P2.6 THE ENHANCEMENT OF RADAR RETRIEVALS BY THE USE OF HIGHER MOMENTS OF DROP SPECTRUM

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1. INTRODUCTION

In this paper, we analyze LES simulations of boundary layer stratiform clouds in order to identify the most sensitive cloud drop spectrum parameters necessary for retrieval of cloud liquid water content (Q_l) and precipitation flux (R). Although radar reflectivity Z (which is proportional to the sixth moment of particle size) contains information about cloud and precipitation particle spectra, depending on the shape of the spectra this information may or may not be sufficient for accurate retrieval of cloud parameters. The retrieval task is the most straightforward in the case of non-precipitating boundary layer stratocumulus where cloud spectra are mostly unimodal and contribution from the large tail of the spectrum is minimal. A simple Z-Q relation in this case is justified (Atlas, 1954; Sauvageot and Omar, 1987; Frisch et al., 1995; Fox and Illingworth, 1997):

$$Z=aQ_l^b \tag{1}$$

Here parameters a and b depend on the assumptions about the drop number concentration and the shape of spectrum.

We evaluate the possibility of improving the retrieval algorithms using microphysical data generated by the CIMMS LES model with size-resolving microphysics. The simulated drop size distributions (DSD) were used to calculate cloud properties and radar reflectivity for both non-drizzling and drizzling conditions reproduced based on ASTEX observations. The objective of the study is to assess the improvements in retrievals due to additional information on the large droplet tail of the DSD.

2. MODEL AND DATA

The CIMMS LES model explicitly predicts CCN and DSD functions (Kogan et al. 1995); model results have been tested against and found in good agreement with integrated observations of microphysical, radiative, and turbulence parameters (Khairoutdinov and Kogan 1999). The drizzle parameterization derived based on the model data was also validated against a large number of observational data sets (Wood, 2000, Wood et al, 2002). We simulated several cases of stratocumulus clouds observed during the ASTEX field experiment in clean and polluted air masses.

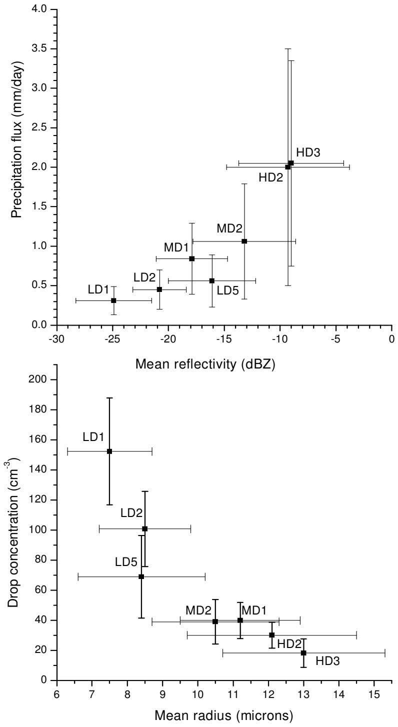

Fig. 1. Range of cloud parameters in the analyzed cases of stratocumulus cloud layers. The black square represents the mean, while the error bars show the standard deviation of the parameter.

The simulated cloud layers represented cases with different intensities of drizzle *in the cloud* (drizzle is defined as drops larger than 25 microns in radius). The range of cloud and drizzle parameters is shown in Fig.1 for separate datasets representing light (LD), moderate (MD) and heavy (HD) drizzle spectra. As cloud layer evolves quite significantly during the

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three to six hour-long simulations, these datasets were further subdivided into subsets corresponding to a particular time of cloud evolution (e.g. LD5 refers to light drizzle case at 5 hrs into simulation). From each simulation we extracted about 4,000 to 6,000 DSD which comprised datasets used for deriving cloud parameters, as well as benchmarks for retrieval performance assessment.

3. RESULTS

We present results for three datasets, LD1, MD1, and HD2; corresponding drizzle distributions *in the cloud* are shown in Fig.2. In the light drizzle case the DSD are all unimodal with negligible amount of drizzle water, Q_r.

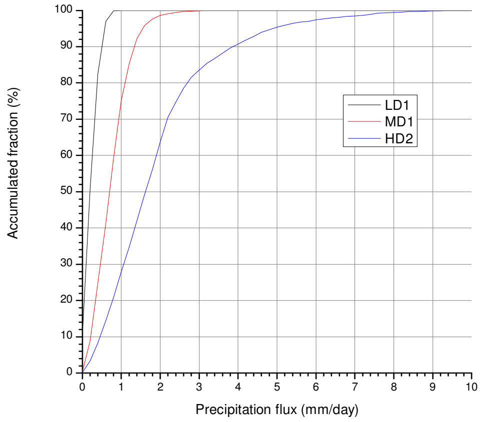

Fig. 2. Distribution of precipitation flux in light (LD1), moderate (MD1) and heavy drizzle (HD2) datasets.

For the LD1 case, the scattergram of cloud liquid water as a function of reflectivity Z in Fig. 3 demonstrates that Q_l can be reasonably well represented as a function of Z_m (Z_m is reflectivity expressed in mm^6/m^3, while Z_d is the same quantity in dBZ). The best fit in the form:

$$Q_l=9.69\, Z_m^{0.61} \qquad (2)$$

is very close to the findings by Fox and Illingworth (1997) who analyzed more than 4000 km of flight data in stratocumulus during ASTEX. For non-drizzling cases they suggested the following relationship between Q_l and Z:

$$Q_l=9.27\, Z_m^{0.64} \qquad (3)$$

The relationship between Q_l and Z becomes more complicated when significant drizzle is present. Analysis of dataset MD1 shows that there is a significant scatter on the Q_l-Z scattergram (Fig. 4a) indicating that retrievals of Q_l based on Z alone will be quite inaccurate. Q_l may, however, be retrieved if information on other moments of DSD is available.

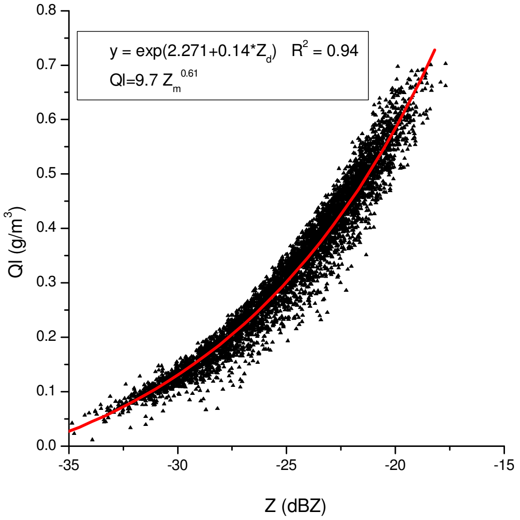

Fig. 3. The scattergram of cloud liquid water as a function of reflectivity Z for the light drizzle case LD1.

The Fig. 4b shows that relationship in the form

$$Q_l = 5.58 Z_m^{1.24} Q_r^{-0.428} \qquad (4)$$

significantly improves retrieval results. The use of the Doppler velocity parameter instead of Q_r leads to even more accurate retrieval:

$$Q_l = 13.89\, Z_m^{0.78} \exp(0.146 V_d^{-0.42}) \qquad (5)$$

Doppler velocity parameter in (5) is defined as:

$$V_d = \int_{r0}^{\infty} n(r)\, r^6\, v(r)\, dr \Big/ \int_{r0}^{\infty} n(r)\, r^6\, dr \qquad (6)$$

where $v(r)$ is *the absolute value* of the fall velocity of the drop with radius r, thus, V_d is greater than 0.

In the case of heavier drizzle (HD2), the information on Q_r , or V_d also increases the accuracy of cloud liquid water retrieval, although the scatter in this case is larger than in MD1 due to the fact that large drizzle drops may contribute appreciably to Z or V_d, although only insignificantly to Q_l.

The information on Z and Q_r or Z and V_d is even more important for retrieval of the precipitation flux R. Similarly to Fig. 4, Fig. 5 shows consistent increase in accuracy and reduction of the scatter, as information on Q_r and V_d is included in the retrieval algorithm.

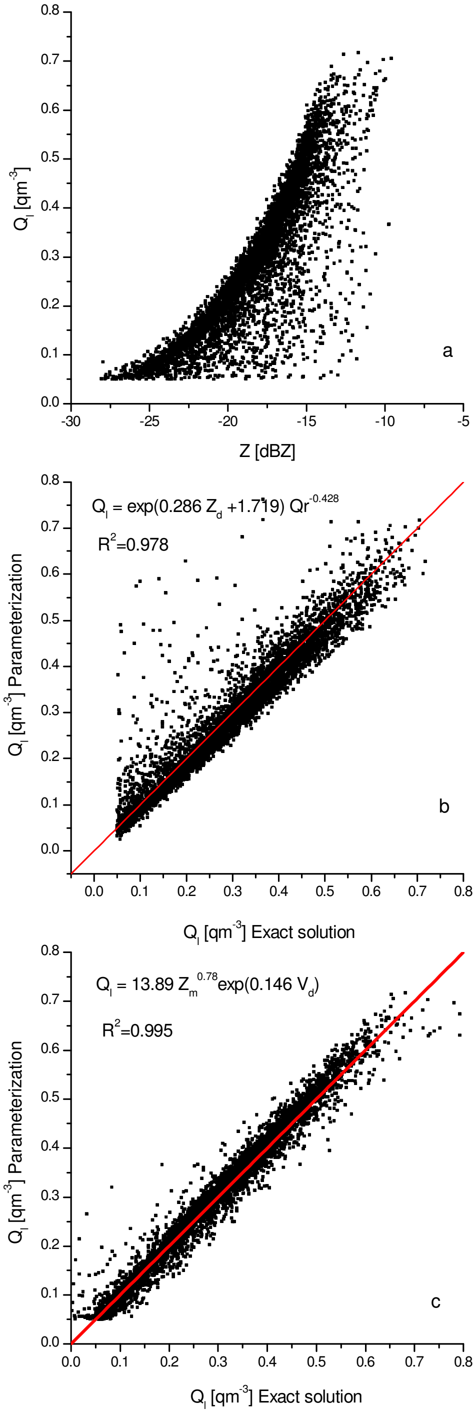

Fig. 4. The approximation of cloud liquid water as a function of: (a) reflectivity Z, (b) reflectivity and drizzle water (Qr), and (c) reflectivity and Doppler velocity, (V_d), for the moderate drizzle case (MD1). Units: Ql and Qr in g/g, Z_d in dBZ, Z_m in mm^6/m^3.

CONCLUSIONS

We evaluate the relationship between radar reflectivity and cloud parameters using data from a large-eddy simulation model with size-resolving microphysics. Based on simulations of a marine stratocumulus cloud observed during the Atlantic Stratocumulus Transition Experiment we show that both cloud liquid water and precipitation flux are very sensitive to the drizzle mixing ratio and/or Doppler velocity parameter.

For all drizzle conditions cloud liquid water retrievals can be substantially improved when information on Doppler velocity is included in retrieval algorithm.

In clouds with substantial amounts of drizzle (R> 2mm/day) Z-R relationships can also be improved with information on drizzle mixing ratio or Doppler velocity. The inclusion of the latter produces the most accurate retrievals. Our study strongly suggests that the velocity parameters collected by Doppler cloud radars should be incorporated in future retrievals of liquid water content and precipitation flux.

In the present analysis, we considered the Doppler velocity as an inherent characteristic of the drop size distribution spectrum alone. In real measurements, the Doppler radar will measure the full velocity which will include the turbulent air velocity as well. The filtering of the signal corresponding to the Doppler velocity parameter of the DSD will present the most challenging task in development of operational retrieval algorithms.

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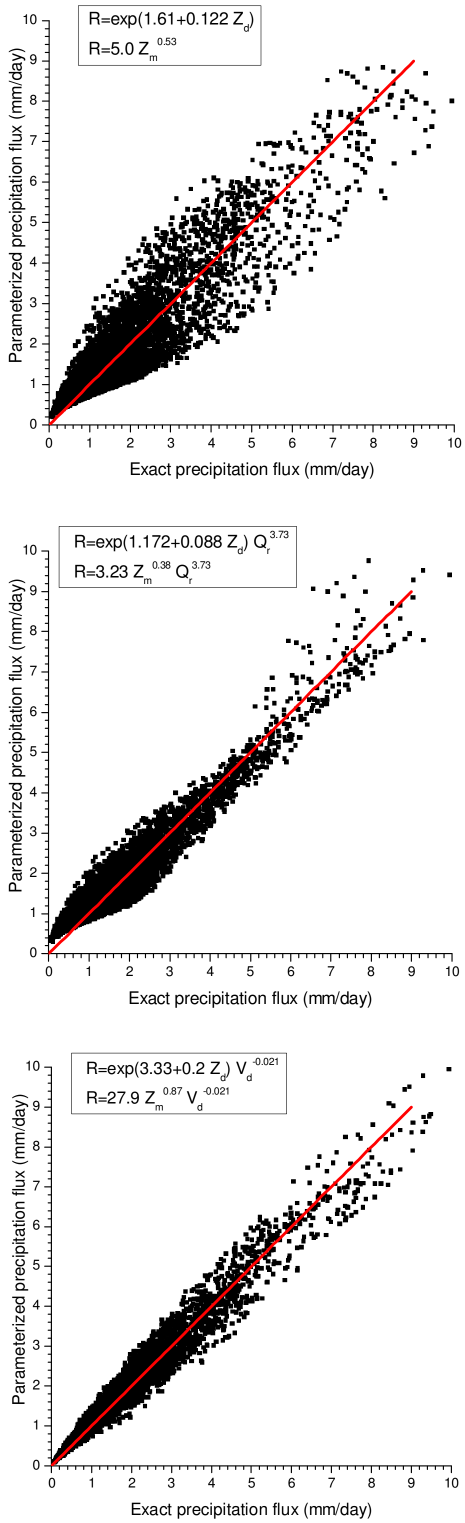

Fig. 5. The approximation of precipitation flux as a function of: (a) reflectivity *Z*, (b) reflectivity and drizzle water (*Qr*), and (c) reflectivity and Doppler velocity, (V_d), for the heavy drizzle case (HD2).