Assessment of the quality of drop size measurements using a non-dedicated present weather sensor

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ABSTRACT

Drop size data from a present weather sensor have been compared to drop size data collected using a nearly co-located dedicated disdrometer. In a rainfall event that lasted more than 9 hours, with rainfall intensities up to 25 mm h^{-1} drop size distributions (DSDs) estimated by the two different types of instruments are found to be significantly different. The present weather sensor severely underestimates the number of large drops, which is likely due to miscalibration of the instrument. The effect of this underestimation on DSD-derived bulk rainfall variables R and Z is significant. A simple linear correction for this miscalibration proves to be quite effective in removing differences between DSDs and resulting bulk rainfall variables. If DSDs estimated from the present weather sensor are to be used in analyses of rainfall spatial variation, careful recalibration is therefore essential.

1. INTRODUCTION

It is well-known that rainfall is highly variable both in space and time on multiple scales [e.g. Uijlenhoet et al., 2003, Berne et al., 2004a,b, Schuurmans et al., 2007]. Because of the usually nonlinear character of rainfall retrieval relations from remote sensors, this variability will affect the quality of the resulting rainfall data [e.g. Gosset and Zawadzki, 2001, Gosset, 2004]. Radar rainfall retrieval relations are often based on point-scale measurements of (rain)drop size distributions (DSDs) made on the ground. However, because radars sample a large volume aloft, these relations may not be appropriate.

In order to be able to quantify the variability of rainfall at small to intermediate scales, it is necessary to measure DSDs at multiple locations in space. DSDs are measured using instruments called disdrometers [e.g Joss and Waldvogel, 1967], of which many different types exist. If a number of different types of disdrometers are used to quantify rainfall spatial variability, one must have confidence that the two instruments will yield the same (or at least very similar) measurements given the same rain. Otherwise purely instrumental effects may be attributed to rainfall spatial variation.

In this paper we compare two types of disdrometers for this purpose. Two present weather sensors are located at the Cabauw Experimental Site for Atmospheric Research (CESAR), one at 3 m above the ground and one located at 200 m above the ground. The locations of these instruments allow us to study the vertical variation in DSDs, which may have important implications for radar rainfall estimation. The present weather sensors were not specifically built to measure drop size distributions. Therefore we will compare DSDs from the lower present weather sensor to those measured by a co-located dedicated disdrometer.

2. DROP SIZE DATA

Drop size distributions are measured using the HSS-PW402b present weather sensors [e.g. Sheppard and Joe, 2000] located at the Cabauw Experimental Site for Atmospheric Research (CESAR) near Lopik, The Netherlands. To validate drop size data from the HSS-PW402b sensors (PWS in the remainder of this paper), we will use data from a nearby 2D Video Distrometer [2DVD, see Kruger and Krajewski, 2002]. The horizontal distance between the 2DVD and the PWS is approximately 5 m. In this paper we consider drop size data collected during a rainfall event that started on November 10, 2008 at 21:13 and that lasted for more than 9 hours, with intensities up to 25 mm h^{-1} and more than 24 mm of accumulated rain.

The HSS-PW402b sensor is designed to be a present weather sensor, which measures variables such as temperature, visibility, precipitation type and approximate intensity. To determine precipitation type and intensity, the PWS measures diameters and fall velocities of hydrometeors passing through a measurement area of approximately 5×10^{-3} m^2. These diameters and velocities are determined through analysis of a backscattered optical signal whereby a peak in the backscattered signal is associated with the passing of a hydrometeor through the measurement area. The amplitude of this peak is related to the size of the hydrometeor, and the duration of the peak is related to its velocity. The accuracy of drop size measurements hence depends on the accuracy of the relation between this drop size and the amplitude of the peak. This relation is usually deter-

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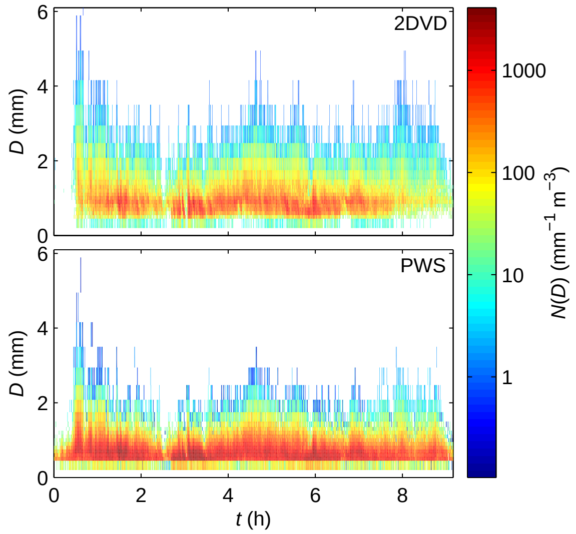

Figure 1. Comparison of DSDs measured by the 2DVD and PWS disdrometers for the event on November 10-11, 2008

mined through calibration.

The 2D Video Distrometer estimates drop sizes, fall velocities and shapes through measurement of the extinction of light. Two sheets of light, located at a slight vertical distance, are emitted horizontally and then both sampled with two line-configurations of CCD sensors. The shapes (and hence sizes) of the particles falling throught the 0.01-m^2 planes constructed in this way can then be determined by the number of CCD sensors that register a decrease in signal. The vertical velocity of the drop can be determined by the delay in signal between the two lines of CCD sensors. Note that the 2DVD does not use signal amplitude to determine properties of hydrometeors. For additional details regarding the measurement principle of the 2DVD, the reader is referred to Schönhuber et al. [1994] and Kruger and Krajewski [2002].

The DSDs analysed in this paper are accumulated over 30-s intervals (the minimum measurement interval of the PWS). Because some mismatching between the drop size and drop velocity measurements may occur for the 2DVD data (i.e., the velocity of one drop is assigned to another and vice versa), only those drops that have diameters and velocities that fall within a ± 40 % band from a theoretical $v(D)$ relation [Beard, 1976] are used, as was suggested by Thurai and Bringi [2005].

Figure 1 shows the number concentrations $N(D)$ (mm^{-1} m^{-3}) of raindrops of various diameters D (mm) during the rainfall event, as measured by the two disdrometers. It can be seen from these figures that the dynamics are similar, with co-varying DSD shapes. However, the numbers of small drops are higher for the PWS (darker red in the lower panel of Fig. 1), whereas the 2DVD estimates much more large drops (the band of nonzero $N(D)$ is broader in the upper panel of Fig. 1).

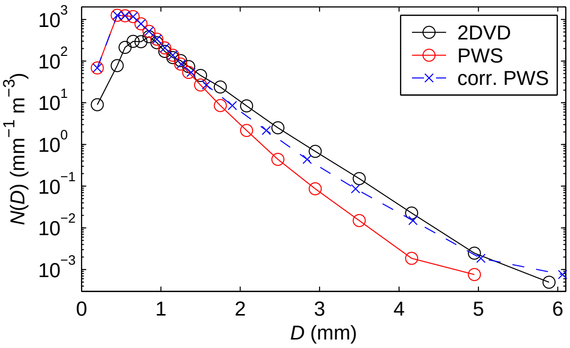

Figure 2. Event-averaged DSDs measured by the 2DVD and PWS disdrometers. The blue line denotes the result of the proposed calibration correction for the PWS data.

This is summarised by the graph in Fig. 2, which shows the event-averaged DSDs estimated by the two instruments. The 2D Video Distrometer has been shown by Nešpor et al. [2000] to have difficulties in correctly estimating the number of small drops, which may account for the differences in $N(D)$ in this drop diameter range. Differences in the number concentrations of larger drops as estimated by the two different disdrometers could possibly be attributed to a miscalibration of the PWS. If the drop sizes estimated by the PWS are smaller than the actual drop sizes, this could indeed result in the underestimations of large drops as seen in Figs 1 and 2. Because of this, it is impossible to derive a consistent diameter-dependent correction function. In case of miscalibration of the instrument, such a function will always depend on the DSD shape. Figure 1 clearly shows that this DSD shape can be highly variable, even within a single event. It would therefore be better to attempt to correct the miscalibration by careful redefinition of the diameter classes.

The result of such an attempt to recalibrate the diameter classes is shown in Fig. 2. We have assumed a simple linear relation between the diameter D (mm) and the corrected diameter $\hat{D}$ (mm) such that

$$\hat{D} = \begin{cases} D & \text{if} \quad D \leq D_0 \\ D + a\,(D - D_0) & \text{if} \quad D > D_0. \end{cases} \qquad (1)$$

Here, $D_0 = 1.25$ mm has been determined based on visual inspection of $N(D)$ (see Fig. 2), and $a = 0.3$ is derived using linear regression of $\hat{D}$ on D, with $\hat{D}$ determined by linearly interpolating the averaged $N(D)$ estimated by the 2DVD at values of the averaged $N(D)$ estimated by the PWS. The resulting average corrected PWS DSD can be seen to lie relatively close to the DSD estimated by the 2DVD. The implications of this correction for bulk rainfall variables will be discussed in Section 3.

3. RAINFALL BULK VARIABLES

The difference in DSDs observed in Section 2 will have an effect on rainfall bulk variables such as the rainfall

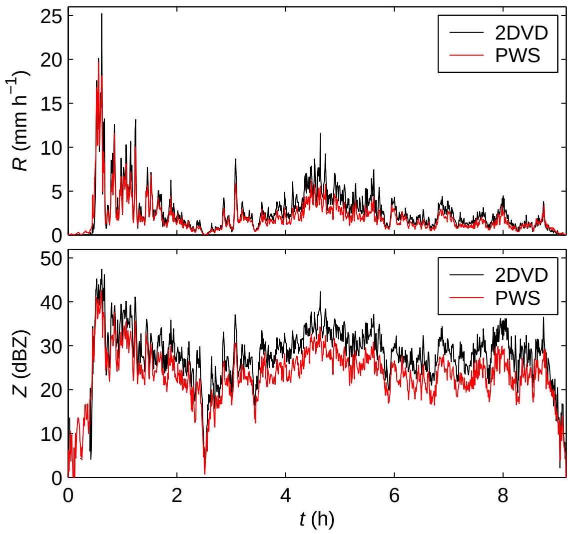

Figure 3. Time series of the rainfall intensity R (top) and radar reflectivity factor Z (in dBZ, bottom) computed from $N(D)$ estimated from the 2DVD and PWS disdrometers

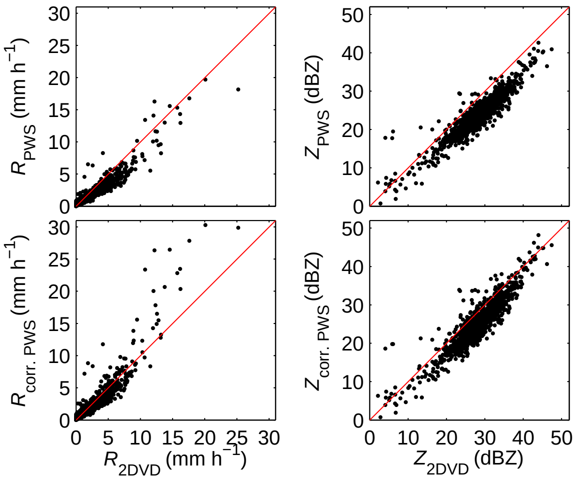

Figure 4. Comparison of R (left) and Z (right) computed from DSDs measured by the 2DVD and PWS disdrometers. Results are shown for uncorrected (top) and corrected (bottom) PWS data. Red lines indicate the 1:1 line.

intensity R (mm h^{-1}) and the radar reflectivity factor Z (mm^6 m^{-3}). Both of these variables can be computed from $N(D)$

$$R = 6\pi \times 10^{-4} \int_0^\infty v(D) D^3 N(D) \mathrm{d}D \qquad (2)$$

$$Z = \int_0^\infty D^6 N(D) \mathrm{d}D, \qquad (3)$$

where $v(D)$ (m s^{-1}) is the terminal fall velocity of raindrops as a function of their diameters. The $v(D)$ relation used here is the semi-empirical relation suggested by Beard [1976], but can also be approximated by $v \sim D^{0.67}$ [Atlas and Ulbrich, 1977]. The rainfall intensity is therefore proportional to approximately the 3.67$^{\mathrm{th}}$ moment of the DSD, whereas Z is proportional to the 6$^{\mathrm{th}}$ moment of the DSD. It can therefore be expected that both R and Z are sensitive to the number of large drops. This will be more severe for Z than for R, as Z is a higher order moment of $N(D)$.

Figure 3 shows the evolution of the rainfall intensity R and radar reflectivity factor Z through time. It can be seen that with regard to R, but especially to Z, the PWS is underestimating with respect to the 2DVD. This shows that the underestimation by the PWS of the number of large drops is not compensated by the underestimation of the number of small drops by the 2DVD for these two bulk variables. As was apparent from Fig. 1, the dynamics of the two time series are similar. For both R and Z the co-fluctuation between the variables estimated from the 2DVD and the PWS is high.

Figure 4 shows a direct comparison of both R and Z computed from DSDs estimated from the two disdrometers. It is apparent from the comparison of the radar reflectivity factors that this variable is consistently underestimated by the PWS. For R, the underestimation by the PWS only becomes apparent when R is greater than approximately 1 mm h^{-1}. This is likely due to the fact that at low R the number of large drops is limited. The effect of the underestimation of the number of large drops by the PWS is then compensated by the underestimation of the number of small drops by the 2DVD. This is not the case for Z, which is more sensitive to large drops. As could be concluded from Figs 1 and 3 the correlation between the variables estimated from the two instruments is high.

The recalibration of the diameter classes can be seen in Fig. 4 to have a positive effect on both R and Z, although the high rainfall intensities seem to be overcorrected. In general, the values of both R and Z derived from DSDs estimated using the two instruments are much closer when a diameter class correction is applied to the PWS data.

4. DISCUSSION AND CONCLUSIONS

In order to assess the quality of DSDs derived from measurements of the HSS-PW402b Present Weather Sensor (PWS), PWS data have been compared to drop size data collected using a nearly co-located 2D Video Distrometer (2DVD). A rainfall event that lasted more than 9 hours, with rainfall intensities up to 25 mm h^{-1} has been analysed for this purpose. It has been shown that the DSDs estimated by these two different types of instruments are significantly different. The 2DVD is shown to underestimate the number of small drops, which is consistent with the analyses of Nešpor et al. [2000]. The PWS severely underestimates the number of large drops. This is likely due to miscalibration of the instrument. A simple linear correction applied to the diameter classes of the PWS yields DSDs that are much closer to those estimated by the 2DVD.

We have also analysed the effect of the underestimation of the number of small drops by the 2DVD on the one hand and the underestimation of the number of large drops by the PWS and correction thereof on the other on bulk rainfall variables, such as the rainfall intensity R and radar reflectivity factor Z. The effect of the underestimations by the PWS dominates for both R and Z. This is due to the fact that both R and Z are high-order moments of the DSD, and therefore sensitive to the number of large drops. The simple linear correction of the diameter classes proposed here is seen to greatly improve results. This also shows that if DSDs estimated from the PWS are to be used in analyses of rainfall spatial variation, careful recalibration is essential (either by calibrating the instrument itself or by redefining the drop diameter classes).

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