A FIELD STUDY TO CHARACTERISE THE MEASUREMENT OF PRECIPITATION USING DIFFERENT TYPES OF SENSOR

Judith Agnew[1] and Mike Brettle[2]

[1]STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, Oxfordshire, OX11 0QX, UK.
Tel.: +44 1235 445774, E-mail: judith.agnew@stfc.ac.uk
[2]Campbell Scientific Ltd, Campbell Park, 80 Hathern Road, Shepshed, Loughborough, Leicestershire, LE12 9GX, UK.

ABSTRACT

Precipitation can be identified and measured by a variety of techniques. Care is needed in the use of these techniques as anomalies can easily be introduced, particularly due to differences arising from the type of detection process and the effect of wind speed and direction on the sensor. Errors can also occur in the identification of frozen precipitation types. Since December 2011 a trial has been carried out at the Chilbolton Facility for Atmospheric and Radio Research (CFARR) in the southern UK. A wide range of precipitation detectors, including raingauges, acoustic and conventional disdrometers and optical scattering detectors, has been operated at this facility for many years. Some measure only accumulated rainfall; others also measure parameters such as particle size distribution and type. Since the start of the trial a new optical present weather sensor, the PWS100, developed by Campbell Scientific, has been evaluated. This measures accumulation, particle size distribution and particle type by measuring the forward scattering of four sheets of laser light in horizontal and vertical planes as individual particles of precipitation fall through. A wide range of other meteorological observing systems including wind sensors, radars, lidars and microwave radiometers are also in continuous operation at the site and can be used to provide further information about meteorological conditions when necessary. The results of a series of cases studies made during different types and intensities of precipitation are reported. The different types of sensor show mainly good agreement in measuring precipitation accumulation and drop size distribution during rainfall, but reduced agreement during snow. Differences in the drop size distribution during rain are more pronounced at small drop sizes. Probable causes of the instrument performance differences are discussed.

INTRODUCTION

Chilbolton Observatory is a rural field site of the Science and Technology Facilities Council (STFC) located in a rural, predominantly arable farming area in the southern UK at 51.1°N, 1.4°W. It is home to the Chilbolton Facility for Atmospheric and Radio Research (CFARR). A wide range of atmospheric remote-sensing instruments including radars, lidars, microwave radiometers and ground-based meteorological sensors are operated as part of CFARR, the majority of them continuously. A wide range of instruments for measuring precipitation is available, including tipping-bucket raingauges, RAL drop-counting raingauges [1], acoustic disdrometers [2, 3] and a meteorological particle sensor (MPS) [4]. The last two of these measure droplet or particle size and so are useful in providing drop size spectra to compare with the PWS100.

On 12th December 2011 a Campbell Scientific PWS100 present weather sensor [5] was installed at Chilbolton Observatory. It is planned to operate the instrument there continuously for a period of approximately 1 year, allowing a detailed intercomparison with existing CFARR instruments. Case studies have been selected to compare measurements of accumulated precipitation and drop size distribution under different precipitation conditions, including frozen precipitation.

TRIAL SITE AND INSTRUMENT DETAILS

The CFARR raingauges are located in a grassy area well away from buildings and other tall features. Figure 1a shows the location of the instruments. It is taken from the north end of the field site, looking approximately south. The drop-counting raingauge and acoustic disdrometer are located in the pit in the foreground of the image. The pit is approximately 3 m in diameter and 1 m deep and is designed to reduce turbulence in the vicinity of the gauges. The tipping bucket gauge is located on the next gravelled area behind the pit, at a distance of approximately 8.5 m. The MPS and the PWS100 are located on the roof of the meteorological cabin. They are at a height of approximately 9 m above ground on a roof with a height of approximately 7m. Their location is shown in more detail in figure 1b. The cabin is approximately 50 m from the raingauge site.

Figure 1a: Location of raingauges and meteorological instrument cabin.

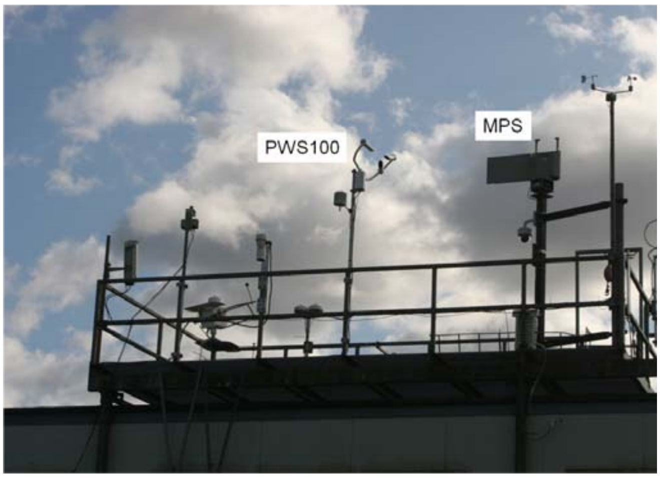

Figure 1b: The MPS and PWS100 on the meteorological instrument cabin roof.

Figure 1: Location of intercomparison instruments

The PWS100 was placed adjacent to the existing MPS on the cabin roof to allow a reliable particle size comparison between them. The height of the sensors above the roof should ensure that they can be directly compared and are free of any effects of turbulence or flow distortion. The 50 m separation between the raingauge and disdrometer site and the optical sensors is potentially more of a problem. However the optical sensors are measuring in free air and the raingauges follow good practice to avoid wind effects on measurement, minimising the effect of the distance between them.

The 25 m radar dish at CFARR is to the south-east of the raingauge site at an approximate distance of 90 m. This can be expected to cause some turbulence across the site, but it is reasonably distant from the intercomparison instruments and not in the direction of the prevailing wind. None of the case studies discussed occurred with wind blowing from the radar.

Details of the instruments included in the intercomparison are given in table 1.

Detector type	**Measurement principle**	**Drop sizes measured, number of bins**	**Comments**
Drop counting rain gauge	Rain collected in funnel, counted in droplets with 0.004 mm or 0.0018 mm resolution	None	System developed by STFC to achieve better rain rate resolution than tipping bucket gauge. Frost heater to protect mechanism but collector itself is not heated.
Tipping bucket rain gauge	Rain collected in funnel, counted in tips of bucket with 0.2 mm resolution	None	Industry standard for measuring rainfall. Frost heater to protect mechanism but collector itself is not heated.
Distromet RD-80 impact disdrometer	Drops hitting Styrofoam cone detected using electro-mechanical detector	0.3 – 5.0 mm in 127 bins	Signal magnitude in detector is related to drop size.

Detector type	Measurement principle	Drop sizes measured, number of bins	Comments
DMT meteorological particle sensor (MPS)	Drops passing through laser beam cause a shadow on a diode array which allows size to be measured.	0.05 – 3.1 mm in 62 bins	Instrument orients itself to align laser beam along wind direction.
PWS100	Light scattered from particles as they pass through 4 horizontal light sheets is detected by 2 sensors, one vertical, the other horizontal.	0.1 – 30 mm in 34 x 34 size and velocity bins.	Size and velocity are both measured along with an assessment of precipitation type distribution.

Table 1: Details of the instruments used in the intercomparison.

The detectors which measure the drop size distribution (DSD) all calculate the rainfall accumulation by integrating the number of rain drops measured. They all measure the DSD using different size bins and in the case of the impact disdrometer the bin width varies with drop size. The PWS100 has a slightly coarser resolution than the other two gauges, so we have compared the DSDs between the instruments by re-assigning the measured disdrometer and MPS counts to the bins used by the PWS. The DSD data have also been normalised to account for the different collecting areas of the drop counting instruments.

Typically a raingauge which collects rainfall and measures the quantity directly is expected to give a more reliable rainfall total than one which sums the contribution from different rain drop sizes. However, the drop size sensors used here have a useful benefit over collecting raingauges in that they sense rain from its onset, rather than needing to wet a collector sufficiently for rain to flow into the gauge. This can be of benefit in light rainfall.

An interesting aspect of rainfall detectors is their ability to sense frozen precipitation accurately. Of the above sensors, the optical sensors (MPS and PWS) are best placed to measure the size of the particles. Due to large variations in their density, large uncertainties can occur if these sizes are converted to the equivalent liquid precipitation. Drop-counting and tipping bucket raingauges are unreliable, unless heated, because frozen precipitation will tend to accumulate in the collector and melt at some later time and impact disdrometers are unreliable because the signal generated will depend greatly on the density of the particle, for example it will be very different for snow and hail. This will result in the particle being assigned to the wrong size bin.

INTERCOMPARISON RESULTS

Figure 2 shows the accumulated precipitation (as its water equivalent) and DSD for five case studies with differing precipitation types, rates and durations. MPS data have only been shown in the DSD plots. As discussed below, the MPS can overestimate the number of larger droplets, an effect observed more frequently during heavy rain. This effect leads to an erroneously large calculated accumulation. Table 2 shows a summary of the meteorological conditions during each case study.

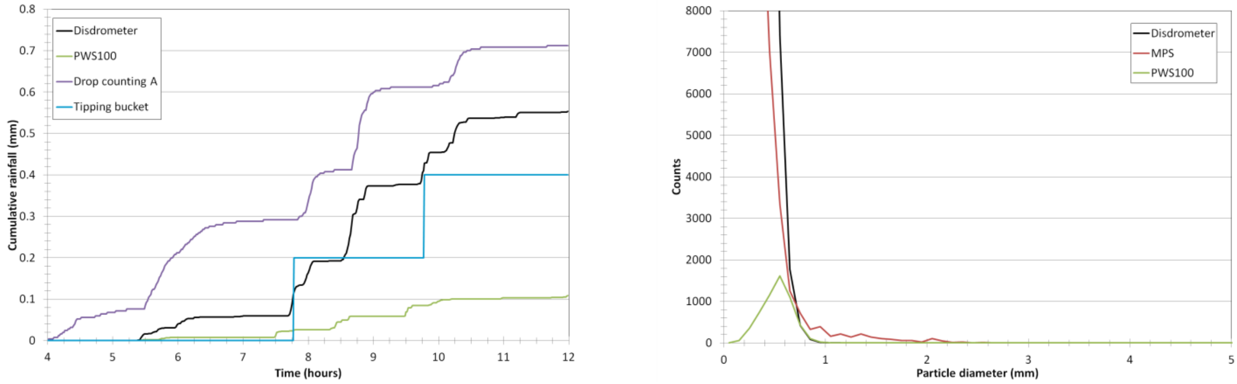

Figure 2a: 04/07/12 04-12 UT stratiform drizzle

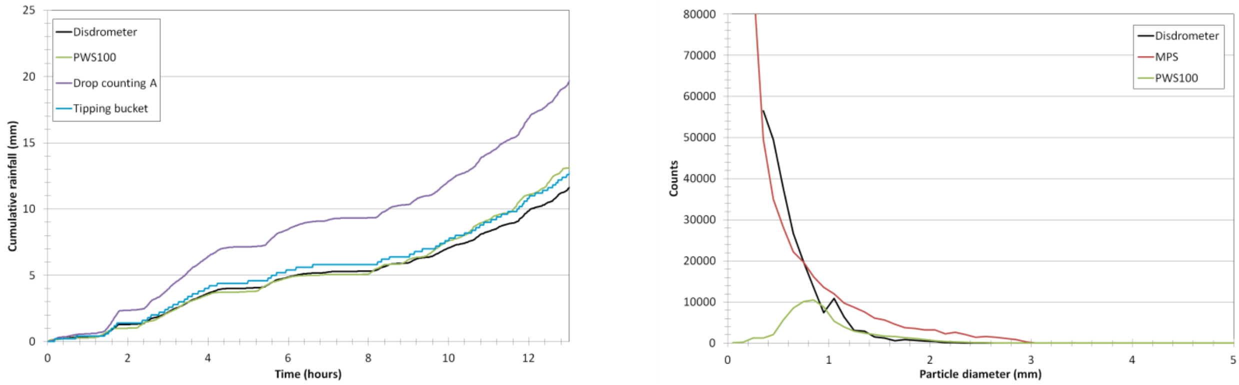

Figure 2b: 29/04/12 00-14 UT stratiform rain

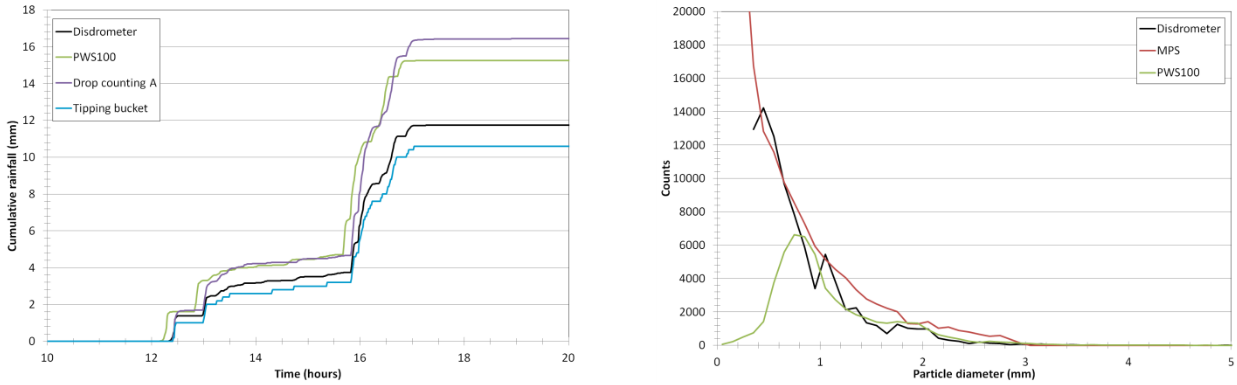

Figure 2c: 22/04/12 10-20 UT convective rain, small amount of ice pellets and hail

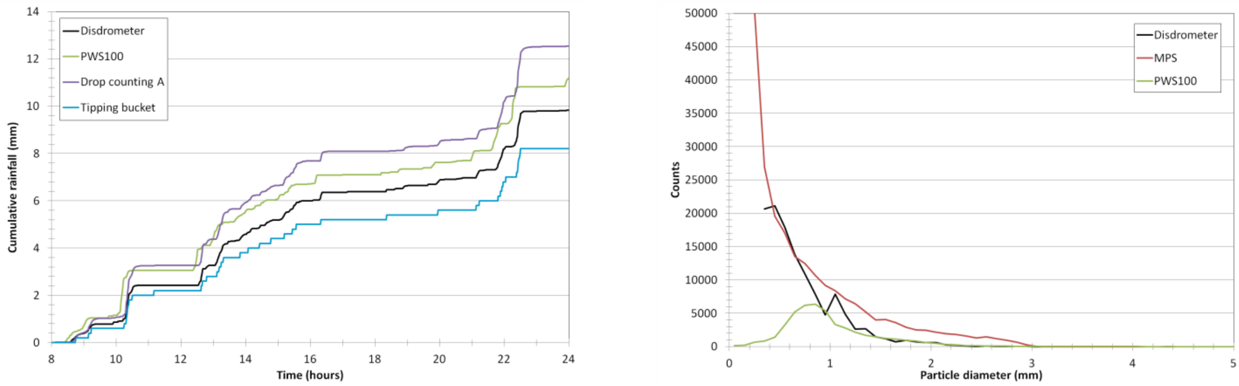

Figure 2d: 25/04/12 08-24 UT convective rain with a few ice pellets and hail

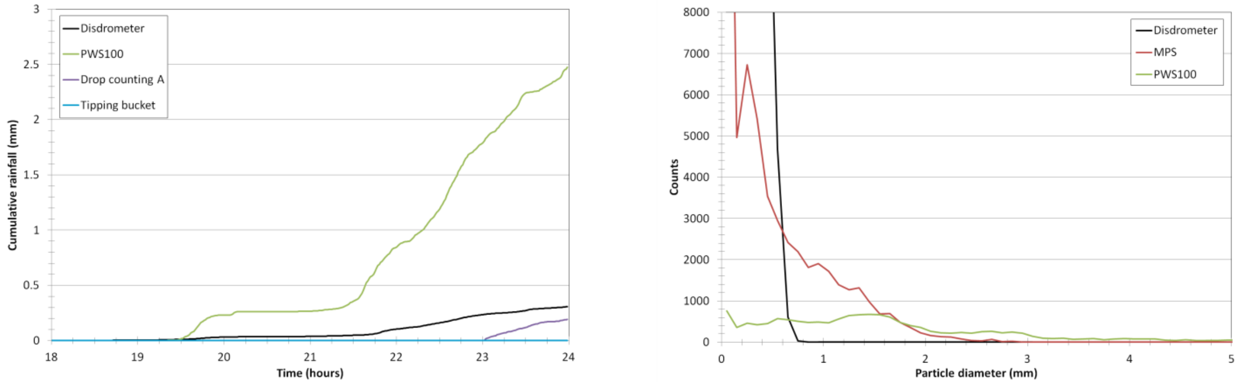

Figure 2e: 09/02/12 18-24 UT snow

Figure 2: Accumulated precipitation (as rain equivalent) and drop size distribution for five case studies with different precipitation conditions.

Date/time	**Precipitation**	**Temperature range (°C)**	**Wind speed (m/s)**	**Wind direction (° from north)**
04/07/12 04-12UT	Drizzle	15-20	4 - 6	180 - 200
29/04/12 00-13UT	Rain, stratiform	5-12	6 - 12	50
22/04/12 10-20UT	Rain, convective, some ice pellets and hail	8	4 - 5	250
25/04/12 08-24UT	Rain, convective, few ice pellets and hail	4-10	7 - 10	150-180
09/02/12 18-24UT	Snow	-1	0 - 2	Variable

Table 2: Summary of meteorological conditions during the case studies

The following observations can be made from the case studies shown:

- The accumulation data generally agree well between the instruments, given the different methods used for measuring or calculating accumulation.
- Compared to the disdrometer and PWS100, the MPS appears to overestimate of the number of counts. This is often more pronounced for larger drops and gives rise to an overestimate of accumulated precipitation compared to the other sensors. Possible causes have been suggested by the manufacturer. These include splashing of large droplets from the heads of the instrument into the field of view and out-of-focus imaging of small drops when they are outside of the depth of field of the instrument. A further investigation with the manufacturer is ongoing.
- The disdrometer DSDs frequently show a peak at around 1 mm diameter, although this is not seen in the drizzle or snow cases. Disdrometers can show effects where larger drops disperse into smaller drops and are detected for a second time. It is possible that such an effect is occurring here.
- The PWS100 consistently shows fewer counts from drops below approximately 0.8 mm in diameter than the other instruments. This is reflected in the precipitation totals for rain events, as well as in the DSDs. In the drizzle case shown in figure 2a, the PWS100 shows the lowest cumulative precipitation, whereas in the stratiform and convective rain cases of figures 2b – 2d it shows a cumulative precipitation in good agreement with the other sensors. This is consistent with it showing better sensitivity to larger droplets which dominate the calculated total precipitation.
- Both the disdrometer and tipping bucket gauge tend to show lower accumulation totals than the drop counting raingauge.
- As expected, during snow the most reliable and consistent data come from the MPS and PWS100. The accumulation totals from the tipping bucket and drop counting raingauges are unreliable due to delays in the melting and subsequent detection of snow. The disdrometer

does not detect snowflakes up to 2 mm diameter which were seen by the MPS and PWS100. Any impact which they cause on the disdrometer cone is equivalent to that from a much smaller rain droplet. There is however a significant difference in the sensitivity of the two optical instruments to smaller particles.

- During these case studies a variety of wind-speeds and directions were observed, however no large impact on the intercomparison data was observed. It is probable that such effects do exist, but until the PWS100 lack of sensitivity to small droplets and the MPS tendency to overestimate drop counts in heavy rain can be resolved, they are likely to be masked.

CONCLUSIONS AND FUTURE PLANS

In the case studies to date, the instruments show consistent behaviour. The agreement in precipitation totals is good when the different measurement methods are taken into consideration, with the exception of the MPS which appears to overestimate the amount of precipitation in heavy rainfall. This effect is being investigated with the manufacturer. There are differences in the DSDs measured by the disdrometer, MPS and PWS100. Compared to the disdrometer, the MPS agrees well at low rain rates but overestimates the number of drops at higher rain rates, particularly for larger drops. The PWS100 shows good agreement with the disdrometer at drops sizes larger than approximately 0.8 mm but underestimates the number of smaller drops. The cause of this effect is being investigated.

All instruments involved in the intercomparison operate continuously, so further case studies are planned as suitable data are collected. Attempts will be made to identify any correlation of the measurements with wind speed and direction. Further cases of snow or hail will also be sought.

ACKNOWLEDGEMENTS

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