AGU Advances

Peer Review History of

Decreased aviation leads to increased ice crystal number and a positive radiative effect in cirrus clouds

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Original Version of Manuscript (2021AV000546)
First Revision of Manuscript [Accepted] (2021AV000546R)
Author Response to Peer Review Comments

Peer Review Comments on 2021AV000546

Reviewer #1

[Please see attachment that begins on the next page.]

Review of

Decreased aviation leads to increased ice crystal number and a positive radiative effect

by Zhu et al.

Summary and general comment:
In this study the impact of the decreased aviation during the first phase of the COVID19 lockdowns in 2020 is investigated. The authors investigate CALIPSO data for showing that the reduction in air traffic leads to an increase in the mean/median number of ice crystal concentrations. The authors formulate the hypothesis that the reduction of aircraft emission, especially the decreased emission of soot leads to a reduction of heterogeneous nucleation. Thus, more homogeneous nucleation events can take place leading to enhanced ice crystal number concentrations. The authors state that this reduction in emission would be similar for a partial replacement of air craft fuels by biofuels.

In general this is an interesting study combining satellite observations with global model simulaitons. Especially the evaluation of the CALIPSO data is robust and show some interesting results. However, the GCM simulations might be over interpreted in some sense, since some major effects are not included.

Therefore I recommend major revision before this manuscript can be accepted for publication in AGU Advances. In the following I will explain my concerns in detail.

Major issues

1. In an aside, it is noted that the HYBRID ice cloud scheme in the GCM does not allow pre-existing ice. However, this is a major drawback for the simulations. It is well known from observations that in the major routes of aviation (e.g. over the Northern Atlantic) the amount of so-called contrail induced ice clouds is very high. This leads to a permanent loading of the air by some ice crystals, i.e. pre-existing ice. As shown in many studies (e.g. Kärcher et al., 2006) pre-existing ice can significantly reduce homogeneous nucleation events in their strength, i.e. in the final number of ice crystal number concentrations. This effect must be compared with the probable reduction of suitable INPs due to reduced emissions. Actually, both effects go in the same direction (i.e. reduction of pre-existing ice, either by less contrail induced cloudiness or less heterogeneous nucleation events), so the effects as seen in the satellite is most probable due to the reduction in the air traffic. However, the relative strength is not clear. For the second conclusion in terms of the use of biofuels, this has to be investigated in more details. If the major effect is due to the reduction of pre-existing ice, then the effect of biofuels is probably overestimated. Nevertheless, these two effects have to be compared: in the best case using a GCM, or if this is not possible then e.g. using a process model.

2. As indicated in the text and in the recent investigations by Kärcher et al., (2021) the ability of soot as ice nucleating particles might be overestimated. It is necessary to investigate this issue in more details, also relative to the effect of pre-existing ice, see point above. This is also important to estimate the impact of biofuels in a meaningful way.

Minor issues:

1. It is hard to find the reduction of the Ni values for the period April/May in the figure following the text (lines 230-233). Maybe determining the period in the description would help here (not only stating panel B).

2. What happens with ice clouds with smaller optical depths (i.e. COD$<$ 0.3)? It might be that there is a shift in the frequency of occurrence in the clouds of different classed (COD$<$ 0.3 vs. 0.3 $<$COD$<$ 3) due to the change in the nucleation pathway. Is there any chance to observe such changes in other satellite data?

3. At some places in the text it is argued that the CALIPSO would missing homogeneous nucleation events, when they occur in the model simulation. I find such augmentations quite critical, since the measurements should give the baseline for the study. If such effects are relevant, the authors should try to estimate the frequency of such events and the maximum resulting deviations.

4. For the estimation of the radiative impact the authors use global estimations. Although this is meaningful in terms of estimating the overall net effect, it would be helpful to see the evaluation for the extratropical regions, which are (a) mostly affected by air traffic and (b) mostly affected by the transition between homogeneous and heterogeneous nucleation.

References

Kärcher et al., 2006: Physically based parameterization of cirrus cloud formation for use in global atmospheric models. Journal of Geophysical Research, 111, D01205, doi:10.1029/2005JD006219

Reviewer #2

Comments on "Decreased aviation leads to increased ice crystal number and a positive radiation effect" by Zhu et al.

This is a very interesting study. Influence of aviation emission on the ice crystal is an important and very challenging topic. The authors mapped the global aircraft emission for Jan-May 2019 and 2020 and quantified the aviation emission reduction due to the lock down in the pandemic in different phases. CALIPO satellite data shows significant increase of ice crystal number has been found during the lock down period compared with the same period in 2017-2019 and in the past ten years. Earth system modelling coupled with deliciated aerosol module and heterogeneous nucleation treatment, and HYBRID ice nucleation scheme is used to gain a mechanistic understanding of influence on the ice crystal by a 70% reduction of aviation emission and the long-term impact of the worldwide adoption of biofuel blending in aircraft fuels. The study nicely shows that reduced soot emission due to decreased aircraft mileage leads increased ice crystal numbers due to a competition effect between heterogeneous and homogeneous ice nucleation, i.e., reduced soot emission leads to a decrease in heterogeneous ice nucleation, but an increase in homogeneous ice nucleation. This is an important contribution and I recommend publication of the study in AGU Advances.

I believe the study would benefit from further discussion on the following aspects:

1. It would be nice to show the mapped air traffic and emissions and their differences in Jan - May 2019 and 2020. As the soot emissions are scaled from the year of 2006 with some yearly increasing rate, I am wondering if the authors have compared soot simulation in their base case (Jan - May 2019 or previous years) against the available soot measurements, e.g., ATOM and/or CARIBIC-SP2 (Ditas et al., 2018) or other missions/flight campaigns?

2. As the global models often largely underestimate the soot/black carbon concentrations in the high altitude, especially in the lower most stratosphere (LMS) and upper troposphere (UP) (e.g., Ditas et al., 2018; Wang et al., 2014), I am wondering if there could be different sensitivities of ice crystal number (Ni) on the INp concentrations (i.e., soot/dust concentrations etc.) similar to the aerosol- and updraft-limited regimes shown in Reutter et al. (2009)?

3. It seems that the capability of soot to be ice nuclei depends on its coating. Ditas et al. (2018) found that almost all soot particles have been thickly coated in UP/LMS, could the author discuss the possible influence of the thick coating of soot here? Maybe it helps on resolving the overestimate of Ni compared with CALIPO observation (or at least works in this direction)?

4. As aircraft emission counts only a certain fraction of black carbon in UT/LMS (up to 20-

30%?) (see Fig 9 of Wang et al., 2014), it is expected that the reduction of anthropogenic emission during the pandemic lockdown will lead to a decrease of soot and other aerosol concentrations and therefore may also contribute to the increase of ice crystal number. Although this study does not attribute the increase of ice crystal number fully to the change in aircraft emission, but more to discuss the mechanism, it would still be better to mention the contribution of changed anthropogenic emissions (maybe also biomass emissions that could contribute significantly to the UP/LMS soot, Ditas et al., 2018).

Minor

1. L49-51: "The novel coronavirus disease 2019 (COVID-19) has been spreading worldwide 49 since the end of 2019, which has led to ~100 million of infections and several millions 50 of deaths (Worldometers, 2020)."
Better update the number of infections and deaths.

2. Fig 1: Figure legends and axis labels are hard to read. I suggest enlarging the font size and put the legends outside of the figures and combine as they are all the same in Panel A and B?

References

Ditas J, et al. (2018) Strong impact of wildfires on the abundance and aging of black carbon in the lowermost stratosphere. Proceedings of the National Academy of Sciences 115(50):E11595-E11603.

Reutter, P., Su, H., Trentmann, J., Simmel, M., Rose, D., Gunthe, S. S., Wernli, H., Andreae, M. O., and Pöschl, U.: Aerosol- and updraft-limited regimes of cloud droplet formation: influence of particle number, size and hygroscopicity on the activation of cloud condensation nuclei (CCN), Atmos. Chem. Phys., 9, 7067-7080, https://doi.org/10.5194/acp-9-7067-2009, 2009.

Wang, Q., Jacob, D. J., Spackman, J. R., Perring, A. E., Schwarz, J. P., Moteki, N., Marais, E. A., Ge, C., Wang, J., and Barrett, S. R. H. (2014), Global budget and radiative forcing of black carbon aerosol: Constraints from pole-to-pole (HIPPO) observations across the Pacific, J. Geophys. Res. Atmos., 119, 195- 206, doi:10.1002/2013JD020824.