

Response to Anonymous Referee #2

Overview

This paper attempts to characterize the raindrop distributions observed during the RICO campaign; focussing on the characteristic shape parameter in both an assumed gamma or lognormal distribution. The data for this study are taken from the in situ measurements made by aircraft flying both through clouds and below clouds. The authors further attempt to parametrize the shape parameter as a function of measurable (or modelled) parameters with a view to obtaining a more accurate representation of rain evolution in models and to assist in the interpretation of remote sensing data.

Response:

We gratefully thank anonymous referee 1 for its comments and suggestions that help to improve the manuscript, the discussions and the language.

General Comments

Overall the paper is relevant to the needs of the community with uncertainty in microphysical evolution being a key aspect to our understanding and modelling of clouds and precipitation. I believe the authors are correct in stating that much of the work done in this area has concentrated on deeper, more heavily precipitation convective cases and so this work contributes to fill a gap in our knowledge.

The methods used are reasonable well explained and the layout is reasonable. There are, however, one or two inconsistencies in the arguments presented and these should be addressed before final publication.

Specific Comments

1) Inconsistencies in the argument:

It is argued, by reference to relation (3), that the variation in volume mean diameter with height makes it unsuitable for use as the independent variable in a parametrization. The authors go on to present a parametrization with $(Nr*qr)$ as the independent variable, but make no attempt to show that this meets their implied criterion of being invariant with height. Plots should be shown, e.g. as an additional row in figure 2, of the product of Nr and qr . By eye, I would suggest that there will still be a systematic decrease with height. If so, a convincing argument as to why $(Nr*qr)$ is more suitable than Dv should be made.

Response:

*The profile of $(Nr*qr)$ is shown below. As expected (from Fig.2 2nd and 4th row) and as pointed by referee 2, $(Nr*qr)$ decreases with height as do $1/nu$ (particularly in the subcloud layer due to size sorting and evaporation). So the parameterization has to reproduce this variation of nu with the altitude.*

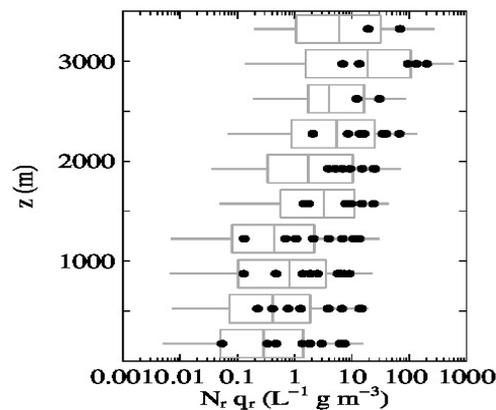
Eq. 3 is referenced P686 L11 to point out the lambda-nu dependency and the expected variation with height (via the dependency on Dv).

In this study, the aim is to express the shape parameter as a function of variables that are known i.e. Nr and qr in a 2-moment bulk microphysical scheme LES model. Dv is a function of qr and Nr only, and Fig 2 shows that Dv continuously decreases as height increases. Thus Dv could be a good candidate for such a parameterization. Indeed Fig 5 c,d show that Dv and nu follow the same trend for larger values of Dv , that is at low altitude before rain

reaches the ground. However, this dependency is not valid for low Dv . For such a cases the spectra are narrow (large ν) and correspond mostly to rain spectra at the early stage of their evolution that is drizzle spectra.

As shown in Fig 6) the use of $1/(Nr qr)$ is a better proxy for the evolution of ν . For large qr , spectra are large if Nr is high (large $1/\nu$, large qr and large Nr), spectra are narrow if Nr is low (size sorting, low $1/\nu$, large qr but low Nr , which dominate the product $Nr qr$ because Nr vary over two order of magnitude whereas qr vary only over one order of magnitude). For low qr , spectra are predominantly narrow (low $1/\nu$), whatever the value of Nr . Then the parameterization is limited in particular for low qr and large Nr . This explains the largest scatter found in Fig 6 for large ($qr Nr$).

We have rewritten the discussion P690, L8 (see response to reviewer 1 first comment).



2) Inconsistencies in the argument:

At the bottom of page 686, the authors state that "...it is reasonable to assume that all kinds of rain spectra typical of shallow cumulus are statistically represented.", However, at the bottom of page 688, it is further stated that "...values derived in this study may be more representative of the first stages of rain development..."

Response:

Yes that's true, we have rewritten the first paragraph :

"In addition most of the measurements are performed inside clouds or close to clouds rather than in clear sky. As the result, the statistics are slightly biased toward initial stages of precipitation formation. Nevertheless, as attested by Figure 3, the data set covers a large range of values, so we assume in the following that it is representative of rain spectra in shallow cumulus."

3) Application to an LES:

It is somewhat unclear as to whether the conclusion to take from this study is that the shape parameter is important or not. While there is a clear indication from the data that the shape parameter can vary substantially, there are implications regarding LES simulations carried out by the authors that demonstrate a lack of sensitivity to the use of a variable shape parameter. This is perhaps not surprising given other uncertainties associated with bulk microphysics schemes and interaction with dynamics which may negate or overshadow the impact associated with the shape parameter. I would point the authors to Shipway and Hill, 2012 (<http://onlinelibrary.wiley.com/doi/10.1002/qj.1913/full>) which explores some of the microphysical sensitivities (including representation of the 3rd moment) in an idealized framework. In particular, figure 7 demonstrates that having a variable shape parameter (triple moment scheme) only seems to provide a significant benefit in very heavily precipitating conditions. It would be nice to see some more detail from the LES simulations including exactly what was simulated (a particular day or the RICO composite period which is weakly precipitating).

Response:

Sensitivity tests to the shape parameter and to the evaporation rate were performed using the Dutch Atmospheric LES (DALES) model coupled with the Seifert and Beheng (2000) (and following papers) 2-moment bulk scheme fully described in Heus et al. (2010). The microphysical scheme assumes a Gamma distribution to calculate rain sedimentation, evaporation, selfcollection and break-up. The coefficient 1/20 in the Seifert and Beheng (2000) autoconversion formulation (resulting from a calculation with a ν value equal to 1) is kept constant for all runs because autoconversion has been tuned for that value.

Tests were performed for two droplet number concentrations. Note that sensitivity test by varying ν in each process separately and all together show that the main sensitivity is due the sedimentation process and slightly to evaporation. Moreover results obtained by varying ν in all processes together are closed to what is obtained by testing sedimentation alone. They are reported in Table 1 below. The parameterization of Stevens and Seifert (2008) (hereafter SS08) and an old version of the parameterized shape parameter (as a function of qr only) were also tested. Values are 4H averaged over the whole domain after 2H of simulation (6H with total spin up) with the tested ν value. ν is set to 1, 2, 6, 11, which correspond to the panel observed in the literature, to the parameterized value according to SS08. The domain is 12.8 km horizontally with a 100 m resolution and 4 km vertically with a 40 m resolution. Initial profiles are derived from RICO intercomparison profiles, with some slight changes in the thermodynamical profiles close to Stevens and Seifert (2008) (hereafter SS08) modifications, in order to obtain a deeper boundary layer than the standard RICO one, which is few precipitating.

These results are qualitatively consistent with SS08 results: when ν increases, the RWP and the LWP increase. The RWP vary of a factor 3 from a MP distribution to a narrow one. An old version of the parameterized shape parameter (as a function of qr only) leads to intermediate results similar to the $\nu = 2$ simulations..

Simulations without evaporation also show variations in RWP of the order of a factor 2 for similar LWP. For a constant production of rain, assuming equilibrium between production and sedimentation rate and integrating over the boundary layer, the RWP and the precipitation flux verify the following equation: $dRWP/dt = R_{surf}$. Without evaporation, production rate and surface precipitation flux are similar (table 1). The amount of rain produced doesn't vary significantly with ν and so does R_{surf} . Because the terminal velocity of the rain water content is larger when ν is higher, the local rain water content decrease and

thus the RWP decrease. This happens during the transition phase between the restart time and the new equilibrium state i.e. during the spin up. Large differences in RWP are mainly due to the fact that rain drops spend less time in the boundary layer when terminal fall velocity is assumed to be larger.

	v	F_c	LWP	$\sigma(\text{LWP})$	RWP	$\sigma(\text{RWP})$	Prod	R_{surf}
No rain.	/	0.13	15.4	4.9	/	/		
$N_c=40$ cm^{-3}	1	0.12	10.9	2.3	5.9	3.5	24.0	14.9
	2	0.11	11.9	2.8	9.5	5.3	34.3	19.2
	6	0.11	13.7	5.0	17.1	11.5	54.4	26.4
	11	0.11	13.6	4.6	19.5	13.2	60.6	31.5
	v_{SS08}	0.11	11.7	3.6	8.5	5.8	33.7	18.2
$N_c=70$ cm^{-3}	1	0.12	13.6	3.2	5.1	3.5	19.4	13.7
	2	0.12	14.4	4.1	7.3	5.5	25.0	16.9
	6	0.12	15.2	3.9	8.5	4.5	25.6	12.7
	11	0.12	16.1	4.1	14.3	9.4	43.9	24.0
	v_{SS08}	0.12	14.5	3.4	7.6	4.3	25.3	15.8
$N_c=40$ cm^{-3} No evap.	1	0.12	9.9	2.9	6.3	3.4	19.1	17.3
	2	0.12	9.0	1.8	8.3	3.4	18.8	20.0
	6	0.12	9.0	1.8	12.1	3.7	20.9	22.5
	11	0.11	9.1	2.0	13.0	3.9	22.2	22.6
$N_c=70$ cm^{-3} No evap.	1	0.12	12.6	2.5	6.3	2.6	17.6	18.1
	2	0.12	12.1	2.9	7.4	4.4	15.3	16.9
	6	0.12	11.8	3.2	11.3	5.9	19.3	20.1
	11	0.12	12.7	3.0	13.2	4.5	21.4	22.5

Table 1: Cloud fraction F_c , liquid water path LWP (g m^{-2}), liquid water path standard deviation $\sigma(\text{LWP})$ (g m^{-2}), rain water path RWP (g m^{-2}), rain water path RWP standard deviation $\sigma(\text{RWP})$ (g m^{-2}), sum of autoconversion and accretion rate prod (Wm^{-2}), surface precipitation flux R_{surf} (Wm^{-2}), values are averaged value over the whole domain, for 4 sets of simulations and a no precipitation case.

Simulation with high RWP are simulation that show the highest LWP, highest evaporation rate and thus steeper precipitation flux profile slope. Because evaporation is higher for simulations with high maximum precipitation flux, the surface precipitation flux intensity do not depend especially of the v value. The increasing LWP with v is due to a positive feedback resulting from a coupling between the sedimentation and the evaporation processes. When the terminal velocity is assumed to be low (large v value), rain drops spend more time in the boundary layer, rain evaporation is larger, which leads to higher LWP and thus more precipitation. Comparison with the LWP of simulations without rain process show that this feedback do not counteract the decrease of LWP due to precipitation except in the less precipitating cases ($N_c=70 \text{ cm}^{-3}$) with a narrow distribution hypothesis i.e. $v=11$. The latter is large for low q_r values. Note that this tendency can be different for longer simulation times because of a change in the regime and feedbacks.

We didn't included these results in the manuscript that was oriented on observations analysis. Moreover, the parameterization of the shape parameter as a function of ($qr*Nr$) was developed after that the experiments were performed. Thus sensitivity tests were not performed for this parameterization. However, the $v=1$ and $v=11$ experiments should provide

an upper and a lower limit of the impact of ν over the mean LWP, and the first results of this paper is to provide a trade off value of this shape parameter.

We modify the sentence in the conclusion and add the Shipway and Hill, 2012 reference:

“For shallow cumulus cloud, tests with a LES model showed that a change of ν from 1 to 11 impacts the mean LWP of about 20% after 2 to 6 hours of simulations (not shown). These tests also suggested that the use of the tradeoff value should be sufficient to represent the magnitude of the precipitation rate in shallow cumulus clouds. Questions remain for deep convection. Indeed a variable shape parameter may impact significantly the results in heavily precipitating clouds (Shipway and Hill, 2012)”

Reference:

Shipway, B. J. and Hill, A. A. (2012), Diagnosis of systematic differences between multiple parametrizations of warm rain microphysics using a kinematic framework. Q.J.R. Meteorol. Soc., 138: 2196–2211. doi: 10.1002/qj.1913

4) The details of figure 5 are too small to make out and needs to be redone. It could perhaps be reorientated to use the full width of the page.

Response

Yes, Fig. 5 is not suitable with ACPD format. However, the ACP paper format is different and fig. 5 should be adequate for this.

5) There are numerous recurring errors in the grammar. Some examples are pointed out below, but the authors should check this again carefully.

Response:

Yes. Thank you for the corrections. We also check and correct the rest of the paper.

Technical comments:

page 678:

line 2: insert ...'AN' analytical distribution...

Response: Fixed

line 3: IT IS COMMON for the Gamma DISTRIBUTION and ... Lognormal DISTRIBUTION TO BE USED

Response: Fixed

line 4: ...studies of the literature... should be ... studies IN the literature...

Response: Fixed

line 4: ...rain DROP distribution...

Response: Fixed

line 6: change to ...rain distributionS THROUGHOUT THE DEPTH OF the cloudy...

Response: Fixed

line 11: clarify what is meant by "the rain variable"

Response:

we modify the sentence:

“the dependence of the shape parameter on the main rain variables (number concentration, water content, mean volume diameter, sedimentation fluxes and radar reflectivity)”

line 12: ..in function of... should be ...as a function of..

Response: Fixed

line 18: should be ... at local scaleS, i.e. at scaleS of...

Response: Fixed

line 19: should be ...of A few dozen...

Response: Fixed

line 24: Could a reference be given to explain why c-c is roughly to the sixth power?

Response: we add a reference and modify the sentence:

“The radar reflectivity, which is a useful quantity for remote sensing measurements, is proportional to the radar reflectivity factor. Assuming Rayleigh scattering, the radar reflectivity factor is the 6th moment of the distribution (Smith et al., 1975).”

Smith, P. L., C. G. Myers, H. D. Orville, 1975: Radar Reflectivity Factor Calculations in numerical Cloud Models Using Bulk Parameterization of Precipitation. J. Appl. Meteor., 14, 1156–1165.

page 679:

line 14: missing article, ...Ultimately, THE local raindrop...

Response: Fixed

line 18: ..as functions.. should be ...as a function of... (singular)

Response: Fixed

line 19: missing comma - ...order p, Mp...

Response: Fixed

line 21: strictly speaking the distribution isn't a probability distribution

Response: we change in:

“and $n(D)$ is the volume number density of raindrops with diameters between D and $D+dD$.”

End of page 679- beginning of 680: It should be made clear that much of this discussion relates to commonly used parametrizations of these processes and there is not a direct relationship between the stated moments and the physical processes. Sedimentation for example is dependent upon Reynolds or Best number, rather than simple the moments.

Response:

Yes. What is discussed here is the dependency between the processes and the raindrop size distribution.

We change L18 p 679 in “can be directly written or parameterized as a function of the integral variables”

We change L27 p 679 “the collection of clouds droplets by raindrop (accretion) is usually parameterized as the product of”

page 680:

line 16: re interval of definition. Why couldn't ν be less than 0 - is it constrained or you just don't see that in this study?

Response: the gamma distribution function is defined for $D > 0$, and $\nu, \lambda > 0$

equation 3: There is an error here. $1/Dv$ should appear outside of the bracketted expression.

Response: Yes, fixed

page 685:

line 6-8: You don't list the rain water content here.

Response: yes, “qr, the” is missing. Fixed.

line 26: No need to repeat "(collection, evaporation, sedimentation)"

Response: Fixed

page 689:

line 8: reference to fig 5a-c. I think there are missing labels on figure 5 (c.f. specific comment 4)

Response: Yes, they are missing. Fixed

page 690:

line 12: I think this should refer to figure 6, not figure 4

Response: Yes, it should refer to figure 6. Fixed

line 12: It isn't clear to me how the powers (0.25 and 0.1) were chosen

Response:

The powers have been found by a preliminary fit as a function of $Nrqr$. Then the exponents have been rounded to the values 0.1 and 0.25. A second fit by fixing these exponents have been performed to adjust the other parameters.

line 12: brackets should be placed around $(Nrqr)$ to avoid confusion.

Response: Fixed

page 691:

line 18: Addition "on" should be removed

Response: Fixed

page 192:

line 3: ...in function... should be ...AS A function...

Response: Fixed

Fig 2 caption, line 2: (top row, right) should be (top row, center)

Response: Fixed