Disdrometric data analysis and related microphysical processes

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Abstract: The present paper consists in the analysis of Rain Drop Size Distribution (RDSD) measurements gathered by an optical based disdrometer. The main precipitation parameters such as accumulated amount, rain rate and median volume equivalent diameter for each episode are recalculated from corrected drop concentration per volume of air after applying a quality control filter. We put special emphasis on how different microphysical processes related to drop formation and evolution can be associated to RDSD modifications.

I. INTRODUCTION

Ordinary rain gauges and pluviographs are the usual instruments to gather measurements of the accumulated rainfall and give important information about how rainfall rate evolves throughout a precipitation episode. Although nowadays most of them can work automatically and provide digital data, they cannot distinguish between different hydrometeors like hail, snow, graupel or rain and do not contribute with additional data to improve our knowledge about related microphysical processes of each precipitation event.

Automatic disdrometers are instruments that can measure the spectra of rain drop size distributions (RDSD) and fall velocity of hydrometeors, providing the precipitation fine-structure of an episode. These instruments can measure the number of drops detected for different diameter and velocity classes which allow us to compute the drop kinetic energy and other precipitation related quantities such as rain rate and accumulated precipitation with 1-minute resolution. There are many rain drop size measurement techniques: acoustic disdrometers based on piezoelectric sensor, optical disdrometers like 2DVD that involves two cameras and finally the one used in this study, which is an optical laser based disdrometer that measures light signal changes when an hydrometeor falls through the beam area.

These instruments offer a wide range of possibilities when studying hydrometeors and here we mention a few of their multiple applications. For example ground based disdrometers can help gathering information about accumulated rain of an area or can help calibrating active remote sensing systems like weather radars [1]. Mobile disdrometers which can collect microphysical information in thunderstorms allows a better understanding of heavy rainfall events [2]. Moreover, 2DVD like disdrometers are even able to measure shape and drop oblateness [3].

The parameters computed by the disdrometer are utilized to provide information about microphysical raindrop formation and evolution processes. This can be done by studying the distribution N(D), which is the concentration drop number per unit volume of air and equivalent diameter written in volume equivalent diameter units ($m^{-3}mm^{-1}$) following:

$$N(D)_i = \sum_{i=1}^{32} \frac{10^6 n_{ij}}{180(30-0.5D_i)V_j \Delta D_i \Delta t} \tag{1}$$

where n_{ij} is the number of drops per each diameter-velocity class combination, V_j is the velocity class, ΔD_i is the bin size category width and Δt is the elapsed recording time per single 1-minute event (60 s) . For the Parsivel (PARticle SIze and VELocity) [4] disdrometer the detection area is set with the lengh and width of the beam, 180 mm and 30 mm respectively.

RDSD changes quickly through time and space but there are some characteristic parameters that let us associate modifications in drop distributions shape to microphysical processes. For instance, if there is a strong influence of evaporation the distribution N(D) will reflect a decrease for all diameters, particularly for small ones, while if coalescence is the dominant process the number of drops with small diameters will be increased. Another example that characterizes thunderstorm are updrafts where larger drops are detected before smaller ones and it is reflected in how the drop concentration distribution shifts with time N(D,t). In order to describe in a more quantitative way the modifications suffered by RDSD is often use an exponential fit like:

$$N(D) = N_0 D_0^{\mu} e^{-\lambda D} \tag{2}$$

where D_0 is the median equivalent diameter, N_0 the interception parameter and λ the exponential coefficient and μ is the Gamma distribution parameter. In the present work μ is taken as zero to obtain an exponential distribution fitting:

$$N(D) = N_0 e^{-\lambda D}. \tag{3}$$

Other complex statistical distributions can be used but with no significant improvements [5]. The aim of this work is to examine disdrometric Parsivel measurements, to check its RDSD spectral data quality, to compute the main parameters of the raindrop concentration distribution N(D) for many episodes, and to study how it evolves through time N(D,t).

II. DATA AND METHODOLOGY

In this paper, the studied data registers are provided by a Parsivel optical based disdrometer placed in the roof of Physics Faculty of University of Barcelona. The generated data files contain 1-minute resolution RDSD and fall velocity collected between March 2013 and July 2016 which contain, for each minute, the total particles detected per diameter and velocity class. There are 32 diameter classes from 0.062 mm to 24.50 mm and 32 velocity classes from 0.05 ms^{-1} to 20.80 ms^{-1}, taking different widths and the median values (D_i and V_i) of each bin as a reference. Notice that the first two diameter classes are always empty as the instrument cannot detect them.

In this study episodes are defined as 24 h period starting at 00 UTC and finishg at 23:59 UTC of the same day. The analyzed episodes were selected by the following criteria:

1. Total number of particles recorded.
2. Duration of the episodes (total minutes with rain).
3. Maximum values of rain rate.

Therefore to ensure a good statistical distribution for each drop diameter and velocity class, episodes with high total number of particles (at least 100.000 total particles per episode) have been selected. Episodes with long time duration provide useful information to describe how N(D) evolves with time, as more minutes of rain per episode are more likely to experience shifting in the drop size distribution shape. Then, episodes with the highest values of 1-minute maximum rain rate are also interesting to examine as they can be easily related with larger rain drop size distributions.

For each episode, the mean concentration value for each drop class has been calculated doing the sum of all 1-minute samples divided by the minutes of rain.

A. Data quality analysis

Although optical disdrometers do not influence the drop shape and velocity while gathering measurements, it had been found [6] that Parsivel usually overestimates or understimates the number of drops depending on the rain rate and diameter class and that in general, it overestimates the total accumulated amount [4]. Moreover, some drops are wrongly classified appearing in a nonsense diameter-velocity class. These spurious particles detected may be originated due to signal beam detection failure or other particles that are not related with the rain event. Therefore, the criterion described by Raupach and Berne [7] has been applied to the Parsivel measurements: First part of the applied criterion is to remove any particle if its drop diameter D_i is greater than 7.5 mm. This limit or larger diameter sizes are very unlikely to be surpassed because then drops normally break up into smaller ones [8]. The next step is to eliminate those particles with a velocity-diameter relation that do not satisfy the following expressions about their fall velocity:

$$\begin{aligned} V &> v(D) + 4 \\ V &< v(D) - 3 \end{aligned} \tag{4}$$

where v(D) is the drop terminal velocity Eq. 5, computed by Gunn and Kinzer [9] in ms^{-1} units:

$$v(D) = 9.65 - 10.3^{-0.6D}. \tag{5}$$

After filtration, the new drop concentration has been recalculated using Eq. 1 as well as the new rain rate:

$$R(mmh^{-1}) = 3.6 \times 10^{-3} \frac{\pi}{6} \sum_{i=1}^{32} N(D)_i D_i^3 v(D)_i \Delta D_i \tag{6}$$

and we use it to turn Parsivel drop concentration to 2DVD like measurements following Raupach and Berne criterion.

B. Raindrop distributions N (D)

After correction procedure of N(D) we can use the exponential fit described in Eq.3 to obtain its characteristic parameters. Hence, we use a semi-logarithmic scale representation to obtain slope parameter λ and interception point N_0 for each episode.

Despite taking μ to zero in Eq. 2, the median equivalent diameter D_0 can be also calculated from Eq. 7 that it is the cumulative distribution function (cdf):

$$cdf = \sum_{i}^{32} D_i^3 N(D)_i \Delta D_i. \tag{7}$$

We take into account the equivalent diameter volume for each diameter class and take the median value as the one that matches the 50% of the total cdf, that has been found by linear interpolation.

C. Microphysical processes

Until now, we have considered the mean concentration distribution N(D) for each episode but, RDSD evolves through time, therefore it is possible to calculate how N(D) changes during the episode and to relate which is the main microphysical process responsible of this modification. First, we divided episodes in various time stages of RDSD concentration, where each one contains the mean distribution for the given time interval. Then, by following Rosenfeld and Ulbrich [8] description of how microphysical processes changes RDSD shape and looking at N(D,t), we can try to identify the most probable or dominant process taking into account the next steps:

1. RDSD shifting to larger diameters, for example due to accretion or if there is also a decrease in the number of particles with smaller diameters, then coalescence is likely the dominant process.
2. Major diameter size of particles at initial and final stage, for example small diameters at initial stage, would suggest a predominant updraft process.
3. The presence of mixed processes is usually displayed and different process sometimes can be undistinguishable, for example evaporation and coalescence both produce a reduction in the number of larger particles.

III. RESULTS AND DISCUSSION

A. Results about corrected data

The applied filter and correction to original Parsivel data does not change significantly the total volume of measurements, in fact, Table 1 shows that in most episodes less than 1% of the gathered data by Parsivel have been removed. However, comparing plots (a) and (b) from Fig. 1, we can see smoother mean fall velocity representation in the corrected spectra and how those drops that do not satisfy the implemented criteria have been removed. On the other hand, the removed particles by filtration can cause important changes in the maximum 1-minute rain rate of an episode. That is the case of episodes 2013-04-27 and 2013-02-28 where the maximum rain rate was obtained thanks to drops that have been removed because they were too large. Otherwise, the correction coefficients can do the opposite effect, for example, in episodes where the accumulated amount of rain were less than 10 mm, there is a small increase in the maximum rain rate.

Episode	Duration (min)	Erased Dops (%)	Old max R (mmh^{-1})	New max R (mmh^{-1})	Old AA (mm)	New AA (mm)
2014-09-28	585	0.45	37.82	36.70	68.10	66.20
2013-02-28	758	3.03	87.02	11.51	43.69	19.60
2013-04-27	1020	0.39	389.95	7.53	37.62	19.78
2013-04-30	331	0.12	8.94	9.85	8.65	8.02
2016-04-21	502	0.09	16.91	16.14	20.57	19.92
2016-04-01	725	0.22	15.74	14.28	18.40	17.25
2013-11-17	993	0.65	41.84	17.77	39.50	36.90
2015-01-19	1363	0.03	2.07	2.40	9.11	6.87

TABLE I: Selected variables for each episode, where Old max R and Old AA refers to Rain rate and Accumulated Amount of rain before filter and correction is applied. New max R and new AA refers to the computed parameters after applying corrections. The accumulated amount of rain per episode has been calculated from each 1-minute rain rate.

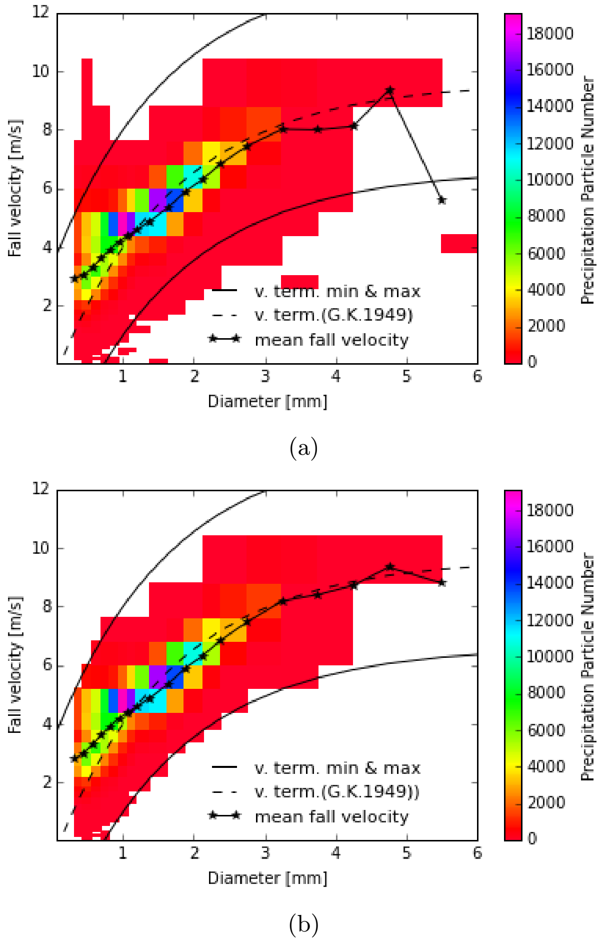
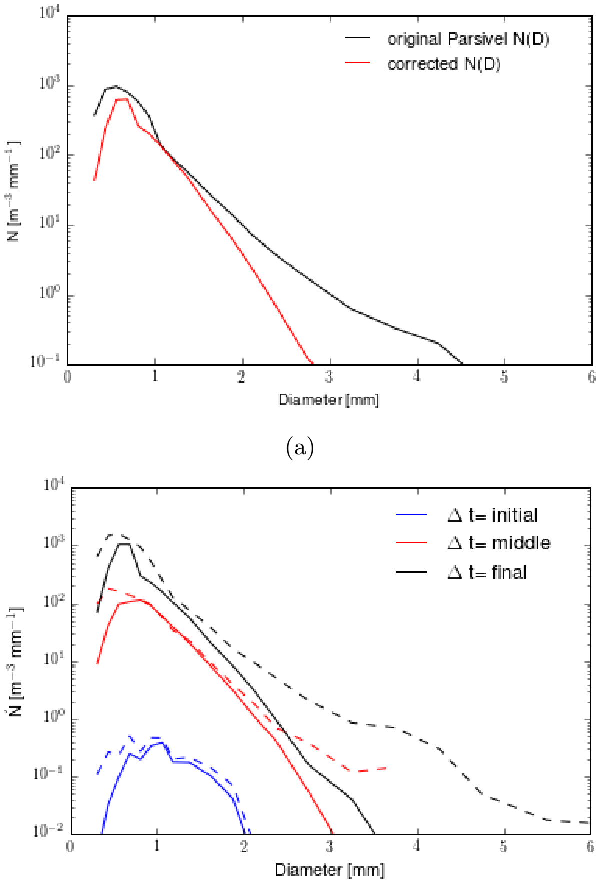


FIG. 1: (a) RDSD and fall velocity spectra from Parsivel measurements recorded during the 2014-09-28 episod before any filter is applied. Maximum and minimum terminal fall velocity accepted (Eq. 4) is represented and also the mean velocity per diameter cathegory V(D). (b) Same as (a) after corrections are applied.

B. Results of N(D) distributions

Fig. 2 shows the effect of the corrections on the N(D) for the episode 2013-02-28. This plot can help to explain why this is the episode with the most difference between rain rates and accumulated amount of rain because the original N(D) distribution is shifted to larger diameters. The rest of episodes does not show such a big discrepancy but all corrected distributions tend to decrease the concentration of drops for small diameters. As presented in Table 2, the exponential fitting shows similar exponent values between 2.8-3.6. Notice that higher λ values are



(a)

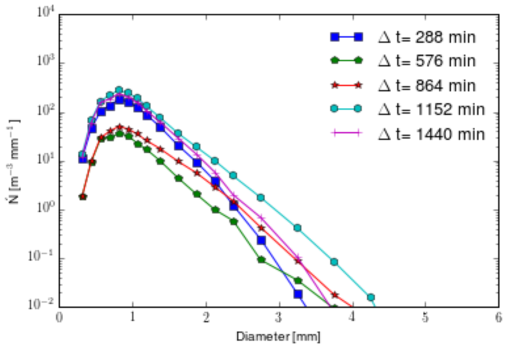
(b)

FIG. 2: Comparison of N(D) distribution for uncorrected and corrected Parsivel data recorded on the 2013-02-28 episoode. (a) Mean N(D) for all episode data. (b) Same as (a) but here N(D) is divided in three samples: Δ $t_{initial}$ from 0 min to 288 min, Δ t_{middle} from 576 min to 864 min and Δ t_{final} from 1152 min to 1440 min. Discontinuous line represents N(D) before the correction while continuous line is the N(D) after correction is applied

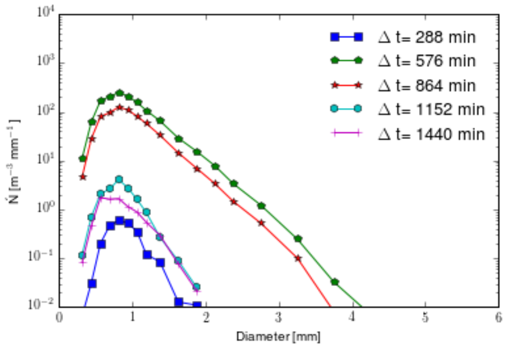
related in most episodes with higher interception parameters (N_0) and with smaller median equivalent diameters D_0. For example we can deduce that mean N(D) for 2013-04-30 and 2015-01-19 episodes is characterized by small drops diameters and a lack of larger diameters as the intercept parameters are big and D_0 are small.

Episode	N_0 ($m^{-3}mm^{-1}$)	λ	D_0 (mm)	About process
2014-09-28	4299.24	2.47	1.13	coalescence + breakup
2013-02-28	6066.94	3.63	1.01	
2013-04-27	3991.19	3.55	0.90	
2013-04-30	91627.05	6.27	0.60	
2016-04-21	3658.57	3.01	1.03	updraft+evaporation
2016-04-01	1813.40	2.85	1.11	accretion+downdraft
2013-11-17	2874.57	2.85	1.09	
2015-01-19	13809.20	5.56	0.86	

TABLE II: Exponential adjustment parameters for rain drop concentration N(D)



(a) 2013-11-17 episode



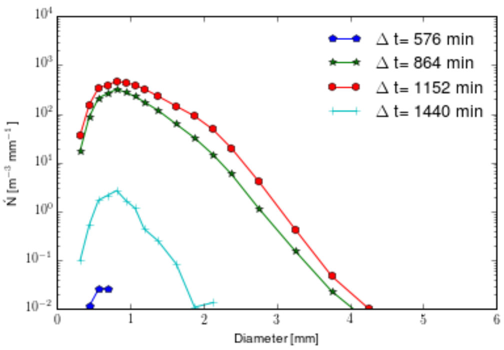
(b) 2016-04-01 episode

FIG. 3: Evolution of RDSD concentration throughout time for the 2013-11-17 espisode (a) and the 2016-04-01 episode(b) N(D,t) is the mean rain concentration distribution for the given Δ t.

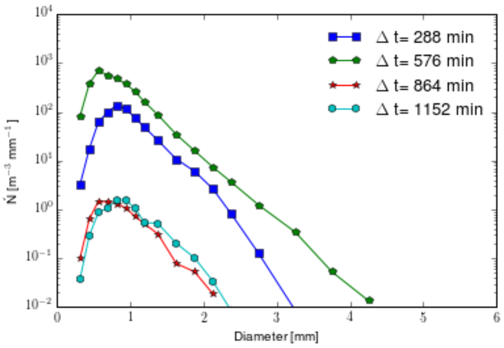
C. Results about related microphysical processes

For all episodes, the evolution of concentrations N(D) throughout time has been obtained. The most interesting cases represented in Fig. 3 are analyzed. Despite these episodes present similar λ and mean D_0 or even the same exponential coefficient (Table 2) they behave very differently during the precipitation episode. The 2013-11-17 episode shows very few changes in the N(D) distribution being almost constant, while RDSD of the 2016-04-01 (Fig. 3 (b)) and 2016-04-21 (Fig. 4 (b)) episodes is significantly modified through time.

In Fig. 3 (b) the episode starts with N(D) distribution in the small diameter regions, then there is a shift toward larger diameters and before it ends it goes



(a) 2014-09-28 episode



(b) 2016-04-21 episode

FIG. 4: Evolution of RDSD concentration throughout time for the 2014-09-28 espisode (a) and the 2016-04-21 episode(b) N(D,t) is the mean rain concentration distribution for the given Δ t.

back to the small diameters region. According to the schematic depictions provided by Rosenfeld and Ulbrich, accretion and downdraft processes are associated with an increase of all diameters cathegories. Since other microphysical processes can be involved, this has to be considered an approximation but it allows us to distinguish between those similar mean N(D) episodes. The 2014-09-28 episode in Fig. 4 (a) present an increase in all diameters classes shiftting towards larger diameters and it has the lowest slope parameter which suggest a combination of coalescence and breakup processes. Same analysis can be done done for Fig.4 (b) where this time the episode distribution starts in large diameters region, first runs to even larger diameters and then come back to diameter region under 2.5 mm, being in agreement with updraft and evaporation processes.

IV. CONCLUSIONS

Although data change due to the correction procedure, it is important to mention that if better accuracy is desired for rain rate and accumulated amount of rain, the removed particles must be considered in order to avoid underestimation issues. Regarding drop concentration distributions we have shown that it is relevant to analyze not only the mean N(D) distribution but also how it evolves because microphysical processes are hidden behind RDSD modifications and are more difficult to understand if using only mean parameters of an episode.

Finally, we note that uncorrected measures are good enough to identify the same microphysical processes as usually there are no big changes between the corrected and uncorrected N(D)s behaviour.

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