An investigation of factors affecting the accuracy of Thies disdrometers

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Abstract

Data were available from March to July 2007 from three Thies disdrometers installed at the UK Met Office site at Eskdalemuir in Scotland. We found that while Thies disdrometers are able to detect small-scale spatial variation in rainstorms they are affected by the orientation of the disdrometer relative to the prevailing wind direction, with the reduction in the number of drops counted being as much as 20% in the case of the smallest drops.. It appears that velocity calibration is carried out separately for different drop sizes and that this calibration can be in error for the smallest drops.

Introduction

The UK Met Office have an ongoing programme of comparative testing of meteorological instruments [1]. As part of this programme, between March and July 2007 three Thies laser disdrometers were installed at the Met Office's Eskdalemuir Observatory in the Southern Uplands of Scotland. Figure 1 gives an idea of the site.

Data from these instruments, together with data from a nearby OTT Pluvio precipitation gauge, and an OTT Parsivel (laser optical) disdrometer, were made available for analysis. Additionally, the information provided by a Vaisala WXT510 weather transmitter concerning wind speed and direction was available for March, and for the first half of April.

The Thies and Parsivel disdrometers

The Thies disdrometer is a modern laser precipitation monitor using a 780 nm infrared parallel light-beam with a cross section of 45.6 cm^2. The manufacturers claim that the instrument is able to distinguish between drizzle, rain, hail, snow grains, graupel and ice pellets by virtue of its ability to accurately measure fall speed and to distinguish drops with diameters as small as 0.125mm. An account of the factory calibration process and

Figure 1: Overview of instruments on the UK Met Office site at Eskdalemuir.

the apparent accuracy of the instrument have been given by Lanzinger *et al* [2]. Its ability to distinguish precipitation type is discussed by Bloemink and Lanzinger [3]. Particle diameters are recorded in 22 classes with lower bounds (in mm): 0.125, (0.125), 0.5, (0.25), 2, (0.5), 8. The bracketed values indicate the class widths used (so that, for example, the first bin stretches from 0.125mm to 0.25mm). Particle speeds (in m/s) are recorded in 20 classes with lower bounds as follows: 0, (0.2), 1, (0.4), 3.4 (0.8), 9, 10. Reports of counts in the 440 possible size-velocity bins are made each minute.

The Parsivel disdrometer is a slightly earlier type of laser disdrometer. Its properties have been discussed by Löffler-Mang and Joss [4]. The Parsivel reports both diameters and fall speeds using 32 bins, so that 1024 size-velocity bin counts are presented each minute. For diameters the lower bounds (in mm) are 0, (0.125), 1.25, (0.25), 2.5, (0.5), 5, (1) 10, (2), 20, (3), 23, while for fall speeds the lower bounds (in m/s) are 0, (0.1), 1, (0.2), 2, (0.4), 4, (0.8), 8, (1.6), 16, (3.2), 19.2. However, the two smallest size categories are not used, while the top 9 size bins are inappropriate for rain (similar remarks apply to the fall speeds).

The disdrometers at Eskdalemuir

The three Thies disdrometers (which we will refer to as T1, T2 and T3) and the Parsivel disdrometer were mounted on poles as indicated in Table 1. In the table the orientations are expressed with the end attached to the pole given first. .

All four disdrometers were situated within a few metres of each other and of the other measuring instruments (see Figure 1).

Results

To simplify comparison across the two types of disdrometer, we ignore counts in the lowest bin for the Thies disdrometers. This then means that the Parsivel and Thies are

Table 1: Arrangement of disdrometers at Eskdalemuir during March-July, 2007

Disdrometer	Pole	Height above ground	Orientation
T1	A	2m	North-South
T2	B	1.75m	North-South
T3	B	2m	West-East
Parsivel	C	2m	West-East

Figure 2: The three Thies disdrometers (T2 and T3 are in the foreground).

reporting the same range of drop sizes (diameters between 0.25 mm and 8 mm) and therefore should give similar values.

We also confine our comparisons to those hours for which we have complete data from all four instruments (some data were lost because of computer problems). To guard against occasional records that might not refer to rainfall we also restrict attention to minutes in which the three Thies recorded an average of at least 50 drops.

Differences in numbers of drops recorded

Over the five months there were 15428 minutes for which the three Thies recorded an average of at least 50 drops; these included 7421 minutes in which (taking the average value) the rainrate was less than 1 mm/hr. The average drop counts per minute were as shown in Table 2.

Table 2: Average drop counts per minute in minutes with an average of at least 50 drops

Rain rate	T1	T2	T3	Parsivel
Less than 1 mm/hr	286	286	284	212
More than 1 mm/hr	886	898	897	719

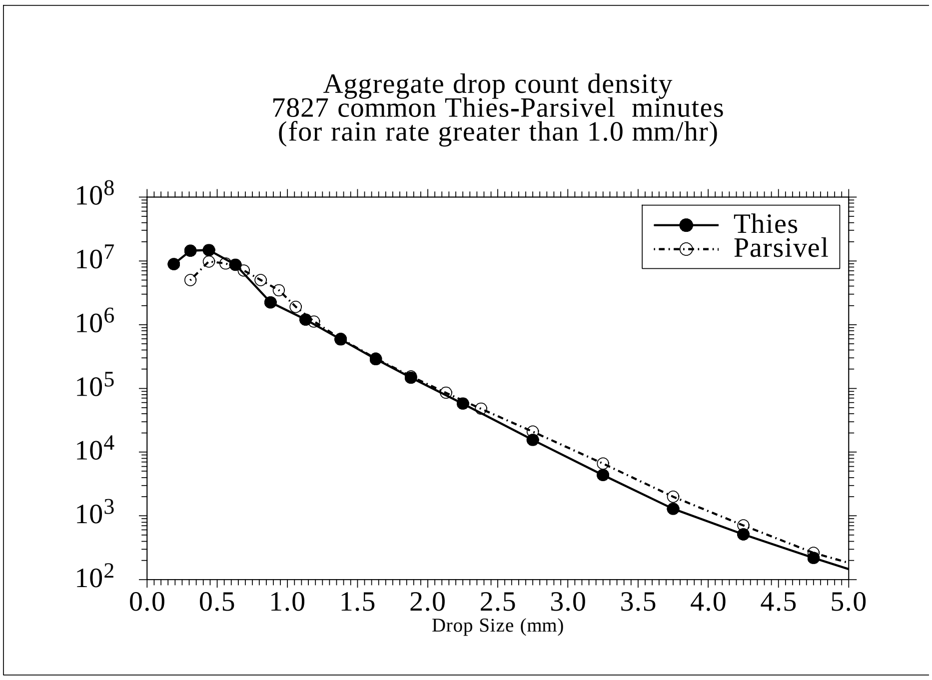
There are two immediately evident results:

1. The three Thies are in excellent agreement with one another;

2. The Parsivel recorded far fewer drops: in the lighter rain the Parsivel count was about 74% of that reported by the Thies disdrometers, with the proportion rising to 80% in the higher rainrates.

Figure 3 (which uses a log scale) reveals that the big difference between the drop counts made by the two types of disdrometers is principally associated with their counts of the the smallest drops: for the lowest bins the numbers recorded by the Thies are typically three times the numbers recorded by the Parsivel. By contrast, for drops with diameters greater than about 2.5mm, the Parsivel reported rather more drops than did the Thies.

Figure 3: The drop count distributions (frequencies per mm) reported by the two types of disdrometer .



We have shown elsewhere [5] that these differences are consistent from minute to minute in the following sense. If we regard drop count distributions as having a gamma form, then the family of gamma distributions for the data reported by a Thies is distinct from that for the data reported by a Parsivel.

Difference in volume of water recorded

To understand the consequences of the differences in these reports, we considered a particularly wet 36 hours that commenced at midnight on the 12th June 2007. During this period the Pluvio precipitation gauge recorded a total of 33.5 mm of rain. The average recorded by the Thies was 34.3 mm (therefore in better agreement than the experiments reported in [2]), whereas the Parsivel reported just 29.9 mm (about 90% of the Pluvio value). Earlier investigations have nevertheless suggested good accuracy for the Parsivel [4].

Variations between Thies examined in relation to wind direction

Table 3 displays counts recorded by the the three Thies during heavy rainfall just after midday on June 30th, 2007. During this period T3 records far fewer drops than either of the other disdrometers. Table 2 has shown that, over the five-month period there was little difference between the total numbers of drops observed, so that the explanation is not that T3 consistently undercounts. The true explanation is that some form of masking is occurring, so that drops are prevented from passing through the field of vision of the instrument. Table 1 showed the orientations of the instruments and reveals that T3 is oriented at right angles to T1 and T2.

Table 3: One-minute drop counts recorded by the three Thies during a heavy rainstorm starting at 12:03 pm on June 30th, 2007.

Time	T1	T2	T3
12:03	1618	1645	1290
12:04	1953	1850	1481
12:05	1688	1715	1417
12:06	2069	2115	1647
12:07	2157	2178	1889
12:08	1965	1800	1648
12:09	2072	2185	2103
12:10	2346	2282	2074
12:11	2222	2279	1879
12:12	2385	2394	2334

During March and the first half of April in 2007 a Vaisala WXT510 weather transmitter was on site, providing minute-by-minute information concerning wind speed and direction. During this period the winds came predominantly from directions between the South-East and the North-West. Table 4 compares the counts for T1 and T3 which were installed at the same height above ground, but at 90° to one another (see Table 1).

Table 4: Comparison between the differently oriented Thies disdrometers T1 and T3. Values in bold are significant at the 5% level

Wind direction	110°-	130°-	150°-	170°-	190°-
$T1 > T3$ (% of minutes)	**85%**	**64%**	**39%**	**27%**	**26%**
No. of minutes	77	196	126	213	178

Wind direction	210°-	230°-	250°-	270°-	290°-
$T1 > T3$ (% of minutes)	**31%**	48%	56%	**61%**	50%
No. of minutes	123	226	204	132	65

The differences between the counts for T1 and T3 are marked. When the wind is coming from an ESE direction it appears that it is the West-East oriented T3 that consistently sees fewer drops. By contrast, when the winds are from the south, it is the North-South oriented T1 that sees fewer drops. These results are consistent with masking by the end of the instrument (see Figure 2). Notice that, for T3, masking is also observed when the wind is coming from the West.

The effect of drop size on under-recording due to masking

Disdrometers T1 and T3 were a few metres apart. For greater spatio-temporal comparability we now compare disdrometers T2 and T3 which are mounted at right-angles to one another on the same pole. Once again the data come from the period in March-April 2007 during which minute-by-minute records of wind velocity were available.

Let b_i denote the 0ne-minute count in some particular bin for disdrometer i. A natural comparison would be $\sum b_2$ with $\sum b_3$ for the same set of minutes (and the same bin). However, this comparison would be dominated by the few minutes with extremely heavy rain. For a robust and more representative measure we have calculated m_{ij} defined by

$$m_{ij} = \text{ Median } b_i/b_j$$

where the ratios $\{b_i/b_j\}$ are calculated only for those minutes in which both disdrometers have recorded at least 50 drops in the bin in question. The results are summarised in Table 5.

Table 5: Comparison between the co-mounted Thies disdrometers T2 and T3. The entries are the values of m_{23} ratio (see text) for varying drop sizes.

Drop size (mm) bin	Wind from the South m_{23}	Wind from the West m_{32}
0.125-	0.81	0.85
0.25-	0.86	0.96
0.375-	0.99	0.98
0.5-	1.00	0.98
0.75-	0.94	0.96
1-	0.98	0.96

In the table the two columns include all wind directions within 20° of that specified. The table shows that (as would be anticipated) it is the smaller drops that are most susceptible to masking. It appears that up to 20% of these drops remain undetected when the wind direction is from behind the body of the instrument. Being nearer the ground, T2 is also slightly masked by T3, and this may account for the greater masking observed for the 0.25- mm category in the case of winds from the South.

The effect of wind speed on under-recording due to masking

Table 6 examines the effect of wind speed on the apparent under-recording due to masking. The results are very clear. In light winds the orientation of the disdrometer is irrelevant, but, as the wind increases in speed so ever higher proportions of drops are lost to the instrument.

Table 6: Comparison between the co-mounted Thies disdrometers T2 and T3. The entries are the values of m_{23} ratio (see text) for varying wind speeds.

Wind speed (m/s)	Wind from the South m_{23}	Wind from the West m_{32}
0-	1.00	1.00
1-	0.97	0.97
2-	0.92	0.99
3-	0.88	0.91
4-	0.89	0.92
5-	0.86	0.78

Naturally the effect of wind speed is most marked for the smallest particles, as is demonstrated in Table 7. At the highest speeds the reduction in numbers may be as much as 20%.

Table 7: Comparison between the co-mounted Thies disdrometers T2 and T3. The values are the medians of the m_{23} ratio (see text) for winds coming from the arc (160°, 200°).

Drop size	Wind speed	
(mm)	< 3 m/s	> 3 m/s
< 0.25 mm	0.87	0.80
> 0.25 mm	0.98	0.93

Fall-speed calibration

Table 8 compares T2 with T1, which have the same North-South orientation as one another and are only separated by a few metres. The difference in distributions of fall speeds or drop diameters should be minimal. Once again we examine the minute-by-minute count ratios, again restricting attention to minutes in which each disdrometer recorded at least 50 drops, but now pooling over all wind speeds and directions.

Table 8: Comparison between the Thies disdrometers T2 and T1, which are both aligned North-South. The entries are the values of m_{21} ratio (see text).

Drop size	Fall speed (m/s)		
(mm)	< 1	> 1	All
< 0.25	1.23	0.93	0.99
> 0.25	0.95	1.04	1.03
All drop diameters	1.16	1.00	1.01

Ideally all the ratios in the table should be approximately 1.00. This is clearly not the case here: the larger differences are certainly real since they are repeated in non-overlapping sub-ranges of particle size and velocity. Table 9 gives the corresponding results when comparing disdrometers T2 and T3.

Table 9: Comparison between the co-mounted Thies disdrometers T2 and T3. The entries are the values of m_{23} ratio(see text).

Drop size	Fall speed (m/s)		
(mm)	< 1	> 1	All
< 0.25	1.55	0.87	0.95
> 0.25	0.95	1.02	1.01
All drop diameters	1.33	0.97	0.99

The encouraging figures in Tables 8 and 9 are those in the row margins: 0.99, 1.03, 0.95 and 1.01. Since these values are greasonably close to 1 they indicate that all three disdrometers are recording (as one would hope and expect) comparable numbers of both small drops and large drops.

For fall speeds the story told by Tables 8 and 9 is not so encouraging. The numbers of drops recorded as falling at speeds in excess of 1 m/s are very comparable (column margins of 1.00 and 0.97), but the numbers recorded as falling at slower rates vary dramatically from one disdrometer to another: the ratios (1.16 and 1.33) imply that, typically, for 6 drops observed by T3, there will be 7 drops observed by T1, and 8 by T2 (9 for the smaller sized drops). Since the overall numbers of drops recorded by the three instruments are comparable, it follows that, for example, T2 recorded fewer small drops as being fast-falling.

Conclusions

1. These three Thies disdrometers were very consistent with respect to their records of the sizes of the drops they sensed.
2. The Thies and Parsivel records are in noticeable disagreement, with the Parsivel recording much lower numbers of the smallest drops.
3. The fall speeds recorded by the Thies disdrometers vary appreciably from one disdrometer to another. This is particularly marked in the case of the smallest drops.

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