Comments of referee #2.

Major comments (structure):

1. Introduction (p.2985, lines 14-22): This section requires more elaboration on the motivation of the study. What is the actual problem with fixed mass-diameter-relationship coefficients? Do we need them to vary with temperature? How will it help Megha-Tropiques retrievals or numerical simulations, especially when cloud-ice probe data and radar data are unavailable? Addressing the purpose more strongly in this section will give the paper clearer focus and should allow for better understanding of why certain figures and discussions appear later in the paper.

The respective part in the introduction/motivation has been rewritten as follows:

" The main focus of this study is to characterize the statistical relationship m(D) *between mass and maximum diameter of ice crystals by developing a retrieval technique that combines radar reflectivity and particle imagery in order to produce reliable calculations of the condensed water content (CWC) as a function of time (along flight trajectory). More particularly, this study focuses on the variability of m(D) relationship in tropical convective clouds. Several previous studies have shown significant variability in m(D) power law including pre-factor and exponent for different flights of one and the same aircraft campaign (McFarquhar et al. 2007; Heymsfield et al. 2010). Concerning the crystal growth by pure vapor diffusion it is well known that the crystal habit is primarily a function of temperature and supersaturation. (Bailey and Hallett 2004, 2009; Kobayashi 1993). Collision growth processes (aggregation and riming) in dynamically more active clouds tremendously complicate the resulting crystal habit and associated properties (crystal geometry, density, optical properties). Therefore, and to improve our understanding of microphysical processes in clouds in general, it is necessary to get a more realistic description of ice crystals and particularly a description of their mass as a function of their size (Schmitt and Heymsfield 2010). Cloud observations are often related to radar measurements or satellite observations. The forward modeling of the remote sensing signal (active or passive) and the retrieval of cloud microphysics is linked to the model capacity to simulate the radiative transfer through a population of ice crystals of complex habits.*

Numerous previous studies already related cloud radar reflectivity (usually at a frequency of 94GHz or 35GHz) and in-situ measurements of cloud microphysical properties. For instance in Protat et al. (2007), Hogan et al. (2006), and Pokharel and Vali (2011) the total water content is calculated assuming a constant mass-size relationship for all clouds. Derived Z-CWC relationships often need a correction which is a function of temperature. This somewhat translates the lack of knowledge of the temperature dependency of mass size relationships."

2. Presentation of method/results: Sections 3 and 4 should be swapped around. Section 4 currently is heavy on methodology and its result, its linear relationship between beta and sigma, will help focus section 3 and understanding of the results in that section.

Since the remainder of the results concern beta_sigma, the authors should consider ignoring the use of beta_i on pages 2992 and 2993. Although interesting, the beta_i do not re-appear once the beta_sigma have been introduced. The discussion on pages 2992 and 2993 could be shortened and focus on the derivation of alpha_sigma.

According to the reviewer's recommendations we suggest merging sections 3 and 4. We'd like to keep sections 4.1 and 4.2 which would become 3.1 and 3.2. A section 3.3 would be a reduced version of the entire current section 3. This section 3.3 would focus on the calculation of the mass-size relationship starting from $ß_\sigma$ *deduced from the equation 11. Figure 4 will be deleted. Figures 2 and 3 will be directly followed by figure 8 (current numbering). Then we wish to keep an explanation on the evaluation of the uncertainty of the retrieval method itself (without counting the uncertainties from PSD, shattering impact, etc….). This part will be illustrated without the* α_i *and* β_i *coefficients, to make the reading of this paper easier.*

« 3.3 Mass-diameter coefficients and CWC retrieval

In order to better understand the importance of coefficients α and β in eq. 1 and their impact on the retrieved CWC, reflectivity simulations at 94GHz have been performed and compared with corresponding measured reflectivities on the flight trajectory. Simulations of radar reflectivities are complex when considering non-spherical ice crystals. In this study, the backscatter properties of the hydrometeors have been simulated with the T-matrix method (Mishchenko et al. 1996) for crystals and/or with Mie theory for spherical particles. In order to model the scattering properties of the ice particles, these particles are assumed to be oblate spheroids with a flattening that equals the mean aspect ratio $\overline{As}$ *of the hydrometeors with* D_{max} *< 2mm, which mainly impact the simulated reflectivity:*

$$\overline{As} = \sum_{D_{\max}=55\mu m}^{2000\mu m} Pi(D_{\max}) \cdot As(D_{\max}) \quad (4),$$

where

$$Pi(D\max) = \frac{N(D_{\max}) \cdot D_{\max}^3 \cdot \Delta D_{\max}}{\sum_{D_{\max}=55\mu m}^{2000\mu m} N(D_{\max}) \cdot D_{\max}^3 \cdot \Delta D_{\max}} \quad (5).$$

$N(D_{max})$ is the concentration of the hydrometeors and $As(D_{max})$ their average aspect ratio. $\overline{As}$ *is calculated every 5 seconds as is done for the composite PSD. Of course at 94GHz the hydrometeors with* D_{max} *> 2mm are not invisible, but the increase of their backscattering cross section (Qback ; Fig. 2) as a function of their size is not sufficient taking into account the very small crystal concentrations beyond a few millimeters. Thus, their impact on the simulated reflectivity is negligible. Fig. 2 also shows the impact of As on the effective reflectivity for 94 GH, for varying As between 0.5 and 1. For As = 1 Mie theory was applied. For diameters less than 600-900 µm simulated radar reflectivities agree well with those*

calculated using the Rayleigh approximation. As can be seen in this figure, the so-called 'Mie effects' appear only for larger diameters and decreasing aspect ratio As. The Pi(Dmax) weighting function impacts the mean aspect ratio $\overline{As}$ *which will be used to constrain the Tmatrix simulations of the radar reflectivity. In Pi(Dmax) the maximum length of hydrometeors is taken at its third order, to take into account the impact of the hydrometeors in the sampling volume. This choice is a compromise to accomplish for the lack of knowledge to constrain the variability of* Q_{back} *for natural ice crystals, and previous approximations using the Mie solution to model the* Q_{back}*. Instead of the third order of* D_{max}*, we could have chosen the number concentration* $N(D_{max})$ *or* $N(D_{max})* S(D_{max})$*, both may overestimate the smaller ice crystals, while* D_{max}^6 *(Rayleigh approximation) does not seem to be the best choice either in this context. To quantify the impact of the uncertainty to the calculation of* $\overline{As}$ *on the retrieved CWC, it has been calculated that (with respect to Pi(Dmax) defined in equation (5), CWC increases by about 12% if Pi is calculated from* $N(D_{max})$*, and CWC increases by about 6% if Pi is calculated from* $N(D_{max})*S(D_{max})$*.*

In general, we assume that hydrometeors consist of a homogeneous mixture of ice and/or air. Their dielectric properties of the particles are therefore a function of the mass-diameter relationship that represents the fraction of ice f_{ice} *(equation 6) in the hydrometeors. Equation 6 explains how the ice fraction of the solid hydrometeor are calculated, with* ρ_{ice} *= 0.917g* cm^{-3}*. The ice fraction* f_{ice} *cannot exceed 1.*

$$f_{ice} = \min\left(1\ ,\ \frac{\alpha \cdot D_{\max}^{\beta}}{\frac{\pi}{6} \cdot \rho_{ice} \cdot D_{\max}^{3}}\right) \quad (6).$$

Once f_{ice} *is determined the refractive index is calculated using the approximation of Maxwell Garnet (1904). The mass of the spheroid does not depend on the aspect ratio As, but the backscattering properties do. By means of the T-matrix method the backscattering coefficient of a particle is calculated assuming the particle volume as a prolate spheroid with a diameter* $D_{Tmatrix}$ *:*

$$D_{Tmatrix} = D_{\max} \cdot \sqrt[3]{\frac{1}{As}} \qquad (7)$$

In order to calculate the 94 GHz radar reflectivity, the particle number distribution $N(D_{max})$*, its mean aspect ratio As, and the ice fraction* f_{ice} *of the hydrometeors, also the coefficients β and α of the mass-diameter relation (eq. 1) must be given. Fig. 3 gives an outline of the technique developed to retrieved the m(D) coefficients. After imposing* β_σ *the prefactor* α_σ *is determined by minimizing the difference between the simulated and measured reflectivities. Then the corresponding CWC in g* m^{-3} *is calculated from the PSD and the mass-diameter coefficients:*

$$CWC(\alpha_\sigma, \beta_\sigma) = 10^3 \cdot \sum_{D_{\max}=50\mu m}^{D_{\max}=6400\mu m} N(D_{\max}) \cdot \alpha_\sigma D_{\max}^{\beta_\sigma} \cdot \Delta D_{\max} \qquad (8).$$

Fig. 8 shows the temporal evolution of the PSD, mean aspect ratio $\overline{As}$*, exponent* β_σ*, derived* α_σ*, and calculated CWC(*α_σ*,* β_σ*) for a cloud sequence of the flight 18 during MT2010. The temporal variabilities of the PSD,* $\overline{As}$*, the exponent* β_σ*, constrained pre-factor* α_σ*, and CWC are considerable..*

Uncertainty of this method, calculating CWC, is evaluated when systematically varying β *in the interval [1;3], while for each* β *the pre-factor* α *is deduced accordingly (by minimizing the difference between the simulated and measured reflectivities). Subsequently, corresponding CWC values are calculated. For a given time step (of 5 seconds) the calculated minimum and maximum values of CWC (*CWC_{min} *and* CWC_{max}*, respectively) are used to estimate the maximum uncertainty (*ΔCWC_{max}*) of the retrieved CWC.* ΔCWC_{max} *is simply defined as the maximum difference between CWC(*α_σ*,* β_σ*) and the largest or smallest value of CWC. This maximum uncertainty can be also calculated in terms of the relative error in percent:*

$$100.\frac{\Delta CWC_{\max}}{CWC(\alpha_\sigma,\beta_\sigma)} = 100.\frac{MAX(\ \left[\left|CWC_{\min} - CWC(\alpha_\sigma,\beta_\sigma)\right|\ ;\ \left|CWC_{\max} - CWC(\alpha_\sigma,\beta_\sigma)\right|\right]\ )}{CWC(\alpha_\sigma,\beta_\sigma)} \quad (9).$$

For both measurement campaigns MT2010 and MT2011, Fig. 5 shows the distribution of ΔCWC_{max} *in percent. For most of the calculated CWC values the maximum error remains below 30%. Average values of the maximum deviations in CWC are 21% for MT2010 and 20% for MT2011, respectively.*

These uncertainties do not take into account the uncertainty related to the measurements of the reflectivity by the cloud radar RASTA. Tab. 2 gives the impact of the reflectivity on the retrieved m(D) coefficient α*. For example, if the reflectivity is shifted by +1 dBZ to simulate a radar calibration error, the CWC retrieval is increased by 11% with respect to the CWC given by the measured reflectivity. The CWC retrieval of this method is pretty sensitive to uncertainties in measured reflectivities and also to the shape (or flattening) parameter used to simulate the radar reflectivity."*

3. Section 5: This results section is currently overflowing with figures which are poorly introduced, and various discussion points seem irrelevant to the paper's main focus. The only results related to the section title ("Mass-diameter relationship") are figures 10 and 11b and 11c; it is unclear why the other figures are included. The authors should consider reducing this section to "Retrieved mass-diameter relationships", which discusses figures 10, 11b, and 11c. This discussion can then continue with figure 9, which compares the CWC simulated from the retrieved mass-diameter relationship with theory and observations. The remaining figures (11a, 11d-f, 12, 13, 14, 15) all show interesting results, but these have no immediate purpose in this paper. If the authors are adamant that these figures should be included, they are advised to combine them in a separate section, for instance "Altitude relationships of cloud-ice properties".

Figure 11 is modified, taking into account the comments of referee#1 and #2. In addition, figures 12 and 15 have been deleted.

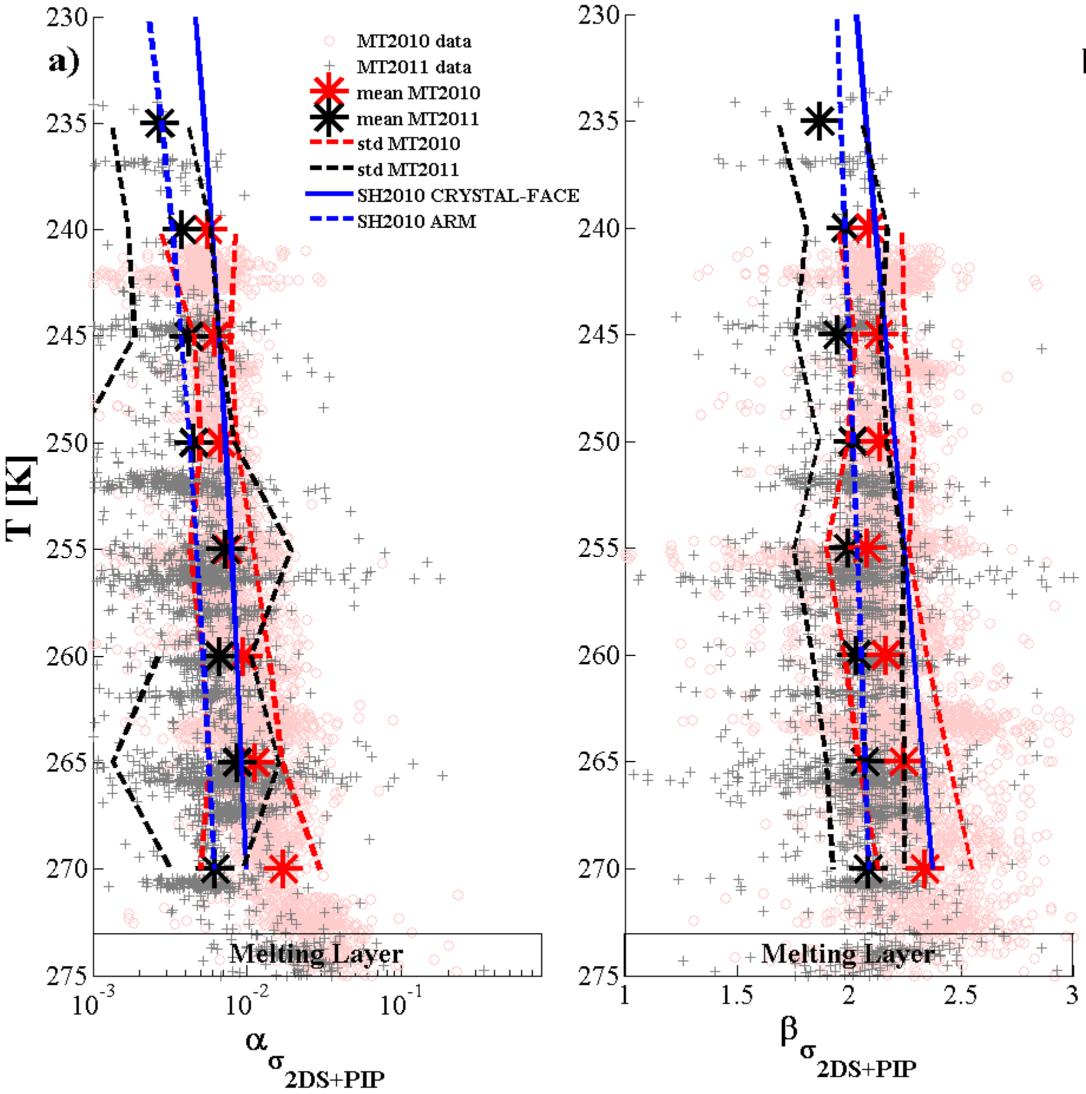

Figure 1 : Vertical profile of m(D) coefficients constrained by T-matrix and the variability of S-D exponent σ calculated from 2D-S plus PIP images. (a) α_σ versus the temperature in K. (b) β_σ versus the temperature in K. Pink circle show data points (5-seconds time step) of MT2010, grey crosses show MT2011 data. Red and black stars present mean values of m(D) coefficients in 5K temperature intervals for MT2010 and MT2011, respectively. Dashed red and black lines show standard deviations of MT2010 and MT2011, respectively, from the mean value. Blue solid and dashed lines show vertical profiles of SH2010 obtained for CRYSTAL-FACE, and for ARM, respectively.

Major comments (science and method):

4. Matching of observations in time and space (pages 2989-2990): It is currently unclear over how many observations the particle size distribution is calculated; what is the stretch of time?

At the end of section 2 :

"The bin resolution of the composite distributions is given by ΔD_{max} equal to 10 microns. Examples of PSD and TSD are presented in Fig. 1. Overall the 2 probes are in good agreement in their common size range. Fig. 1a shows the PSD composite distribution and the individual PSDs of the individual probes. The AsD composite distribution is shown in Fig. 1b.

It can be seen that the transfer function smoothes the transition from the 2D-S to the PIP. PSD (as AsD) and RASTA reflectivity are synchronized and averaged over the same time step which is 5 seconds. RASTA reflectivities are measured in nadir and zenith of the flight trajectory and interpolated to the flight level. Interpolation is made …"

And what is L^-1 (line 9, pages 2989)?

Total hydrometeor concentrations are given per liter, concentrations in PSD are given per liter and per micrometer.

The authors should include a paragraph at the end of section 2 to describe the radar data: how are the radar observations matched in time and space to the PSD detected by the aircraft? This currently partly appears elsewhere but the information is required here for the reader.

*See answer above presented to respond to "*Major comments (science and method):"

5. Equation 4 (mean aspect ratio): At a later stage, the authors mention that <As> is calculated only for Dmax within the 94GHz radar sensitivity - is this true for equation 4 as well? If so, please adjust this in the summation. Since the mean aspect ratio is used for radar reflectivity calculations, it is worrying that the summation is weighted by particle number concentration, and not by mass or mass-squared. The radar reflectivity will be dominated by large particles, so the effect of flattening observed in Z should mostly come from large particles. The <As> however is weighted towards the more numerous (likely smaller) particles, which are expected to be more spherical, thus <As> might be closer to 1 than what would be observed by the radar. Could the authors consider changing the equation to weight it with mass or mass-squared instead of number, or at the very least consider this option in the text?

*See answer above presented to respond to the first part of the 2nd point of the reviewer's "*Major comments (structure):"

6. Vertical trends of mass-diameter coefficients: This appears to be only weakly supported by the results, but is stated as a major conclusion in both the abstract and the conclusions. In a revised section 5, the authors are advised to more carefully establish these "vertical trends": what is the relationship of alpha and beta individually with temperature, and how significant is this relationship? These trends look rather vertical in figures 11b and 11c and certainly within the error bounds presented.

In the revised version of section 5 (which becomes section 4 in the revised manuscript) we will focus more on the variability of the mass-diameter relationships (see also the subsequent answer to the reviewer's point 7). The vertical variability will be described by fitting the mean profiles as a function of the temperature.

7. Use of a single m(D) relationship to calculate CWC (page 3003): This seems a

missed opportunity to test the effect of having a variable m(D) relationship. The authors have the tools to assume a single m(D) relationship (e.g. beta=2.44, page 3005) and calculate a Z-CWC relationship, or even use BF95 on their observations to calculate Z-CWC. This will test how advantageous it is to have a variable relationship, rather than comparing with P2007. Using their own data to test this, the authors could possibly add a major conclusion and scientific advance to this paper.

To answer to the reviewer's comment, different methods have been applied to calculate CWC from measured PSD (in order to use Brown and Francis m(D) relationship, PSD were also calculated as in Brown and Francis's paper such that the diameter is D = (Lx+Ly)/2). Subsequently, CWC can be calculated for Brown and Francis, and the other methods (H2010, SH2010). Finally, for all methods Z-CWC relationships, and Z-CWC-T relationships have been deduced (fitted), taking Z from RASTA. For each method applied to both MT datasets, correlation coefficients (cc) between Z and CWC, and model errors ($error_z$) as described in equation 16 (in the current version of this paper) were calculated. From this $error_z$, average values, median, first quartile, last quartiles and 90^{th} percentile were calculated. As it has been suggested by the referees #1 and #3, we used the σ coefficient (exponent from S-D fitted relationships) calculated from 2DS plus PIP images to calculate β_σ and subsequently constrain α_σ .The results are presented in table 1. Moreover, table 2 shows corresponding results when using only 2DS images to fit the σ exponent with subsequent calculation of β_σ and α_σ.

The Z(CWC ;T) –Z(CWC) columns demonstrate the improvement when the temperature is parameterized in the fitted relationships between Z and CWC.

The main result of this study is that $error_z$ is minimal when comparing the CWC(Z) parameterization retrieved from T-Matrix calculations of CWC and Z from RASTA radar with CWC (α_σ , β_σ) calculated with the help of m-D relationships constrained by the 2D images (2D-S plus PIP on the one hand and solely 2D-S on the other hand). The CWC(Z) parameterizations fitted for the other methods and compared to CWC (α_σ , β_σ) all produce significantly larger values for $error_z$. When taking into account the temperature in fitting Z(CWC;T) for the time resolved T-matrix method, this does not improve significantly correlations as compared to Z-CWC parameterization only. In contrast, for the other methods applied to MT2010 and/or MT2011 datasets (averaged T-matrix, H2010 (NAMMA), H2010 convectively generated, B&F, SH2010 (Crystal Face), SH2010(ARM)), the improvement is significant when the temperature is taken into account for the MT2010 dataset. For the MT2011 dataset taking into account the temperature is not sufficient to improve Z-CWC models. The MT2011 dataset seems to have more complicated microphysical processes than MT2010.

Tableau 1 : Error$_z$ in percent when comparing Z-CWC and Z-CWC-T relationships with CWC calculated according to different methods applied to MT2010 and MT2011 datasets. Correlation coefficients between CWC and reflectivity are given in the column denoted cc. Average errors are given in column E. Quartile, median, third quartile and ninetieth percentile, are given in 1/4, 1/2 , 3/4 and 9/10 columns. σ is calculated using S-D relationships from 2DS plus PIP.

Sigma = f(2DS+PIP)

Z(CWC)

	MT2010						**MT2011**					
method	cc	E	1/4	½	3/4	9/10	cc	E	1/4	1/2	3/4	9/10
Tmatrix+2D Images of OAP	0.95	25	8	16	29	52	0.94	39	13	29	48	71
Averaged coefficients for Tmatrix	0.81	54	16	30	49	115	0.83	76	19	41	65	126
H2010 (NAMMA)	0.81	56	16	31	51	118	-	-	-	-	-	-
H2010 (convectively generated)	-	-	-	-	-	-	0.83	76	19	40	65	124
Brown & Francis	0.8	60	17	33	54	126	0.82	76	20	41	67	129
SH2010 (CRYSTAL-FACE)	0.81	56	16	30	50	114	-	-	-	-	-	-
SH2010 (ARM)	-	-	-	-	-	-	0.84	74	18	38	62	121

Z(CWC ;T)

	MT2010						**MT2011**						**Z(CWC; T) – Z(CWC)**	
													MT2010	**MT2011**
method	cc	E	1/4	½	3/4	9/10	cc	E	1/4	1/2	3/4	9/10		
Tmatrix+2D Images of OAP	0.95	23	7	15	26	47	0.95	37	13	26	44	67	-2	-2
Averaged coefficients for Tmatrix	0.82	44	11	24	42	89	0.83	72	18	37	61	115	-10	-4
H2010 (NAMMA)	0.82	43	11	23	41	87	-	-	-	-	-	-	-13	-
H2010 (convectively generated)	-	-	-	-	-	-	0.84	72	19	37	61	115	-	-4
Brown & Francis	0.81	43	11	23	42	87	0.84	71	18	38	63	119	-17	-5
SH2010 (CRYSTAL-FACE)	0.81	44	11	24	43	91	-	-	-	-	-	-	-12	-
SH2010 (ARM)	-	-	-	-	-	-	0.82	72	18	37	61	114	-	-2

Table 2 : As table 1 but when σ is derived from the 2DS S-D power law.

Sigma=f(2DS)

Z(CWC)

	MT2010						**MT2011**					
method	cc	E	1/4	1/2	3/4	9/10	cc	E	1/4	1/2	3/4	9/10
Tmatrix+2D Images of OAP	0.95	24	7	16	29	54	0.94	41	14	29	47	74
Averaged coefficients	0.81	52	15	29	48	109	0.81	91	19	41	65	137

Z(CWC ; T)

	MT2010						**MT2011**						**Z(CWC; T) – Z(CWC)**	
method	cc	E	1/4	1/2	3/4	9/10	cc	E	1/4	1/2	3/4	9/10	**MT2010**	**MT2011**
Tmatrix+2D Images of OAP	0.95	22	7	15	26	49	0.95	38	12	26	44	67	-2	-3
Averages coefficients	0.83	42	11	24	42	89	0.82	85	20	38	61	129	-10	-6

Minor comments:
8. p.2986, line 24-25: "Retrieved relationship are finally used..." - by whom? By Lawson et al.? By the authors?

Heymsfield et al (2002) then used the retrieved m(D) relationships to compute Ka-band radar equivalent reflectivities, which are in good agreement with measured reflectivities.

9. p.2987, line 2-3: "vertical profiles" - of what? Radar reflectivity?

" McFarquhar et al. (2007) derived vertical profiles of m(D) relationships in the stratiform part of Mesoscale Convective Systems (hereafter MCS) above the North American continent within and below the melting layer"

10. p.2987, line 6: What numerical simulations? Of scattering properties?

The beginning of the sentence has been deleted.

"Schmitt and Heymsfield (2010, hereafter SH2010) have simulated the aggregation of plates or columns."

11. p.2987, line 13-16: What was the strong relationship from H10 based on? Theory, observations, simulations, something else?

Heymsfield et al. (2010, hereafter H10) have calculated m(D) coefficients by minimizing the differences with measured CWC for different airborne campaigns. They demonstrate that a strong relationship exists between α and β coefficients, which was mathematically demonstrated with a gamma distribution to model the PSD. Furthermore, they argue that the BF95 relationship overestimates the prefactor α for stratiform clouds, whereas α is underestimated for convective clouds."

12. p.2989, eq.2: How good is the PIP at Dmax<950, if it will only measure 9 pixels across?

In the range [450µm; 950µm] the two probes 2D-S and PIP are in agreement with respect to the size of the particle. The 2D-S is very reliable up to particle sizes of 700 µm. Below 950µm in diameter the PIP particles are taken into account with decreasing weight, in order to ensure the continuity of the composite PSD. PIP particles of 5-7 pixels have low weight as compared to the corresponding 2D-S particle images. In contrast the weight of PIP particle images increases for particles of 8-9 pixels as compared to the 2D-S. Above 9-10 pixels, the 2D-S starts to be considerably affected by the truncation of the particles. Therefore the transition from the 2D-S to the PIP is needed before.

13. p.2991, line 21-22: The authors are advised to call alpha_i here alpha_j, and use alpha_i only for the alpha which minimizes the reflectivity difference. (Though this part of the text may be removed if the revised discussion solely focuses on alpha_sigma).

This part has been modified.
*See the answer above presented to respond to the 2nd point of the reviewer's "*Major comments (structure):"

14. p.2992-2993: Are there no error calculations for alpha, beta, and CWC?

Errors on α and CWC are given in table 2 and 3. An error on the calculation of As of about 10% would result in an uncertainty of about ±6% on α and ±6% on CWC. In the same way, an uncertainty of 2dBZ of the measured reflectivity would result in an uncertainty of ±26% on α and ±26% on the retrieved CWC.
Furthermore, the calculation of β has an uncertainty about ±11%, which is the error between the β calculated with the linear fit and the β calculated through the 3D simulation (a more detailed explanation of that error is presented in the response to reviewer 3).

The uncertainty from the reflectivity differences when finding the alpha_i could be used to weight-average CWC in equation 8.

Simulated and measured reflectivities are identical.

15. equation 10: It is not clear which measurements are used to find gamma and sigma.

*S-D power laws are calculated for 5-second time intervalls and are synchronized with PSD and RASTA reflectivity. Inorder to calculate the S-D power law, we plot the mean surface of the particles (measured during 5 seconds) versus their D_{max} (figure2) for the two probes. S-D are then fitted by a power law described by two parameters: prefactor γ and exponent σ, individually for both probes. On a log-log scale, ln(γ) is the y-axis intercept, and σ the slope of the linear relationship such that log(S) = σ*ln(D)+ ln(γ).*

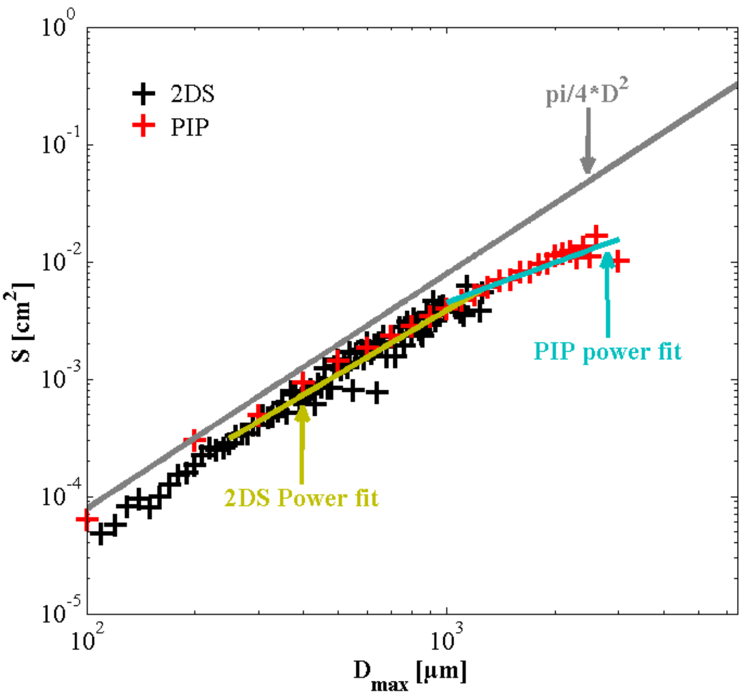

Figure 2: Mean projected surface in cm2 on y-axis versus Dmax in µm on the x-axis. Black symbols represent the 2DS image data and red symbols the PIP data. The grey line would be the power law fit for spherical particles. The golden line is the power law which fits the 2DS data for Dmax larger than 250µm and the blue line fits the PIP data with a power law for Dmax larger than 950µm.

16. equation 11: Is there any evidence in literature of such a fit? Should we expect a linear relationship between beta and sigma? A bit more discussion is required here.

There is no evidence in literature of such a fit. SH2010 have related the fractal dimension in 2D and 3D by box counting (Falconer 2003; Mandelbrot 1982; Tang and Marangoni 2006). In this study, S(D) and m(D) relationships are studied with 3D modeled ice-crystal shapes. Then σ and β are related with the objective to preserve the variability of the m(D) exponent as a function of the 2D images recorded for the 2 campaigns (where σ is calculated each 5 seconds step and β is calculated as a function of σ). The standard deviation of the model error using equation 11 is about 11%.

From comments of Referee #3, an additional paragraph on the uncertainty of β and also the impact of an eventual orientation of ice crystals during the cloud sampling has been added to the study.

17. p.2996 lines 9-16: What type of growth speed do the authors consider? Growth in time? Growth with change in diameter?

" In view of the results produced by the 3D simulations, it seems that β (and also σ) does not relate much to the sphericity of the crystal shape, but more to how a population of ice crystals is growing in the 3D space (axis x, y, z) as a function of its evolution in the direction of the maximum length."

18. p.2997 line 14: Where is this Sierra Nevada?

"The data set of hydrometeors is coming from winter storms in the central Sierra Nevada in the western part of the North American continent. The crystals have been collected at the ground, and subsequently fitted to build the B&L scheme. This is not necessarily best adapted for the hydrometeor data set used in our study."

19. p.2997 lines 9 and 17-18: These statements appear related and should be combined in a single sentence (exponent close to 1 and good correlation).

A good correlation between two parameters does not imply that the exponent of a power law is close to 1. An exponent close to 1 describe a linearity between to parameters, while a correlation coefficient describes to what extent two types of dataset are related.

20. p.2998 line 5-6: Is this correlation between alpha and beta expected from theory, or is it a result of the methods used in this paper?

For this it is a result. But it has also been demonstrated in H2010. See also answer to the comment 11.

21. p.2998 line 14: How would the different beta-calculation of H10 affect the slope?

Beta-calculation from fractal Dimension or by minimizing differences with a measured CWC?

Figure 3 shows results obtained when the m(D) coefficients are calculated flight by flight thereby minimizing the differences with the retrieved mean CWC. The mean CWC has been chosen, in order to avoid biasing the findings in favor of the coefficients where β is constrained by the σ (2DS or 2DS +PIP). This isdescribed in the current version of the paper. The huge standard deviation of ln(α) observed when we use a constant exponent β shows that it is important to describe variability of β in space and time.
Since it has been decided that the discussion of solutions of (α_i, β_i) and CWC(α_i , β_i) is no longer discussed in the current version of the manuscript, the study of the variability of the m(D) coefficients is tackled with the variability of Z-CWC and Z-CWC-T parameterizations for different methods of retrieved m(D) and thus CWC. The below figure will not be taken into consideration in the revised manuscript.

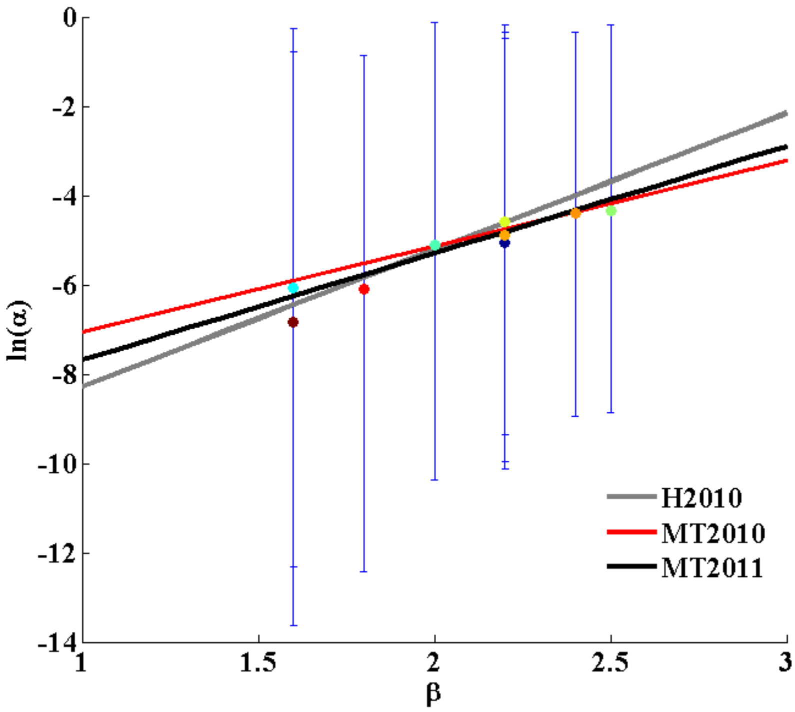

Figure 3: m(D) coefficients are obtained by minimizing differences with a the retrieved CWC. Red to orange points are obtained for MT2011. Blue to green points are obtained for MT2010. The grey line represents the results shown by H2010 for convective clouds with α=1.17.10^{-5}*exp(3.066*β). The red line represents results obtained for MT2010 using the coefficient α_σ and β_σ with σ calculated from the PIP plus 2DS images , with ln(α_σ)=1.9211*β_σ-8.9831. The black line is identical to the red line but for MT2011, with ln(α_σ)=2.396*β_σ-10.095. Error bars represent the first quartile and the last quartile of ln(α) for each flight.

22. p.2998 line 17: How does this (weak) variation with temperature relate to CWC(Z,T) relationships?

See answer of the 7 question in “Major Comments (science and method)”.

23. equation 12: Why not use a single exponent for the constant and the beta-dependence?

We simply wanted to keep explicitly the dependency of α_σ from β_σ, since β_σ is calculated from fitted σ.

24. p.2999 line 17: What is this horizontal variability? Horizontal across the width of an

anvil?

In general, flight at constant levels were performed in the anvil as close as possible and parallel to the convective line for MT2010. For MT2011 flight pattern were performed downstream the convective cell, but not crossing the most active part.

25. equation 13: Note that this equation is very similar to that for f_ice, that is, rho_eff = rho_ice * f_ice. Any reason why?

This part has been completely removed to take into account the comment 3 in the "Major Comments (structure)".

26. p.3001 line 12-13: "most of the total mass resides in the range" - This is a confusing statement, as the total mass referred to here is actually the sum of M(Dmax) over the different Dmax, whereas the authors have already defined M(Dmax) to be total mass. Better to define M(Dmax) as the mass of particles of size Dmax, not as "total mass".

This part has been completely removed to take into account the comment 3 in the "Major Comments (structure)".

27. p.3002: How do the authors' findings relate to existing CWC-Z relationships, and why do they think there is no CWC-Z-T relationship?

In the initial manuscript version, the $Z-CWC-T$ could not be modeled with linear or quadratic functions as it is shown in the literature. After the final corrections of the RASTA dataset (details are given below this paragraph), $Z-CWC-T$ can be modeled. However, as is demonstrated in the answer to comment 7 of "Major comment (science and method)", the temperature in the $Z-CWC $relationships does not add significant improvements.

Mass-diameter relationships are calculated in this study with the help of measured reflectivity at 94GHz. Subsequently CWC can be calculated from PSD and m(D). Most recently the international HAIC-HIWC campaign which took place during January- March 2014 out of Darwin allowed to confront the radar reflectivities of the RASTA radar and the direct measurements of the IWC using the IKP (isokinetic evaporator probe).This confrontation allowed to improve the method correcting the radar reflectivity close to the aircraft within 900m below and above the aircraft.
We integrated into our answers to the reviewers and in the new version of the radar RASTA data these results taking into account the corrections of the reflectivity of RASTA in the vicinity of the aircraft.

Is this because the temperature dependence is incorporated in alpha and beta, which both affect CWC and Z? (also p.3004, line 9-16).

For MT2010, the variability of m(D) coefficients somewhat implicitly takes into account the temperature dependency in CWC-Z parameterizations, most likely due to the horizontal homogeneity if cloud microphysics..
For MT2011 the microphysical processes seem to be more complicated to be better parametrized if temperature is incorporated in the parametrisation (CWC-Z-T).

28. p.3005 line 4-5: Is there any significance in the MT2010 and MT2011 sharing the same beta?
How do these average alpha and beta compare with literature?

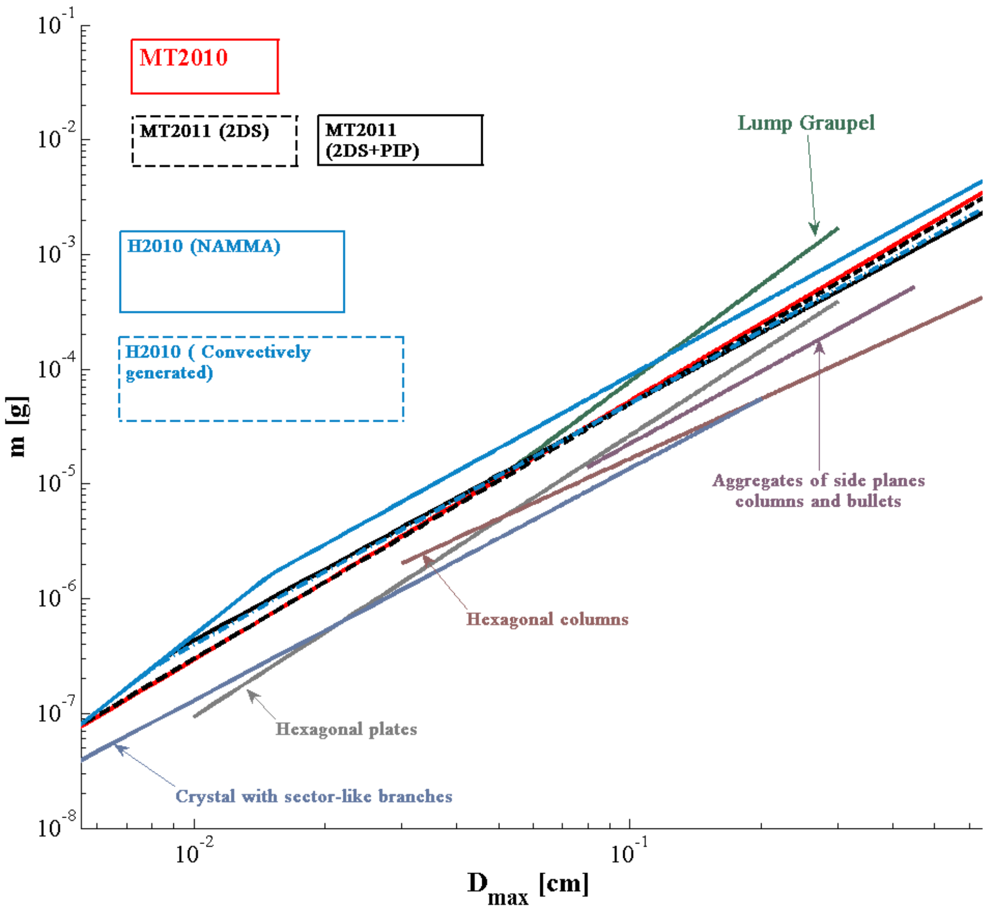

Figure 4 : Mass of ice crystals in gram on y axis, as a function of their Dmax in cm on the x axis. The red line represents mean values of m(D) coefficients for MT2010 when σ is determined from 2D-S plus PIP images with α=0.0098 and β=2.26. Likewise, the black dashed line represents m(D) coefficients for MT2011 with α=0.0057 and β=2.06. The black line represents MT2011 when σ is determined from 2DS only with α=0.0082 and β=2.22. The blue line represents m(D) coefficients taken from H2010 for the NAMMA campaign with α=0.011 and β=2.1. Dashed blue line stands for H2010, but for convectively generated systems with α=0.0063 and β=2.1. Blue grey line is given by Mitchell 1996 for crystal with sector-like branches with α=0.00142 and β=2.02. Grey line (Mitchell 1996) represents hexagonal plates with α=0.00739 and β=2.45. Brown grey line (Mitchell 1996) represents hexagonal columns with α=0.000907 and β=1.74. Purple grey line (Mitchell 1996) is for aggregates of side planes columns and bullets with α=0.0028 and β=2.1. Green line (Mitchell 1996) is for Lump Graupel with α=0.049 and β=2.8.

Averaged values of m(D) coefficients found for MT2010 and MT2011 with σ determined from 2DS only are relatively close. They give less mass for a same D_{max} if they are compared with m(D)coefficients of H2010 for NAMMA. Average values for m(D) coefficients when 2DS plus PIP are used to determine σ, show similar trends between H2010 for cloud convectively generated and MT2011. m(D) coefficients given by Mitchell 1996 give less mass for a same D_{max} compared with the m(D) relationships cited before, with an exception for the lump graupel's m(D) coefficients which give largest mass for particles beyond 1mm compared to all the other m(D) relationships. Mitchell's lump graupel still give larger mass for particles

beyond 500µm compared to MT2010 and MT2010 m(D) from T-matrix and H2010 convectively generated m(D).
Note that for MT2010 when using the 2DS plus PIP to determine σ we find m(D) coefficients close to those found with 2DS with $\alpha=0.0093$ and $\beta=2.25$

29. p.3005 line 10-11: "Since <As> increases with altitude, the reflectivity of the larger diameter particles decreases with altitude" - a large particle's reflectivity will change with altitude if its own As increases with altitude, not necessarily the mean As. The mean As could simply change because there are more numerous small (spherical) ice particles. The current statement is confusing and should be rewritten.

This section has been deleted since the corresponding figure has been removed, as proposed in the comment 2 of "Major comments (Structure)".

30. Figure 16: What is the purpose of this figure and why is it introduced at this stage? Its discussion on p.3005-3006 reads as a description of observations and would have made more sense in section 2.

See also referee #1 specific comments.

"Next to the Doppler Cloud radar RASTA (Protat et al. 2009) in-situ measurements of microphysical properties were performed using a new generation of optical array probes (OAP): the 2-D stereo probe (2DS) from Stratton Park Engineering Company (SPEC) Inc. which allows to monitor 2D images in the size range 10-1280µm, and the Precipitation Imaging Probe (PIP) from droplet Measurement Technologies (DMT) which measured hydrometeors in the size range from 100-6400 µm. Figure 16 (in the first manuscript version) summarizes the observations of typical crystal morphologies observed during the 2 campaigns. 2D images are presented as a function of altitude. On the left side of Fig. 16 hydrometeors observed in continental MCS are shown, whereas on the right side hydrometeors observed in oceanic MCS are presented. In the two first levels (-1°C and -5°C) hydrometeors are similar with one exception. For others levels ice crystal shapes are in general different. Observations of significant amounts of dendrites (which typically develop due to water vapor diffusion only) occurred in MT2011, while 2D images for MT2010 generally look more like aggregates and graupels."