15R.7

ALGORITHM FOR RAIN RATE RETRIEVAL FROM SPECTRAL MOMENTS OF VERTICALLY POINTING DOPPLER RADAR

Remko Uijlenhoet[1*], Hidde Leijnse[1], and Alexis Berne[1]

[1]Environmental Sciences Group, Wageningen University, The Netherlands

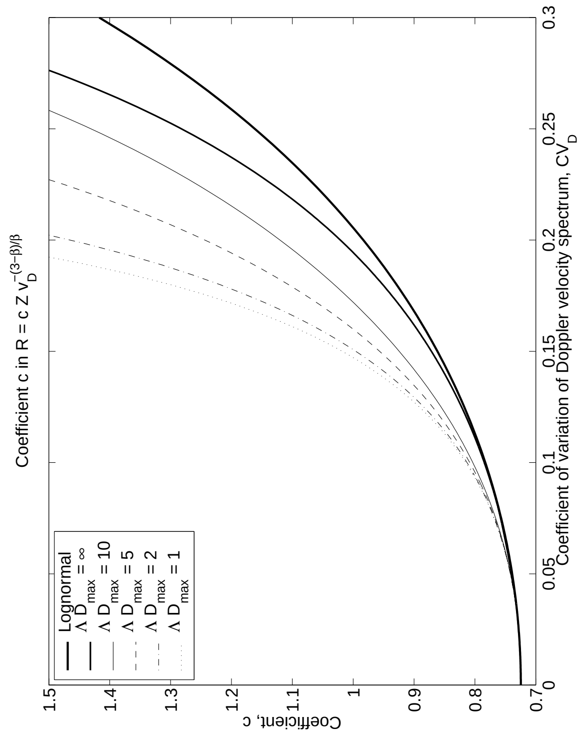

Figure 1: Dependence of the coefficient c in $R = c\,Z\,v_{\mathrm{D}}^{-(3-\beta)/\beta}$ on the coefficient of variation $\mathrm{CV_D}$ of the Doppler velocity spectrum of the (truncated) gamma and the (untruncated) lognormal raindrop size distribution.

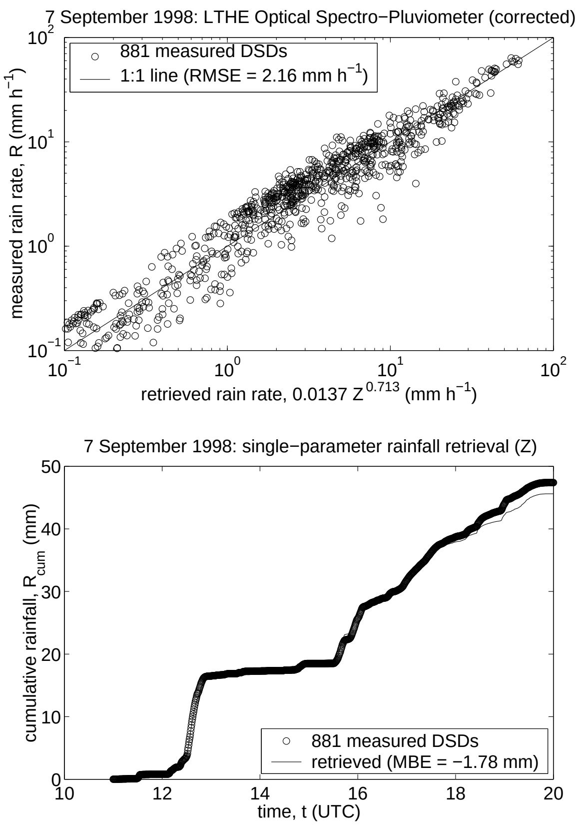

Figure 2: Results of single-parameter $R(Z)$ rain-rate retrieval using optical spectropluviometer data collected during HIRE'98 on 7 September 1998.

1 INTRODUCTION

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 propose a rainfall retrieval algorithm which bypasses the need for estimating drop size distribution parameters on a spectrum-by-spectrum

[*] *Corresponding author address:* Dr Remko Uijlenhoet, Wageningen University, Environmental Sciences Group, Chair of Hydrology and Quantitative Water Management, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands; e-mail: remko.uijlenhoet@wur.nl

basis. 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 (0th order moment), the mean doppler velocity (1st order moment), and the doppler spectral width (2nd order moment). These relationships are in fact generalizations of the widely used power law radar reflectivity - rain rate relations.

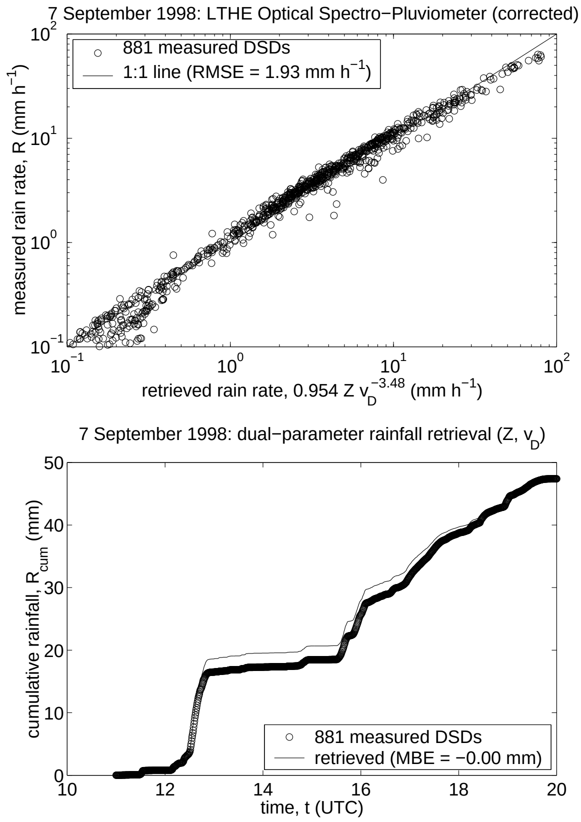

Figure 3: Results of dual-parameter $R(Z, v_{\rm D})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 7 September 1998.

2 RESULTS

- If the raindrop terminal fall velocity-diameter relation follows the power law $v(D) = \alpha D^{\beta}$, then the rain rate estimator for *any* parameterization of the raindrop size distribution (DSD) follows the general (*double* power law) form

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

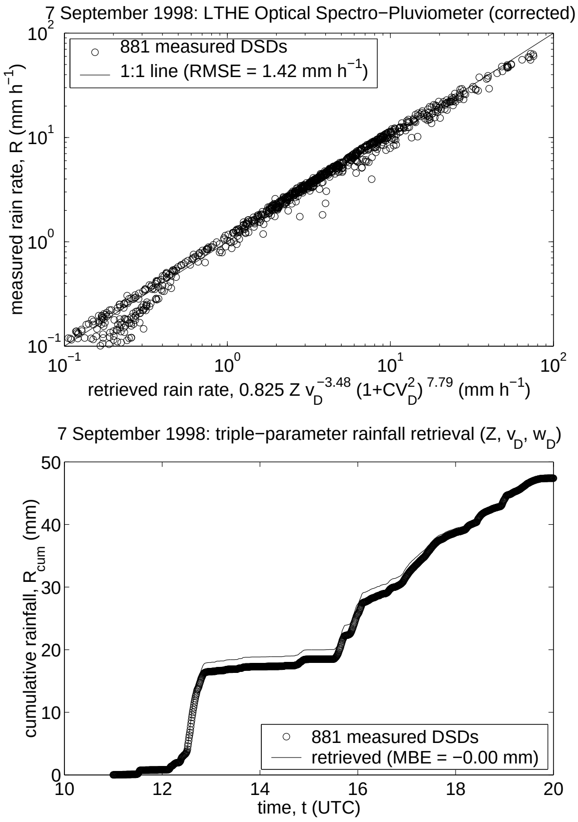

Figure 4: Results of triple-parameter $R(Z, v_{\rm D}, w_{\rm D})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 7 September 1998.

where c is a function of α and β, of the upper diameter truncation limit $D_{\rm max}$ 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 ($\mu = 0$) and for $D_{\rm max} \to \infty$, $c \approx 1.31$ (see Fig. 1) 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 $\mu > -1$) and a given upper diameter truncation limit $\Lambda D_{\rm max}$, the expression for c becomes a rather complicated function of α, β, $\Lambda D_{\rm max}$, and μ, involving multiple incomplete gamma functions (see Fig. 1).

- For a lognormal parameterization for the DSD

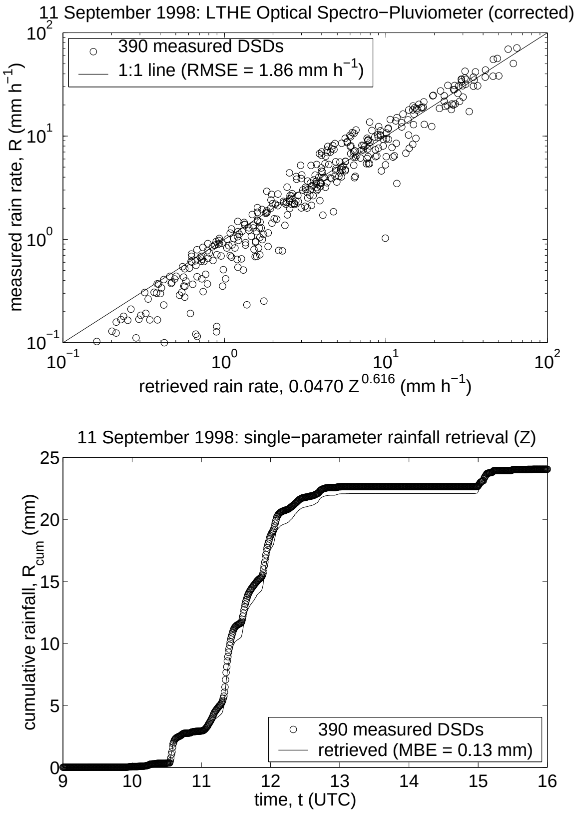

Figure 5: Results of single-parameter $R(Z)$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 11 September 1998.

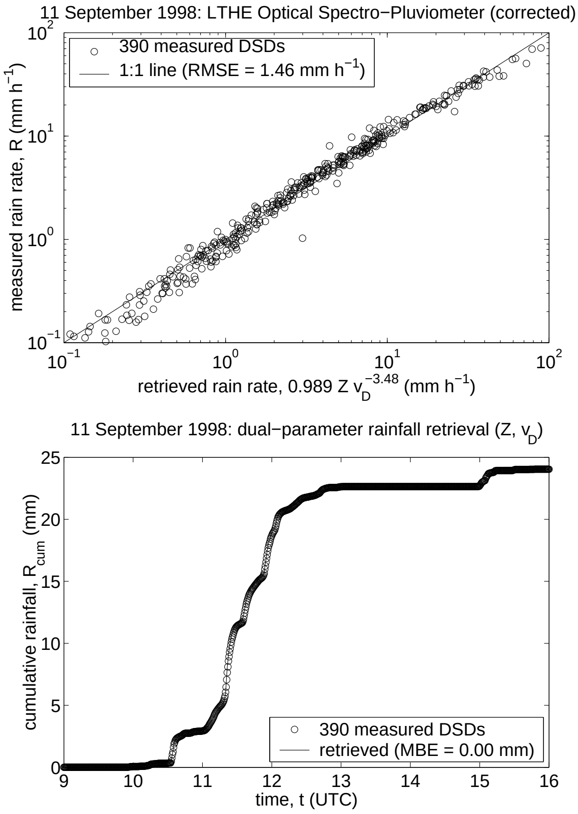

Figure 6: Results of dual-parameter $R(Z, v_{\mathrm{D}})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 11 September 1998.

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

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

where $d = 6\pi \times 10^{-4} \alpha^{3/\beta} \approx 0.725$, $-(3-\beta)/\beta \approx -3.48$, and $3(3-\beta)/(2\beta^2) \approx 7.79$ (see Fig. 1). For finite values of $D_{\max}$ (assumed to be a fixed multiple of the geometric mean diameter) d tends to increase as a function of the width of the DSD (and consequently as a function of the width of the Doppler spectrum).

- 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, reveals that the parameters of the estimators are much more stable than those of the traditional single-parameter reflectivity-based $(Z - R)$ estimator (see Figs. 2–10).

- 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.

- The next step in this investigation will be to apply the developed rainfall retrieval algorithms to measurements from S-band (the Transportable Atmospheric Research Radar TARA from TU Delft) and K-band (METEK Micro Rain Radar) vertically pointing Doppler radar measurements collected at CESAR.

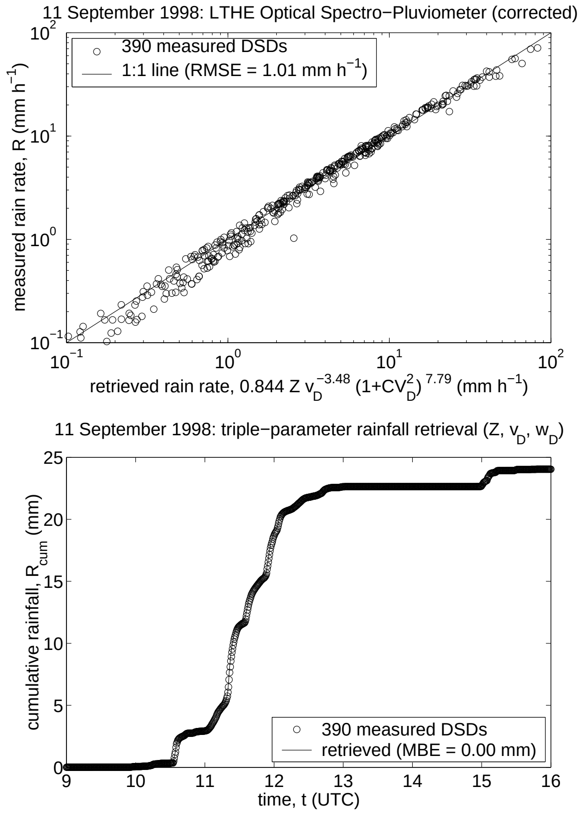

Figure 7: Results of triple-parameter $R(Z, v_\mathrm{D}, w_\mathrm{D})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 11 September 1998.

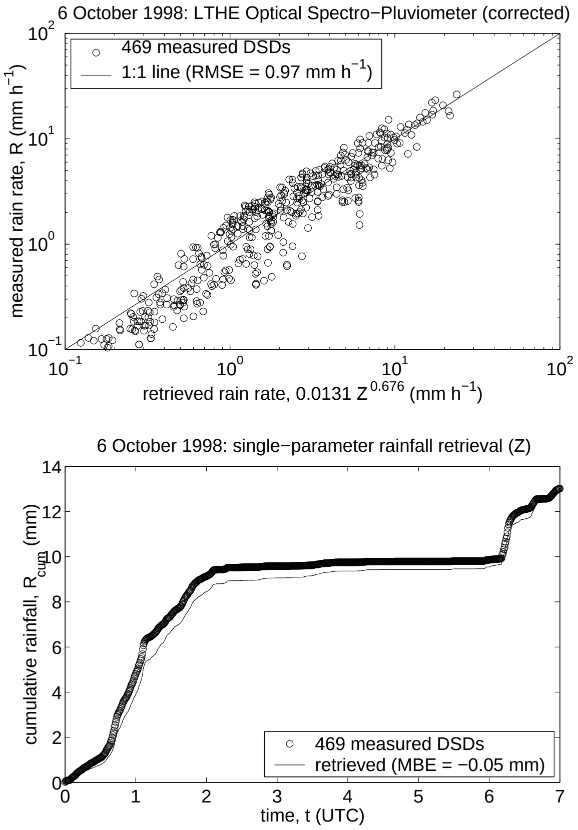

Figure 8: Results of single-parameter $R(Z)$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 6 October 1998.

3 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 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 (The Netherlands, south of France). We are currently investigating the implications of our approach for the scaling (normalization) of raindrop size distributions and doppler spectra. Finally, we are in the process of assessing the potential of the proposed methodology for practical purposes by investigating its sensitivity to the magnitudes of vertical wind and turbulence-induced spectral broadening.

ACKNOWLEDGMENTS

R.U. and H.L. are supported by the Netherlands Organization for Scientific Research (NWO) through Grant 016.021.003 (*Vernieuwingsimpuls*). A.B. is supported by the European Commission in the framework of the projects VOLTAIRE and FLOODSITE.

REFERENCES

Atlas, D., R. C. Srivastava, and R. S. Sekhon, 1973: Doppler radar characteristics of precipitation at vertical incidence. *Rev. Geophys. Space Phys.*, **11**, 1–35.

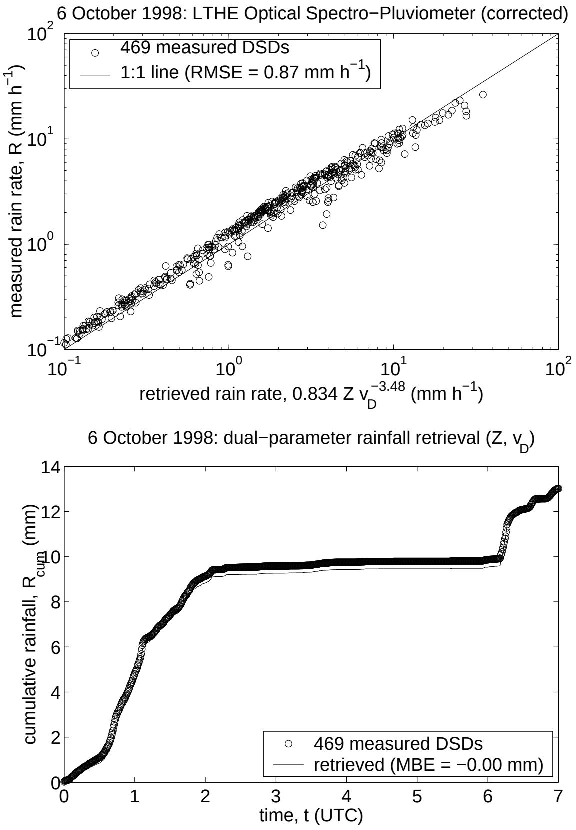

Figure 9: Results of dual-parameter $R(Z, v_\mathrm{D})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 6 October 1998.

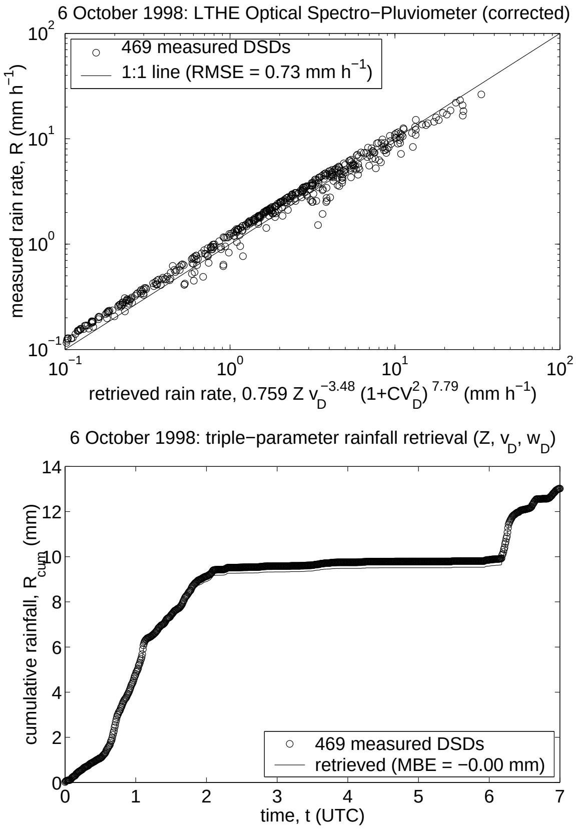

Figure 10: Results of triple-parameter $R(Z, v_\mathrm{D}, w_\mathrm{D})$ rainrate retrieval using optical spectropluviometer data collected during HIRE'98 on 6 October 1998.

Atlas, D. and C. W. Ulbrich, 1977: Path- and area integrated rainfall measurement by microwave attenuation in the 1–3 cm band. *J. Appl. Meteorol.*, **16**, 1322–1331.

Doviak, R. J. and D. S. Zrnić, 1993: *Doppler radar and weather observations*. Academic Press, San Diego, 2nd edition, 562 pp.

Hauser, D. and P. Amayenc, 1981: A new method for deducing hydrometeor-size distributions and vertical air motions from Doppler radar measurements at vertical incidence. *J. Appl. Meteorol.*, **20**, 547–555.

— 1983: Exponential size distributions of raindrops and vertical air motions deduced from vertically pointing Doppler radar data using a new method. *J. Clim. Appl. Meteorol.*, **22**, 407–418.

Lee, G. W., I. Zawadzki, W. Szyrmer, D. Sempere Torres, and R. Uijlenhoet, 2004: A general approach to double-moment normalization of drop size distributions. *J. Appl. Meteorol.*, **43**, 264–281.

Sangren, K. L., P. S. Ray, and G. B. Walker, 1984: A comparison of techniques to estimate vertical air motions and raindrop size distributions. *J. Atmos. Oceanic Technol.*, **1**, 152–165.

Sekhon, R. S. and R. C. Srivastava, 1971: Doppler radar observations of drop-size distributions in a thunderstorm. *J. Atmos. Sci.*, **28**, 983–994.

Williams, C. R., 2002: Simultaneous ambient air motion and raindrop size distributions retrieved from UHF vertical incident profiler observations. *Radio Sci.*, **37**, doi:10.1029/2000RS002603.