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Improvement of vertical profiles of raindrop size distribution from micro rain radar using 2D video disdrometer measurements

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ABSTRACT

A measurement scheme aimed at investigating precipitation properties based on collocated disdrometer and profiling instruments is used in many experimental campaigns. Raindrop size distribution (RSD) estimated by disdrometer is referred to the ground level; the collocated profiling instrument is supposed to provide complementary estimation at different heights of the precipitation column above the instruments. As part of the Special Observation Period 1 of the HyMeX (Hydrological Cycle in the Mediterranean Experiment) project, conducted between 5 September and 6 November 2012, a K-band vertically pointing micro rain radar (MRR) and a 2D video disdrometer (2DVD) were installed close to each other at a site in the historic center of Rome (Italy). The raindrop size distributions collected by 2D video disdrometer are considered to be fairly accurate within the typical sizes of drops. Vertical profiles of raindrop sizes up to 1085 m are estimated from the Doppler spectra measured by the micro rain radar with a height resolution of 35 m. Several issues related to vertical winds, attenuation correction, Doppler spectra aliasing, and range-Doppler ambiguity limit the performance of MRR in heavy precipitation or in convection, conditions that frequently occur in late summer or in autumn in Mediterranean regions. In this paper, MRR Doppler spectra are reprocessed, exploiting the 2DVD measurements at ground to estimate the effects of vertical winds at 105 m (the most reliable MRR lower height), in order to provide a better estimation of vertical profiles of raindrop size distribution from MRR spectra. Results show that the reprocessing procedure leads to a better agreement between the reflectivity computed at 105 m from the reprocessed MRR spectra and that obtained from the 2DVD data. Finally, vertical profiles of MRR-estimated RSDs and their relevant moments (namely median volume diameter and reflectivity) are presented and discussed in order to investigate the microstructure of rain both in stratiform and convective conditions.

1. Introduction

An important property characterizing rainfall is raindrop size distribution (RSD), defined as the concentration of number of raindrops as a function of diameter. Accurate knowledge of RSD is a key factor for understanding precipitation processes and developing and validating precipitation remote sensing retrieval techniques. The characteristics of RSD at ground (such as the shape) result from several different precipitation formation processes (such as coalescence, break-up and drop sorting). Typically, RSD at ground is measured by disdrometers, drop-sampling devices using different measurement principles, such as drop impact (Joss and Waldvogel, 1967), video analysis (Schönhuber et al., 2007), laser measurements (Löffler-Mang and Joss, 2000), or microwave returns from precipitating particles (Sheppard, 1990, and Prodi et al., 2000). However, it is also important to characterize changes of RSD in height, even in layers closer to the ground. Just to mention an application, errors in precipitation estimation from satellite-borne or ground-based weather radar depend also on vertical gradients of RSD in rain (Chandrasekar et al., 2003 and Gorgucci and Baldini, in press). Investigation of RSD vertical profiles has been conducted with several instruments and methods (e.g., Bringi et al, 2009, and Giangrande et al., 2012). Profiler observations, although limited to the rain column above the instruments, have a higher vertical resolution than that achievable by scanning weather radar that varies depending on the distance between radar sample volume and radar antenna. Moreover, they can provide more frequent measurements.

Within the Hydrological Cycle in the Mediterranean Experiment (HyMeX) Special Observing Period 1 (SOP1) framework (Ducrocq et al., 2014, and Ferretti et al., 2014 as far SOP1 activities in Central

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Italy are concerned), a disdrometer and a vertically pointing radar profiler were collocated on a rooftop at Sapienza University of Rome in the historic center of Rome. Specifically, installed were a 2D video disdrometer (2DVD) by Joanneum Research mbH, Graz, Austria (Schönhuber et al., 2007) and a radar vertical profiler termed micro rain radar (MRR) by Meteorologische Messtechnik GmbH (Metek). Drop diameter spectra and drop fall velocity spectra measured by 2DVD are considered to be more accurate within all the typical sizes of drops with respect to similar measurements collected by other disdrometers based on different measuring principles (Tokay et al., 2013). The collocated profiling instrument is supposed to provide complementary measurements, referred at different heights of the precipitation column above the instrument. MRR is a relatively cheap frequency-modulated continuous-wave (FM-CW) radar operating at K-band with a low-power solid state transmitter and a 60 cm offset antenna (2° beam width) pointed along a fixed direction. In the configuration adopted in the experiment in Rome, MRR measurements were provided from near ground level (the first gates were not usable) to 1085 m, with a height resolution of 35 m, for the purpose of investigating variability of precipitation within a narrow layer close to the surface. MRR estimates power spectra at different heights determined by backscatter of raindrops falling at different velocities. Since fall velocities are related to the diameters of drops, under certain assumptions, MRR spectra can be converted into drop size spectra (Metek, 2012). Peters et al. (2005) and Tokay et al. (2009) investigated the performance of MRR using the same configuration adopted in Rome. The first study analyzed the influence of different error sources using theoretical modeling and a dataset composed mainly of light to moderate rain. The second study took advantage of measurements collected by collocated impact disdrometer, raingauge, and an S-band radar profiler during a 16-month experiment. The S-band profiler was taken as a reference, being a pulsed system (therefore unaffected by the FM-CW artifacts described later) using an S-band frequency, hence almost unaffected by attenuation and able to provide reflectivity factor measurements in the Rayleigh scattering regime. Reflectivity measured by the S-band profiler agreed quite well with the reflectivity factor (i.e., the sixth moment of estimated raindrop size distribution) obtained from MRR, at a common gate at around 175 m. Moreover, both reflectivities agreed with measurements of an impact disdrometer at ground. However, reflectivity measured by the S-band profiler showed a smaller mean vertical gradient: the mean bias between MRR and profiler reflectivity was within 1 dB for heights below 500 m. Moreover, the bias between disdrometer and MRR reflectivity increased both with height and with reflectivity. Such findings suggest that MRR overestimates the vertical variability of reflectivity because of some artifacts related, for example, to spectra aliasing and underestimated attenuation effects.

Successful investigations using MRR in snow and light rain are reported in the literature, although required changes of several aspects of the MRR standard processing chain such as noise level estimation and detection and correction of spectra aliasing and height-Doppler ambiguity (Tridon et al., 2011, Kneifel et al., 2011 and Maahn and Kollias, 2012). Conversely, the utility of this instrument in heavy rain or in convection has been questioned (Calheiros and Machado, 2014) and deserves more investigation since heavy rain conditions were frequently observed during the HyMeX SOP 1. For this purpose, HyMeX SOP 1 data were examined to highlight the influence of different factors on vertical profiles estimated by MRR, focusing on heavy rain; also in order to propose some changes in the processing chain to improve the reliability of MRR profiles. The suggested processing takes advantage of techniques already introduced for snow and light rain and of the reference RSD estimated at ground by a disdrometer.

This paper is organized as follows. Section 2 presents an overview of the data available and of the processing of 2DVD and MRR, highlighting and justifying the proposed changes to the standard processing chain of MRR. Results concerning comparison of 2DVD and MRR measurements at the lowest reliable range gates are presented in Section 3. Finally, profiles resulting from the HyMeX campaign are illustrated in Section 4, while Section 5 summarizes important results of the paper.

2. Data and instrumentation

2.1. Overview of the HyMeX SOP 1 measurements in Rome

The study was performed using measurements collected by the MRR and the 2DVD installed on the roof (41.89°N, 12.49°E, 70 m above sea level) of the Department of Electrical Engineering and Telecommunications at Sapienza University of Rome (hereinafter Sapienza site) in the historic center of Rome. A detailed description of instrumentation made available for HyMeX SOP 1 in Central Italy by cooperating institutions for SOP1 is in Ferretti et al. (2014).

Measurements from the two instruments used in this study, namely MRR and 2DVD were available from 4 September to 11 November 2012. Eight days with total rainfall exceeding 5 mm and rain duration exceeding 15 min were chosen for this study. Table 1 lists the main characteristics of these rain events revealed by 2 DVD and MRR "averaged data". For each date in the first column (in the format MMDD—2 digits for the month and 2 digits for the day), the number of rainy minutes registered by the two instruments (see Section 2.2 for a definition of "rainy minute" for 2DVD) is reported in the second column, while the seventh column is the maximum drop diameter detected by the 2DVD during the event. Note that along the manuscript, the subscript "2DVD" means that a quantity has been computed from the 2DVD data, while subscripts like "AVE@105" means that it has been derived from the data provided by the standard Metek processing (namely the "*Averaged data*" described in Section 2.3) at the height of 105 m above the ground every minute. Most of the events that occurred in September and October were related to the presence of convection, while from the end of October, stratiform precipitation prevailed. Two events in October presented maximum rain rates above 100 mm h^{-1} (Table 1, fifth column), while the longest-lasting event was registered on October 31. In all cases, the melting layer was above the highest gate of the MRR.

2.2. 2DVD processing

The 2D video disdrometer measures the diameter, fall velocity, and oblateness of individual drops that fall through its virtual measuring area of 10 × 10 cm^2 (Schönhuber et al., 2007). In order to eliminate spurious drops, namely data potentially affected by instrumental errors or environmental factors (such as wind effect and splashing), the filtering criterion proposed by Tokay et al. (2001) was applied. The criterion implies that drops with velocity outside ±50% of the Atlas et al. (1973) diameter-fall speed relation

$$v_t(D_i) = 9.65 - 10.3\exp(-0.6\,D_i)\ (\mathrm{m\ s^{-1}}) \tag{1}$$

were removed. For the selected rain events, the percentage of drops removed by this criterion is reported in the last column of Table 1. For

Table 1
Summary of 2DVD and MRR recordings during HyMeX SOP 1 in Rome.

Day	Rainy minutes	R_{cum_2DVD}	$R_{cum\_AVE@105}$	max (R_{2DVD})	max ($R_{AVE@105}$)	D_{max}	% of filtered drops
0913	313	19.56	9.18	49.99	23.3	6.21	13.2
0914	401	11.10	6.96	11.15	6.96	5.35	9.5
0930	435	16.02	10.05	88.18	98.02	6.15	13.3
1012	252	37.98	17.49	154.23	50.35	7.79	18.4
1015	189	25.33	14.82	114.34	110.33	7.49	19.5
1026	245	14.85	10.77	39.23	33.06	5.02	15.6
1031	916	37.64	28.05	56.89	43.31	6.18	15.6
1111	331	11.11	8.95	35.09	52.11	6.69	13.2