Reply to Reviewer #1:

We thank the reviewer for the time and efforts she/he spent reading our manuscript and providing valuable suggestions and advices. Please find below a discussion of the reviewer's comments (italic). Changes/additions made to the text are underlined and given in quotes.

- The combination of geometric retrievals and hyperspectral measurements is new and can give additional cloud structure information. In addition its an important information to analyze angle dependent reflectance properties of the DCC relative to the Sun, but the derived parameter of cloud distance from the geometric retrieval is only one single parameter. The observed area by the imaging instrument depends on the field of view, cloud structure and distance and could lead to a 3D cloud structure, but the simple assumption of a homogenous vertical cloud area within the field of view of a single imaging pixel might lead to errors in the analysis of cloud scattering effects.

The reviewer is right, that we used a simplified assumption in this work. A complete cloud structure retrieval needs much more efforts. In an upcoming publication (Zinner et al.) such a retrieval based on stereographic methods and the signature within the O2-A band will be presented. However, 3D effects due to horizontal photon transport is reduced at the wavelengths which are used for calculation of the phase index. The free photon path length is reduced due to cloud particle absorption in this spectral range. Marshak et al. (2006) and Martins et al. (2011) discussed the usage of 1D radiative transfer simulations for calculation of reflected radiation from cloud sides at different wavelengths. They concluded, that after adaption of the viewing and zenith angle, 1D assumptions are applicable for wavelengths, where cloud water absorption gets relevant and clouds have an optical thickness larger than 40 (Marshak et al., 2006), which is mostly fulfilled for DCCs. However, for the retrieval of the cloud particle radius the cloud structure gets more important due to a much higher contribution of scattering events.

- A cloud masking procedure is introduced to distinguish between directly reflected areas of the cloud and diffuse shadow regions. The analysis of the manuscript is restricted to directly reflected areas only, which in fact is a sum of direct and diffuse light.
- Why does the described method of the distribution of the cloud phase does work only for direct reflected light of the Sun?
- What is the influence of the diffuse light?

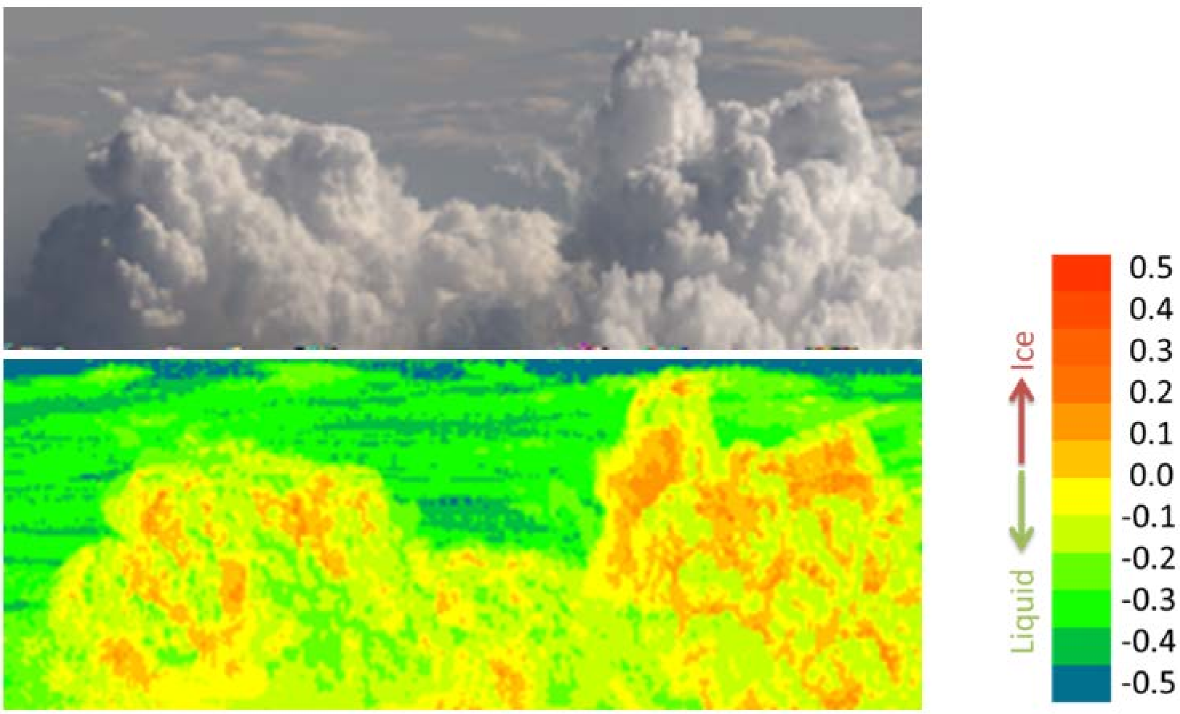
As the three comments above relate to each other, we give a joint response on them.
The reviewer makes good point here. In fact it is better to use the phrase "illuminated cloud regions" than talking about directly reflected areas. Of course, the measured reflected radiation contributes both, directly reflected radiation but also diffuse (multiple-scattering) radiation coming from other directions which fall into the sensor viewing angle. Since we are using radiation with wavelengths in the near infrared, the contribution of the diffuse radiation which is in-scattered from other directions is less dominant. For spectral radiation with wavelengths which are affected by Rayleigh scattering this in-scattering would be more relevant.

We added some more explaining sentences in the beginning of the section:

<u>Compared to illuminated cloud sides, the photon paths in shadowed cloud regions are longer, which is related to more absorption events. This absorption due to cloud particles is not locally restricted to the cloud side parts where the camera is pointed at. In fact, the spectral radiation coming from shadowed cloud regions is affected by absorption by cloud particles from cloud parts outside the FOV of each individual spatial camera pixel. Since the spectral signature of</u>

reflected radiation from shadowed regions of cloud sides is contaminated by a significant fraction of diffuse radiation originating from unknown cloud regions, a cloud masking technique was developed to discriminate illuminated and shadowed cloud regions.

For illustration of the effect of shadowed cloud parts we plotted the phase index of a cloud scene without cloud masking below. Flight altitude was about 4 km. All clouds shown here are liquid water clouds, because air temperature is higher than 0°C for this altitude range. The RGB image in the upper panel illustrate the position of the clouds, the lower panel displays the phase index of the same image section. The shadowed cloud regions show a phase index larger than 0.2, which would indicate the presence of ice particles. This illustrates clearly that shadowed cloud regions should be excluded from the data set, because the typical spectral signature of liquid and water clouds is lost.



- It would be nice to see some more direct and detailed comparisons to the methods of Marshak (2006, reference missing) or Zinner (2008), MODIS, possibly Cloudsat and insitu. The description of Figure 9 could be in much more detail and as the major part from my point of view this is worth more than just one page.

We surely could use several other satellite observation products for comparing our results, but we limited the measurement strategy to in situ (three instruments already) and the MODIS observations (ensemble method which was already applied for similar studies). The phase retrieval as presented by Marshak et al. (2006) (it's cited now) and Zinner et al. (2008) rely on the same approach. As shown in the reply on comment to Page 3 line 17, there is just a difference of the phase index in absolute numbers, but not in the height of the mixed phase layer itself (see directly reply to Page3 line 17). Furthermore, we modified the application section at various points. The main changes are given below.
When introducing the in situ measurements, we added the following sentences to specify the ideas behind the comparison of the different observation strategies:

The variability of the mixed phase layer in depth and height within a single cloud cluster shows that the vertical distribution at least at the cloud edges is variable. In situ data are used to investigate if such a variability is also observed in the more inner part of the cloud.

Later we added the following:

Furthermore, a second but smaller peak of the particle size was found at about 6 km altitude. From the conceptual model of cloud particle size profiles inside a DCC (e.g., Rosenfeld and Woodley (2003)) it might indicate the bottom of the mixed phase layer, when cloud particle size starts to increase. However, this increase is less pronounced than presented in Rosenfeld and Woodley (2003).

At the end of the subsection we added:

This shows that the satellite-based ensemble method may be representative for a large cloud field. But for individual clouds NIXE-CAPS and specMACS measurements have shown lower glaciation heights. The most likely reason is related to the fact that the ensemble method relies on cloud top observations of growing clouds in different stages of evolution. As shown in Fig. 9g mainly particle sizes between 22 and 27 µm were derived indicating that the profile is dominated by measurements of clouds in the mature stage. At this stage, the particle phase may be altered by up- and downdrafts within the clouds as was shown in Fig. 9e. This leads to an enhanced horizontal variability of the cloud phase state which cannot be resolved by passive remote sensing from cloud top observations. Another, but minor reason of the discrepancy between ensemble method and NIXE-CAPS / specMACS measurements is related to the retrieval uncertainty of the effective cloud particle radius. While scattering properties are well defined for liquid water particles, they are variable for ice particles due to differing habits and crystal shapes (Eichler et al., 2009). This gets even more complicated for cloud tops where phase transition starts. Additional retrieval uncertainties of the particle size directly contribute to the derived profile of r_{eff}.

Page 2 line 5: A mixed phase state of water does not exist. I would rather describe it as an area of phase transition levels from existing state phases eg. from liquid to ice which can vary in temperature gradient, altitude and vertical depth (line 17 is here more precise than 5)

That is a good point made by the reviewer. We changed the sentence as follows:

DCCs exhibit a high variability of cloud particle sizes and a complex vertical microphysical structure. This includes the different phase states of water (liquid and ice) of the cloud particles and the occurrence of layers where phase transitions between liquid water and ice particles (further referred to as mixed phase) take place.

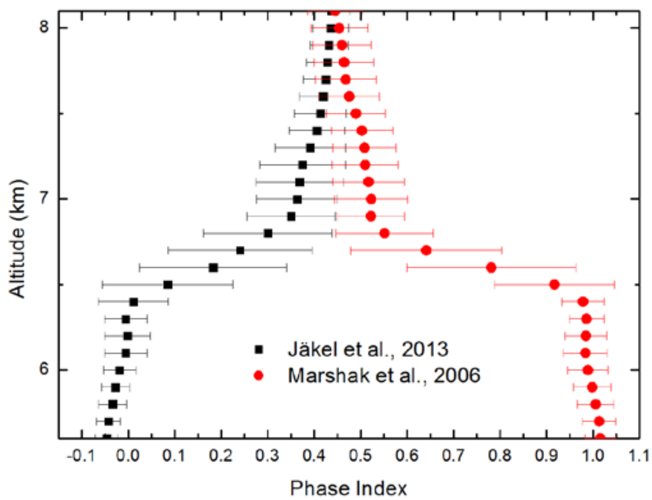
Page 2 line 13: ... (more aerosol particles ...)

Changed into:

more aerosol particles

Page 3 line 17: Why did Martins and Marshak use a different Wavelength? With SpecMACS it could be used as well and compared.

The choice of wavelength pair is originated from the method described by Jäkel et al., (2013) which was designed for spectrometers not measuring at 2.1 and 2.25 µm wavelength. There are several methods and wavelength ranges used and discussed in the past as listed in the introduction. The change of the sign of the phase index as calculated in this manuscript between liquid and ice phase is kind of illustrative. However, we compared the phase index profile for one of the cases derived by both methods as can be shown in the plot below. Apart from the absolute numbers we see a similar effect within the transition zone with a distinctive slope of both phase indices. So we don't see additional information when using 2.1/2.25 µm instead of radiances between 1550 and 1700 nm. The physics behind for both methods is similar; where the imaginary part of the refractive index which determines the spectral absorption is different between ice and liquid water particles in these two wavelength ranges. So it is not surprising, that the vertical profiles show the indication of the phase transition zone in the same vertical levels.



Page 4 line 14: Temperature profiles are mentioned and it would be very helpful to have some graphs. Sidewards looking IR-camera would be interesting.

We tried to reduce the number of figures. Therefore, we omitted an individual plot showing the temperature profiles which are similar, as also stated in the overview paper by Wendisch et al., (2016). However, the relations between altitude and temperature can be estimated from the secondary y-axis showing the temperature as vertical coordinate in Fig. 9a for AC13 and in Fig. 10a,b for AC10 and AC18.

The reviewer makes a good point here to bring up the usage of an IR camera. Unfortunately, we had no IR-camera available for this campaign. But another ground-based campaign is scheduled for September/October in 2017 in the Brazilian rainforest using IR-camera and imaging spectrometers together for cloud side observations.

Page 5 line 2: Again a comparison to the method of Marshak, ... is possible with SpecMACS.

Please see answer on comment concerning Page 3 line 17.

Page 5 line 29: mixed phase layer...→ phase transition layer

The "term mixed" phase is commonly used in literature. We are aware that there is no mixed phase state as already commented by the reviewer. But we think the term "mixed phase" is not misleading here. For simplicity and consistency with literature we defined the layers of phase transition between liquid and ice particles as mixed phase in the introduction.

Page 5 line 29: A retrieval of cloud particle size of the measurements would demonstrate this sentence

The retrieval of the cloud particle size from cloud side observations needs a lot of efforts and will be presented in a different publication entitled: “How accurately can we remotely sense cloud vertical profiles of droplet radius and phase from the cloud side perspective?” which is in preparation by Ewald et al.

We added a citation here where profiles of particle sizes together with estimations of the phase are presented:

<u>The mixed phase layer is characterized by a strong increase of cloud particle size with height (Martins et al., 2011), whereas for fully glaciated cloud layers the largest ice particles can be found directly at the height where the glaciation temperature is reached.</u>

Page 6 line 11: Please explain this statement, if its true. Please compare state of polarization with Mie-Theory.

The scattered and incident intensities of the polarization components are related by the phase function. This phase function is simplified for spherical particles due to their particle symmetry. We will not show the matrix operations here but we added a reference here which describes also mathematically the polarization of aspherical and spherical particles as measured with NIXE-CAPS:

<u>Spherical particles do not strongly alter the polarization state of the incident light as discussed in detail by (Meyer, 2012), while non-spherical ice crystals change the polarization depending on their size and orientation (Nicolet et al., 2007; Meyer, 2012).</u>

Page 6 line 23 and 30: detection limit unclear. >1 cm-3 or 0.3 g/m-3

These data and detection limits are from two different instruments integrated in the CAS-DPOL. We use the laser spectrometer on the CAS-DPOL (Cloud and Aerosol Spectrometer) to derive the aspherical particle fraction. Here, the cloud data are given for the size range between 3 and 50 µm and for clouds with a cloud particle number density > 1 cm-3. In addition, the hotwire instrument on the CAS-DPOL measures the liquid water content with a (conservative) detection limit of 0.3 g/cm-3.

Page 7 line 3: Please explain the adjustment of the temperature, humidity, ... profiles

In particular, the density of water vapor was re-calculated from measured temperature, pressure and relative humidity for each model height level. For simplifications we will not give the equations as they can be read in textbooks.

However, we adapted the sentences as follows:

<u>For the model input, the atmospheric profiles of temperature, atmospheric pressure, and gas densities are taken from Anderson_et al., (1986). From a radio sounding from Alta Floresta (-9.866° S, -56.105° W) and measurements of temperature, humidity and pressure performed by HALO, the temperature and pressure profiles are adjusted to represent the atmospheric conditions on 19 September 2014 (AC13) in the region of one of the measurement flights</u>

(representative of the three flights considered in this study). The density of water vapor is re-calculated using the relative humidity, temperature and pressure measurements.

Page 7 line 11: adjustment of the aerosol profile?

The standard Shettle profile was scaled by the vertically integrated AERONET measurements. We are aware that this adjusted profile is just a rough estimate of the true vertical profile, but it will serve as input for radiative transfer simulations for sensitivity tests concerning cloud microphysical properties. As AOD decreases with wavelength, the aerosol extinction in the wavelength range between 1550 and 1700 nm is less important than cloud particle extinction in this spectral range.
We replaced “adjusted” by “scaled”:

For the polluted case, aerosol properties are described with the model by Shettle (1989) and scaled by AERONET (AErosol RObotic NETwork) measurements (site Alta Floresta) of aerosol optical depth, single scattering albedo, and asymmetry parameter (used for the Henyey-Greenstein phase function).

Page 7 line 19: As mentioned before. Why is the diffuse light restricted to shadow regions or does it have the same amount in the other regions as well?

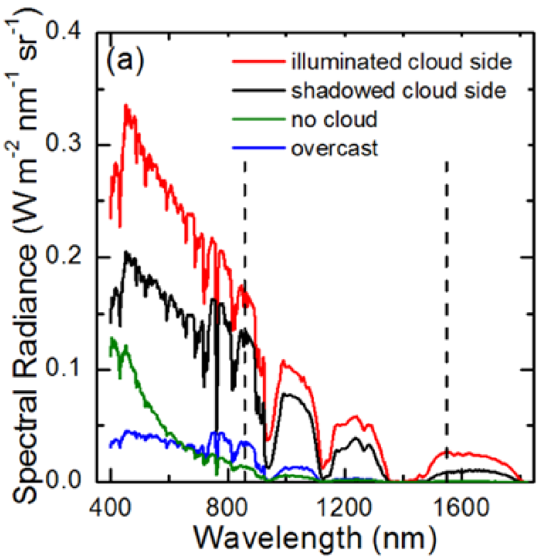
Please look for response on comments 2-4 above, since it deals with the same topic.

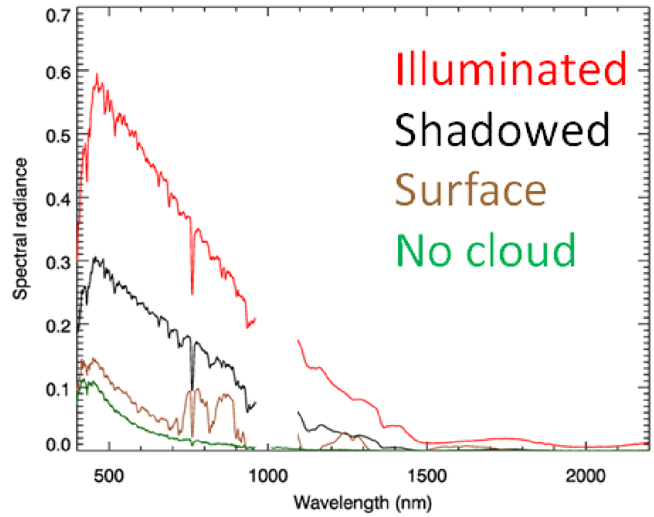
Page 7 line 21: Here we have some weak indications why the diffuse light in shadow regions is not used in this study. While a thoroughly radiative transfer simulation can include the influence of ground reflectance, surface albedo in this manuscript can’t be taken into account because of this influence. Why is that and a view sentences later the influence of the surface can’t be seen in the airborne data? The reasoning in this part of the manuscript is somehow very weak.

The reason for excluding the shadowed cloud regions from data evaluation is given above (see comments 2-4). It is a good question, why the effect of surface reflection was not observed during the aircraft measurements. Compared to ground-based observations, where the spectral features of the surface albedo (here vegetation step around 700 nm) can be found in the spectra of the reflected radiation of shadowed cloud regions (see left panel of the figure below from Jäkel et al., 2013), the cloud and observation geometry is different for the aircraft measurements during ACRIDICON-CHUVA. This is related to changes of the range of scattering angles, because reflected radiation is observed from higher altitudes than from the ground. Furthermore, for deep convective clouds the distance between surface and upper parts of the clouds is enhanced, which reduces the contribution of radiation coming from the surface. However, a detailed model study would be needed to quantify the surface effects on the reflected radiation coming from shadowed cloud regions to estimate the measurement conditions when significant spectral features can be used for shadow detection. Since we didn’t observe such features, such a study will not be included in this work. In the figure below, the right panel shows clearly no indication of the vegetation step in the shadowed cloud region, while the surface observation shows the typical increase of radiation above 700 nm wavelength.

We modified this part as follows:
In ground-based observations the reflected radiation measured from shadowed cloud regions showed spectral signatures influenced by the spectral surface albedo due to interaction between clouds and the surface (Jäkel et al., 2013). This interaction is reduced for several reasons for aircraft observation of DCC. The reflected radiation is observed from higher altitudes than from the ground. This is related to changes of the range of scattering angles. Furthermore, the

distances between surface and in particular the upper parts of the cloud are much larger. Therefore, scattered radiation from the immediately adjacent cloud regions has a greater effect on the spectral features in the shadowed cloud areas than the surface. Since spectral indication of the surface could neither be observed nor simulated for airborne measurements, a different approach is chosen based on the distribution of color values in the observed cloud scene.





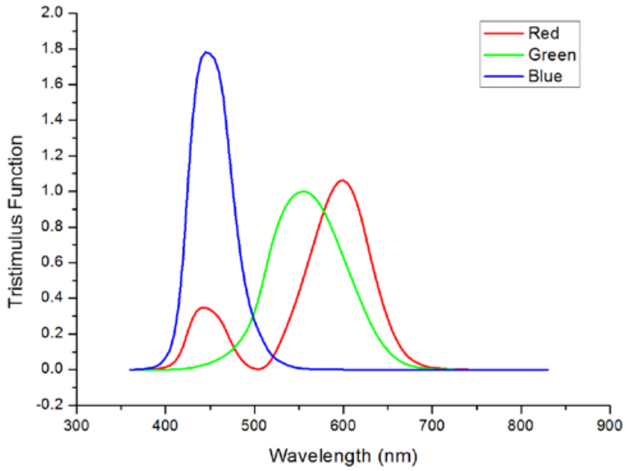
Page 8 line 29: Where does this formula and the constants come from? I would propose to use a spectrum to rgb conversion via a CIE 1931 color space. SpecMACS has a broad spectral range and a large number of spectral channels why not using them? This would reduce noise as well.

The equation calculates the relative luminance (CIE, 1999). We added the reference:

.., which takes into account the sensitivity of the human eye on the different colors by differential weighting of the three wavelengths (IEC, 1999)

IEC: Multimedia Systems and Equipment – Colour Measurements and Management – Part 2-1: Colour Management – Default RGB Color Space – sRGB, IEC 61966-2-1, International Electrotechnical Commission: Geneva, Switzerland, 1999.

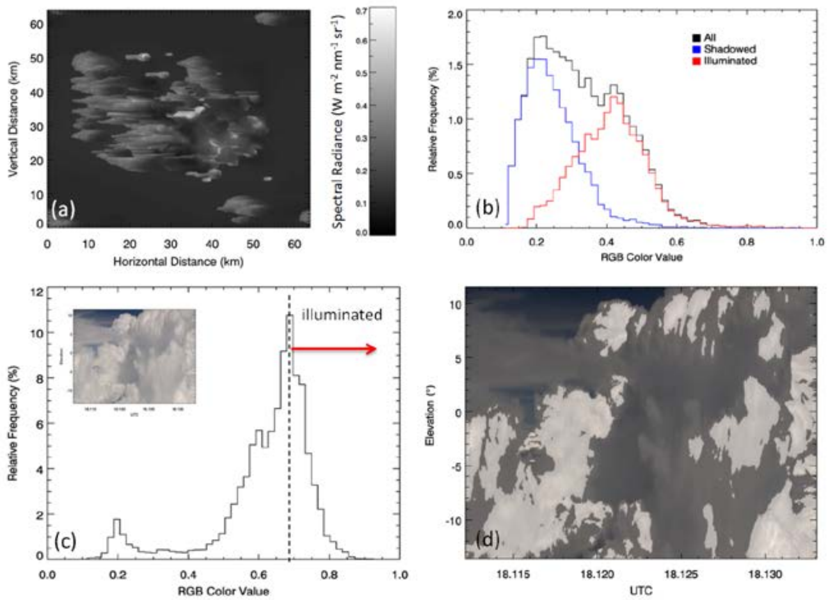
We omitted the usage of “relative luminance” in the manuscript because it is a photometric quantity used in digital image processing and less known in the field of atmospheric science. As explained by Magisa et al. (2005), the “relative luminance (RL) is the relative brightness of any point in a color-space, normalized to 0 for the darkest black and 1 for the brightest white. For a certain point (or pixel) in a color image encoded in the standard RGB (sRGB) color-space, the RL can be computed based on the value of the sRGB components through the equation $RL = 0.2126R + 0.7152G + 0.0722B$”.
RGB conversion via CIA 1931 uses a spectral weighting of the red, green, and blue channels, where the weighting function corresponds to the spectral response of the human eye. The color matching function as taken from CIE is shown below:



The spectral bandwidth of the three weighting functions is quiet broad. If there is a difference in the spectral signature of the radiances between shadowed and illuminated cloud areas, then the usage of CIE bands is not recommended, due to the loss of spectral information after applying the spectral convolution. However, using RGB values to classify the brightness of the individual pixels doesn't require the full spectral information as it could be provided by specMACS. The simple approach to identify the directly illuminated cloud areas based on the three wavelengths (436, 555, 700 nm), has been approved by the simulations.
But for the upcoming ground-based campaign in September/October 2017 we will use the whole spectral information from 400 – 2500 nm to gather information on the illumination conditions as found in Jäkel et al. (2013).

Page 8 line 1, ...: How is the histogram of the RGB values converted or evaluated to the frequency distribution? Please explain in more detail. Where does the relative and absolute frequency come from in fig. 3? Why are the simulated once in Fig 3b absolute and the measured once in Fig 3c relative? The calculation of a single RGB value with the formula is used to find the threshold of "directly !" illuminated pixels. What are the model simulations for if you dont use them?

The RGB histogram (= frequency distribution) derived from the simulations was shown to illustrate that such histograms can be used to discriminate between the illuminated and shadowed cloud regions. The threshold estimated from the distribution of the RGB values is just an example and not valid for other cloud scenes with different observation geometry. But we see clearly that the modes in the histogram match with the illuminated and shadowed cloud regions as classified from the known geometry in the model. We plotted now both histograms (from simulation and from measurements) as relative frequency as suggested by the reviewer:



Furthermore, we modified the text:

The histogram of the RGB color values for each cloud scene is used to identify the illuminated and shadowed cloud areas. Before showing an application, the procedure is illustrated using simulated cloud side reflectivity observations. In this manner, we can directly compare the classification of illuminated and shadowed cloud regions (i) derived from known cloud and viewing geometry, and (ii) derived from the histogram of the RGB color values.

And later:

The histogram of the simulated RGB color values is shown in Fig. 3b as black line. Two modes are visible, which coincide with the two sub-classes of illuminated (red) and shadowed (blue) cloud regions as calculated from the cloud and viewing geometry.

Page 8 line 3: What is the max height of the model domain?

The maximum height was 120 km corresponding to the top of atmosphere. We added the top height and vertical resolution to the text:

The cloud field was generated by the Goddard Cumulus Ensemble model (Tao et al., 2003, Zinner et al., 2008) for a model domain of 64 x 64 km with a horizontal resolution of 250 m and a vertical resolution between 0 and 10 km altitude of 200 m. From 10 to 120 km altitude the simulations are performed with a vertical resolution ranging between 1 and 5 km. The maximum extension of the liquid water clouds from bottom to cloud top ranges from 1.0 to 7.4 km altitude.

Page 8 line 16: What is a relative azimuth angle of exactly 68 degree with a changing attitude and Sun elevation during airborne missions?

The data given here are valid for the cloud scene (about one minute of flight with constant heading) which is shown in the Figure 3. Of course the distribution of RGB color values has to be calculated for each cloud scene separately. It is not meant here, that this histogram and the related threshold is valid for the entire flight. In fact, the thresholds depend on the illumination conditions and viewing geometry. We modified the section to make it clearer for the reader.

The procedure is applied exemplarily for a cloud scene observed during ACRIDICON-CHUVA from 19 September 2014. During the roughly one minute flight leg the aircraft did not change its flight attitude, resulting in almost constant relative azimuth angle (angle between the sun and the viewing direction of specMACS) of 68° and solar zenith angle (theta = 39°). Note, that all other selected cloud cases in this study have similar restrictions concerning the flight attitude and time period (about one minute) to guarantee comparable illumination conditions in one cloud scene. Fig. 3c illustrates the RGB histogram as calculated for observations of specMACS with an elevation ranging between -13 and +12°.

Page 8 line 22,23: The simulation shows an increase in cloud particle size in Fig 4 for that region. What is wrong?

In the beginning of Section 3.2 a short motivation is given why a phase index may be a better indicator for the location of the transition layer than using the vertical profile of the cloud effective radius as used by Rosenfeld and Woodley (2003). But as mentioned, there are cases where the particle radius doesn't increase with decreasing temperature. For this reason, we used the phase index.
Fig. 4b shows one example of a profile with variable effective radius and water content. There was no intention to derive the profile of the phase index typical for marine, continental and polluted conditions. We restricted the simulations to two special cases, first, a constant distribution of Reff and LWC/IWC with height, where the effect of variations in the microphysical properties (apart from the particle phase) on the phase index can be neglected and second, a typical cloud profile with variable microphysics.

Furthermore, modified the motivation for showing additional radiative transfer simulations:

In the following, results from radiative transfer simulations using MCARATS are presented. The viewing geometry and the atmospheric description are adapted to the conditions during ACRIDICON-CHUVA on 19 September 2014. These simulations are performed to demonstrate that ice and liquid water phase can be separated from the transition layer under different conditions similar to the results reported by Jäkel et al. (2013). Note, that due to the different viewing geometry, another angular range of the scattering phase function is observed than for ground-based measurements. This might have an effect on the characteristics of phase index profile in particular with respect to separation of the mixed phase layer.

And later the two cloud scenarios are introduced as follows:

Two simplified cloud scenarios with different profiles of cloud effective radius and water content are assumed. In both cases the clouds ranged from 4.0 to 11.0 km altitude with a mixed phase layer between 6.4 and 7.0 km. While the first scenario uses constant values of cloud effective radius (r_{eff} = 20 µm for liquid water and ice) and water content (0.7 g m^{-3}), the second scenario assumes variable profiles of the microphysical parameters. These two cases are chosen to identify effects on the I_P-profile caused by changes of (i) the phase state itself (scenario 1), and changes of (ii) the cloud particle size and water content (scenario 2).

Page 8 line 28: How does this simple formula compare to the methods from Marshak, Martins and Zinner?

We gave some additional information:

For ground-based application with corresponding viewing geometry vertical profiles of the phase index were simulated by Jäkel et al. (2013). A significant gradient in the vertical profile of the phase index was observed between liquid water and mixed phase layer, but also between mixed phase layer and ice phase. A similar behavior was also found for the reflectance ratio at 2.10 and 2.25 µm as reported by Martins_et al. (2011). They observed a strong gradient in the profile of the reflectance ratio. This is due to the fact, that the imaginary part of the refractive index, which determines the spectral absorption, is different between ice and liquid water particles in the two wavelength ranges used by \Martins_et al. (2011) and Jäkel et al. (2013).

Page 9 line 5: Is the combined Ip profile a simulated or measured profile. I don't understand how the combined profile is calculated and where it comes from.

We modified the sentences as follows:

From the 3D simulations of the spectral radiance at 1550 and 1700 nm the phase index is calculated following Eq. (2). For each modeled grid cell in the model domain with a horizontal distance between 3 and 8 km to the cloud, a combined I_P-profile is derived from the different viewing elevation angles. Such I_P-profiles are plotted in Fig. 4a in black dots.

Page 9 line 7: three phases ?

We changed the sentence, also later in line 11.

For the first scenario with constant microphysical parameters, three distinct clusters corresponding to the phase state of water and the zone of phase transition, with negative values for pure liquid water, can be found.

And:

The variability of the phase index for constant microphysical conditions in each of the phases is caused by the effect of the different viewing geometries.

Page 9 line 10: What is a pronounced absorption, of what?

Changed as follows:

This might be caused by the fact that the contribution of ice particles within the mixed phase layer leads to an increased absorption of radiation resulting in an increase of the phase index.

Page 9 line 12: Each cloud height → The cloud vertical structure is ...

Changed as suggested:

The vertical cloud structure is observed from different sensor elevation angles and distances.

Page 9 line 14: To derive the particle size is first mentioned here. Is that the goal or what is the reason? A look up table would do as well, please look at AMT Zinner 2016.

It seems that this sentence is misleading. Therefore, we deleted it from the manuscript. The retrieval of the effective radius is not object of this work.

Page 9 line 15: What is a more realistic cloud? Are the other clouds not realistic?

We modified this part as follows:

The second cloud scenario assumes variable cloud microphysical properties. In general, in convective clouds, the size of ice particles is higher than the size of liquid water particles. Therefore, the second scenario represents a more realistic vertical distribution of the particle effective radius and water content than the first scenario.

Page 9 line 17: What is the first case?

We better introduced now the two cloud setups as used for the radiative transfer simulations and omitted the phrase "case" in this section. See also reply on comment Page 8 line 22,23.

Page 9 line 18: The transition layer is characterized by a strong increase in particle size and change in the value of phase index. See Fig 4b (simulations) and Fig. 8

The sentence refers to the description of the microphysical parameters as illustrated in Fig. 4b. Therefore, no information about the phase index is given here. It follows some lines below.

Page 9 line 24: I assume that we have a polluted and a clear case, but it's not clear in this part of the manuscript. Here we have only two cloud cases, one with fixed microphysics and one with changing cloud properties. Please clarify.

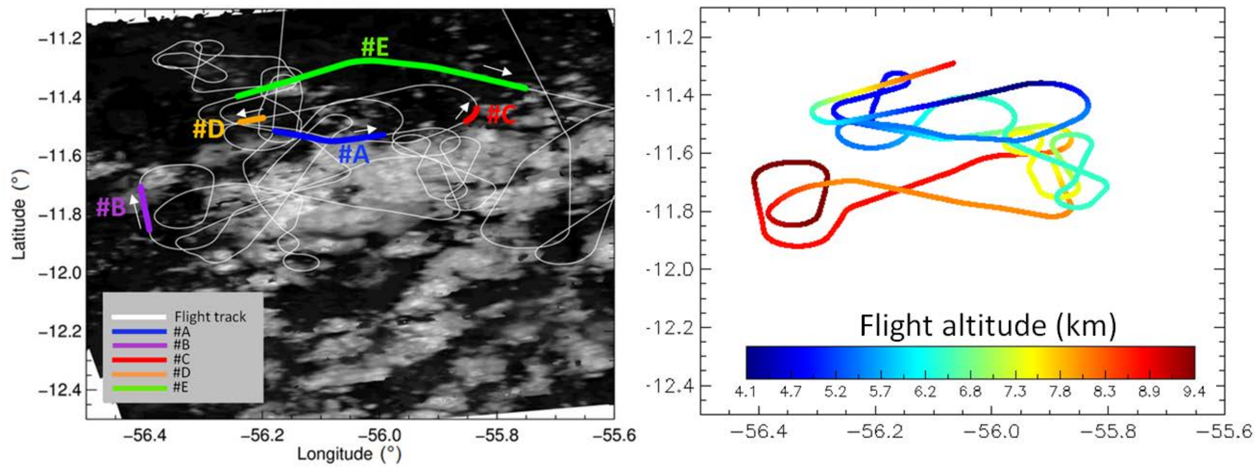
The two scenarios shown here are intended to demonstrate if the phase index can resolve the three layers with viewing geometry from the aircraft observations. So, we haven't chosen the two scenarios with respect to aerosol conditions. It should be getting clearer for the reader after modification of the beginning of the section (see reply on comment Page 8 line 22,23:)

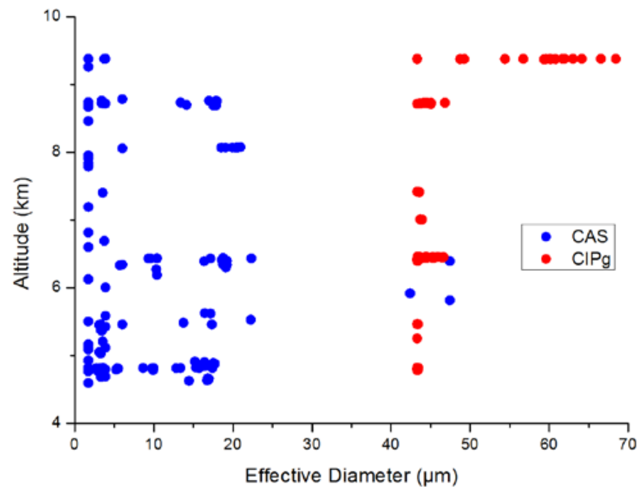
Page 10: Geometry is Ok, but could be shorter. Except a real 3D cloud structure would be the final product.

Another publication is in preparation for AMT which will discuss the 3D reconstruction of clouds based on photogrammetry and O2-A band absorption (Zinner et al.).

Page 12 line 12: A profile and comparison of remote sensing and insitu droplet size would be interesting. A sharp transient of the droplet size shows the transition layer.

Indeed, a profile of the in situ measured particle size would be interesting. But in situ measurements have the disadvantage that they provide only data along the flight path. As we see from the satellite picture, a large cluster was probed during AC13. The flight altitude is color coded in the right panel (see plot below). From this flight pattern no profile of a single cloud is available, because the flight altitude varied over a large area comprising different clouds of different evolution stages in the cluster.
A combined profile of the effective particle diameter is shown below. The data are based on measurements of the CAS-DPOL and CIPg (Cloud Imaging Probe grayscale, size range: 15 to 960 µm, operated by Mainz University). A distinct increase of the particle size cannot be observed, neither by the CIPg, nor by the CAS-DPOL (size range < 50 µm).



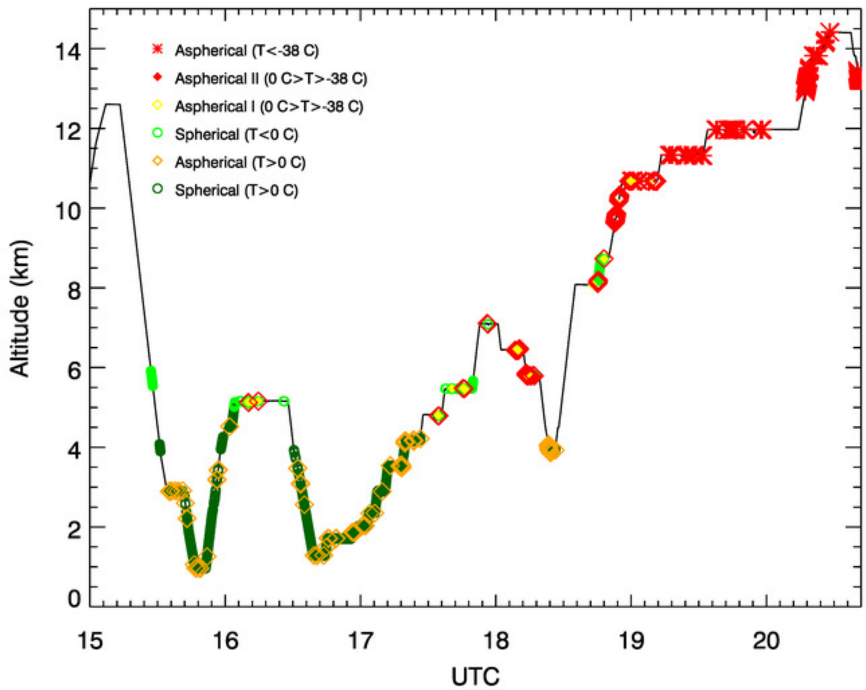


Page 12 line 30: mixed phase levels → phase transition levels or better layer

<u>*Fully developed deep convective clouds with cloud tops between 10 and 14 km (classified as ice cloud) and low level cumulus clouds up to 6 km (liquid water clouds) are detected. Cloud phase information from the assumed phase transition layers is not available in Collection 6.*</u>

Page 13 line 20: Why are liquid water data from up to 8.7 km not shown

We didn't show the time series of the NIXE-CAPS data for AC18 as a separate plot as provided for AC13. The phrase "not shown" is removed from the text. In case the reviewer is interested in the time series, please find the plot of the data below:



Page 14 line 2: A temp profile is missing.

Fig. 10 also includes a secondary y axis illustrating the temperature as vertical coordinate.

Page 14 line 25: three phases?

The sentence was changed as follows:

<u>Depending on the viewing geometry and cloud distance, layers of pure liquid and ice phase, as well as phase transition layers were identified.</u>

Page 14 line 29: Is there only one polluted case during the whole campaign?

Cecchini et al., (2017) have listed the characteristics of the flights illustrating the aerosol conditions:

Table 1: General characteristics of the cloud profiling missions of interest to this study: condensation nuclei (N_{CN}) and CCN concentrations (N_{CCN}, with S = 0.48% ± 0.033%), cloud base and 0 °C isotherm altitude (H_{base} and $H_{0°C}$, respectively), start and end time and total number of DSDs collected. The data are limited to the lower 6 km of the clouds. The unit for N_{CN} and N_{CCN} is cm^{-3} and the unit for altitudes is in m. Profile start and end are given in local time.

Region	Flight	N_{CN} (cm^{-3})	N_{CCN} (cm^{-3})	H_{base} (m)	$H_{0°C}$ (m)	Start	End	# DSDs
Atlantic Coast	AC19	465	119	550	4651	13:17	14:57	630
Remote	AC09	821	372	1125	4823	11:30	14:21	665
Amazon	AC18	744	408	1650	4757	12:32	14:14	397
Arc of Deforestation	AC07	2498	1579	1850	4848	13:49	17:16	674
	AC12	3057	2017	2140	4938	12:55	15:16	381
	AC13	4093	2263	2135	4865	12:46	15:36	204

AC13 was the most promising flight to measure polluted conditions with the largest number of condensation nuclei. For AC12 most of the flight was performed at flight altitude below 6 km, therefore no deep convective clouds have been observed by specMACS.

Page 14 line 30 bottom: Low statistics? Are those 2 flights analysed in this study the only possible ones of the whole campaign?

From the 14 scientific flights we selected the three days (AC10, AC13, and AC18) with the best conditions as stated in beginning of Sect. 4:

(i) no cloud layer above the observed cloud (no cirrus), which contaminates the spectral signature,
(ii) high proportion of illuminated cloud parts in the vertical direction of the cloud,
(iii) flight altitude that allows measurements of an extended vertical region of the cloud considering the limited FOV of specMACS, and
(iv) isolated clouds with recognizable structures for cloud geometry retrievals.

This limits the number of cases. Similar limitations are also reported for the in situ data sampling as shown in Costa et al., (2017). They had data from cloud passages lasting between 1 and 18 minutes in sum per flight.