Atmos. Chem. Phys. Discuss., referee comment RC2
https://doi.org/10.5194/acp-2021-833-RC2, 2021

Comment on acp-2021-833

Anonymous Referee #2

Referee comment on "In situ observation of riming in mixed-phase clouds using the PHIPS probe" by Fritz Waitz et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-833-RC2, 2021

General comments to the manuscript acp-2020-833

The study titled “In-situ Observation of Riming in Mixed-Phase Clouds using the PHIPS probe” by F. Waitz et al. presents airborne in-situ observations of cloud particles with the PHIPS acquired at three field experiments ACLOUD (Arctic), SOCRATES (Southern Ocean), and IMPACTS (East Coast of USA). The riming state of the ice particles was identified and correlated with temperature, ice particle size, liquid water content, relative cloud height, supersaturation with respect to ice, cloud droplet size, airborne radar mean Doppler velocity and ambient vertical air velocity. Additionally, for a case study of the IMPACTS campaign, the evolution of epitaxial riming (small, faceted rime oriented to the crystalline axis of the host particle) is described in detail.

Without doubt, in-situ observations of riming in mixed-phase clouds under different conditions (different ranges of temperature, liquid water content etc.) as done in this study are valuable for validation of remote-sensing microphysical retrievals as well as for assessing the performance of cloud simulations in different situations. However, several main issues need to be addressed before publication.

Recommendation:

I would suggest the manuscript to be published after major revisions. The authors should address the following points:

Major comments:

- The facts and previous studies presented in the paragraphs of the introduction section seem not always well-structured. Some terms are used without explaining what they mean (e.g. l.66 "riming state" and l.76 "riming degree").
- The way data was grouped and analyzed and plotted needs to be explained more clearly. Specifically:
- a) l.159: Why is "aggregate" used as attribute to the ice particles and not as particle habit? The term aggregate is introduced here but not used subsequently. Does that mean aggregates were not observed with the PHIPS?
- b) l.167-178: In this second classification step different attributes are introduced (sublimated, one-sided riming, epitaxial riming). How do you assess if a particle is sublimated? How do assess one-sided riming for more opaque particles?
- d) l. 177: You mention the total number of PHIPS particles analyzed for ACLOUD and SOCRATES. To put those numbers more into context of the field experiments, it'd be helpful if you added how many minutes of flight time this refers to.
- e) The absolute number of particles in Fig2a and Fig S4a are different for the warmest temperature bin even though the caption says that the same data is used. – why?
- f) l.201-202: According to Fig 2a, the high fraction of rimed particles of approx. 50% does not happen in a wide T-range of -10°C to 0°C as stated but rather at T of -7 to -8°C. Please rephrase. State how many particles were analyzed around -17°C (instead of "low number", l.204).
- f) Fig. S1, S2, S3: It has not become clear to me why for the temperature dependent frequency of occurrence distribution of different ice particle habits the data is divided into ACLOUD (S1) and SOCRATES (S2) but then combined for both campaigns in the histogram plot (S3) of the percentages of rimed particles per ice particle habit. – Please explain.
- The secion 239-251 on correlation of riming with mean radar Doppler velocity needs revision. All of the experimental studies listed in the introduction that employ vertically-pointing radar Doppler velocity measurements are using ground-based Doppler radar observations. The Mosimann approach as well as Kneifel and Moisseev, 2020 clearly state that their method of using absolute values of mean Doppler velocity to infer riming is only possible if vertical air motion (up- and downdrafts) can be neglected and the mean Doppler velocity thus is close to the ice particle terminal fall velocity. In the present study however, airborne radar Doppler velocity measurements are used instead which are much more complicated to interpret due to the aircraft motion and the two possible radar-pointing scenarios. Depending on where the aircraft was flying with respect to the cloud, sometimes the HIAPER cloud radar (HCR) was pointed upward or downward. According to the description, the radar pointed to zenith (up) when flying beneath clouds or doing ascents in boundary layer clouds. It pointed to nadir (down) "at other times". For the two different configurations, the Doppler velocities towards the radar should thus have different sign conventions OR different interpretations, correct? Please mention if this paid attention to/adjusted in the HCR data before it is used here? Depending on the radar-pointing scenario and the location of the aircraft within the clouds different parts of the clouds are observed with the radar. If for example the HIAPER did an ascend in a boundary layer cloud it pointed upward toward cloud top whereas if it descended it pointed downward towards cloud base. In other words, in the zenith-pointing scenario the radar observes the "history" of the particles that the PHIPS measures in-situ whereas in the nadir-configuration, the radar shows the "future" of the PHIPS-observed particles. In both cases different parts of the cloud with potentially different microphysical composition and different dynamics (up-/downdrafts, turbulence) are observed by the radar leading to different mean Doppler velocities that are here correlated with riming. This has to be entangled and so simple averages of

mean Doppler velocities over the whole vertical column (up-or downward from the in-situ observation) don’t seem to be sufficient. Also, the reader wonders about the vertical extent of the clouds probed. More details on the HCR should be mentioned as well: radar frequency? Temporal resolution of data?

Also, in the current interpretation of the Fig2d), the mean Doppler velocity seems mostly be explained by dynamics and its influence on residence time of the particles and not the terminal fall velocity of the hydrometeors itself. In that context, please clarify l.249-251.

As a minor additional comment, L.242 states that positive Doppler velocity refer to updrafts which should be replaced with “upward direction” as it is again the superposition of vertical air motion (up- and downdrafts) and reflectivity-weighted particle terminal fall velocity.

Also, in the description of Fig. 2 it is not very obvious that Fig2d) only refers to the SOCRATES data set (and not ACLOUD+SOCRATES as stated in l.206). This restriction to SOCRATES only becomes clear on l.244-245. The same is true for Fig 6c) and Fig 8c). It should be mentioned more clearly that these plots are based on SOCRATES HCR data only. The description of Fig 6c and 8c should also be revised.

l.252-260: Explain how the vertical air velocity is measured. Turbulence and vertical air motion of large magnitude (strong up- and downdrafts) seem to be not correctly disentangled.

Minor comments:

-l. 36: replace “following” with “followed by”

- l.90: “scale” of riming refers to “degree” of riming?

-l.180: Do you plan to do automated image processing for the large amount of PHIPS images for the entire IMPACTS data set?

-l.160: “distribution” should be more precise: “temperature dependent frequency of occurrence distribution” l.161: In Fig S3, the percentage of rimed particles per habit (here: "riming fraction") is subdivided into "normal", "epitaxial" which should be mentioned here.

-l.183: What do you mean by "number of rime"? – maybe "amount"?

-l.188-189: ice particle trajectory is also a function of ice particle density and terminal fall velocity. Regarding vertical air motion, "updrafts" are explicitly mentioned but "downdrafts" are also relevant as they decrease the residence time of ice particles in the cloud. Please rephrase.

-l.194: "in-situ" aircraft data instead of "experimental" data

-l.195: Subsequently, you also correlate the relative occurrence of rimed and unrimed particles with LWC, ice particle size etc. which are microphysical parameters (not meteorological parameters). Please rephrase accordingly, also in the abstract and elsewhere.

-l.196: replace "were rimed" with "experienced riming"

-l.199: Add an introductory sentence to Fig.2 and move the sentence regarding the fit parameters (l.205) behind it.

-l.209: acronym HCR needs to be introduced

-Table 1: It is not mentioned that the linear fit for Fig2c) (Riming percentage vs LWC) was made with a logarithmic y-axis

-l.219: replace "above that" with "For larger ice particles"

-l.227,230: "rimed droplets" sounds like as if the droplets are rimed which is misleading. Please rephrase. Also it is unclear if the two droplet size examples of 20mum "and" 50mum are representative and show the span of droplet sizes that lead to riming. Please clarify.

-l.246: add “clouds” after “flying beneath”

-l.259: replace “one-sided” with rimed on one side

l.268: the subsection “riming degree” is introduced here. Consider using the title in l.182 as subsection a) for the first part of the analysis and find a Section title.

-l.281: This sentence seems to contradict the previous statements in line 278-280. Please rephrase.

-l.360: It looks like a subsection for Section 4 is introduced here. The previous analysis in Section 4 should then also be grouped into a subsection.

Comments on Figures in Supplement:

S1, S2,S3: It has not become clear to me why for the temperature dependent frequency of occurrence distribution of different ice particle habits the data is divided into ACLOUD (S1) and SOCRATES (S2) but then combined for both campaigns in the histogram plot of the percentages of rimed particles per ice particle habit. – Please explain?