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Vertical profile of drop size spectra

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Abstract. This work is dedicated to measurements of precipitation drop size spectra. It is well known that weather radars measure reflectivity at a certain height but adaption of the rainrate is done by calibrating to ground-sensors' data. The space and time in between is usually neglected. With the aid of a vertically pointing radar measuring Doppler spectra at several altitudes, this black box shall be highlighted.

According to comparisons with disdrometers and tipping-buckets at ground level and with the weather radar aloft this sensor provides reliable measurements.

As a result of this work, a change of spectrum shape with altitude, dependent on rainfall intensity, can be observed. Integration leads to height-dependent Z-R-relationships which all of them tend to be linear.

Information gained by this study will result in a correction algorithm for weather radar data, in terms of vertical profiles of reflectivity or rainfall.

1 Introduction

Among the variabilities of precipitation in time and space, changes of drop size spectra with height play an important role. Usually this is disregarded because there are only few measurements of drop size spectra at different heights (measurements from airplane...). But the problem exists as weather radar measurements take place at a certain altitude whereas their calibration is usually done by ground based data - either the radar data is adjusted to surface based sensors or transferred to rainrate by Z-R-relationships established at ground-level.

Within the framework of APOLAS (Areal Precipitation measurements Over Land And Sea), a project under the German Climate Research Programme DEKLIM in the Baltic area (http://miraculix.dkrz.de/~gerhard/apolas.html), we attend to this problem. The aim is to achieve more accurate areal precipitation measurements by coupling novel and standard surface based rain sensors with the radar network of the German Weather Service. Drop size spectra are measured by three different instruments: an optical disdrometer (Großklaus et al., 1998), a Joss-Waldvogel-disdrometer and a vertically pointing radar all of them situated next to each other at Zingst, 52 km to the northeast of Rostock, where the closest weather radar is located. The vertically pointing radar provides measurements at different altitudes and thus closes the gap between ground based measurements and the weather radar as has been reported before (Wagner et al., 2003). Here the spectral development is considered for the first time.

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2 Methodology

The vertically pointing Micro Rain Radar MRR (Peters et al., 2002) is a 24 GHz FM-CW radar measuring Doppler spectra at 30 altitudes. From these Doppler spectra, drop size spectra, reflectivities or rainrate can be derived. Its temporal resolution has been set to 1 min and its spatial resolution to 100 m (30 steps up to an altitude of 3000 m). The lowest altitude is neglected because of noise. Mean spectra are used for the analysis of rain structure by adding up all drops per drop size class and normalising them. In addition, data was separated into three classes of rain intensity: light rain with intensities below 0.5 mm/h, moderate rain ranging from 0.5 to 4 mm/h and heavy rain exceeding 4 mm/h. Very strong rain which is expected to originate from strong convective cells was excluded because strong updrafts are possible sources of error for Doppler spectra.

3 Quality of data

To check the quality of MRR data, extensive comparisons between different sensors were performed which are mentioned here only in brief. Data is based on an amount of nearly 7000 measurements of rainfall simultaniously observed by all sensors.

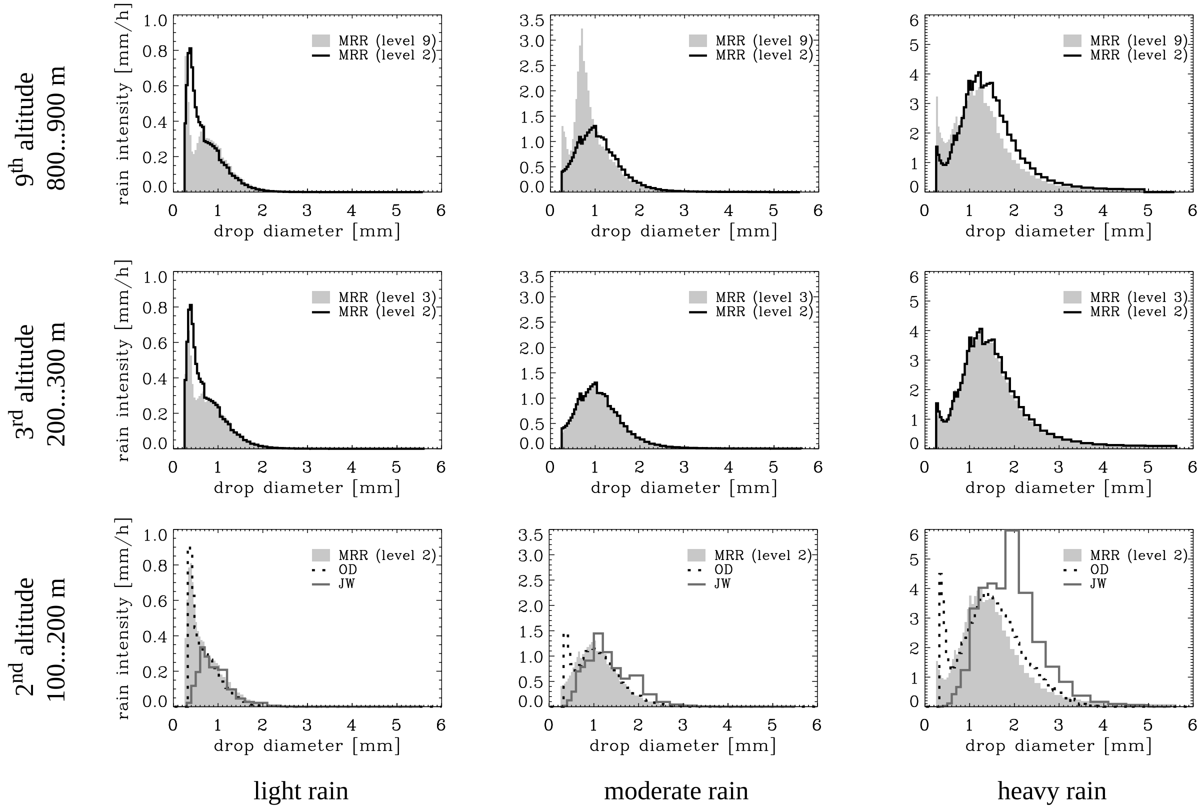

Fig. 1. Spectra of rainfall at three altitudes (100–200 m; 200–300 m; 800–900 m) separated into three classes of intensity (light, moderate and heavy rain) – presented in different scaling. The second level of MRR spectra is overplotted by simultaneous spectra of JW-disdrometer (JW; solid line) and optical disdrometer (OD; dotted line) for reason of comparison. The other two heights are overplotted by the appropriate MRR spectra of the second altitude in order to demonstrate changes of spectra with height.

The correlation coefficient between MRR data and different tipping-buckets on the basis of rainrate was 0.8. A more comprehensive comparison was possible between the two disdrometers and the MRR, as they all offer reflectivity, rainrate and drop size spectra. Correlation coefficients here have the same dimension as before.

Even the agreement of spectra from the MRR and from the optical disdrometer is very good (see Figs. 1 and 2). Only spectra from the Joss-Waldvogel-disdrometer differ to some extent: the number of small drops is clearly underestimated and at higher rainrates big drops are overestimated. Especially the first effect is well known but even current correction algorithms seem not to be able to correct adequately. So the discrepancies of spectra are likely to originate from the JW-disdrometer.

Validation of the MRR above ground level is only possible with weather radar data on the basis of reflectivity. The three lowest beams of the weather radar cover the range of the MRR. The correlation coefficient ranges between 0.6 and 0.9 depending on season because snow or the bright band may cause considerable discrepancies.

These results serve as a verification of the MRR even if the correctness of spectra above ground level cannot be proved.

4 What's the benefit of vertical measurements?

First of all, we want to know if there is any considerable change of rain structure with height. If so, where are these changes located and what are the reasons for them? Thus, we try to gain knowledge about underlying precipitation processes.

The next step would be the application of this additional information to correction algorithms for radar data which is in progress but will not be presented here.

The possible changes of rain structure are analysed using spectra with respect to three different aspects:

Firstly as a measure of major drop sizes the mass-weighted drop diameter D_m is used. The second aspect is the slope of the falling edge of the drop size spectrum (see Fig. 2) which is used to characterise the displacement of drop sizes with height. The last aspect is a visual comparison of the shape of spectra at different heights.

5 Interpretation of spectra

According to Table 1, D_m clearly indicates a change of major drop sizes with rainfall intensity and height. Separated into different classes of rainfall intensity it is not very astonishing

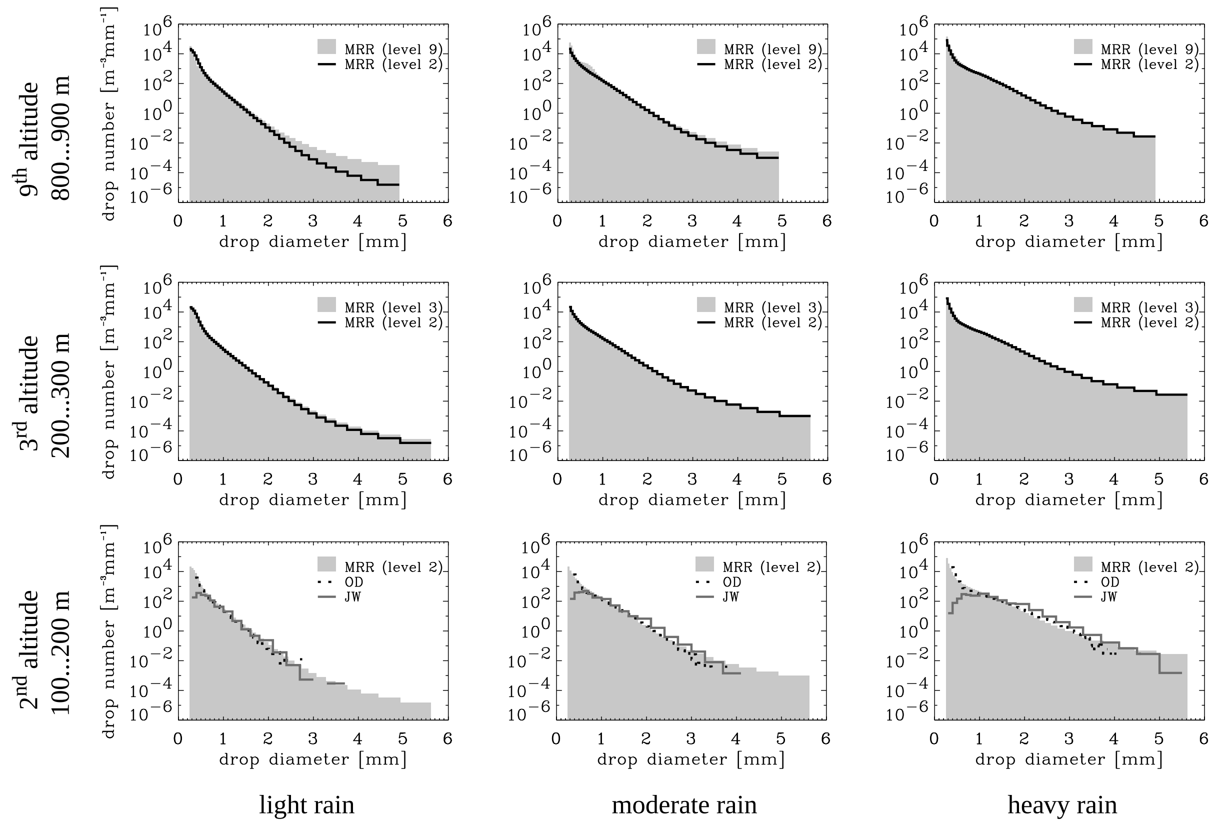

Fig. 2. Same as Fig. 1 but for spectra of drop number.

that heavier rain includes more bigger drops as the increase of D_m from 0.658 mm for light rain to 1.392 mm for heavy rain shows. This has been presented by numerous publications. The more interesting thing is the different shift of major drop sizes with height for light rain on one hand and for moderate and heavy rain on the other hand. D_m of light rain increases continuously and significantly with height. Heavy rain shows the opposite behaviour, D_m decreases with height, whereas at moderate rain intensities a decrease with height is only obvious from the fifth height level (500 m) upwards. The behaviour of heavy rain spectra can be explained by coagulation and other effects where big drops grow at the expense of smaller ones. For light rain, evaporation or other processes which cause a bigger number of small drops seem to dominate. A mixture of different effects (e.g. coagulation, evaporation, drop-sorting, etc.) could be responsible for the changes of D_m at moderate rain: processes which diminish (increase) drop sizes seem to prevail below (above) around 500 m.

If only D_m is regarded it is possible that the shape of the spectra doesn't change but D_m does. This may happen if all drops have been shifted uniformly to bigger or smaller drops. In contrast the slope of the falling edge of the drop size spectrum only changes if there is a nonuniform shift of drops. From Table 1 a difference of the slope between the three intensity classes is obvious. The smaller slope of heavy rain indicates a higher amount of big drops and a lower amount of small drops compared to light rain which has already been mentioned. But looking at the change of the slope with height within one class of intensity things are different. The higher the altitude the lower the slopes are. This is very conspicuous at light rain, the slope of moderate rain has fewer changes and that of heavy rainfall stays more or less constant. This means that a shift from bigger drops to smaller ones occures only at lower altitudes based on all spectra.

Table 1. Dm and the slope of the drop size spectra for altitudes 2–9 (100–900).

altitude	light rain		moderate rain		heavy rain	
	Dm	slope	Dm	slope	Dm	slope
2	0.658	−5.10	0.992	−4.03	1.392	−3.23
3	0.701	−4.88	1.054	−3.94	1.445	−3.23
4	0.730	−4.70	1.082	−3.96	1.435	−3.27
5	0.757	−4.56	1.097	−4.09	1.422	−3.31
6	0.757	−4.15	1.064	−3.88	1.370	−3.16
7	0.783	−4.05	1.054	−3.84	1.330	−3.20
8	0.785	−4.02	1.043	−3.82	1.290	−3.22
9	0.801	−4.01	1.037	−3.79	1.295	−3.18

These findings are supplemented by visual interpretation of Figs. 1 and 2 as neither parameter D_m nor the slope

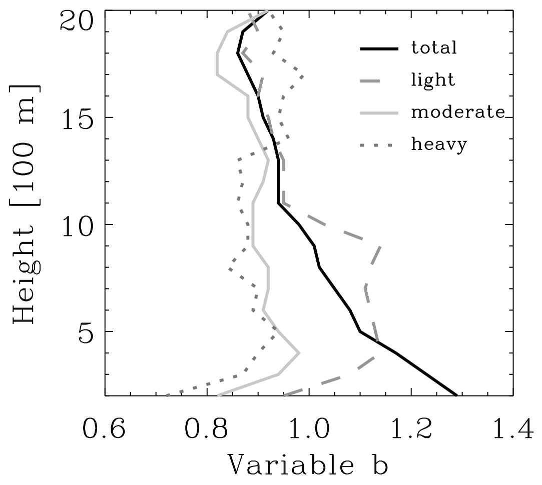

Fig. 3. Variable *b* of Z-R-relationship derived from 7000 MRR measurements at different heights (200 to 2000 m) and for different classes of intensity.

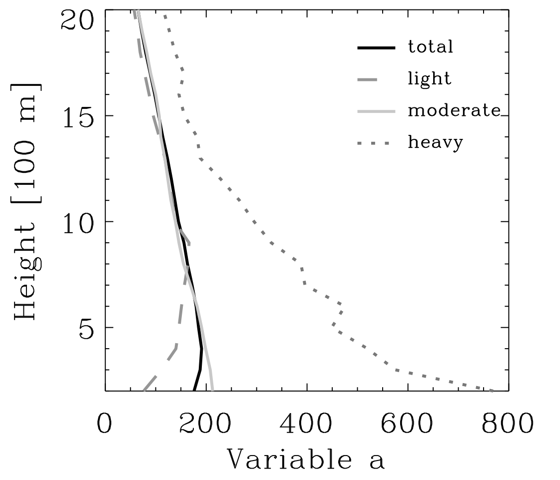

Fig. 4. Variable *a* of Z-R-relationship derived from 7000 MRR measurements at different heights (200 to 2000 m) and for different classes of intensity.

describe the shape of the spectrum or its changes completely. To this end, the third and ninth heights are overplotted by the second height (black steps; first height is neglected). The difference between intensity classes mentioned above is evident, as is the behaviour of light rain's spectra. Drops with diameters lower than 0.8 mm increase in number with lower altitude whereas larger ones decrease. Moderate and heavy rain spectra show the opposite: bigger drops with diameters greater than 1 mm grow at the expense of smaller ones with lower altitudes. The reason why the slope does not show this behaviour can be seen in the drop size spectra. According to the spectra at 800–900 m drops smaller than 1 mm and drops bigger than 3 mm diameter increase in number whereas drop number with diameters in between decreases. But the amount of big drops is so small that this increase is of minor importance for the rainrate (see Fig. 1).

6 Consequence for Z-R-relationship

Usually the Z-R-relationship ($Z=a*R^b$) is established by using drop size spectra from disdrometers at ground level and transferring it to radar data aloft. But the changes of spectra with height indicate that also Z-R relationships will be affected. Therefore, these relationships have been calculated from the mean spectra described before by regression with the independent variable R (rainfall) and the dependent variable Z (reflectivity). Variable *b* is equal to the regression coefficient.

Figures 3 and 4 show the results for heights 2 to 20 (200 m to 2000 m). For the whole number of spectra variable *b* decreases from 1.3 to 0.9 which is unexpected because we know from the discussion above that the amount of smaller drops increases with altitude which should lead to a greater variable *b*. However, separated into the three classes of intensity *b* behaves different. From 200 to 1500 m *b* acts as expected with highest *b* at low rain intensities and lowest *b* with highest rain intensities.

The more interesting matter is that for all intensities *b* is oscillating around 1 which would lead to a linear Z-R-relationship. Even for all spectra this variable is around 1 from the fifth height upwards.

Variable *a* decreases with height – rapidly for heavy rain and more slowly for moderate rain whereas for light rain it decreases only from the ninth height upwards, below there is a clear increase of *a*. Factor *a* is ranging between 60 and 210 for light, moderate and total rainfall, but for heavy rain *a* exceeds 500 at lower altitudes corresponding to Z-R-relationships for severe convection. An overview is given by Battan (1973).

Overall it is obvious that Z-R-relationships change with height, but differently for various rain intensities. Some kind of linearity between Z and R seems to exist (Jameson and Kostinski, 2002). The difference of spectra from light rain on one hand and spectra from moderate and heavy rain on the other hand is mirrored in variable *a* by an increase with height (lower altitudes) at lower rain intensities and a slight (moderate rain) or strong (heavy rain) decrease for other intensities.

7 Future plans

With the knowledge about changes of spectra gained here, two different approaches to correct radar data vertically seem reasonable.

The first one is to use a Z-R-relationship derived at the weather radar height. After that one can decide whether to additionally correct these precipitation data to ground level or not. This could be called a correction of the vertical precipitation profile (VPP).

The other approach would be to use the vertical information of reflectivity directly (VRP), by correcting radar reflectivity to ground level and afterwards calculating rainrate from it. All these attempts should be tested to yield a correction algorithm of vertical profiles for weather radar data of the German Weather Service.

Within the planned project AQUARADAR continuative research in terms of analysing rain structure is intended. In a special experiment in southern Bavaria up to 10 MRRs shall be closely spaced to offer not only profiles but volume measurements so that wind drift and spatial variability can be taken into account more thoroughly.

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