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Rain rate retrieval from spectral moments of vertically pointing doppler radar

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1 Introduction

The Cabauw Experimental Site for Atmospheric Research (CESAR) is the national atmospheric remote sensing facility of The Netherlands. Several major Dutch universities and research institutes involved in atmospheric and land surface research have formed a research consortium and carry out collaborative research at CESAR (~ 25 km SW of Utrecht). One of the focal points of CESAR is the long-term monitoring of the macro- and microstructure of precipitation, with a view to an improved process representation in regional weather and climate models, and to provide a ground validation site for planned satellite precipitation missions (e.g. GPM). The development of improved rainfall retrieval algorithms for operational weather radars and atmospheric research radars is one of the central activities in this endeavour.

Our investigations currently focus on detailed comparisons of time series of doppler spectral moments as measured by the 3 GHz doppler-polarimetric Transportable Atmospheric Research Radar (TARA) and several types of disdrometers (impact-, optical-, and video-) and a local rain gauge network during rainfall experiments organized at CESAR, in particular the CESAR Rainfall Experiment 2002 (C-Rex'02, Fall 2002) and the Baltex Bridge Cloud campaign, phase II (BBC-2, May 2003). We are investigating the influence of sampling errors on disdrometer estimates of the doppler spectral moments and the influence of the vertical wind and turbulence on radar measurements of these moments.

The measured time series are employed to test a recently proposed rainfall retrieval algorithm based on doppler spectral moments (Uijlenhoet et al., 2005). This algorithm bypasses the need for estimating drop size distribution parameters on a spectrum-by-spectrum basis. It is based on statistical relationships between the rain rate R and the low-order moments of the doppler spectrum, i.e. the radar reflectivity factor Z (0th order moment), the mean doppler velocity v_{D} (1st order moment), and the doppler spectral width w_{D} (2nd order moment). These relationships are in fact generalizations of the widely used power law Z–R relations.

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2 Methodology

Most retrieval algorithms for estimating rainfall rate from vertically pointing doppler radar observations operate on a spectrum-by-spectrum basis (e.g. Hauser and Amayenc, 1981, 1983; Sangren et al., 1984; Williams, 2002). In other words, these algorithms estimate the parameters of the raindrop size distribution, the magnitude of the vertical wind, and the magnitude of the turbulence-induced spectral broadening (i.e. 4 to 5 parameters in total) for each doppler spectrum separately (e.g. Doviak and Zrnić, 1993). Hence, they generally do not take into account the spatial and temporal correlation structure that is characteristic for these parameters in rainfall.

We have proposed a rainfall retrieval algorithm which bypasses the need for estimating drop size distribution parameters on a spectrum-by-spectrum basis (Uijlenhoet et al., 2005). It is based on statistical relationships between rain rate and the low-order moments of the doppler spectrum (Sekhon and Srivastava, 1971; Atlas et al., 1973), i.e. the radar reflectivity factor Z (0th order moment), the mean doppler velocity v_{D} (1st order moment), and the doppler spectral width w_{D} (2nd order moment). These relationships can be seen as generalizations of the widely used power law radar Z–R relations. The algorithm can be summarized as follows:

If the raindrop terminal fall velocity-diameter relation follows the power law $v(D) = \alpha D^{\beta}$, then the rain rate estima-

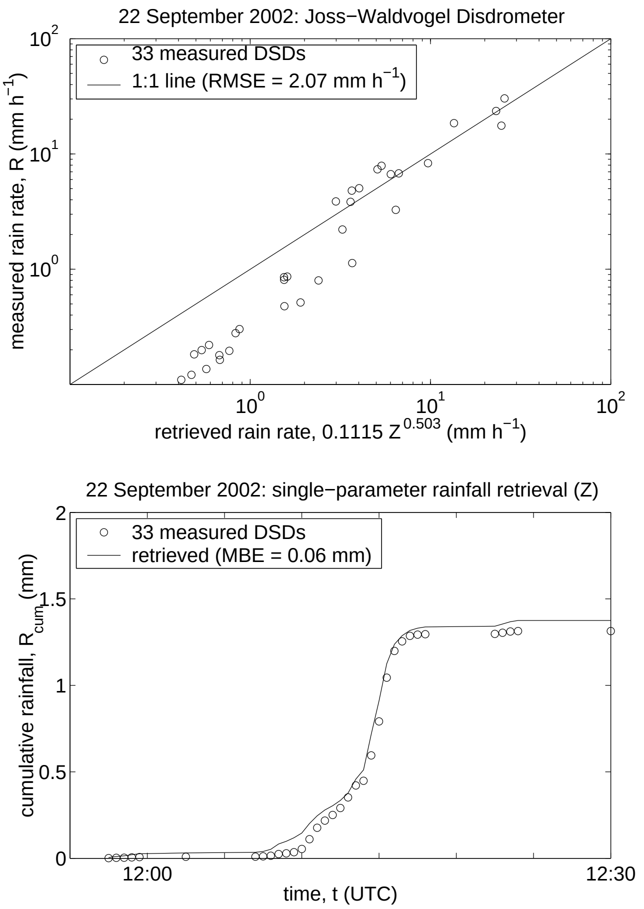

Fig. 1. Results of single-parameter $R(Z)$ rainrate retrieval using Joss-Waldvogel disdrometer data collected at CESAR during C-Rex'02 on 22 September 2002.

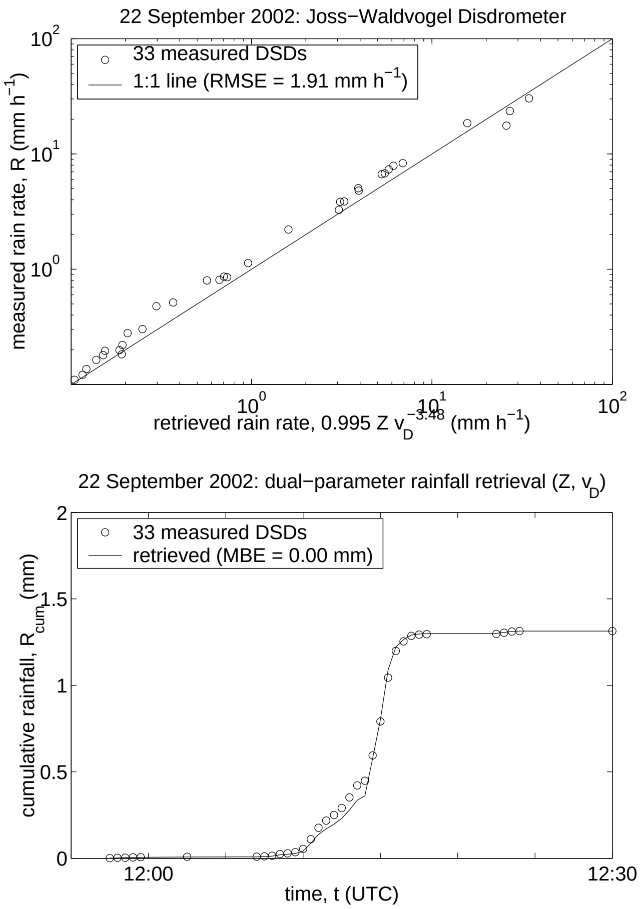

Fig. 2. Results of dual-parameter $R(Z, v_{\rm D})$ rainrate retrieval using Joss-Waldvogel disdrometer data collected at CESAR during C-Rex'02 on 22 September 2002.

tor for *any* parameterization of the raindrop size distribution (DSD) follows the general (*double* power law) form

$$R = c\, Z\, v_{\rm D}^{-(3-\beta)/\beta}, \qquad (1)$$

where c is a function of α and β, of the upper diameter truncation limit $D_{\max}$ of the DSD, and of the width of the DSD (or, equivalently, the width of the doppler velocity spectrum). This is actually a special case of the double-moment normalization of drop size distributions proposed by Lee et al. (2004).

For an exponential parameterization for the DSD (gamma DSD with $\mu = 0$) and for $D_{\max} \to \infty$, $c \approx 1.31$ if $\alpha = 3.78$ and $\beta = 0.67$ (Atlas and Ulbrich, 1977), where v in m s^{-1} and D in mm.

For a gamma parameterization for the DSD (arbitrary values of $\mu > -1$) and a given upper diameter truncation limit $\Lambda D_{\max}$, the expression for c becomes a rather complicated function of α, β, $\Lambda D_{\max}$, and μ, involving multiple incomplete gamma functions.

For a lognormal parameterization for the DSD and for $D_{\max} \to \infty$, on the other hand, the rain rate estimator takes the simple explicit (*triple* power law) form

$$R = d\, Z\, v_{\rm D}^{-(3-\beta)/\beta} (1 + {\rm CV}_{\rm D}^2)^{3(3-\beta)/(2\beta^2)}, \qquad (2)$$

where $d = 6\pi \times 10^{-4} \alpha^{3/\beta} \approx 0.725$, $-(3-\beta)/\beta \approx -3.48$, and $3(3-\beta)/(2\beta^2) \approx 7.79$. For finite values of $D_{\max}$ (assumed to be a fixed multiple of the geometric mean diameter) d increases as a function of the width of the DSD (and consequently as a function of the width of the doppler spectrum).

3 Results and discussion

Application of the proposed dual- and triple parameter rainfall retrieval algorithms to optical spectropluviometer (SPO) measurements for three contrasting precipitation events during HIRE'98 (HYDROMET Integrated Radar Experiment 1998) in Marseille, France, has revealed that the parameters

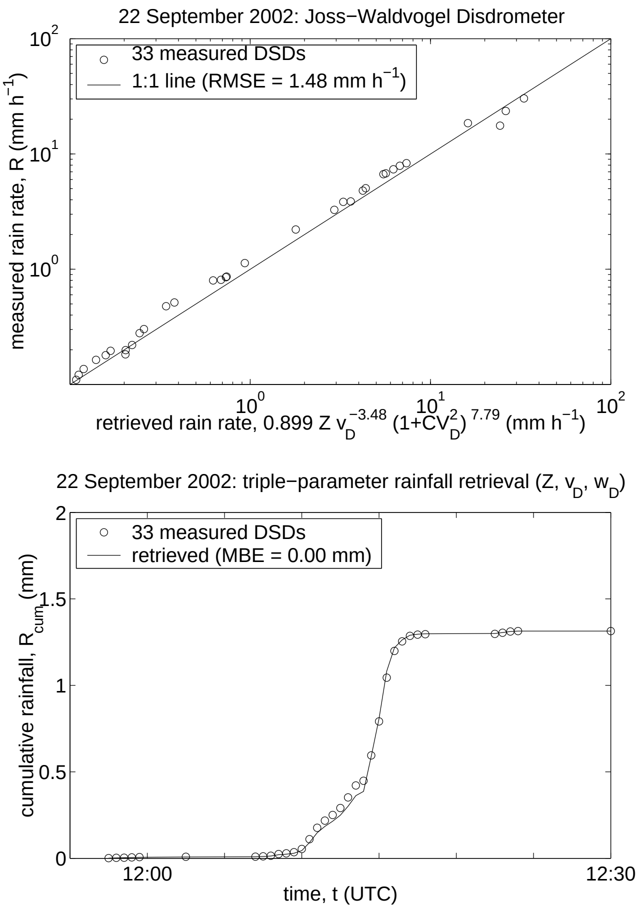

Fig. 3. Results of triple-parameter $R(Z, v_\mathrm{D}, w_\mathrm{D})$ rainrate retrieval using Joss-Waldvogel disdrometer data collected at CESAR during C-Rex'02 on 22 September 2002.

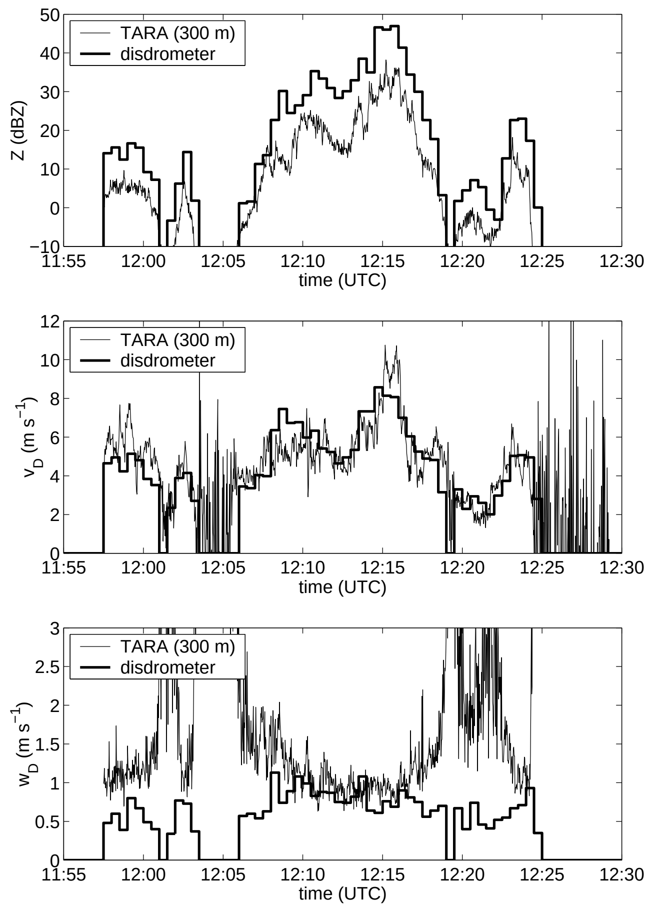

Fig. 4. Time series of doppler spectral moments from TARA compared to those from Joss-Waldvogel disdrometer collected at CESAR during C-Rex'02 on 22 September 2002.

of the estimators are much more stable than those of the traditional single-parameter reflectivity-based (Z–R) estimator (Uijlenhoet et al., 2005).

Here we focus on a rainfall event that occurred on 22 September 2002 during C-Rex'02. The cumulative rainfall as measured using a Joss-Waldvogel disdrometer amounted to 1.4 mm and the maximum rain rate was $\sim$ 30 mm h^{-1}. Figures 1–3 show the results of the presented methodology as applied to the Joss-Waldvogel disdrometer measurements. The estimated parameter values are comparable to those obtained during HIRE'98 (Uijlenhoet et al., 2005).

Figure 4 shows a comparison of the doppler spectral moments measured by TARA at an altitude of 300 m and those estimated from the (colocated) Joss-Waldvogel disdrometer. The radar data were shifted by 1 min 30 sec to compensate for the height difference. There is a systematic bias in the measured reflectivities, which was found to be related to a faulty calibration of the radar. The measured mean doppler velocities on the other hand correspond quite closely, indicating that the vertical wind does not play a major role during this event. During the heaviest rainfall, when the signal-to-noise ratio is large, the doppler spectral width measured by TARA approaches that obtained from the disdrometer.

Figure 5 shows the resulting single-, dual- and triple-parameter rainfall retrievals from the doppler spectral moments measured by TARA, as compared to rain rates estimated from the raindrop size spectra measured by the Joss-Waldvogel disdrometer. For the single-parameter retrieval, a 10 dB recalibration was applied to the measured reflectivities. Clearly, the doppler spectral width is too noisy to improve the (triple-parameter) rainfall retrieval in this case.

4 Conclusions

We have derived theoretical relations between rain rate and the doppler spectral moments for several widely used parametric forms of the raindrop size distribution (gamma, lognormal), taking into account diameter truncation effects. We

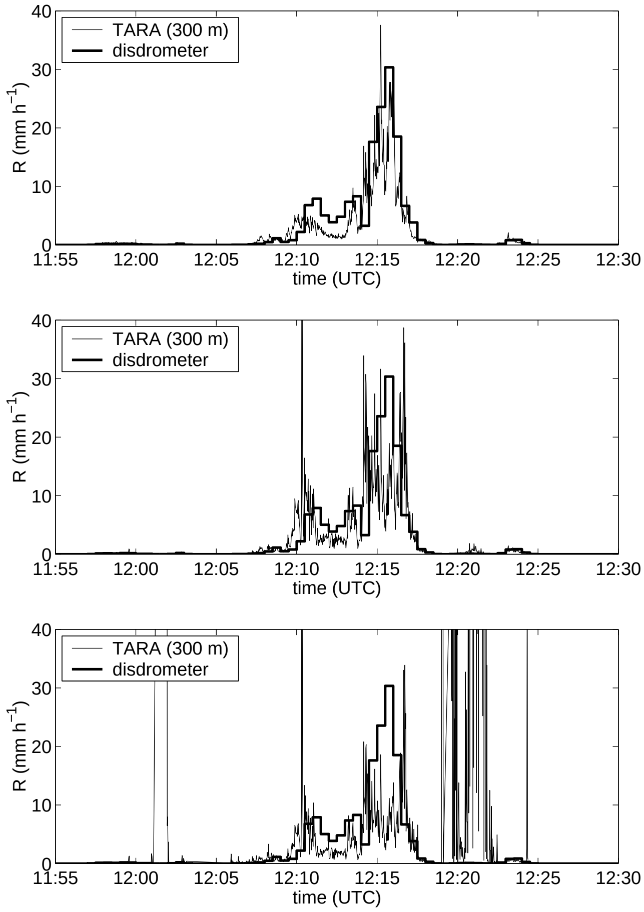

Fig. 5. Results of single- (top panel), dual- (middle panel), and triple-parameter (bottom panel) rainrate retrieval from TARA doppler spectral moments compared to rain rates from Joss-Waldvogel disdrometer collected at CESAR during C-Rex'02 on 22 September 2002.

have demonstrated that by taking into account additional information provided by higher order spectral moments, the parameters of the derived statistical relations should become less dependent on the raindrop size distribution and its variability.

Using measured raindrop size spectra, we have demonstrated the validity of the derived theoretical relations in different types of rainfall (convective, stratiform) in different climatic settings (south of France, The Netherlands). In addition, we have presented a first application of the presented approach to spectral moments measured by a vertically pointing doppler radar.

The universality of the parameters of the studied rainfall estimators is currently being investigated using a large dataset of raindrop size distribution measurements collected with different types of disdrometers (impact-, optical- and video-disdrometers) at the Cabauw Experimental Site for Atmospheric Research (CESAR) in the Netherlands. We are also investigating the implications of our approach for the scaling (normalization) of raindrop size distributions and doppler spectra.

At the same time, we are applying the developed rainfall retrieval algorithms to a larger dataset of measurements from S-band (TARA) and K-band (METEK Micro Rain Radar) vertically pointing doppler radar measurements collected at CESAR. Of particular interest in this respect is an assessment of the potential of the proposed methodology for practical purposes by investigating its sensitivity to the magnitudes of vertical wind and turbulence-induced spectral broadening.

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