Classification of Arctic, Mid-Latitude and Tropical Clouds in the Mixed-Phase Temperature Regime

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This document contains the comments of and answers to referee 1. Referee comments are marked in blue. Changes in the paper text are given in green.

Page 4: The way the first paragraph is worded, a reader gets the impression that there are no advantages of using in situ observations over remote sensing for detecting the microphysical quantities of clouds since every technique out there has its flaws. It is not clear why you are using in situ measurements. For example, there are 4 sentences going into the flaws of shape identification algorithms in the first paragraph, and the CAS-DPOL is it's a good idea to say how the CAS-DPOL data helps to fill in the gap, but I think this should be emphasized more in this paragraph instead of 2 paragraphs down. Since the CAS-DPOL data in your paper are probably the most novel part of the paper, I would almost say that the limitations of current probes in identifying shape and the introduction of the CAS-DPOL and how it helps to provide a solution to this problem should be its own paragraph. I would also, after you mention the limitations of remote sensing measurements, go into some detail about how in situ measurements are the only direct way to measure the size, shape, and count of liquid and ice particles and are used to develop remote sensing retrievals. This would provide a better context as to why you specifically chose in situ measurements.

Thank you for your comment, We have restructured the first section in the following way:

...Usually, they require a minimum number of pixels (corresponding to cloud particles with diameters of 70 μm and more) to recognize round or aspherical particles reliably. Due to these limitations, the shape identification of small particles has not been considered in many microphysical cloud studies. In the paper presented here, we use a new detector that can measure the asphericity of small (< 50 μm) cloud particles (Baumgardner et al., 2014) together with a visual shape inspection of particles > 50 μm. We thus hope to provide new insights into the microphysical evolution of clouds in the mpt regime. To this end, we use in situ airborne cloud measurements in the cloud particle size range from 3 μm to 937 μm to classify the above described types of clouds in the mpt regime (see Figure 1): 'Mostly liquid' clouds after drop formation, 'coexistence clouds' after initial freezing, 'secondary ice' clouds influenced by ice multiplication, and clouds after the WBF process. This classification enables us to revisit a statistical overview published by Pruppacher et al. (1998), stating at which temperatures purely liquid or ice-containing clouds were found....

Lines 33-35, page 7: Why were the glaciated periods identified manually over using automated algorithms?

The CIP probe records images in three shade intensities. The choice which shade intensity pixels are considered to be part of the particle image can influence the percentage of detected irregular particles by shape analysis algorithms. In particular, large ice crystals with several fully and several slightly shaded pixels can be erroneously identified as 'several small spherical particles'. Using all, i.e. also the slightly shaded pixels bears the risk of classifying out-of-focus droplets as irregular large ice crystals. The manual identification, on the other hand, allows to make these distinctions in a fast and easy way.

Line 12-14, page 8: While only 5% of the particles may be shattered artifacts as determined by IAT, these particles tend to be less than 500 microns in size. The sample volume of the CIP is significantly smaller for particles in this size range than for larger sizes, so any addition of smaller particles can easily change the number concentration by potentially a few hundred percent. Therefore, it is misleading to think that shattered artifacts would only have a 5% impact on the number concentrations. For example, Jackson et al. (2014) have shown that using IAT algorithms on 2DC probes with K-tips reduces the number concentration down by a factor of 2. Therefore, I think an analysis of how different the number concentrations are when the IAT algorithm is used and when it's not provides a better way to quantify the uncertainty due to shattered artifacts.

Our assumption is based on internal quality checks. To illustrate this, we attach a histogram which shows how strongly the IAT algorithm alters the CIP concentrations for ACRIDICON, the campaign with the largest particles and the highest aircraft speed (Figure 1). In most cases, no deviation for the CIP concentration with or without IAT algorithm is found. In addition, deviations stronger than a few percent are rare.

Line 5, page 9: This analysis really needs to go into more detail as to how the modes were determined, because while the authors identify two modes in their data, a reader can look at Figure 6 and see at least five, with three in the Type 1 region alone. How were the number of modes determined? How did you determine where the overlap region is between the modes? Does the smallest mode really have a peak at 10-4 cm-3? It looks like it's more around 10-1 cm-3 if the two modes are defined as they are in Figure 6.

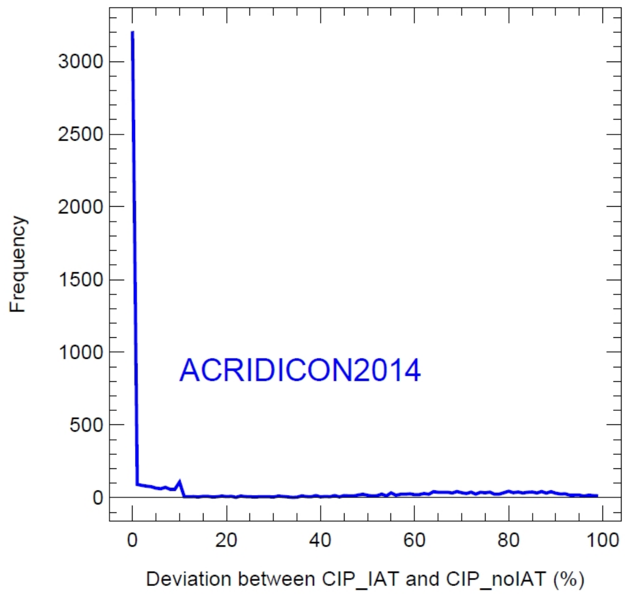

Figure 1. Frequency of occurrence of deviations between IAT corrected and uncorrected CIP data for ACRIDICON-CHUVA 2014.

Thank you for pointing out this slightly unclear paragraph. We mention two modes in the beginning and then discuss three. This will be changed as shown below.

With regard to the determination of the two main modes, they are found via smoothing the histogram by taking into account the measurement uncertainties as discussed in section 2.2. With a concentration uncertainty of 20%, only the two main modes remain which cover 39% and 53% of the dataset, respectively, and the slightly elevated frequency of occurrence of very low concentrations, which we trace back to the CIP detection limit.

In Figure 6, ... In this study, these measurements were assigned to Type 1 clouds. In addition to the two modes, a small peak at very low cloud particle concentrations (about 10^{-4} cm^{-3}) indicates slightly elevated concentrations around the detection limit of the CIP (a total of 5% of all observations). ....

Line 10, page 9: Figure 7 shows data from all campaigns, not just VERDI, since it does not look like there is any data at < 255 K for the Arctic in your dataset.

Thank you, this is corrected now.

Type 1 cloud characteristics measured during all campaigns described in section 2.1 are shown in Figure 7.

Line 29, page 10: I do not think that you can exclude primary nucleation as a source of the ice particles shown. What Figure 10 shows is that the ice particle concentrations exceed ice nuclei concentrations by orders of magnitude, which shows that secondary production is likely occurring. It does not, though, exclude primary nucleation from also contributing to the observed concentrations. However, it would be safe to assert that primary nucleation does not make a large contribution to the number of ice particles observed.

Thank you, we will follow your suggestion and change the text to:

In general, we can exclude primary ice nucleation as a main contributor for cloud particles in the Type 1 clouds.

Lines 21-26, page 11: Do you have any more in depth statistics for the amount of irregular particles as a function of temperature for the Type 1 and Type 2 clouds. I think two extra panels on Figure 11 showing how many spherical vs. irregular particles you identified for each of the cloud types would be of great use.

With respect to the small particle fraction, the shown data are all we can provide. Figure 11 shows the aspherical fractions, e.g. the percentage of aspherical to all observed small particles for all campaigns. The cloud types are defined via these aspherical fractions, i.e. you can read in the figure what the identified aspherical fractions e.g. for 'secondary ice' clouds at 265 Kelvin were. Figure 15 provides additional information on how often this cloud type occurred at the respective temperature.

Section 3.5.1. You go into x% are weak updrafts versus very low updrafts. To me, it looks like, in general, $|w| < 1$ m/s, indicating weak vertical motion throughout, which would be expected with stratiform clouds. Given that the uncertainty in measured w from aircraft is on the order of 0.5 m/s, I would argue that the difference between the four curves is within measurement uncertainty and that there are no real differences between them. The same applies for the other two panels as well.

Thank you for this remark. The uncertainties with regard to the vertical velocity measurements need to be pointed out. We have therefore added a comment (see below). In general, we think that the vertical velocity measurements should be shown despite the non-negligible uncertainties. While single data points might contain large errors, the fact that the distribution is smooth and centred near zero indicates that larger systematic differences between cloud types or campaigns should be visible, if they exist. Another interesting point to see is the rare occurrence of large vertical velocities during the tropical campaign, which holds true even for uncertainties of 0.5 m/s.

...which is consistent with the theoretical considerations shown in Figure 2 for the 'Coexistence' regime. Note that due to large uncertainties in the vertical velocity measurements, the statistical differences found between the cloud types should be regarded as an incentive for future investigations. While single data points might thus contain measurement errors, the distribution of observed vertical velocities is smooth and centred near zero, which is expected for the meteorological situations discussed in section 2.1. Due to this and because our dataset consists of a large number of observations, we would like to point out the systematic differences found between cloud types and campaigns.

Page 13, lines 12-13: You can't determine this by looking at Figure 13 alone, since you have no observations $<$ 255 K, and the observations of INP concentration at $>$ 255 K actually look higher in the Arctic than in the midlatitudes.

Thank you for pointing this out. We've changed the text to:

The WBF process depends on the presence of INP, which are likely available in higher quantities at mid-latitudes in comparison to the Arctic (compare section 3.5.2 and Figure 13).

Page 14, lines 1-5: I would argue all 4 vertical velocity p.d.f.s differ by less than the uncertainty in the measured vertical velocities, and hence, the differences seen are not statistically significant.

Thank you for this remark, we've emphasized the uncertainties in section 3.5.1 (see above).

Figure 14: I honestly do not think this figure adds a whole lot to the paper outside of saying that the arctic is colder than the midlatitudes which is colder than the Tropics. I think this can generally be assumed and Figure 14 removed.

We agree that this is basic knowledge. However, since these temperature distributions have a strong effect on the actual spatial extent of the temperature range discussed throughout this paper, we feel that we need to make sure that readers keep these differences in mind. On former presentations, this Figure was explicitly requested by the audience. We would therefore like to keep it.

Minor changes: Lines 9-11: p.2. Run-on sentence. I would suggest fixing this up. Line 15: p.2. "Formed" ! "forms"

Thank you, the respective parts were corrected.

Text changes: see paper

Figures 7/8: Scale needed for CIP images. Do the habits change with temperature? I think that information would be useful to provide. Also, 275 K is above freezing. Are you sure you are observing ice at that temperature?

A scale was added. We did not perform a habit analysis for the presented study; this kind of analysis has not been done yet for the NIXE-CAPS dataset. This might be considered for a future study on the investigated cloud types.

With regard to your second concern, yes, there is clearly ice, often even large crystals. We assume that precipitating ice does not melt instantly when falling into regions slightly warmer than 273 K. When probing low cloud edges of precipitating clouds, it is therefore likely to find ice at these temperatures.

References

Baumgardner, D., Newton, R., Krämer, M., Meyer, J., Beyer, A., Wendisch, M., and Vochezer, P.: The Cloud Particle Spectrometer with Polarization Detection (CPSPD): A next generation open-path cloud probe for distinguishing liquid cloud droplets from ice crystals, Atmospheric Research, 142, 2 – 14, doi:http://dx.doi.org/10.1016/j.atmosres.2013.12.010, http://www.sciencedirect.com/science/article/pii/S0169809513003591, the 16th International Conference on Clouds and Precipitation, 2014.

Pruppacher, H. R., Klett, J. D., and Wang, P. K.: Microphysics of clouds and precipitation, Taylor & Francis, 1998.