histogram of the differences between the 10-minute intensity measurements of any 2 precipitation sensors is presented in Figure 1 using a bin size of 0.03mm/h. The histogram is plotted using a logarithmic scale. The histogram roughly resembles a Gaussian distribution. Both histograms peak at a difference of 0.00mm/h, where the bin for Pluvio–Gauge contains 41% of the cases and PWS-Gauge 33%. The number of cases within ±0.1mm/h is 66% for Pluvio-Gauge and 68% for PWS-Gauge. The number of cases in the bins for larger differences decreases exponentially. The histogram for PWS-Gauge shows more cases with positive than negative differences leading to the larger monthly sums for PWS compared to the

KNMI gauge. The histogram for Pluvio-Gauge shows almost a constant value for differences between +0.03 and +0.18mm/h. This feature can probably be explained in terms of the reporting threshold of 0.03mm of the Pluvio. The cases with precipitation amounts of less than 0.03mm in 10 minutes, i.e. a 10-minute averaged intensity of less than 0.18mm/h, will be reported by the KNMI gauge, but not by the Pluvio. Such events add cases to the slightly negative bins of the histogram, as do faulty KNMI gauge readings. However, there are no or in any case less corresponding events adding cases to the slightly positive bins. As a result the number of cases with positive differences Pluvio-Gauge less than 0.18mm/h is reduced.

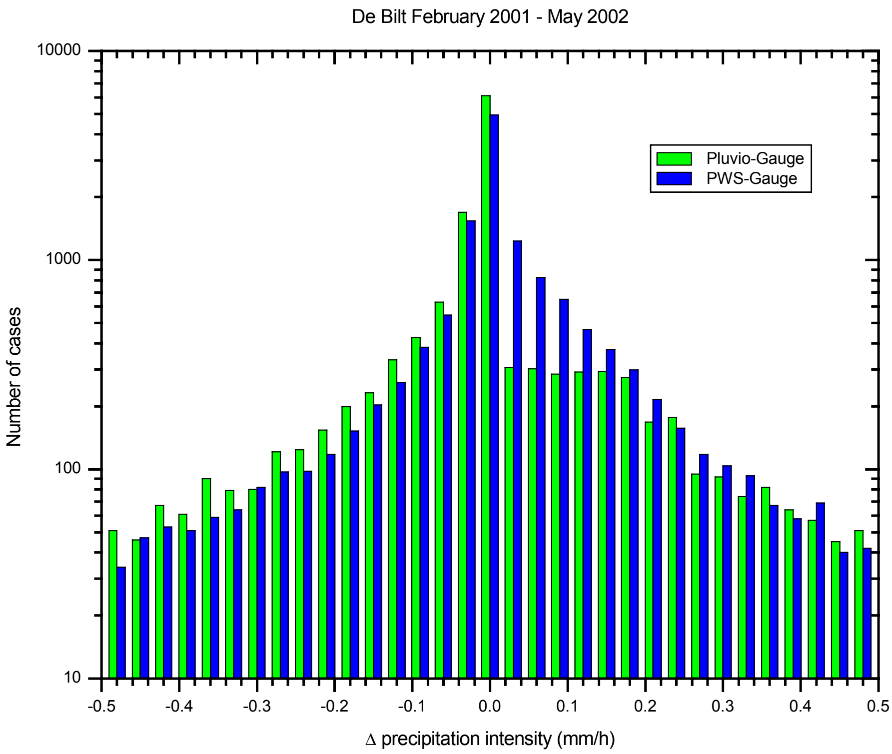

Figure 1: Histogram of the differences between the raw 10-minute averaged precipitation intensity measurements for any combination of 2 precipitation sensors during the field test in De Bilt. The bin size is 0.03 mm/h. All cases are included where at least one of the sensors reports precipitation.

Next the differences between the measured 10-minute precipitation intensities are studied as a function of wind speed in bins of 1m/s. The differences are calculated for different wind speed bins in order to determine any wind speed effect. The averaged differences between the 10-minute precipitation intensities for 2 precipitation sensors per wind speed interval are given in Figure 2. The results are given as the percentage of the total precipitation amount per wind speed bin as measured by the KNMI gauge. The precipitation amount measured by the KNMI gauge and the total number of cases involved is also shown per wind speed bin. In addition, the number of so-called ‘faulty’ sensor only cases, i.e. the cases where one precipitation sensor reports precipitation but the other 2 sensors do not report precipitation nor in the previous and in the next 10-minute interval if available, are given as the sensor only cases in Figure 2. First of all note that the behaviour of the curves for Pluvio-Gauge and PWS-Gauge are generally the same. Between 1 and 8m/s the differences Pluvio-Gauge show no wind speed effect. The results above 8m/s are not shown because statistics is poor in that region. Below 1m/s the differences Pluvio-Gauge increase up to about 12%. A similar increase can be observed for PWS-Gauge. At low wind speeds the KNMI precipitation gauge reports less precipitation compared to the Pluvio and PWS. It is unlikely that this behaviour is related to a wind effect, but it is partly the results of the relatively large number of faulty Gauge only events at low wind speeds. Any wind speed effect also depends on the type of precipitation such as solid or liquid precipitation and the droplet size since small/light particles have a smaller fall velocity, and hence are more sensitive to the wind. The under catch due to the wind effect will be larger for snow compared to rain, but it will also be larger for smaller particles. The influence of droplet size will be investigated by analysing the results as a function of the precipitation intensity, although this is not a real measure of the droplet size.

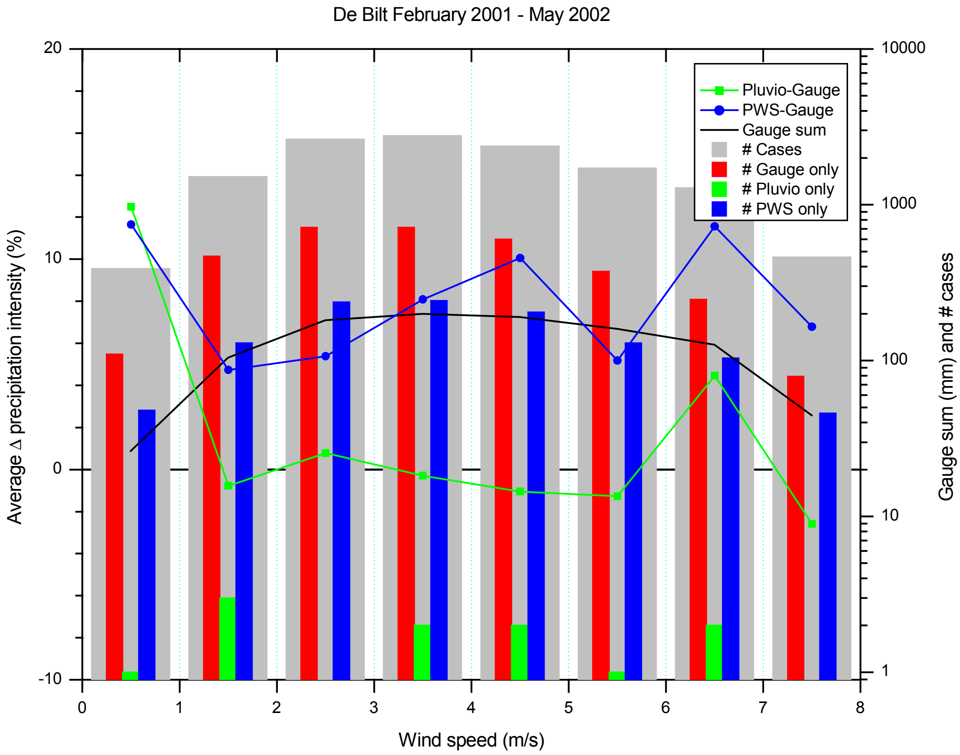

Figure 2: Averaged relative differences between the 10-minute precipitation intensities measured by 2 precipitation sensors as a function of the wind speed in bins of 1m/s for the field test in De Bilt. The results are presented as the percentage of the total precipitation amount per wind speed bin as measured by the KNMI gauge, which is indicated by the black line. The total number of cases involved is indicated by the histogram, as is the number of 'faulty' sensor only events.

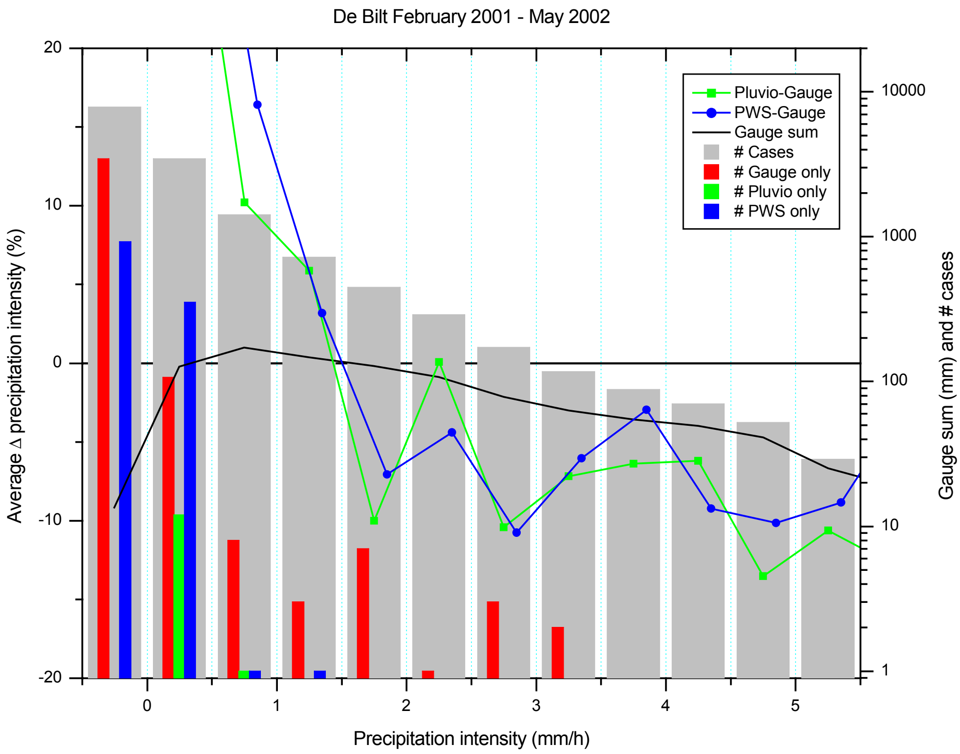

Figure 3: As Figure 2, but now the relative differences are given as a function of the precipitation intensity. The binning in steps of 0.5mm/h is performed on the intensity measured by the KNMI gauge. The first bin contains the cases with intensity less than 0.05mm/h. The number of 'faulty' sensor only events is reported in the intensity bin derived from their own reported precipitation intensity.

Figure 3 shows the relative difference between the precipitation intensity measured by 2 precipitation sensors as a function of the precipitation intensity. Again, the curves for Pluvio-Gauge and PWS-Gauge show generally the same behaviour. The first bin at zero contains the cases where the KNMI gauge reported traces of precipitation with intensities less than 0.05mm/h. This mainly consists of the 'faulty' cases when the KNMI gauge only reports traces of precipitation. Since the other 2 precipitation sensors report generally a higher intensity, if any, and the faulty cases of these 2 sensors are also added to this bin when calculating the relative differences, the relative difference at the first bin is large and positive. Note that Pluvio and PWS report faulty cases when the intensity of the sensor is below 1 and 1.5mm/h, respectively, whereas the KNMI gauge reports faulty cases up to 3.5mm/h. The differences Pluvio-Gauge and PWS-Gauge decrease with intensity between 0 and about 2mm/h. Above 2mm/h, the differences between Pluvio-Gauge and PWS-Gauge are generally about –5% to –10%, respectively. The behaviour of the curves resembles the curves given by Nešpor and Sevruk (1999) obtained by numerical simulations. However, the curves are such that the measurements of the KNMI gauge in the so-called English set-up seem to be affected by the wind effect. This is contrary to the results obtained by Wauben (2004) when comparing the measurements for 2 KNMI gauges, one placed in the English set-up and the other on the measurement field surrounded by a windscreen. The above results seem to indicate that the Pluvio installed on the measurement field in a windscreen is not affected by the wind effect. If such an effect does exist, it must be masked by other error sources that occur when comparing different types of precipitation gauges (cf. WMO, 1994). Since both the Pluvio and the PWS show the same general behaviour, it could be concluded that the KNMI gauge seems in general to underestimate precipitation intensities below 1.5 mm/h and to overestimate intensities above 1.5mm/h. This could be caused by wetting and evaporation losses in the collector of the KNMI precipitation gauge. These losses are relatively largest at small precipitation intensities. The Pluvio and PWS measure precipitation more directly and it is therefore expected that these instruments will be less affected by wetting and evaporation losses.

5. FIELD TEST DE KOOY

The results of the field test at the coastal station in De Kooy show much larger differences, although the same Pluvio sensor was used. The differences in monthly precipitation sums between Pluvio and KLIM range between –1 and 8mm. Generally the Pluvio gives higher precipitation amounts. Overall the differences between Pluvio and KLIM in De Kooy are 34mm or 4.5% compared to –5mm or –0.5% for De Bilt. In order to find the reason for these differences the 10-minute data are analysed in more detail. The averaged differences between the 10-minute precipitation intensities for 2 precipitation sensors per wind speed interval are given in Figure 4. In contrast to the corresponding results for De Bilt (cf. Figure 2) the differences Pluvio-Gauge show a wind speed effect between 1 and 8 m/s. A linear fit to the data gives a slope of about 2.5%/ms^{-1}. The results above 8m/s are not considered because statistics is poor in that region, but in that region the differences Pluvio-Gauge decrease again. Figure 4 also shows that the number of faulty Pluvio cases increases between 3 and 8 m/s. The sign of the slope suggests that the KNMI gauge in the English set-up reports less precipitation under high wind speed conditions compared to the Pluvio on the measurement field in a screen. Again this effect is opposite to the results obtained by comparing 2 KNMI precipitation gauges in a similar set-up (Wauben 2004), where the gauge on the measurement field and within a windscreen reported less precipitation with increasing wind speed. The differences PWS-Gauge show a different behaviour as a function of wind speed in the region 4 to 7 m/s. This is in contrast to the results for De Bilt, where Pluvio-Gauge and PWS-Gauge showed generally the same behaviour as a function of wind speed. The faulty Pluvio readings are a probably reason for the observed differences at De Kooy. A major difference between the faulty Pluvio readings for De Bilt and De Kooy is that the number of faulty cases is much higher for De Kooy (776 out of a total of 4226 precipitation reports) than for De Bilt (13 out of 6117). Most faulty Pluvio cases occur in the 0.05 to 0.5mm/h intensity bin. The results of the KNMI gauge also shows differences between De Kooy and De Bilt. The faulty cases for the KNMI gauge at De Kooy occur mainly for traces (1893 out of a total of 7042 precipitation reports), but some faulty cases (63) occur at the next intensity bin at 0.5mm/h, whereas for De Bilt the faulty cases occur up to 3.5mm/h. The faulty readings for the PWS (812 out of a total of 5341 precipitation reports) occur mainly in the lowest precipitation intensity bins. The total amounts of precipitation included in the faulty cases at De Kooy are 5, 34 and 6mm for KNMI gauge, Pluvio and PWS, respectively, whereas for De Bilt the corresponding values are 16, 1 and 9mm. Since the Pluvio overestimates the total precipitation amount at De Kooy as measured by the KNMI gauge by about 38mm, the exclusion of the above mentioned “faulty” cases will reduced the overall difference by 29mm.

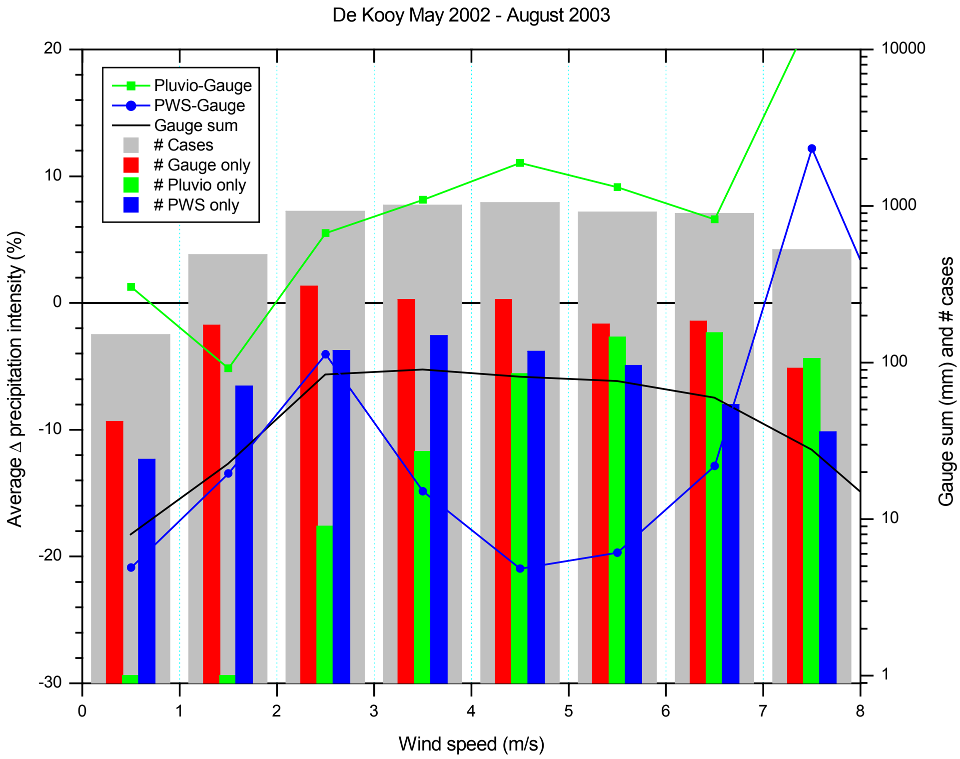

Figure 4: Averaged relative differences between the 10-minute precipitation intensities measured by 2 precipitation sensors as a function of the wind speed in bins of 1m/s for the field test in De Kooy. The results are presented as the percentage of the total precipitation amount per wind speed bin as measured by the KNMI gauge, which is indicated by the black line. The total number of cases involved is indicated by the histogram, as is the number of 'faulty' sensor only events.

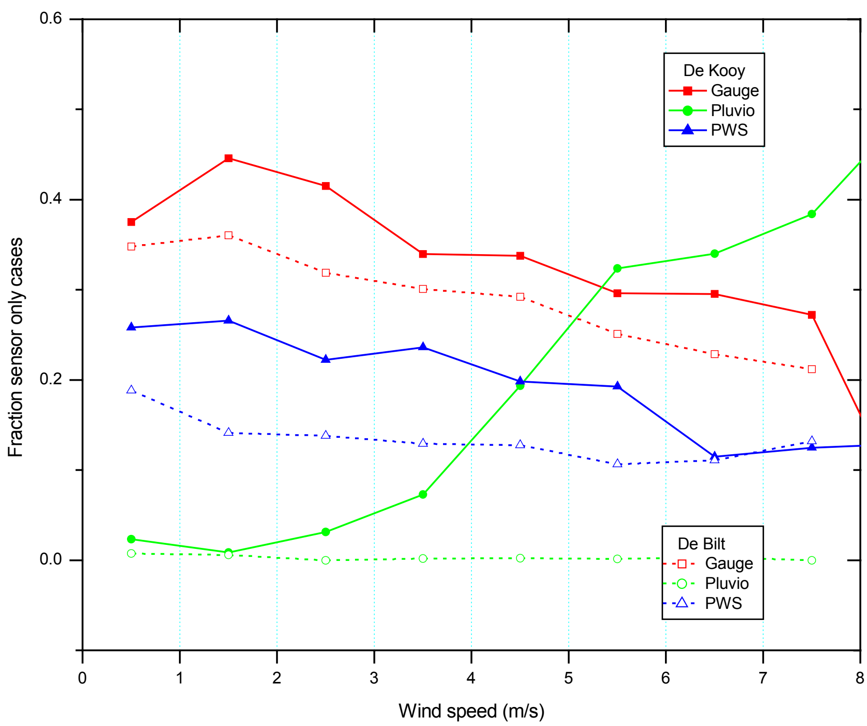

Figure 5: The ratio of the number of 'faulty' sensor only readings and the total number of sensor readings with precipitation as a function of the observed wind speed in bins of 1m/s. The ratios are given for the 3 precipitation sensors involved and for the field test in De Bilt and in De Kooy.

The reason for the faulty cases is studied next. Figure 5 shows details of the ratio of the number of faulty sensor readings and the total number of sensor readings with precipitation as a function of the observed wind speed. The ratios are given for each precipitation sensors and for the field tests in De Bilt and in De Kooy. In general, the faulty readings for the field test in De Bilt show no clear dependence on wind speed for all three sensors. The KNMI gauge and PWS also show no wind speed dependency at De Kooy, but the number of faulty cases is in general about 5% higher at De Kooy. The faulty Pluvio readings for De Kooy, however, show a clear dependency with wind speed, although the wind speeds considered are the same as for De Bilt. The faulty Pluvio cases in De Kooy occur mainly when the collector is nearly empty and hence more sensitive to wind induced vibrations, and are probably as a result thereof also related to the ambient temperature, relative humidity and global radiation. There is a slight dependency of the number of faulty Pluvio cases on wind direction, but this is not correlated to the gustiness of the wind. Therefore it is still unclear why the faulty Pluvio cases that occurred at De Kooy have not been observed at De Bilt. Note, however, that the wind mast in De Kooy is located at about 500m from the measurement field where the KNMI gauge and Pluvio are situated. Faulty Pluvio precipitation reports could also be observed when the sensor was placed in a climate chamber and the temperature gradient changed more than 0.5°C/min. However, during the field test in De Kooy the faulty cases occurred also at lower gradient.

6. CONCLUSIONS

The results obtained with the Pluvio precipitation sensor during the field test in De Bilt showed that the Pluvio agrees within WMO requirements with the current operational KNMI gauge and in case of differences the Pluvio generally shows the same behaviour as the results obtained with a present weather sensor. Based on the De Bilt results the Pluvio seemed to be a good alternative for the KNMI gauge. However, the results obtained during the field test in De Kooy showed many cases with faulty precipitation reports by the Pluvio and the observed differences between Pluvio and KNMI gauge are not corroborated by the PWS. The faulty Pluvio events are most probably induced by wind effects, although it is still unclear why these faulty reports were not observed at De Bilt in the same the wind speed conditions. The field test furthermore showed that the Pluvio is not suitable for precipitation detection. For that purpose the usage of a precipitation detector will be considered by KNMI. The use of separate sensors for the determination of precipitation amount and precipitation detection not only overcomes the compromises one has to make in the design when making an instrument for 2 different purposes including accurate overall sums and a high sensitivity, but furthermore the usage of 2 separate sensor makes it possible to perform online quality checks which is particularly useful for a meteorological parameter that shows large spatial differences.

The tested Pluvio is not suitable for operational use at KNMI due to the faulty precipitation reports observed in De Kooy although their effect on total amounts is small. Ott has currently an updated version of the Pluvio that should overcome the faulty reports. KNMI now considers usage of a precipitation sensor in combination with a precipitation detector and considers an upgrade of the current KNMI precipitation gauge.

7. REFERENCES

Nešpor, V. and Sevruk, B.: Estimation of Wind-Induced Error of Rainfall Gauge Measurements Using a Numerical Simulation, *J. Atmos. Oceanic Tech*., Vol. **16**, 450, 1999.

Ott Hydrometrie: Pluvio Precipitation Sensor DWD-Version (in German), User Manual, Ott Hydrometrie, 2000.

Ott Hydrometrie: Pluvio, Brochure, Ott Hydrometrie, 2002.

Wauben, W.M.F.: Precipitation Amount and Intensity Measurements using a Windscreen, Technical Report **TR 2004-262**, KNMI, De Bilt, 2004.

Wauben, W.M.F.: Precipitation Amount and Intensity Measurements with the Ott Pluvio, Technical Report **TR 2005-270**, KNMI, De Bilt, 2005.

WMO: Guide to Hydrological Practices, Fifth Edition, WMO-No. **168**, WMO, Geneva, 1994.

WMO: Guide to Meteorological Instruments and Methods of Observation, Sixth edition, WMO-No. **8**, WMO, Geneva, 1996.