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Interactive comment on "Aerosol concentrations determine the height of warm rain and ice initiation in convective clouds over the Amazon basin" *by* Ramon Campos Braga et al.

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Reviewer B

Title: Aerosol concentration determines the height of warm rain and ice initiation in convective clouds over the Amazon basin. Submitted: Braga et al To: ACP Date: March 30 2017 Decision: Rejected Summary: This manuscript studies the effects of aerosol particle number concentration on the initiation of raindrops and ice hydrometeors in growing convective cumulus over the Amazon. Data from aerosol and cloud probes on board of the HALO aircraft are used. The values of the estimated Na at cloud base were applied to classify the atmospheric conditions where convective clouds developed as a function of aerosol particle number concentration (i.e., clean, polluted,

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and very polluted regions). Main conclusion was that cloud depth, assuming adiabatic assumptions) is related to aerosol characteristics at the surface.

A: The reviewer writes: "Main conclusion was that cloud depth, assuming adiabatic assumptions) is related to aerosol characteristics at the surface." Where did the reviewer get such an idea from? We did not make or even hint to such a claim.

Major issues:

This paper claims that cloud depth and precip initiation are related to aerosol number concentrations at the cloud base.

A: We did not claim that depth is related to aerosol number concentrations at the cloud base. We show that the height above cloud depth for rain initiation is related to cloud base drop concentrations.

I argue that precip formation in the clouds are related to saturation rate, updrafts and shear (turbulence), T gradients, stability, and particle type.

A: Indeed, precipitation initiation depends on saturation, which is determined by cloud base updraft and CCN. T gradient and shear determines the updraft and vertical extent of the cloud. Particle type is water drops. So where does the reviewer disagree with us?

I really do not like simplified convective clouds dependency on only aerosol concentration at the cloud base. Doing this you ignored non-adiabatic terms that include radiation, turbulence, and mixing can play important role for cloud structure.

A: We have shown in a series of papers referenced here why the adiabatic approximation to adiabatic re works. We also show the goodness of the simplified relationships. The disliking of the reviewer of this reality is not relevant to its validity.

In fact difference between the adiabatic ref and observed indicates that. There are several issues with figs such as averaging time, RWC but images do not show any, and

Fig. 1b concept.

A: This comment is incomprehensible.

Why this work uses reff rather than use of full spectra for precip? Ref can be 12 micron but no droplets can be at that size range. Is this for a climate study or cloud study? Author should emphasize this.

A: This comment is incomprehensible.

Ref usually is almost constant above 3000 m in the plots but you show like exp curves.

A: The lines are the adiabatic re. This is stated very clearly.

You mention rain water content but none of the images is shown for rain droplets.

A: Images of rain drops are show in Figures 11a, 11b, 14a, 14b.

You are using different time segments for each case that is not acceptable (see figures top titles).

A: Which figures?

You need to show time series of ref, lwc, nd and ni for 2 cases (polluted and clean and pitch angle). Your physical values can be affected by aircraft INS system conditions.

A: We present here a higher level data for all cases. The raw data are available for anyone to inspect from the ACRIDICON archive.

Fig. 1b; shows a conceptual sketch but I feel that is not true. Droplets cant grow continuously to the cloud top level. Any work that reference the similar conditions cannot be considered for publication.

A: Before making such invalid statements so strongly, we recommend that the reviewer will read: Beals, M. J., Fugal, J. P., Shaw, R. A., Lu, J., Spuler, S. M. and Stith, J. L.: Holographic measurements of inhomogeneous cloud mixing at the centimeter scale, Science, 350(6256), 87–90, doi:10.1126/science.aab0751, 2015.

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Major issues can be listed as

1. DWC=0.01 g m-3 used for DWC to get rain out of the cloud. What this is selected not clear. DWC can be 0.01 g m-3 but 5 droplets ot 100 of droplets. I argue that this is not an acceptable assumption for cloud structure?

A: The reviewer writes that the threshold is "to get rain out of the cloud". This is not what we wrote. This threshold is used for in situ rain initiation. We wrote that "DWC, defined here as the mass of the drops integrated over the diameter range of 75–250 μm (Freud and Rosenfeld, 2012)". The reason for limiting the maximum drop size to 250 μm is because it has a terminal fall velocity of 1 m/s. This minimizes the chance that the rain fell from above and not initiated near the penetration height.

2. You say that rain occurred at higher levels in more polluted clouds; no RH profile is shown or icing detector (pg 10) ; how do you know the cloud structure and particle phase? In fact none of your figures show rain or cloud droplets at larger sizes.

A: Images of rain drops are show in Figures 11a, 11b, 14a, 14b. RH is irrelevant within the cloud. Why should we use icing detector while we have liquid water content and temperature, thereby quantifying supercooled liquid water content? Cloud phase is known by the hot wire liquid water content and CIP images.

3. Figure 1b; this figure really mean nothing for me, and doesn't help anything about understanding of cloud macro structure. We know that aerosols can play significant role in cloud development, specifically for stratiform clouds. Below the cloud base aerosols act as nuclei, and they are activated within the cloud base, then dynamics of the system play a role faster that diffusional growth of particles. Certainly mixing happens at the base and edges of the system. Conditions are not adiabatic clearly. In fact if saturation is high enough and lots of moisture exist, many droplets forms. Do you show any vertical profile of the cloud T, w, and qv? In fact when cloud top increases at the upper troposphere not many particle reach to cloud top. Therefore, cloud depth is not only function of Na but vertical air velocity which is lowest at the cloud top at the

upper troposphere. In fact because of collision/coalescence/aggregation processes, many particles fall down as precip before reaching the cloud top. Therefore, I will not accept your claims here for your work.

A: The captions of Figure 1b read: "Flight patterns below and in convective clouds during the ACRIDICON-CHUVA campaign". The title of the paper reads: "Aerosol concentrations determine the height of warm rain and ice initiation in convective clouds over the Amazon basin". It should have been very clear to the reviewer that our study focuses in the lower parts of the clouds between cloud base and height of precipitation initiation. All the objections of the reviewer pertain to processes that affect cloud microstructure and precipitation above the height of precipitation initiation.

4. Fig.2; most of ref is between 11-14 micron for precip occurrence>50%; then how accurate to use ref as a precip condition. Precip is function of Nd, Vt, wa, and shape. Differences of these parameters at various T, can affect reff strongly. Suggests that cloud depth is not only function of Na but other physical and dynamical para,eters.

A: Indeed, cloud depth is not a function of Na, and we never made such a strange claim.

5; I like to see time series of Nd, Ni, RH, and ref for clean and clean cases. Use of reff for a cloud microphysics case study may not be appropriate. Ref can be 15 micron with no rain or with rain depends on psd.

A: How is this comment relevant to the subject of the study?

6; fig 4 may not be needed, this is well known. A: Its validity has to be demonstrated to the subject clouds. 7; figure 5; I like to see time series of Nd, showing about 2000 cm-3, also Na, please provide.

A: We don't see what will the time series of Nd would add to the points made in this study? We have too many figures already.

This figure shows that Nd is constant above 0C, and increases to warmer T. To me this is an artifact. Please also show LWC time series. Also show the weighted line on the plot.

A: We don't agree. Figure 5 shows clearly a steady decrease of Nd with height.

Fig. 6a; thi is shown for 25 sec but others are for 656 sec, please be consistent.

A: At cloud base we have much more sampling than at the narrow towers aloft. We took all the samples that we could get with the aircraft.

Fig6b; looks like no changes in reff are for T<0C. For a given T difference is about 2-3 micron; it means that uncertainty in reff can be up to 3 micron, then how can someone use your method for cloud depth.

A: The reviewer repeats his misconception about what we do in this paper.

Fig. 7a; Combination of cip and cdp? Based on image shown, there are cloud droplets, CIP doesn't show anything.

A: The images are made by the CIP. Indeed, the CIP shows only cloud droplets.

Fig 7b; doesn't show droplets or drizzle? Where is the rain water come from?

A: All CIP images are converted as if they were rain.

Fig 7c; same again where is the RWC come from? Image shows ice crystals or rimed particles. A: See response to the previous comment.

Fig. 9; again for Dc>3000 m, re is constant. This shows that re-Dc relationship doesn't hold.

A: We don't agree. re increases up to Dc=4500 m. At that height ice forms on expense of the cloud droplets, as shown in Figure 18.

Fig. 10a; Nd is constant within the cloud, looks like well mixed layer. Then how ref increases with depth? Flight is only 3 mins? Looks like ref increases with LWC. Can you show reff versus LWC?

A: The lack of decrease of Nd with height could be related to some secondary droplet nucleation, as indicated in Figure 11a.

Fig 11a; assumed that drizzle has sizes >50 micron why we don't have RWC? Or precip? Again image shows ice crystals, not drizzle.

A: The image shows nice rounded rain drops. It even shows one pair of drops while coalescing!

Fig. 11b; image shows graupel, where is the rain coming from, you say 0.27 g m-3?

A: The image shows large rounded rain drops. It even shows one pair of drops while coalescing!

Fig. 12: I really have issues with this figure. If you look at the lines for a given Na say 1 or 100; and then check the Da. Not easy to make any conclusion based on this figure. In fact any uncertainty for less than about 20 cm-3 can results no discrimination among these cases.

A: The figure clearly shows that while total PCASP in AC12 is 10 times the PCASP in AC19, concentrations of particles > 2 ïĄ■m are 5 time larger in AC19 compared to AC12.

Fig 13; same as before. How do you know they are droplets?

A: The CDP is rather insensitive to ice particles, and the hot wire LWC was similar to the CDP LWC.

13a; again like rimed particles. RWC=0 but you show only 5 sec spectra, you are not consistent with time averages.

A: The reviewer probably means Figure 14a. We take the sample size that we can get under these challenging flight conditions.

13b; again not rain water but mostly they are graupel or rimed particles. Only 4 second average? Not consistent. If CWC=0.247 and RWC=0.27 and DWC=0.16, then rain amount is more than cloud water content? How do you explain this over 4 sec?

A: Again, we take what we can get. At this height most cloud water was converted to precipitation.

Fig. 16; why there is no RWC? You have particles more than 100 micron but not rain?

A: See the CIP precipitation images.

Fig. 17; Dc versus Na relationship can't be a linear relationship. Increasing aerosols doesnt result in larger Dc values. Other factors should be considered e.g. updrafts, stability, diabatic heating etc.

A: These are our results, whether we like it or not, and whether it support or contradicts our concepts. We refer the reviewer to read: the paper which we reference in this context: Freud, E. and Rosenfeld, D.: Linear relation between convective cloud drop number concentration and depth for rain initiation, J. Geophys. Res. Atmos., 117(2), 1–13, doi:10.1029/2011JD016457, 2012.

Fig. 18; as noted previously above 3000 m, ref is almost constant but here you show all DC values increase with increasing ref exponentially. This figure should be discussed based on my previous points.

A: The figure caption states that the lines are the adiabatic cloud drop effective radius (rea).

Other point I am not comfortable is that almost largest WC is at the cloud top which cant be correct. This is function of Vf, and you never mentioned this.

A: We don't agree strongly with the reviewer, for reasons that we explained in a previous response.

Discussion section should focus on the uncertainty of the observations and method. Presently it is not focusing on observations/analysis uncertainties such as averaging

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over various time segments.

A: The averaging over various time segments is part of the analysis.

Conclusion section should have clear findings that are related to observations collected from the field project. It can be good idea to list them.

A: The findings will be listed in the new version.

Minor points are not considered in this point.

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