P1.17 SENSITIVITY OF THE RETRIEVAL OF STRATOCUMULUS CLOUD LIQUID WATER AND PRECIPITATION FLUX TO DOPPLER RADAR PARAMETERS

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1. INTRODUCTION

We analyze errors in retrievals of cloud liquid water content (Q_l) and precipitation flux (*R*) based on three different sets of parameters: a) radar reflectivity, *Z*, b) radar reflectivity and Doppler velocity, V_d, and c) radar reflectivity and Doppler velocity spectrum width, σ_d. As radar reflectivity represents the sixth moment of the drop size distribution (DSD), one can expect it to be correlated with other moments of the DSD, such as liquid water content Q_l (third moment of DSD), or drizzle flux *R*, which in stratocumulus clouds is proportional to the fourth DSD moment. Thus, a number of studies have been devoted to retrievals of Q_l and *R* in boundary layer stratocumulus based on radar reflectivity *Z* alone. The success of the Q_l retrievals depended on cloud type, but even more on the absence of drizzle, both in the cloud and below cloud base. The retrieval of Q_l is rather straightforward in non-drizzling stratocumulus where cloud spectra are mostly unimodal and the contribution to reflectivity from the large droplet tail of the spectrum is minimal. A simple *Z-Q* relation in this case is justified (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.

Our evaluation is based on the concept of the Observing System Simulation Experiments (OSSEs) (Parsons and Dudhia, 1996). Based on this concept, cloud radar parameters are obtained from data generated by the high-resolution CIMMS LES model with Explicit MicroPhysics (CIMMS LES EMP). Applying the OSSE framework for stratocumulus clouds, we quantitatively evaluate the errors of several cloud liquid water and drizzle flux retrievals. As both V_d and σ_d are defined as intrinsic parameters of the DSD and, thus, neglect the contribution from air turbulence in the sensed volume, our assessment should be considered as the lower limit on the retrieval errors.

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.

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 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.

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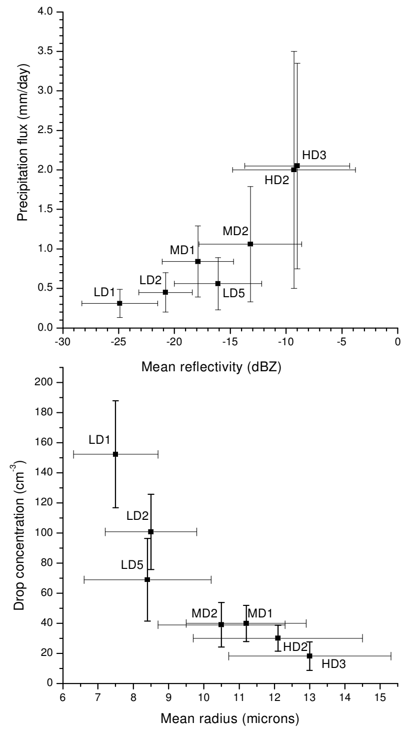

Fig. 1. Range of cloud parameters in the analyzed cases of stratocumulus cloud layers. The black square represents the mean, while the error bars show the standard deviation of the parameter.

3. RESULTS

3.1. Errors in the retrieval of cloud liquid water

For the LD case, the scattergram of cloud liquid water as a function of reflectivity Z in Fig. 2 demonstrates that Q_l can be reasonably well represented as a function of Z_m (Z_m is reflectivity in mm^6 m^{-3}, while Z_d is in dBZ). The best fit in the form:

$$Q_l = 9.7\, Z_m^{0.61} \qquad (2)$$

is quite accurate with the correlation coefficient R^2=0.941. Less than 10% of the data has errors outside the (-10%, +20%) interval for the whole range of Q_l (see Fig. 3). The success of the retrieval in this case is primarily due to the relatively simple unimodal shape of the rather narrow drop spectra with relative drop spectrum dispersion σ of about 0.25 (see Table 1). The mean drop radius, R_m, for the LD case is rather small (7.5 μm) and the mean precipitation flux is 0.3 mm/d. Note that the Q_r fraction in the liquid water content Q_l (FQ_{Qr}) is less than 0.1% and the fraction of reflectivity which comes from the drizzle part of the spectrum (FZ_{Qr}) is <1%. Obviously this is the main reason for the success of one-parameter (1P) retrieval in this case.

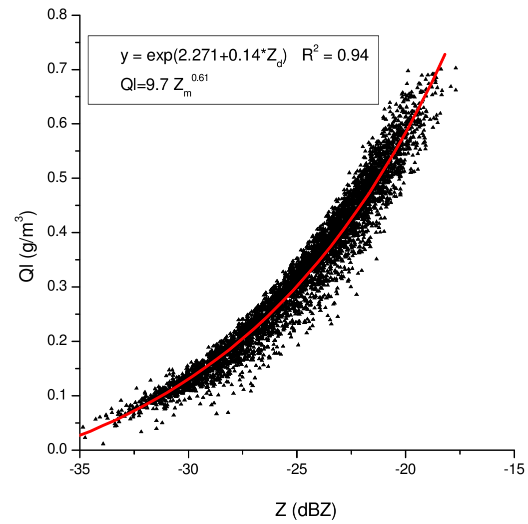

Fig. 2. The scattergram of cloud liquid water as a function of reflectivity Z for the light drizzle case LD. Q_l in g m^{-3}, Z_d in dBZ, Z_m in mm^6 m^{-3}. R^2 is the square of correlation coefficient often referred to as coefficient of determination (COD).

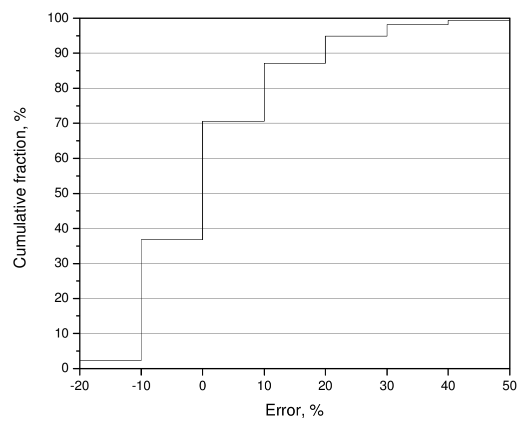

Fig. 3. The cumulative distribution of Q_l retrieval errors for the LD case.

The retrieval of liquid water content is more problematic in drizzling clouds, primarily because the correlation between Q_l and Z weakens when DSDs contain a larger fraction of drizzle drops which contribute increasingly to reflectivity (78% for HD, see Table 1). Analysis of the MD dataset reveals a significant scatter in the Q_l - Z scattergram indicating that retrievals of Q_l based on Z alone are rather inaccurate (R^2 =

0.756). However, the accuracy of the Q_l retrieval can be substantially increased when information on Doppler velocity is included. The top panel in Fig. 4 shows that a relationship in the following form results in a rather small degree of scatter and a quite accurate retrieval of Q_l (R^2 = 0.969).

$$Q_l = \exp\,(2.63+0.179\,Z_d - 0.146\,V_d) \qquad (3)$$

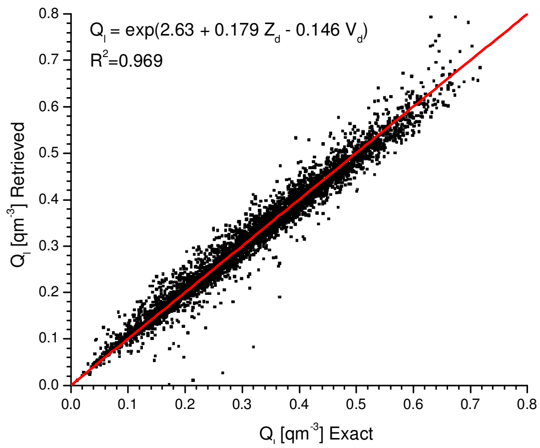

Fig. 4. The retrieval of cloud liquid water as a function of reflectivity and Doppler velocity, (V_d). Top – the moderate drizzle case MD, bottom - the heavy drizzle case HD. Q_l in g m^{-3}, Z_d in dBZ, V_d in cms^{-1}.

The Q_l retrieval based on Z alone in the heavily drizzling case HD is very poor (R^2 = 0.181). Including V_d in the HD case (bottom panel in Fig. 4) results in a significantly improved retrieval (R^2 = 0.618) relative to that based on Z alone. However, the scatter in the HD case is larger than in MD case and R^2 has decreased from 0.969 to 0.618. As evident from Table 1, the more numerous and larger drizzle drops in the HD case contribute appreciably both to Z and V_d, (mean fraction of drizzle contribution to Z increased from 17 to 78%); however, the mean fraction of Q_r in Q_l increased only from 4 to 14%.

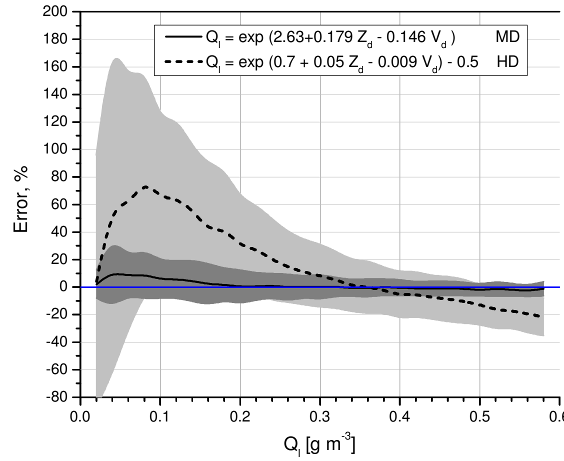

Fig. 5. The errors of retrieval of cloud liquid water as a function of Q_l. The solid and dashed black lines are the MD and HD mean errors; the shading areas represent the mean plus/minus one standard deviation. Light/dark gray shading corresponds to the HD/MD case, respectively.

The retrieval errors are not uniformly distributed over the range of Q_l (Fig. 5). They can be as large as 100% for small values of Q_l near cloud base; however, for larger values of Q_l the standard deviation of the errors in the HD case is less than 20-30%. For the moderate drizzle case MD the standard deviation of the errors is less than 10% for Q_l >0.2 gm^{-3} and less than 30% for the whole range of Q_l. The dependence of errors on drizzle is quite evident from histograms shown in Fig. 6. For heavy drizzle case about 35% of data points have errors larger than 25%, while for the medium drizzle case only 3% have errors this large. The use of Doppler spectrum width σ_d instead of Doppler velocity affects the accuracy of the Q_l retrieval rather insignificantly (Fig. 7), thus demonstrating that both Doppler parameters have approximately the same informational potential for microphysical retrieval. The decision which to use should be based on such considerations as, e.g., which parameter has smaller contribution from the air turbulence component, signal-to-noise ratio, etc.

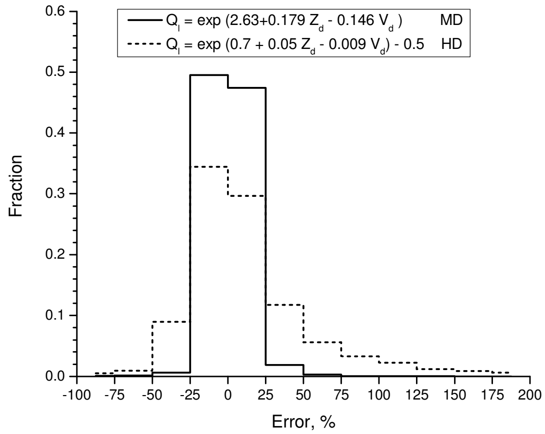

Fig. 6. The comparison of Q_l retrieval errors in the MD and HD cases based on two-parameters Z_d and V_d.

3.2. Errors in the retrieval of drizzle flux

The retrieval of drizzle flux R using Z and $V_{d,}$ is more robust than retrieval of Q_l, obviously because R, Z, and V_d, all represent higher moments of the DSD (M_4, M_6, and the ratio M_7/M_6, respectively). Thus, strong correlations between them are expected, and this is indeed the case for MD and HD datasets. In the moderate drizzle case MD the use of a 2P retrieval based on Z and V_d yields a nearly perfect correlation (R^2 = 0.997). In this moderate drizzle case the errors are less than 5% in the whole drizzle flux range, except for drizzle rates less than 0.2 mm d^{-1}.

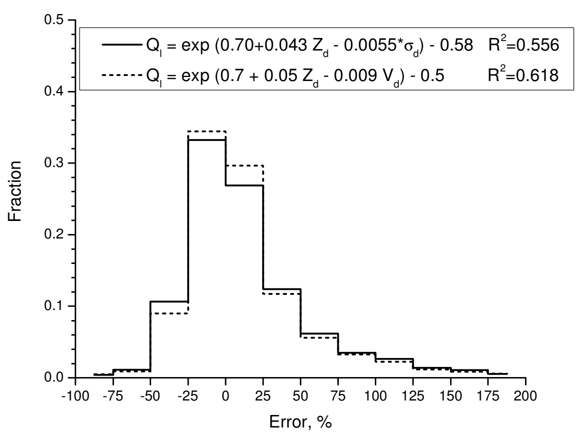

Fig. 7. The comparison of Q_l retrieval errors in the HD case based on two-parameters: Z_d - V_d (dashed) and Z_d - σ_d (solid).

For the heavy drizzle case HD R^2 increased from 0.794 for the 1P retrieval based on Z only to 0.962 when the 2P retrieval based on Z and V_d is used (Fig. 8). The standard deviation of errors in this case is approximately in the 20-40% range for the 1P retrieval but decreases to about 10% for the 2P retrieval (Fig. 9). As in the case of Q_l retrieval, the errors of 2P retrievals based on Z-V_d and Z-σ_d (not-shown) fall approximately into the same range.

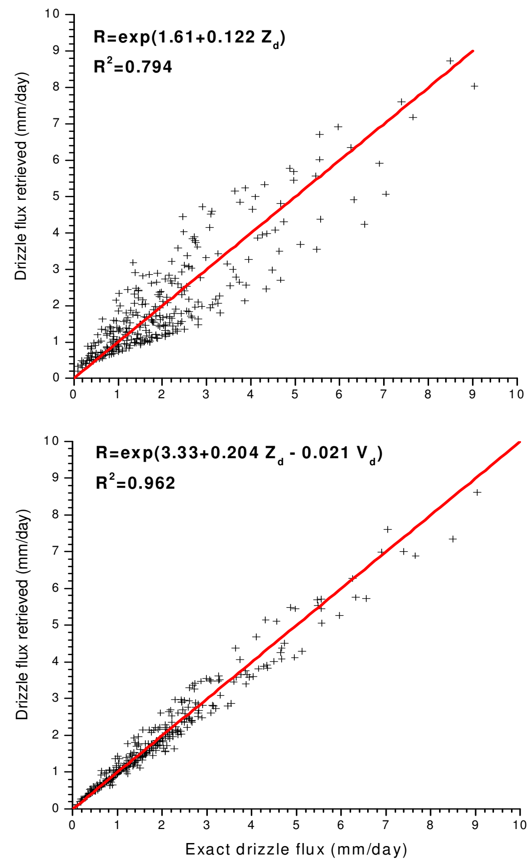

Fig. 8. The scatter plot of the retrieved vs exact drizzle flux for the HD case based on one and two (Z-V_d) parameters (to reduce clatter only a fraction of data points is shown).

CONCLUSIONS

We performed simulations of marine stratocumulus clouds observed during the Atlantic Stratocumulus Transition Experiment using the CIMMS large-eddy simulation model with size-resolving microphysics. Drop size distributions (DSD) from these simulations represented a wide range of drizzling conditions and were used to evaluate the errors of retrievals of cloud microphysical parameters based on radar reflectivity, Doppler velocity and Doppler spectrum width.

For stratocumulus clouds with negligible amount of drizzle, the retrieval of cloud liquid water based on radar reflectivity alone is quite accurate and the parameters of the Q_l-Z relationship are in good agreement with the retrieval obtained from ASTEX observations by Fox and Illingworth (1997). When drizzle is present, Q_l is poorly retrieved based on Z alone; however the retrieval is substantially improved when Doppler velocity or Doppler spectrum width is included. For Q_l values larger than 0.2 g m^{-3}, the standard deviation of errors is less than 10% in the moderate drizzle case; in the heavy drizzle case the errors are less than 20-30%. The use of Doppler spectrum width σ_d instead of Doppler velocity decreases the accuracy of the Q_l retrieval only insignificantly, demonstrating that both Doppler parameters have approximately the same potential for improving microphysical retrievals.

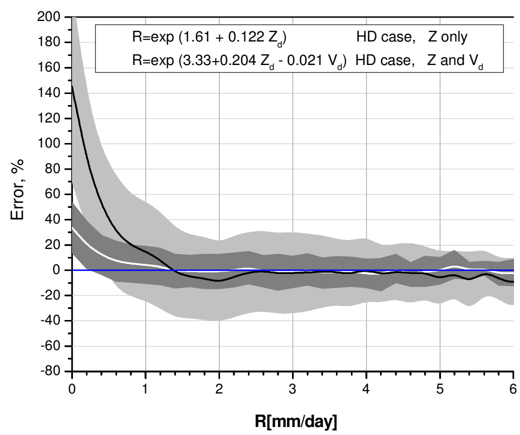

Fig. 9. The errors of drizzle flux retrieval for the HD case. The black and white lines are the 1P and 2P mean errors; the shading areas represent the mean plus/minus one standard deviation. Light/dark gray shading corresponds to the 1P and 2P retrievals, respectively.

The retrieval of precipitation flux R is generally more robust than Q_l, evidently because R (proportional in stratocumulus clouds to the fourth moment of the DSD) is more closely correlated with the drizzle portion of the DSD than is Q_l. In stratocumulus with heavy drizzle (R > 2 mm d^{-1}) Z-R relationships can also be substantially improved by using the two parameter retrievals. Errors of the two parameter retrieval for the moderate drizzle case are less than 5%. For the heavy drizzle case, employing the two parameter retrieval reduces the standard deviation of errors of the 1P retrieval from the 20-40% range to about 10%. We emphasize that our error estimates represent the theoretical lower bound on retrieval errors, because the actual errors will inevitably increase, first and foremost, from uncertainties in estimation contributions from air turbulence. If the latter can be constrained and minimized (as in Babb et al., 1999; Kollias et al. 2001; O'Connor et al. 2005), then the informational potential of radar reflectivity and Doppler parameters may be sufficient for substantial improvement in retrievals of cloud liquid water and precipitation flux under a wide range of drizzling conditions.

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Table 1. Mean and standard deviation (in brackets) of drop spectra parameters for light (LD), moderate (MD) and heavy (HD) drizzling cases. Q_l and Q_r is liquid and drizzle water content, N_c and N_d is total and drizzle concentration, R_m and σ is the mean radius and relative dispersion of drop spectrum, R drizzle flux, V_d –Doppler velocity, Z_d – reflectivity in dBZ, FQ_{Qr} and FZ_{Qr} – fractions of Q_l and Z_m from Q_r, respectively.

Parameter	L D	M D	H D
Q_l (g m^{-3})	0.33 (0.15)	0.32 (0.14)	0.34 (0.16)
R_m (μm)	7.5 (1.2)	11.2 (1.7)	12.1 (2.4)
N_c (cm^{-3})	153 (35)	34 (12)	30 (8)
σ	0.25 (0.07)	0.34 (0.06)	0.34 (0.1)
Q_r (g m^{-3})	<0.0001	0.012 (0.018)	0.047 (0.042)
FQ_{Qr}	0.01 (0.03)	3.9 (5.5)	14.1 (9.1)
N_d (cm^{-3})	<0.00001	0.016 (0.22)	0.33 (0.38)
R (mm d^{-1})	0.31 (0.18)	0.84 (0.45)	2.03 (1.5)
Z_d (dBZ)	-24.8 (3.3)	-17.8 (2.9)	-9.3 (5.5)
FZ_{Qr}	0.31 (0.42)	16.6 (12.7)	77.7 (21.8)
V_d (cm s^{-1})	1.35 (0.2)	4.8 (1.7)	47.0 (26.5)