



Science & Technology
Facilities Council

**Final report on the operation of a Campbell Scientific
PWS100 present weather sensor at Chilbolton Observatory**

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14th January 2013

Introduction

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 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 on 12th December 2011 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. A statistical comparison is made of 1 hour accumulation measurements from the PWS100 and a drop-counting raingauge to highlight any effects of wind speed and direction on the sensors. 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.

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 [5].

Summary of trial

Figure 1 shows a not-to-scale sketch of the site and the location of instruments. Those most relevant to the current work are the raingauge site (2), the raised cabin roof (4) and the CS135 ceilometer (6).

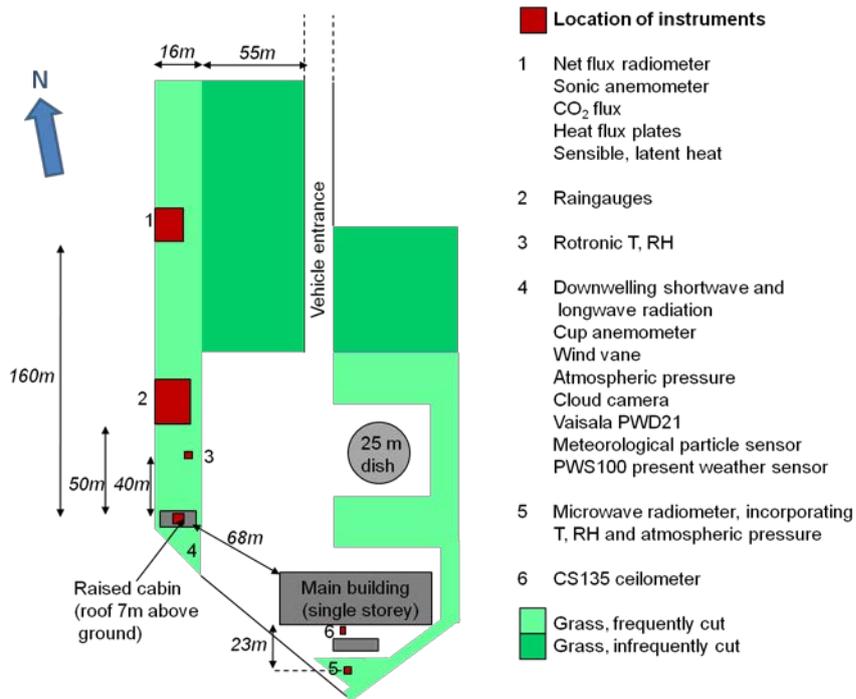


Figure 1: Location of instruments at the Chilbolton site.

The CFARR raingauges are located in a grassy area well away from buildings and other tall features. Figure 2a 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 7 m. Their location is shown in more detail in figure 2b. The cabin is approximately 50 m from the raingauge site.



Figure 2a: Location of raingauges and meteorological instrument cabin.

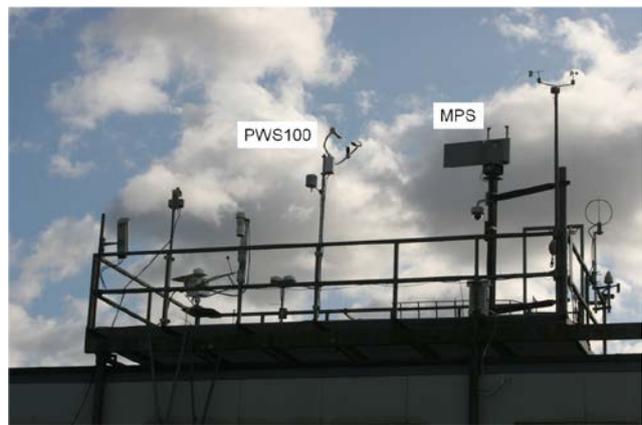


Figure 2b: The MPS and PWS100 on the meteorological instrument cabin roof.

Figure 2: 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 occurred with wind blowing from the radar.

Precipitation trial details

Details of trial instruments

For the PWS100 the most relevant sources of intercomparison rainfall data are the tipping bucket raingauge, drop-counting raingauges, impact disdrometer (all located at area 2 in figure 1) and the meteorological particle sensor (located on the raised cabin roof adjacent to the PWS100).

Table 1 shows the details of the instruments as they relate to this intercomparison.

Detector type	Measurement principle	Drop sizes measured, number of bins	Comments
Drop counting rain gauge	Rain collected in funnel, counted in droplets with 0.0033 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 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 is not heated.
Distromet RD-80 impact disdrometer	Drops hitting Styrofoam cone are detected using electro-mechanical detector	0.3 – 5.0 mm in 127 bins	Signal magnitude in detector is related to drop size.
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 with wind direction.

Detector type	Measurement principle	Drop sizes measured, number of bins	Comments
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 CFARR and Campbell Scientific rain sensors.

Expected performance of the trial instruments

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 in some way is expected to give a more reliable rainfall total than one which sums the contribution from different rain drop sizes, as the measurement method is more direct. 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 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 texture 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.

Further details of all the Chilbolton instruments, including descriptions of the instruments and technical specifications, can be found at <http://www.stfc.ac.uk/Chilbolton/facilities/24806.aspx>.

Results of PWS100 intercomparison with Chilbolton Observatory instruments

Two methods of comparing the performance of the PWS100 with the Chilbolton rain gauges were used: a selection of case studies made using days with different precipitation conditions and a statistical approach which compared measurements during all significant periods of rain as a function of wind speed and direction.

Case studies

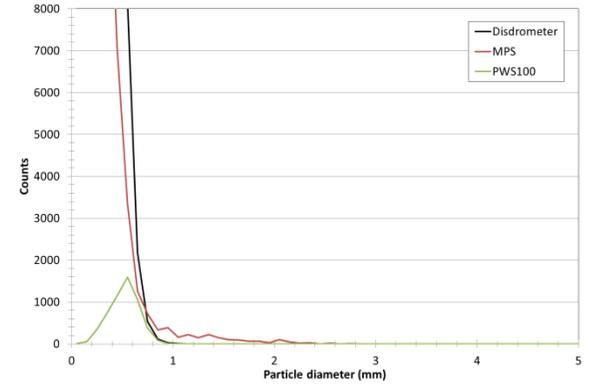
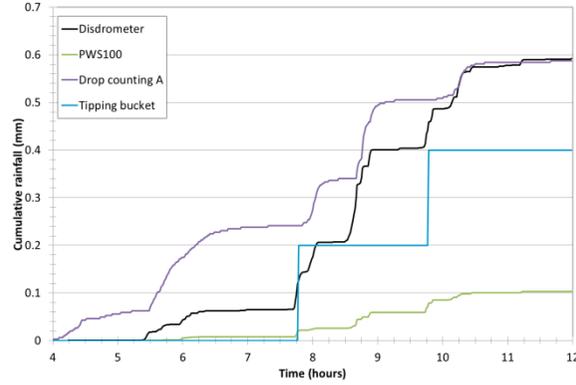
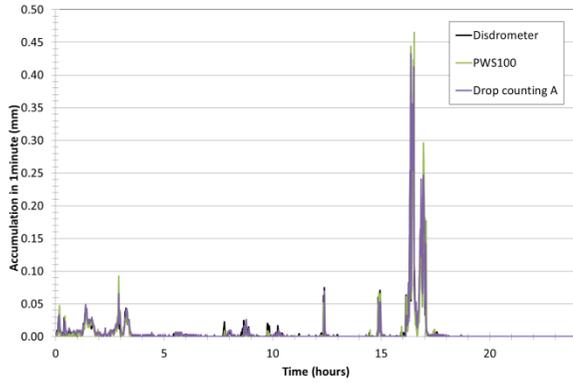
A selection of days on which to make intercomparisons was made so as to include different precipitation types. These were drizzle, heavier stratiform rain, convective precipitation (rain with some hail) and snow. If the precipitation type changed during the day only the data from part of the day were used.

Precipitation data from 6 days are plotted in 3 ways in figure 3. Firstly the accumulation of rain (assuming the precipitation was entirely rain) over 1 minute intervals (the timebase for PWS100 measurements) is shown for each gauge. The tipping bucket gauge is excluded from these plots as its data are more quantised than for the other gauges. Secondly the cumulative precipitation is shown. These two plots use the same data but there can be benefits in displaying the data in different ways. Thirdly the DSDs for the precipitation event are plotted using data from the impact disdrometer, MPS and PWS.

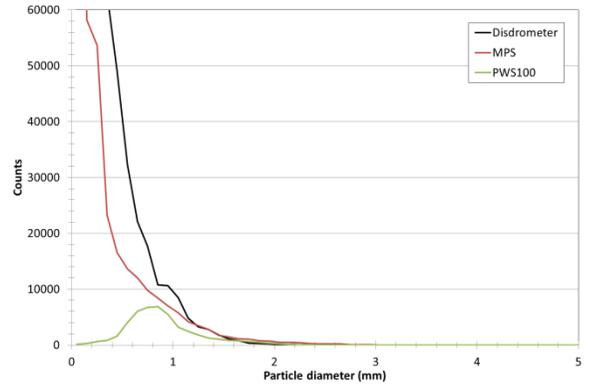
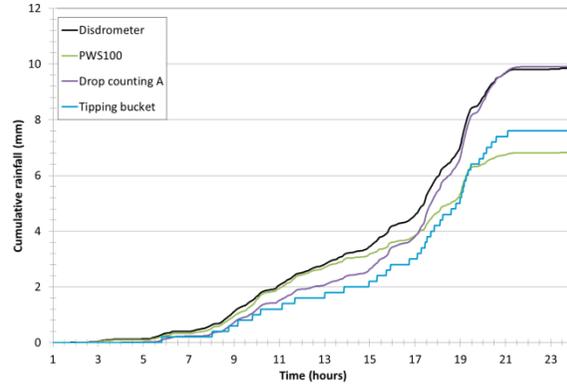
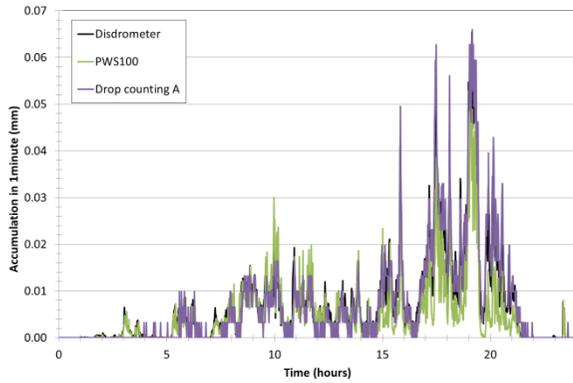
The PWS100 reports a code which identifies the precipitation particles. Histograms of the total number of counts of each type of precipitation during the events are shown in figure 4. The 11 classifications are drizzle (D), freezing drizzle (FD), rain (R), freezing rain (FR), snow grains (SG), snow flakes (SF), ice pellets (IP), hail (H), graupel (G), error (E) and unknown (U).

A table summarising the meteorological conditions during the measurements is shown in table 2.

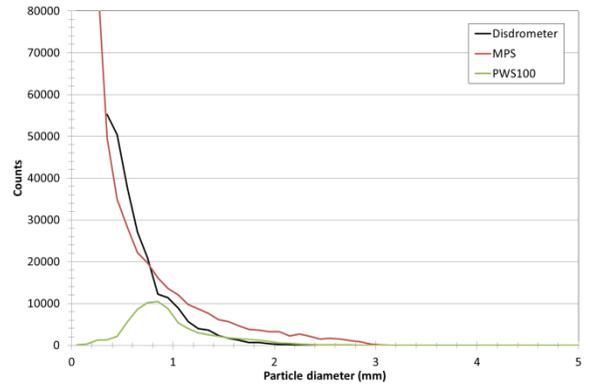
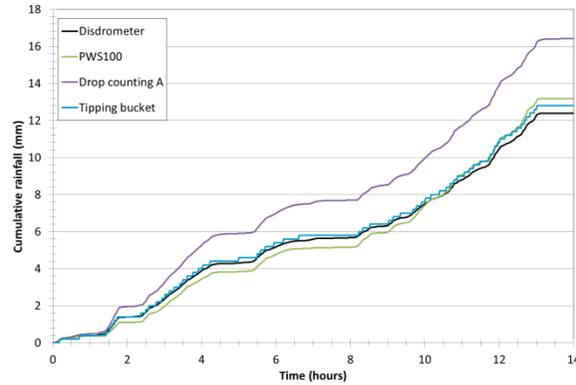
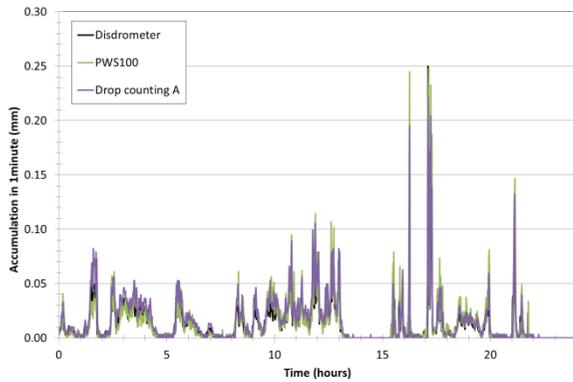
Stratiform drizzle 04/07/12 04 – 12 UT



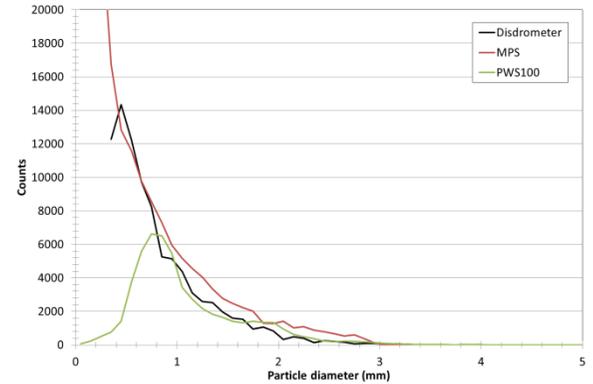
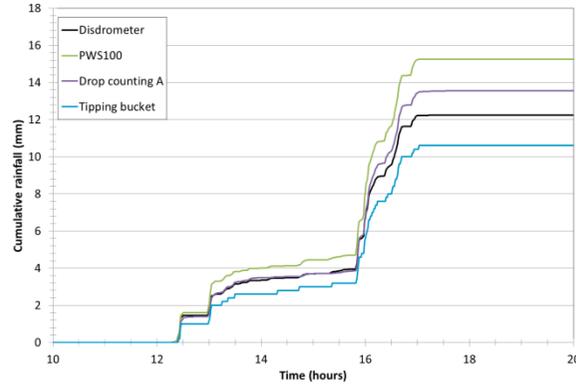
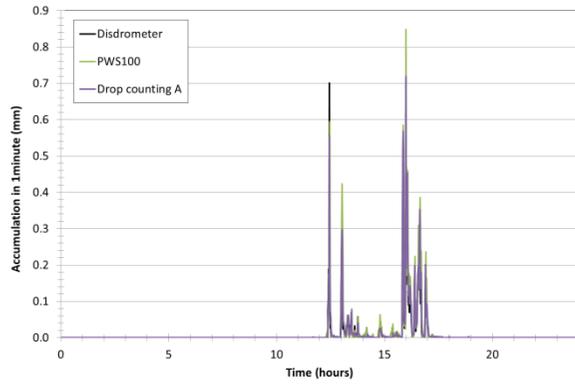
Stratiform 09/04/12 01 – 24 UT



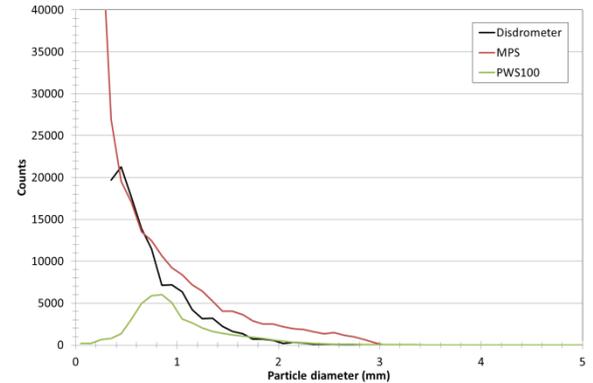
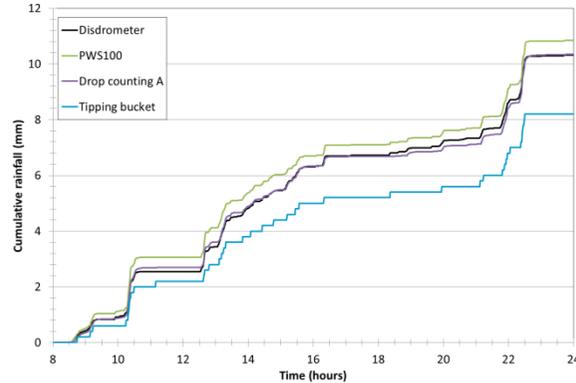
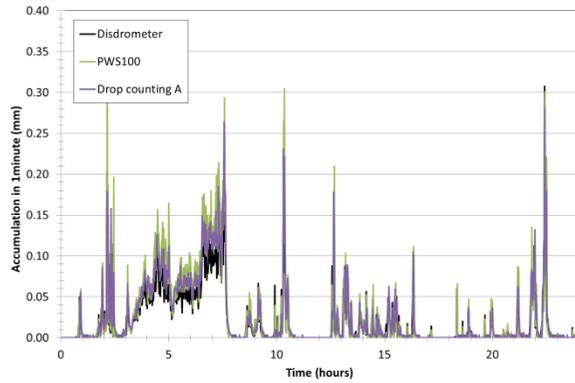
Stratiform 29/04/12 00 – 14 UT



Convective 22/04/12 10 – 20 UT



Convective 25/04/12 08 – 24 UT



Stratiform snow 09/02/12 18 – 24 UT

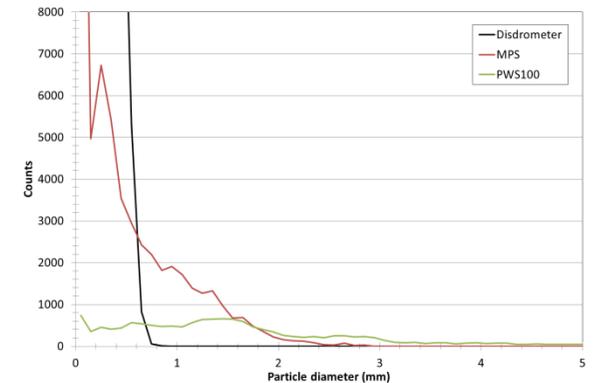
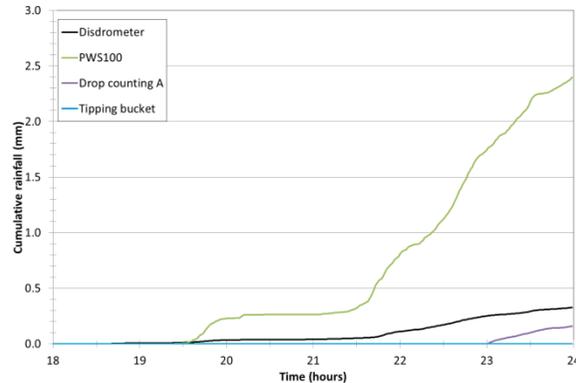
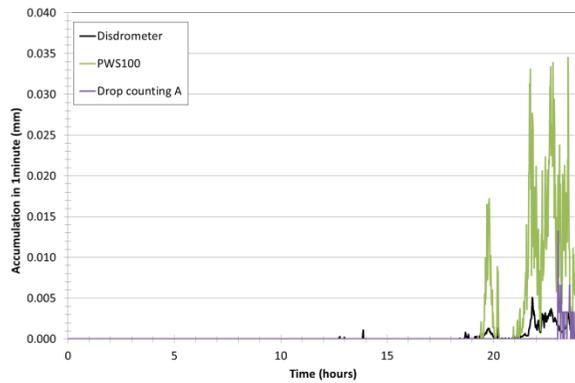
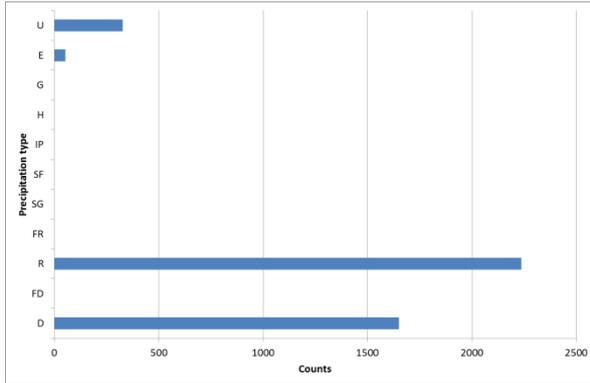
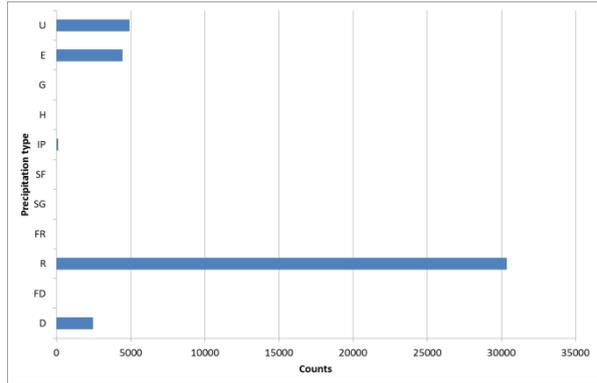


Figure 3: Precipitation data for intercomparison days

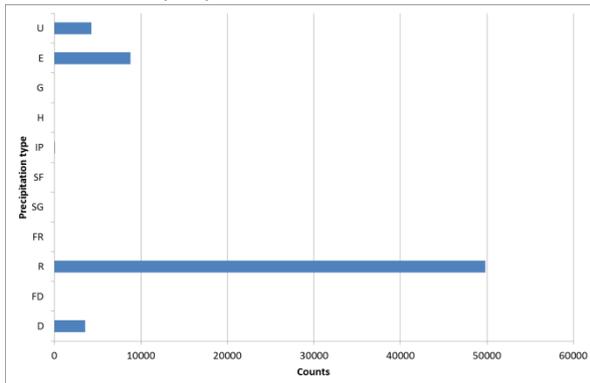
Stratiform drizzle 04/07/12 04 – 12 UT



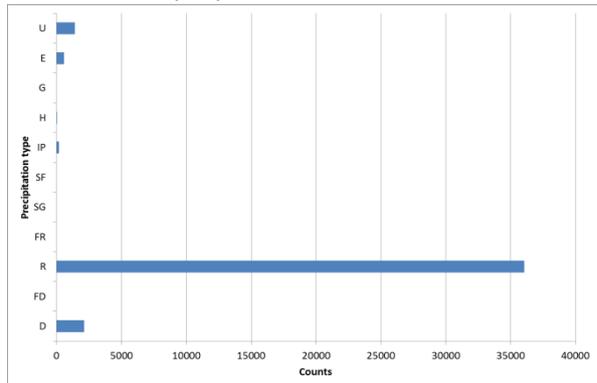
Stratiform 09/04/12 01 – 24 UT



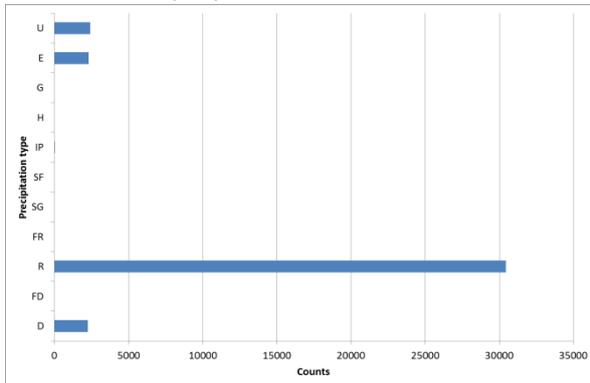
Stratiform 29/04/12 00 – 14 UT



Convective 22/04/12 10 – 20 UT



Convective 25/04/12 08 – 24 UT



Stratiform snow 09/02/12 18 – 24 UT

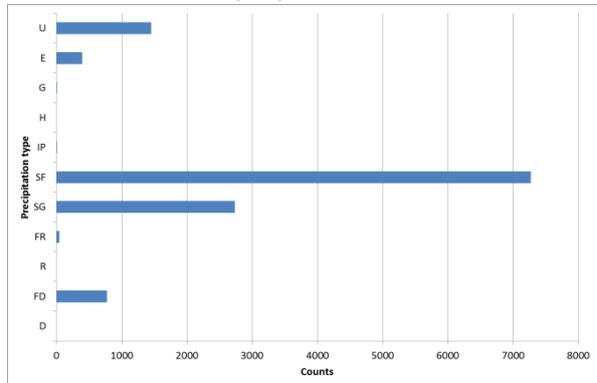


Figure 4: Classification of precipitation for each event

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
09/04/12 01-24 UT	Rain, stratiform	8 - 10	4 - 10	220
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.

Observations from the case studies

The accumulation data generally agree well between the instruments when the precipitation is dominated by rain (i.e. all days except 09/02/12).

Compared to the disdrometer and PWS100, the MPS sometimes greatly overestimates the precipitation total. This appears to occur more commonly and to a greater extent in heavier precipitation. The effect is also shown in the DSDs, where it shows as an overestimate of the number of counts which is often more pronounced for larger drops. 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. Other recent work at CFARR suggests that the discrepancy becomes worse as wind speed increases.

The PWS100 consistently shows fewer counts from drops below approximately 0.8 mm in diameter than the other instruments. In the drizzle case shown in figure 3, the PWS100 shows the lowest cumulative precipitation, whereas in the stratiform and convective rain cases of figure 3 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. The disdrometer could also potentially suffer sensitivity issues in this size range, but comparisons between the Chilbolton disdrometer and an identical instrument located at Sparsholt, approximately 8 km from Chilbolton, show good agreement. This indicates that the disdrometer is likely to be performing consistently across its drop size range.

In the drizzle event of 04/07/12 figure 4 shows slightly more rain drops during the event than drizzle drops. However, it is likely that the drizzle total is affected by the lower sensitivity of the PWS at diameters below 0.8 mm, as seen in figure 3. The same effect is likely to be observed in all the stratiform and convective events.

During the convective event on 22/04/12 a small amount of ice pellets and hail are detected, consistent with some hail embedded within the rain events. During the convective event on 25/04/12 a smaller amount of ice pellets and no hail are detected.

The DSDs measured by the disdrometer show a tendency for similar features to be seen in the measurements from most days. For example, the plots from days with stratiform or convective rain all show a similarly shaped feature at around 1 mm. This is not real – it is an artefact resulting from small uncertainties in how the boundaries of disdrometer size bins are defined. A small error, when it occurs at the interface of PWS100 bin sizes, can cause “jitter” in how disdrometer counts are re-assigned to PWS100 bins. This results in a slight excess of counts in 1 size bin and a corresponding deficit in the next.

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.

Conclusions

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.

References

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- [2] Joss, J. and A. Waldvogel, “Raindrop size distribution and sampling size errors”, *J. Atmos. Sci.*, **26**, 566-569, 1969
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