**Response to Anonymous Referee #1**

This study examines the raindrop size distribution for precipitating shallow cumulus, using in situ observations from RICO campaign. The vertical variation of raindrop size distribution due to microphysics processes are documented in this study. As reference for future determination of shape parameters in the raindrop spectrum, relationships between the shape parameters and rain water content and number concentration are proposed. The results from this study are valuable because such characteristics of precipitation have rarely been discussed for shallow cumulus, and an accurate representation of raindrop spectrum can help better simulate the shallow precipitation processes in models.

This paper should be accepted after some revisions. Improvements should be made to the figures and the writing, for a better presentation of the results.

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

**Major comments**:

1) The figures are difficult to interpret due to their poor quality.

a) Box plots are used in most of the figures for representing 5, 25, 50, 75, 95 percent of the data. But, this information was rarely used in the discussion.

*Response:*

*In descriptive statistics the percentiles provide a quantitative information of the distribution of the observations. The box plots are used here because it is a convenient way to graphically indicate the degree of dispersion(spread) in the data. We add the following sentences P684 L27 as a general comment to emphasize this point at the description of Fig.2:*
*"Box plots with $5^{th}$, $25^{th}$, $50^{th}$, $75^{th}$ and $95^{th}$ percentiles of the distribution are used to indicate the spread of the data. Symbols are mean values for each flight and are superimposed to illustrate the flight to flight variability."*

*- Figure 2: We add P686, L3 a discussion about the scatter and a comparison with the vertical structure of the rain properties given in van Zanten et al (2010) (their Fig. 8). (See response to comment b) bellow).*

*- Figure 4. We add P687, L10 the following comment:*
*"For each minimization, there is a strong scatter of the shape parameter. The values of $\nu$ range roughly from 1 to 10. As a general trend, we observe that spectra become narrower as the value of the considered moment increases. This is shown by the increase of $\sigma$ and the decrease of $\nu$, for both percentiles and the mean values. This trend is especially pronounced for the M1 and the M2 minimizations. "*

*- Figure 5. We have rewritten the whole discussion P689, L16:*
*"The data for the shape parameter $\nu$ are reported on Figure 5a,b,c as function of $N_r$, $D_v$ and $q_r$, respectively, in order to examine the sensitivity of this shape parameters to variables prognosticated in 2-moment bulk schemes. Only M1 and M4 moment values are presented*

*here because they are the most important with respect to the parameterization purpose, especially for the sedimentation and the evaporation processes. The largest scatter in the 6$^{th}$ box plot of Fig. 5b corresponds to the transition between the OAP-200-X and the 2DP measurements marked by an important decrease in the size resolution (from 10 to 200 µm). Measurements show a clear negative trend as a function of $q_r$ , as already depicted in Fig. 4. In contrast no obvious trend is observed for $N_r$ and $D_v$ over the whole range. For both lowest and largest $D_v$ values, $\nu$ is large (median values > 5) corresponding to narrow size distributions. The broadest spectra correspond to large concentration values greater than about 4 $L^{-1}$ and intermediate mean volume diameter values from about 200 to 400 µm. but with a large dispersion as reflected by the 25$^{th}$ -75$^{th}$ percentile interval that could reach an order of magnitude.*
*At the early stage of the rain formation, samples are characterized by high concentration values, especially in the upper part of the cloud as attested by the figure 2, low Dv values and narrow spectra. As drops growth by collision-coalescence and are mixed by turbulence, that is for high rainwater content samples, the size spectra broadens and the mean volume diameter reaches intermediate values while the concentration slightly decreases but still remains relatively high. As a result, the flight average concentration values are larger than 10 $L^{-1}$ above 1500 m as indicate by Figure 2. Consequently, spectra with large concentration may be young narrow spectra characterized by low mean volume diameter, or on the opposite aged broad spectra with a large amount of rain. This explains the large scatter of $\nu$ for large concentration values. The vertical profiles of Fig. 5d show an increase of $\nu$ with decreasing altitude more pronounced in the lower part of the cloud boundary layer. This is consistent with experimental studies that show narrower distributions at the surface than in clouds (Tokay and short, 1996; Ulbrich and Atlas, 1998) and with 1-D numerical studies focusing on the effect of size sorting (Milbrandt and Yau, 2005; Seifert, 2008)."*

*- Figure 6. We have rewritten the discussion P690, L8:*
*"As for cloud droplet spectra (G10), the shape parameter is mostly sensitive to the water content as shown by Figure 5e,f. However the size sorting process also modulates the drop spectral width. For samples with low qr, spectra are predominantly narrow (low 1/$\nu$) whatever the value of Nr. For samples with large qr, the spectra are predominantly broad for large Nr and narrow for small Nr due to size sorting. Thus we parameterize the shape parameter as a function of a power law of $q_r$ and $N_r$. Figure 6 a, b shows scatterplots of $\nu$ and $\sigma_g$ as a function of $N_r q_r^{0.25}$ and $N_r q_r^{0.1}$, respectively, for the 4 moments and the values that minimize both absolute and relative errors in each bin. The percentile intervals indicate that the data dispersion increases as (Nr qr) increases, especially for moments M1 and M2. This is consistent with Figure 5a,b that reveals that the spread of $\nu$ is larger for large values of Nr while it remains constant over the qr range."*

b) Figure 2 seems gigantic for the amount of information it actually conveys. The color symbols are difficult to read, and they are barely mentioned in the discussion. I don't see much necessity of having the color symbols in the figure. In section 2, the authors mostly discuss the vertical structure/trend of the variables that are buried in the current Figure 2. There should be a better way to make this figure more clear, and consistent with the discussion.

*Response:*
*Yes, the information given by colour and symbol are not mentioned in the discussion. The blue colour was used to represent the flights with the Fast FSSP measurement. The symbol*

*and the other colours were used to distinguish each flight in order to indicate the flight to flight variability. However, they were not labelled and not discussed in the text. So we choose to remove colours and use the same symbol for all cases that clearly improves the clarity of the figure.*
*We also add a comparison with van Zanten et al. (2010) profiles and a discussion about the scatter p686 L3:*
*" In comparison to the results of van Zanten et al. (2010) (their Figure 8), the profiles show the same trends, with a pronounced increase of $N_r$ with the altitude while $q_r$ remains more or less constant. However both profiles reveal higher values with median values of $N_r$ and $q_r$ ranging from 1 to 100 $L^{-1}$ and from 0,1 to 0,3 $gm^{-3}$, respectively. These differences come from the cases selected here: 9 precipitating cases have been added and 3 cases with a very low precipitation amount have been removed. It follows that the statistics are shifted to larger values as reflected by the flight average values. Note that the profiles presented here are closer to the simulations of the LES models reported in van Zanten et al. (2010).*
*As shown by the box plots, the scatter of the rain variables is large, especially for the rain water that cover about 2 order of magnitude. This scatter is due to the large heterogeneity of the rain field inside a given cloud system and to the differences in the microphysical and macrophysical properties of the sampled cloud systems. In boundary layer clouds, the strength of the precipitation production depends on both the cloud droplet concentration and liquid water path or cloud depth (Geoffroy et al., 2008; Jiang et al., 2010, Burnet and Brenguier, 2010), that both vary among the different flight cases. However note that for the profiles of Nr, Fnr and Dv, both box plots and flight averages follow the same pronounced vertical trend reflecting the consistency of the observations."*

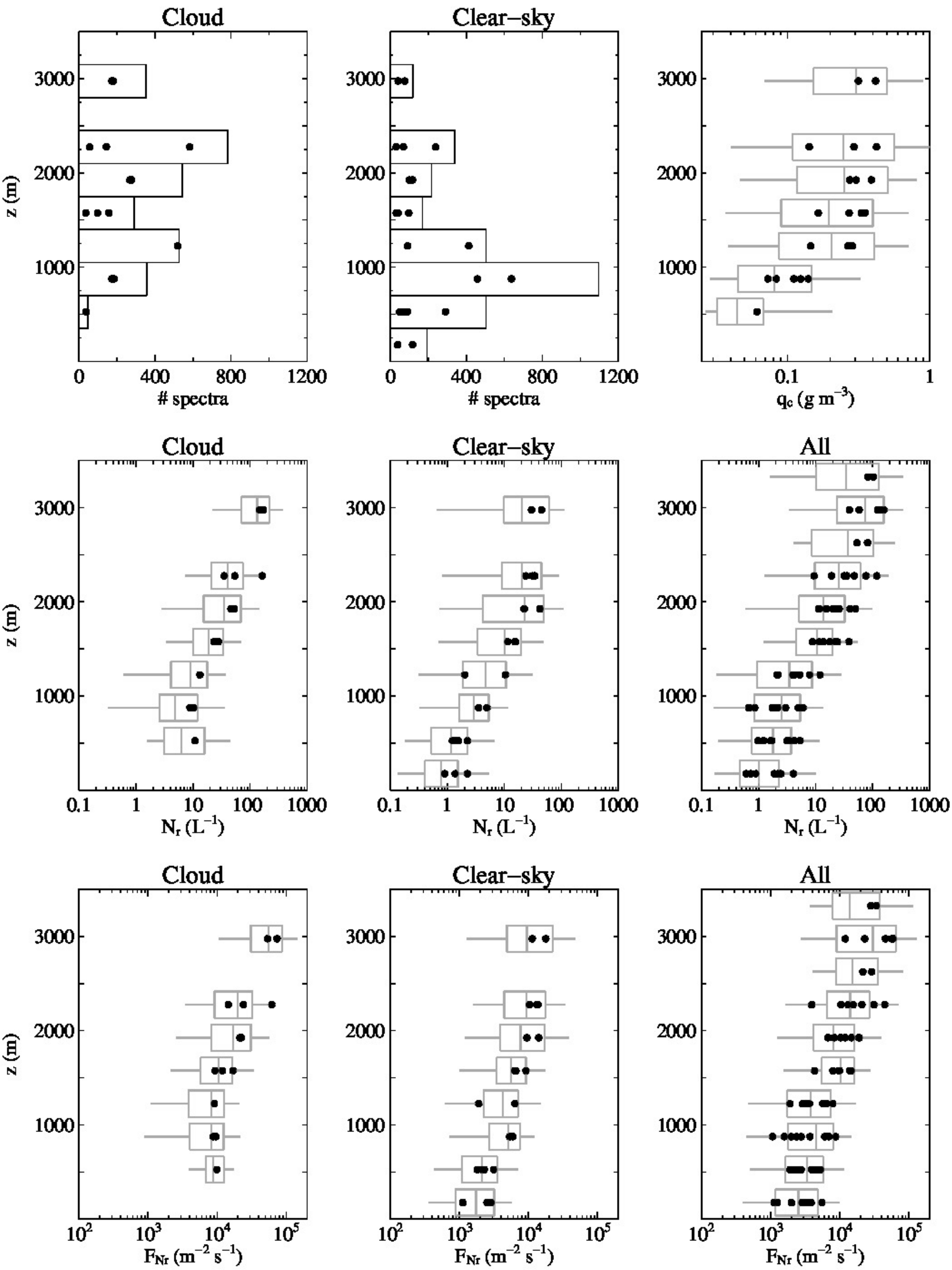
*References:*

*Van Zanten, M.C., B.B. Stevens, L. Nuijens, A.P. Siebesma, A. Ackerman, F. Burnet, A. Cheng, F. Couvreux, H. Jiang, M. Khairoutdinov, Y. Kogan, D.C. Lewellen, D. Mechem, K. Nakamura, A. Noda, B.J. Shipway, J. Slawinska, S. Wang, and A. Wyszogrodzki (2010): Controls on precipitation and cloudiness in simulations of trade-wind cumulus as observed during RICO. J. Adv. Model. Earth Syst. (3), Art. M06001, 20 pp*

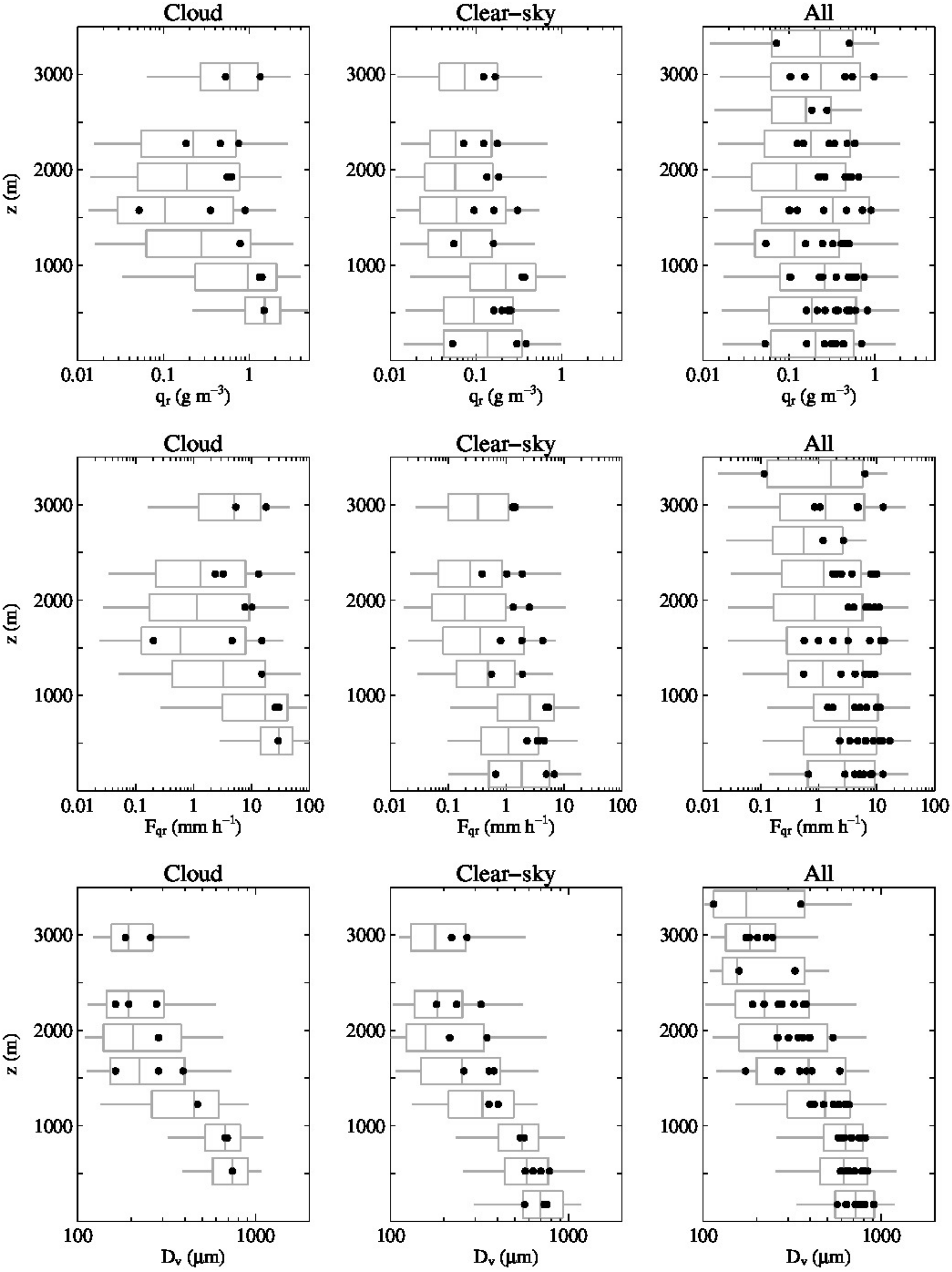
*Geoffroy, O., Brenguier, J.-L., and Sandu, I.: Relationship between drizzle rate, liquid water path and droplet concentration at the scale of a stratocumulus cloud system, Atmos. Chem. Phys., 8, 4641-4654, doi:10.5194/acp-8-4641-2008, 2008.*

*Jiang, Hongli, Graham Feingold, Armin Sorooshian, 2010: Effect of Aerosol on the Susceptibility and Efficiency of Precipitation in Warm Trade Cumulus Clouds. J. Atmos. Sci., 67, 3525–3540.*

Burnet, F., and J. L. Brenguier, 2010: The onset of precipitation in warm convective clouds: A case study from SCMS. *Quart. J. Roy. Meteor. Soc.,* ***136****, 374-381,* DOI 10.1002/qj.552.



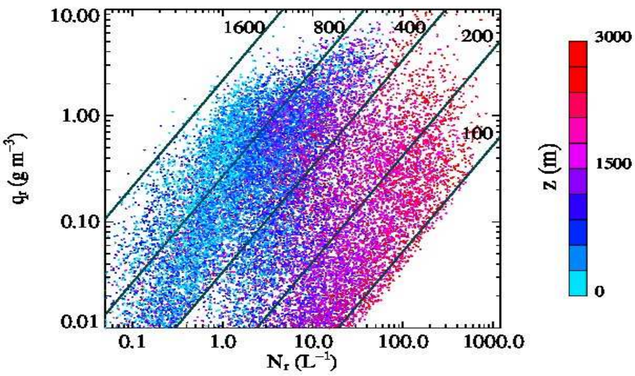
Cloud
Clear−sky
Cloud
Clear−sky
All
Cloud
Clear−sky
All
z (m)
3000
2000
1000
0
400
800
1200
# spectra
0.1
1
$q_c$ (g m$^{-3}$)
0.1
1
10
100
1000
$N_r$ (L$^{-1}$)
$10^2$
$10^3$
$10^4$
$10^5$
$F_{Nr}$ (m$^{-2}$ s$^{-1}$)



Cloud
Clear−sky
All
z (m)
3000
2000
1000
0.01
0.1
1
10
100
1000
$q_r$ (g m$^{-3}$)
$F_{qr}$ (mm h$^{-1}$)
$D_v$ (μm)

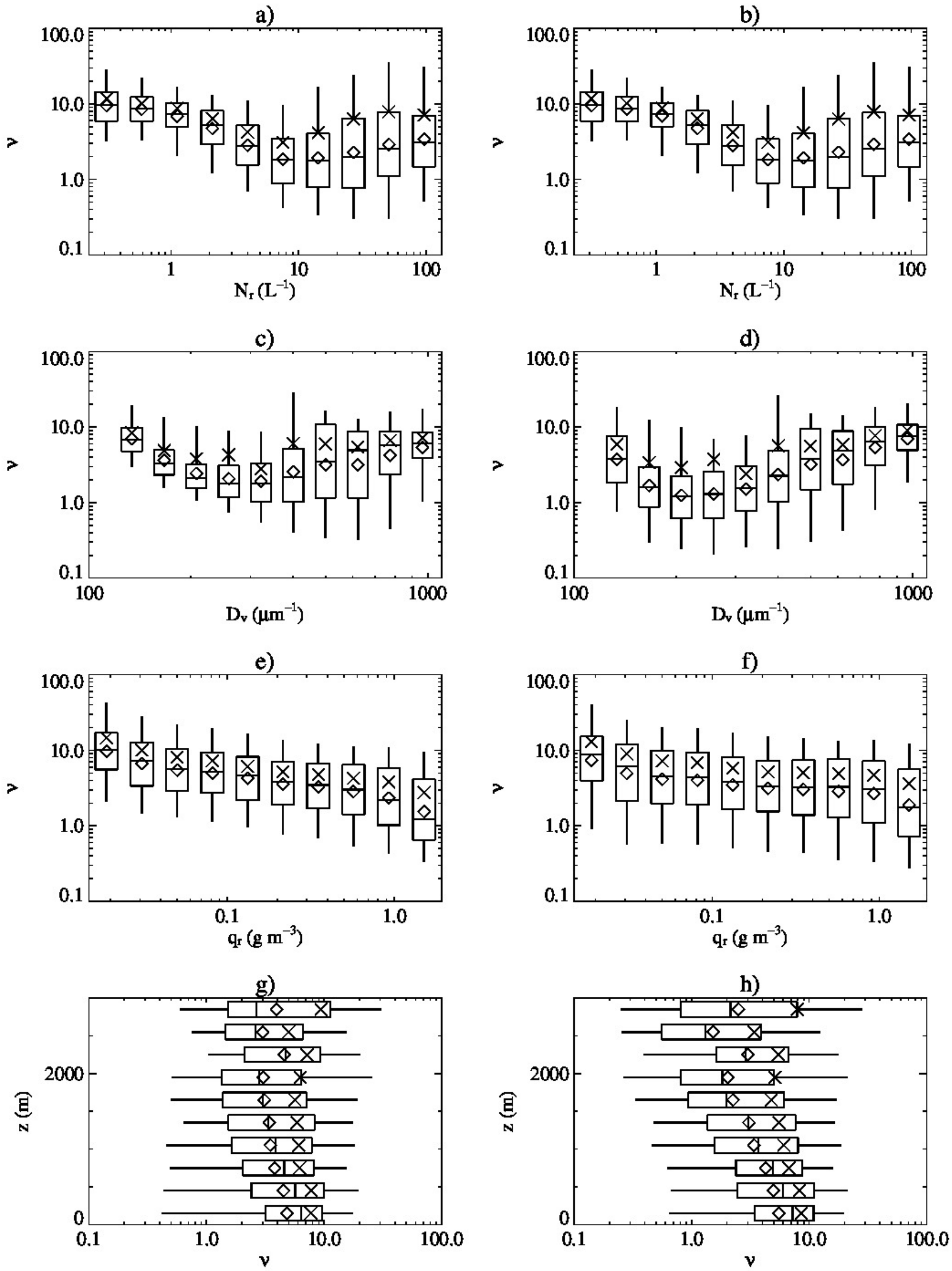
c) In Figure 3, it would be interesting to see how the qr-Nr relationship different at various altitudes. Maybe color code each data point by their altitude.

*This figure is shown below. The colors show the strong decrease of Nr with decreasing altitude, the decrease of Dv with decreasing altitude and no clear signal for qr. These behaviour are already shown in Figure 2 of the manuscript.*



d) Figure 5, please label each plot, since they are referred to in the discussion as Figure 5a, b, c, d. . .

*Response: Fixed. The labelled figure is shown below. We change the text accordingly.*



2) As I understand, the moment 1, 2, 4, and 6 are used in this analytical study because each of them is associated with a physical process during the raindrop evolution. However, the strength of such analyses is weakened since the physical processes associated with the moments are not consistently discussed through the paper. In fact, they are only briefly mentioned in line 24-26 of section 2.

*Response:*
*The rain drop spectrum evolves due to different processes that depend on different moments of the size distributions. The list of these processes and their relationship with the integral values of the rain drop size distribution are given in the introduction in order to summarize which moment of the distribution need to be parameterized. Then we study whether one single value of the shape parameter is able to represent the various moments and which value* could *correctly represent these moments. The aims of the paper is to provide a quantitative evaluation by using a comprehensive observational data set. A detailed analysis of the impact on each process would considerably lengthen the paper and is beyond the scope of this paper. However, we have reorganized the structure to improve the clarity of the paper. In particular, the method to determine the shape parameter is explained in the introduction. We move the description of the method (initially at the end of introduction, from L12 P682 to L3 P 683) to the beginning of section 3. We also move the two last paragraphs of section 2 to the beginning of section 3.*

3) The overall language is not fluent and precise enough for a good presentation of the scientific results.

*Response:*
*We take into account language corrections of referee 2 and correct the rest of the paper where language is not fluent and precise enough.*

**Minor comments**:

1) Page 678 line 6, "This study focuses on shallow cumulus rain distribution at every level in the cloudy boundary layer", "every level" is a obscure term

*Response; we change, as suggested by referee 2, in:*
*"throughout the depth of the cloudy boundary layer"*

2) Page 679 line 9, this sentence is supposed to explain "raindrops are sorted by size", how about "because large drops fall faster, the raindrop distribution tend to favor larger drops at lower levels"

*Response: Fixed.*

3) Page 670 line19, add "," between p and Mp

*Response: Fixed.*

4) Page 683 line 5, seems to me there is no need to use abbreviation for "section 3"

*Response: Fixed.*

5) Page 683 line 10, “raindrop spectra used in that study”, which study?

*Response: we meant “the present study”. We remove “in that study”.*

6) Page 683 line 16, “assume that the diameter is the drop height”, not sure what does this mean

*Response:*
*We replace “height” per “thickness along the diode array” L 16, L18 and L21.*
*We replace “depth” per “width along the flight path” L21.*
*We add Heymsfield et al (1978) as a reference for the Entire-in and the Center-in methods.*

*Reference:*
*Heymsfield, Andrew J., Joanne L. Parrish, 1978: A Computational Technique for Increasing the Effective Sampling Volume of the PMS Two-Dimensional Particle Size Spectrometer. J. Appl. Meteor., 17, 1566–1572.*

7) Page 685 line 13- 14, could you provide a reference or two for such LES simulation study?

*Response:*
*We refer to simulations performed with the DALES model that were not published (and are unfortunately not available anymore).*

8) Page 688 line 27-29, the structure of this sentence and the use of the parentheses have weakened the emphasis of the short sentence currently in the parentheses. It might be better to remove the parentheses, and rephrase the whole sentence.

*Response: we change the sentence in:*
*“These discrepancies are likely due to differences in rain characteristics specific to the cloud regime. In shallow cumulus, the mean volume diameters are lower and the rain number concentrations are larger than in deeper clouds.”*

9) The abbreviation “i.e.” is overused throughout the paper, some of them are inappropriate, such as page 682, line 17. Please consider rephrase many of the sentences that contain “i.e.”.

*Response:*
*P679 L 14. we replace “; i.e., “ per “. Microphysical processes are”*
*P680 L4: we replace “ ; i.e., they are” per “. Hence they are”*
*P681 L6: we replace “; i.e.,” per “:”*
*P682 L17-19 We remove “i.e. such that”, Eq. 5 and the following sentence.*
*P682 L8 We remove “, i.e.”*
*P692 L18: we replace “ i.e.” per “hence”*