Reviewer #1 Comments (italicized), and responses (blue):

The general topic of this work -- how formation within natural cirrus may affect contrail properties and thereby their potential impact on climate -- is a potentially important one. The results of the present paper concentrate on two topics: how the presence of natural cirrus changes the number of contrail ice crystals nucleated and how it changes the fraction of contrail crystals that survive the wake-vortex regime of the contrail evolution. Despite what the paper's title and abstract suggest, neither of these processes are actually simulated in the present work. The ICON-LEM simulations are employed purely to provide large and hopefully representative sets of sample atmospheric conditions with different levels of natural cirrus (which, on its own, is a potentially useful approach). Existing parameterizations taken from the literature for contrail nucleation and crystal loss are then evaluated on these sets of conditions. In the vast bulk of these cases the results of the cirrus on contrail nucleation and crystal loss are found to be essentially insignificant. This is not a new result; Gierens (2012) earlier reached the same results in more succinct and robust fashion. The authors here highlight the differences for the less common case of very heavy cirrus. Unfortunately, the parameterizations relied on here for contrail nucleation and crystal loss were not designed for, or tested on, the case of contrails forming within natural cirrus. The authors' extensions of these parameterizations to apply to this case leave out critical physics that is involved in these processes. In my opinion this makes the new conclusions drawn regarding changes in nucleation and crystal loss due to heavy natural cirrus untrustworthy and, in some regimes, even of the wrong sign. Nor are the results critically examined within the context that is really of interest here: how the natural cirrus might affect the potential impact of contrails on climate.

The text is generally clearly written, but verbose. Several statements are repeated in multiple places within the body of the paper. Further, much of the text is taken up paraphrasing old results from elsewhere rather than providing more explicit specifications of the present study.

→Thank you for the in-depth review of the paper and for the many good suggestions. We have introduced many changes to our contrail scheme following your suggestions and reanalyzed the results. Our new results confirm many of your comments and we believe the paper was significantly improved.

We have modified the title and abstract in order to make sure that our approach, that is applying existing parametrizations in strongly differing atmospheric conditions and estimating the impact of the cirrus ice crystals by modifications to the parameterizations, is clear from the very beginning. We have rewritten large parts of the paper, describing the changed approach and results. We have not shortened the methods section including the descriptions of the parameterizations, on which our work is based, because we believe they are necessary in order to understand our approach and results. After all, we want our paper to be readable also for people that are not specialized in contrail modelling. Nevertheless, we have rewritten large parts of the paper and shortened the text in a number of sections.

We agree that most of the time changes in ice nucleation and ice crystal survival due to the presence of cirrus ice crystals are insignificant but we believe that this does not mean that the effects are not important. First of all, the fraction of cirrus cloud volume that leads to significant changes in contrail formation depends on the definition of a cirrus cloud. Since we consider cirrus clouds down to a cirrus ice water content of 10^{-11} kgm^{-3}, it can be expected that large parts of the cloud field do not have an impact on contrail formation. Likewise, most contrails that form dissolve within seconds or minutes but that does not mean that the formation of contrails is not important. Instead it means that the climate impact is composed of a few large events. The impact of cirrus ice crystals on contrail formation turns out to be particularly large in synoptic situations when the climate impact of contrails forming in cloud free air is large as well. This means that the contrails that form within cirrus and that are impacted by the presence of cirrus have a relatively large life time and possible a large climate impact as well. We expand on the study of Gierens (2012) by scanning many different atmospheric states in order to analyze if pre-existing cirrus ice crystals have the potential to be important and therefore should be included in a contrail parametrization. Cloud properties can vary strongly and using typical values, as done by Gierens, cannot cover the whole breadth of possible effects.

Specific points:

(1) In assessing the impact of existing cirrus on contrail nucleation the authors only consider the contribution of cirrus ice sublimated within the jet engines. The effects of cirrus ice that is mixed into the jet plume later are not considered. Depending on the temperature of the diluting jet at the time, these crystals might sublimate (providing an extra moisture source) or grow (providing a moisture sink). The authors use the change in contrail formation threshold temperature (T_sa), occurring through a change in the slope of the mixing line G in eqn. (1), as their primary metric of cirrus impact. This approach is already problematic in the presence of significant cirrus. The usual mixing line analysis and computation of T_sa relies on conservation of the water vapor during the mixing process (so that G is constant). But with the existing cirrus it is only the total water that is constant in the mixing process, not the vapor portion alone, because of growth and sublimation of the cirrus crystals. Furthermore, the contrail nucleation parameterization employed (Karcher et al., 2015) is based around the approximation that all droplets form at the same instant, and so the effects of existing ice crystals competing for available moisture during the nucleation process are not included. A recent LES study of contrail formation (Lewellen 2020) has shown that competition between ice crystals that form earlier and ones trying to form later can, in some regimes, significantly reduce the number of contrail ice crystals that would otherwise be produced. While for thin natural cirrus this effect on contrail nucleation should be negligible (as is the sublimation contribution considered by the authors), where the authors are reporting a significant cirrus effect (i.e., for very heavy natural cirrus and/or near contrail threshold temperatures) it need not be. This neglected contribution could lead to the presence of the cirrus sometimes reducing contrail ice nucleation, rather than always increasing it as concluded by the authors.

→We have changed our representation of contrail ice nucleation to consider the cirrus ice crystals mixed into the aircraft plume and their sublimation or the deposition depending on the ice saturation ratio. We added an appendix describing how we estimate the sublimation/deposition on the cirrus ice crystals mixed into the plume based on the diffusional growth equation. Figures and text were modified throughout the paper.

We estimate that in some instances the impact of the preexisting cirrus ice crystals is to reduce contrail ice nucleation while in most occasions ice nucleation is enhanced. The likelihood of this happening depends on the atmospheric conditions. We find that ice nucleation on the 26th April in the upper levels where the contrail formation threshold is well exceeded the likelihood of reduced ice nucleation is around 20%, which is larger than at lower levels where atmospheric conditions are close to the formation threshold and larger than in the case of the thin cirrus section 3.2, line 517 to 521. In both synoptic situations that we study and in both height levels reductions in ice nucleation are a few orders of magnitude smaller than the increases.

It is true that when considering the sublimation and deposition of cirrus ice crystals the usual mixing line approach is not fulfilled since the slope G would evolve in time. We calculated the slope of the curve describing the temporal evolution of G at the time of aerosol activation and compare with the mean slope when modifying the mixing line according to equation 3. We find that differences are below 1% which agrees with Gierens (2012) who found that the reduction in supersaturation due to deposition is far smaller than the production of supersaturation due to mixing. The largest changes to the plume's water vapor content due to sublimation / deposition happen very early in the plume life time so that treating the sublimation/deposition similar to the emission due to the combustion of fuel is a reasonable approximation. We added text accordingly right after equation 3.

We have mentioned the uncertainty coming from the assumption that all aerosols activate at the same time within the nucleation parameterization in several places:

In the introduction ' The number of ice crystals nucleated during contrail formation depends on the thermodynamic state of the ambient atmosphere and on aircraft and fuel parameters, in particular the number of aerosol particles released by the engine (Kärcher et al., 2015) but also on aerosol properties (Kärcher et al., 1998) and variable aerosol properties and inhomogeneities within the plume leading to ice crystals nucleating successively which has an impact on plume relative humidity and acts to decrease ice nucleation (Lewellen, 2020).'

In section 2.2.1 'All aerosols are assumed to activate and form droplets at the same time, t_{act}, called the "activation-relaxation time" neglecting the fact that aerosols that activate slightly earlier would have an impact on the plume relative humidity. This impact can sometimes be large in particular for large aerosol emissions (Lewellen, 2020).'

We have added a section on remaining uncertainties in the conclusions that mentions uncertainties coming from the assumption that all aerosols activate at the same time in the nucleation parameterization together with other sources of uncertainty (starting from line 769).

(2) *In extending the parameterization for the fraction of contrail crystals surviving the wake-vortex regime developed by Unterstrasser (2016) to include the effects of existing natural cirrus, the authors again only consider the cirrus crystals as a moisture source. Furthermore, they ignore the Kelvin effect in their implementation (e.g., in lines 283-285). This is a problem because it has been explicitly demonstrated in LES studies that crystal losses in this regime are significantly greater when the Kelvin effect is included than when it is not (see e.g., Lewellen et al 2014). The reason is that a significant portion of the crystal loss in the plume occurs in a regime where the water vapor pressure equilibrates to conditions which are subsaturated for the smaller crystals but not for the larger ones due to the Kelvin effect. Indeed, it has been shown in exact analytic solutions of ice crystal populations under different conditions (Lewellen 2012) that significant crystal loss can occur even if the overall ice mass is slowly growing in time: the larger crystals grow at the expense of the smaller ones (a process known in more general contexts as ``Ostwald ripening''). In the present application this dynamic could lead to greater losses of contrail crystals in the presence of the larger natural cirrus crystals rather than reduced losses, including losses in the secondary wake where no adiabatic heating is occurring. Again, this effect on the contrail (like those included by the authors) should only negligibly be affected by the presence of thin cirrus, but for conditions where they are reporting significant cirrus effects (i.e., high cirrus ice number concentrations and IWC), this Kelvin-dependent process could even*

change the direction of their reported effect, decreasing rather than increasing contrail crystal survival fractions.

→We changed our parameterization in several ways. We included the diffusional growth phase after ice nucleation and before vortex descent in our analysis of the impact of cirrus ice crystals on the survival in the vortex phase. We calculate the competition of cirrus and contrail ice crystals after nucleation and before the start of the vortex descent using the whole diffusional growth equation. Once the vortex is descending we use again the whole diffusional growth equation to estimate the cirrus and contrail ice sublimation. We set the relative humidity to a constant slight subsaturation, choosing a saturation ratio of 0.98, a value that is often found in the descending vortices (personal communication Simon Unterstrasser). While we change the implementation of the parameterization of the vortex phase loss in our model we found an error in the earlier implementation. The survival fractions and in particular the changes in the survival fraction are now significantly reduced compared to our earlier estimates. Nevertheless, we find that in cirrus that has a large water content and additionally cirrus ice crystals are large the survival fraction is reduced and when instead the cirrus ice crystals are small then the survival fraction is increased. We changed figures and text accordingly.

(3) The authors report greater relative changes in contrail ice crystal numbers due to natural cirrus for near-contrail-threshold conditions, largely because fewer crystals are nucleated there. It must be noted, however, that contrail ice numbers prove highly sensitive to a large host of variables near threshold conditions (see e.g., the simulation results in Lewellen (2020)). As a result, simple parameterizations in this regime, including both the nucleation and crystal-loss parameterizations that the authors are relying on for their conclusions, are much less trustworthy near-threshold than in most other regions of parameter space.

-->We have added a sentence in the conclusions 'Furthermore, contrail formation close to the formation threshold is connected with a larger uncertainty than contrail formation far away from the threshold since details in the plume development may have a large impact, leading to varying ice crystal numbers resulting from slightly different LES simulations (Lewellen, 2020).'

(4) In this work the authors only consider the changes in contrail ice crystal numbers due to the presence of the cirrus, not the changes in cirrus due to the passage of the aircraft (e.g., in metrics like equation (4)). For assessing the impact of aircraft on climate (presumably the ultimate motivation here) what matters is the net effect on the total system of contrail plus natural cirrus. For heavy cirrus or in near-contrail-threshold conditions where the authors claim significant increases in contrail ice crystal number, to what extent are these increases offset by losses in natural cirrus in the hot jets and descending wake? Further, the methodology for conducting the ``with'' vs ``without'' cirrus comparison is never explicitly defined, e.g., by specifying what variables are held fixed in the comparison. For example, it is never actually stated whether it is water vapor or total water that is held fixed in the comparison. Given the results it is presumably the former, but the latter choice would in some sense give a more robust comparison (since water vapor changes more in time as the natural cirrus ages).

→We do consider the loss of cirrus ice crystals due to sublimation in the engine. We do not consider the loss of cirrus ice crystals that are mixed in right after emission and that may be lost until plume saturation is reached since we do not have information on the size distribution of the cirrus ice crystals. We have now added a figure on the change in ice crystal concentrations due to contrail formation versus the original cirrus ice crystal concentrations (Figure 11). Changes in ice crystal concentrations are between 2 and 4 orders of magnitude larger than the original cirrus ice crystal concentrations. That means that even if many cirrus ice crystals within the plume would additionally sublimate then the error in our estimate of the change in ice crystal number concentration due to contrail formation would not show up in the figure. But since reductions in ice crystal numbers due to contrail formation are much smaller and the error may possibly of a similar order of magnitude we refrain from showing the negative changes.

In lines 341-343 we specify now that we keep water vapor fixed when estimating the impact of cirrus ice crystals on contrail ice crystal loss. It depends on the question that you are asking whether water vapor or total water needs to be fixed. Keeping total water fixed our question would have been 'does the phase of the water in the grid box matter when we calculate contrail formation?' I believe that the answer is clear – it does matter. We instead ask the question 'Is the dependence of contrail formation on atmospheric variables unchanged even if ice crystals preexist in the background?'.

It is true that the ultimate motivation of our research is to estimate the climate impact of aviation induced cirrus perturbations. In this study we make the first step studying the contrail formation phase that is important for simulating the microphysical processes and the evolution of the contrail properties. In our future work we plan to study the evolution of those cirrus perturbations and their impact on optical properties.

(5) *It seems to me that the regimes where the current work concludes that effects of existing cirrus on contrail properties may be significant (e.g., heavy cirrus or near-threshold conditions) are not in fact ones where contrail climate impacts are potentially very significant. But how different cirrus scenarios might affect contrail radiative impact or longevity are never addressed in the paper. Radiative effects of contrails are clearly of potential concern when they seed significant, long-lived contrail cirrus in otherwise clear skies (i.e., where natural cirrus is optically thin or absent). On the other hand, the net radiative impact of a contrail shrouded within optically dense natural cirrus will naturally be expected to be much less (as well as occurring much less frequently). Likewise near-threshold contrails can be expected to have less impact because they occur less frequently, have fewer ice crystals and tend to be shorter-lived.*

→We agree that there are many questions and studies that can and should build on the work presented in this paper. We believe that any discussion of if or when contrail induced cloud perturbations are important for climate would be highly speculative. We have mentioned in our conclusions that the presence of cirrus impacts cloud properties in the outflow of conveyor belts and that those areas often support cloud for a very long time. That may point at cloud perturbations having a large impact simply due to their long life time. But this is speculation as well.

The aim of this paper was to introduce a contrail parameterization within ICON-LEM and study the contrail formation within preexisting cirrus, its variability and the impact of cirrus ice crystals on the formation.

Reviewer #2 Comments (italicized), and responses (blue):

The paper addresses the question of contrail formation within cirrus clouds. Contrails constitute an important part of aviation impact on the atmosphere but the evaluation of their radiative forcing remains difficult to determine because of limited scientific understanding and complexity of the different processes to take into account. This paper is focused on the formation of "real life"-contrails, that do not only form in clear sky but also within existing clouds and we expect to know whether the effects are negligible or not. Therefore, the work provides valuable effort in order to better understand the processes and evaluate the effects. It uses a model including a cloud microphysical model and study the influence of contrails/cirrus clouds on each one for two synoptic situations. The paper focusses on the potential effects but is not meant to evaluate since it would require proper integration in a climate model. As a matter of fact, it is difficult to draw your own conclusions after reading whether preexisting cirrus clouds are important for contrail impact since the effects depend on the synoptic situation, the properties of cirrus clouds, the soot El, the way the processes are treated etc. But it is important to go forward with such a work. It is perfectly in the scope of ACP.

The paper is a bit long, some details are repeated several times, and the paper is not very easy to read through, especially because within a paragraph you may have to refer to a lot of figures at different locations (see for example section 3.3.1 where figures 4b, 7a, 2, 3 are called in the first 10 lines).

A list of acronyms could also be useful to the reader since a lot of them are used in the text, sometimes unnecessarily (RBF or CWP are only mentioned once for instance).

→Thank you for the review of our paper. We changed our paper according to your suggestions.

In the process of revising the paper according to both reviewer's comments we included a number of additional processes that have implications for the contrail ice nucleation and for the contrail ice crystal survival in the vortex phase. In particular, we included the impact of cirrus ice crystals that get mixed into the aircraft plume in the first second of the plume's lifetime before contrail ice nucleation section 2.2.2. Furthermore, we include now the diffusional growth phase of the plume ice water content after contrail ice nucleation and before vortex descent in our estimate of the impact of cirrus ice crystals on the contrail ice crystal loss within the vortex phase (section 2.2.4). For this estimate we use now the full diffusional growth equation (Appendix A). Finally, we found an error in our implementation of the parameterization of ice crystal loss in the vortex phase that we corrected. All together we find now that the impact of cirrus ice crystals on contrail ice nucleation is larger than estimated before and that the impact of cirrus ice on the vortex phase loss is most of the time negligible except for the parts of the natural cirrus that include many small ice crystals and those where contrail ice nucleation is very low and the cirrus ice crystal radius relatively small (section 3.3).

Accordingly, large parts of the paper were changed. In the context of the revision the text was shortened in many places in order to avoid repetition and we improved our use of abbreviations.

Specific comments/remarks

The soot emission index that was used in the simulation, 2.5xl0^{15} particles per kg fuel was fairly high. It is indeed mentioned that this is for the soot-rich regime. Recent works on the non-volatile particle emission certification process have also emphasized the importance of particles loss in the measurement system, and that could lead to underestimates of soot emissions, especially from previous studies and in flight. Surely the choice of this index has some consequences on the results and the sensitivity study of the survival fraction to the soot emission index that has been performed in section 3.3.1 should have been more emphasized (or advertised at the beginning of the paper as the reader may think that only one soot emission case has been treated).

→ The soot number emission index of $2*10^{15}$ kg-fuel^{-1} was chosen according to Bräuer et al. (2021) but we agree that this value is very uncertain and highly variable. We mention this uncertainty now in the conclusions. When choosing a lower soot number emission index, changes in ice nucleation due to the impact of cirrus ice crystals would remain the same for the lower soot number emission index except that the new AEI_i would be limited to the lower soot number emission index. In the analysis of the impact of cirrus ice crystals on the survival of contrail ice crystals the soot number emission index and the number of nucleated contrail ice crystals is very important so that we have analyzed the sensitivity of our results to a range of soot number emission indices. We mention this sensitivity analysis now earlier in the paper e.g. in the last sentence of the introduction and in the last sentence of section 2.3.

Regarding the effect of ice crystals sucked into the engine, Gierens (2012) indicates that the change in the water vapour emission index is very small, of the order of its variability regarding the fuel's composition. In this work, the effect depends on the air to-fuel ratio and the cirrus cloud ice water content (eq. 2). It would be nice to have at this point some example values so that the reader can figure out how much water vapour can be added to the plume. Besides, eq. 2 give an upper limit to the added H20 since it may be affected while going through the engine, including the hot combustion chamber.

→In Gierens (2012), as well as in our paper, the change in the water vapor 'emission index' is dependent on the air to fuel ratio and the cirrus ice water content. We choose the same air to fuel ratio and the same water vapor emission index (1.25 kg per kg-fuel) as Gierens (2012). The cirrus cloud properties that we use are displayed in our figure 2. Our results are consistent with Gierens (2012) regarding the impact of the sublimation of cirrus ice crystals in the engine. Our figure 3 (dashed lines) shows that the sublimation of cirrus ice crystals within the engine amounts to maximally a few percent of the 'aviation induced change in the plume water vapor' that is the sum of the water emission due to fuel combustion and the sublimation of and deposition on cirrus ice crystals. For our thin cirrus we get a maximum change in water vapor 'emission' of about 0.2% (blue lines) and for our frontal cirrus day a change of about 4% (red lines) at a probability of about 10^{-2}, which agrees with the 'order of percent' result of Gierens. The sublimation and deposition on cirrus ice crystals that were mixed into the plume after emission can occasionally be larger than the sublimation of cirrus ice crystals within the engine but it can be also negative. Gierens did not consider the impact of cirrus ice crystals that are mixed into the plume on the water vapor 'emission index'. Therefore, the maximum increase in the water vapor 'emission' due to the sublimation /deposition of cirrus ice crystals (figure 3, solid lines) is larger than the estimate of Gierens and, when assuming an IWC that would be representative of a relatively thick in-situ cirrus, can also be larger than the variation in the water vapor emission index given by IPCC. these results are described in section 3.2.

We have added a sentence in 2.2.2 shortly after equation 2 saying that the impact of cirrus ice crystals on the aviation induced water vapor content of the plume is discussed in section 3.2. We have also added a sentence in section 3.2 saying that we use the cloud properties as displayed in figure 2 for our calculations. Furthermore, we mention in the figure caption of figure 3 that the water vapor emission index is 1.25 and that the cloud properties are displayed in figure 2. In the summary and comparison to literature we compare our results to Gierens as explained above.

To our knowledge the H_2O content of the air is not changed when going through the engine. Water does not accumulate in the engine.

Please add some justifications on the choice of a "rough(ly) estimate" in equation 5: no Kelvin effect (are particles large enough at this point to exclude it?), spherical particles (correct for young contrails but not for cirrus clouds).

→We use now the full diffusional growth equation (including the Kelvin effect) for calculating the diffusional growth of mixed-in cirrus ice crystals before nucleation and the growth of contrail and cirrus ice crystals after nucleation and when estimating the cirrus and contrail ice sublimation during vortex descent. Please see our new Appendix A for details.

We assume spherical particles as we have no information on the particle shape or the mix of particle shapes of the cirrus ice crystals from our model. When estimating the impact of cirrus ice crystals that are mixed into the plume on ice nucleation and on the survival of contrail ice crystals we find that it is mainly cirrus containing very many small ice crystals that have the largest impact. This cirrus is connected with the frontal system crossing Germany on that day and has properties representative of a medium thick in-situ formed cirrus and partly a liquid origin cirrus (Krämer et al., 2020). Those ice crystals are likely close to spherical so that the assumption is likely a good one. Nevertheless, when cirrus ice crystals are larger our assumption of spherical particles may often underestimate the real sublimation and deposition on the mixed in cirrus ice crystals. Nevertheless, the changes in contrail ice nucleation and survival in the vortex phase are so much lower when cirrus ice crystals are large that we do not expect our results to change significantly even if we would have more information on the shape of cirrus ice crystals.

We have added a few sentences in the new appendix just after the introduction of the diffusional growth equation Line 819 to 824. We have also mentioned the dependency of our results on the shape as one of the uncertainties in our analysis (conclusion, line 769).

Following point (3) in the summary, from line 627, the role of the temperature change on the saturation vapour pressure and in turn on the relative humidity is described. The sublimation of cirrus ice crystals and contrail crystals releases water vapour so that the system tries to reach a vapour/ice equilibrium. The change in the survival rate due to cirrus ice crystal sublimation should be considered a maximum since (if) cirrus crystals are treated the same way as contrail ice crystals (spheres, no influence of size). The competition between contrail and cirrus cloud particles during sublimation seems to be the important part and should be treated with the maximum accuracy.

→As mentioned in the above points we have changed our parameterization and use now the full diffusional growth equation. Please see our new Appendix A for details.

As argued above, the impact of cirrus ice crystals on contrail ice nucleation and on the survival of contrail ice crystals during vortex descent is largest when the cirrus consists of many relatively small ice crystals. In this situation the assumption of spheres may not be that bad. If cirrus ice crystals deviate significantly from spheres then the deposition on the ice crystals would be larger as well as the sublimation would be faster during vortex descent. It is not clear to us if this would have mostly a positive or negative impact on contrail ice crystal survival. Since it is mainly large ice crystals that have shapes that are far from spherical and since large ice crystals usually lead to a very slight change in the survival fraction, we believe that the impact of assuming different shapes for large ice crystals would not be very large. But we agree that there is an uncertainty connected with our assumption that we can treat ice crystals as spheres. As mentioned in the answer to the previous point, we have added in the appendix a few sentences about the problem treating the impact of particle habit. We also added in the conclusions that the shape of ice crystals and its influence on the diffusional growth is one of the uncertainties that should be in future tested with LES modelling.

In the conclusion section line 706, the authors conclude that "the pre-existing cirrus can lead to changes in the contrail formation criterion and, therefore, can lead to contrail formation when otherwise none would have formed". This is a strong statement for someone who would only read the conclusions, regarding to the text for instance statement line 607 "In large parts of the cirrus cloud field the presence of cirrus does not impact the contrail formation criterion and contrail ice nucleation significantly".

→We have rewritten the conclusions and the statements should sound now less contradictory. In large parts of the cirrus clouds, the cirrus ice crystals have little impact on contrail formation except when IWC and ice crystal number concentration is high or if contrail formation is happening very close to the contrail formation threshold.

Line 708-710 seems not so clear to me. "That means that the pre-existing cirrus ice crystals can lead to contrail formation in cases when otherwise the passage of an airplane would have dissolved the cirrus". Does this refer to taking into account or not the effect of pre-existing cirrus in the contrail formation process?

→Yes, when we take them into account during contrail formation. We have reformulated the sentence and hope it is now less ambiguous. 'The presence of pre-existing cirrus ice crystals leads often to an increase in the contrail formation threshold temperature. Therefore, contrails may form and cause locally relatively high ice crystal number concentrations when, in the absence of the pre-existing ice crystals, no contrails would form so that only the sublimation of cirrus ice crystal in the engine would lead to a change in the ice crystal concentrations.'

Sometimes "forgotten" in plume microphysical model studies for convenience or for the sake of simplification, ambient aerosols and especially ice cirrus clouds could be taken into account for a more detailed sensitivity analysis. It could be one more recommendation of the conclusion.

→We do analyse the impact of cirrus clouds on the contrail ice nucleation and the survival of ice crystals in the vortex phase. We do not consider the full impact of ambient aerosols on contrail ice nucleation. While prescribing soot-rich emissions the ambient aerosols do not play an important role in determining ice nucleation unless their properties are significantly different from the soot properties which could lead to larger errors when using the contrail ice nucleation parameterization of Kärcher et al (2015). We added in the conclusions that variability in aerosol properties together with inhomogeneities have an impact on ice nucleation and constitute an uncertainty of the parameterization of contrail ice nucleation and therefore of our approach.

Technical corrections

Line 34 "since in IPCC style double C02..."

It is not clear to us what this comment refers to.

Line 146 "vertically consistently"

done

Figure 2 (a), (b), (c), typo in the vertical axis legend "Tamperature"

done

Figure 4, in the caption unit hPA instead of hPa in (~250 hPA)

done

Community Comments I (italicized), and responses (blue):

Any shift in estimates of effective radius forcing of aviation CO2 and non-CO2 emissions has important repercussions for assessing the trade-offs between the long-lived (CO2) and short-lived (contrail cirrus, for that matter) forcing agents [Simpkins, 2020]. This study is an important stepping stone towards research into the global climate effects of in-cirrus contrail formation, a hitherto under-researched aspect of contrail formation.

The authors focus on the contrail formation stage and modify an existing contrail parameterization scheme [Kärcher et al., 2015] to account for in-cirrus contrail ice formation by enhancing the water vapor emission index consistent with adding cirrus ice water sublimated within aircraft engines/combustors. Changes in the water vapor emission index as input to the original parameterization should lead to robust results regarding changes of the contrail formation threshold temperature.

With regard to the proposed modification, the sublimated cirrus ice water content was added to the mass emission index of water vapor resulting from fuel combustion with an assumed efficiency of 100%, cf. eqs 2+3. It might be appropriate to note that this assumption does not consider vapor losses e.g., on wall surfaces and the effects studied are therefore upper limit estimates.

Moreover, this approach does not capture the possible impact of sublimating cirrus ice crystals entrained into the expanding jet plume prior to and alongside contrail formation. The sublimation of entrained cloud ice in the bypass regions away from the jet core might lead to an increase in the plume water vapor mixing that may be larger than that from ice crystals sucked into the engines, based on microphysical studies of contrail ice formation including entrained cirrus ice [Kärcher et al., 1998]. This increase depends on the ambient cirrus ice crystal number-size distribution and temperature. Ideally, a quick yet reasonably accurate estimate of the contribution of a continuously entrained sublimating cirrus ice crystal population to total plume water vapor may be obtained by applying the flow field model described in Kärcher & Fabian [1994].

‘*Warm’ contrails are those observed at flight levels at temperatures well above those obtained by the standard thermodynamic model [Jensen et al., 1998], i.e. typically above about 225 K. It is possible that they form in high humidity (possibly cloudy) regions. The formation of such contrails might be explainable by one of the above mechanisms associated with in-cirrus contrail formation, or by both.*

→Thank you for your comment. We have introduced many changes to our study that consider the reviewer’s and your comments.

We do now consider the ice crystals that are mixed into the plume after emission. We estimate the sublimation of the cirrus ice crystals and the deposition that is happening after the plume reaches ice saturation and modify the slope of the mixing line accordingly. We added an appendix describing how we estimate the sublimation/deposition on the cirrus ice crystals mixed into the plume based on the diffusional growth equation. Figures and text were modified throughout the paper.

We estimate that in some instances the impact of the preexisting cirrus ice crystals is to reduce contrail ice nucleation while in most occasions ice crystal nucleation is enhanced. The likelihood of this happening depends on the atmospheric conditions.

To our knowledge the H2O content of the air is not changed when going through the engine. Water does not accumulate in the engine.

We do reference now to the ‘warm’ contrail estimate in Kärcher et al. 1998.

The authors are aware of the fact that during contrail formation within cirrus, contrail ice crystals get entrained in to jet plumes (line 259f). Consequently, they estimate the sublimation losses that are expected to occur when entrained cirrus ice crystals get captured in downward propagating wake vortices, albeit again with an assumed efficiency of 100%. Equation 5 makes total sense to me, as in the initial phase of sublimation, the total cloud ice crystal number stays constant while the ice water mass is decreasing. However, at some point cloud ice crystal numbers will start to decrease as well, once the smallest ice crystals fully sublimated to their aerosol cores [illustrated in fig S1 in Kärcher & Voigt, 2017]. The point where this happens obviously depends on the mean ice crystal size.

→We changed our representation of the contrail ice crystal loss in the vortex phase to include the ice crystal growth phase after contrail nucleation and before vortex descent. We treat that phase using the full diffusional growth equation which can lead to significantly reduced contrail ice crystal sizes.

It is true that the microphysical two-moment scheme of ICON LEM (without an explicit representation of the size distribution) is one of the reasons for uncertainty in our simulations. But since the impact of pre-existing cirrus ice crystals on the vortex phase loss is very low, this uncertainty should be of limited importance.

Due to their smaller mean size, the contrail variables (total number and mean size) will change much faster during sublimation than the corresponding cirrus variables. I was just wondering whether eq 5 accounts for effects of changing number and size of cirrus and contrails during the sublimation process. If not, how much will the application of eq 5 with constant integral radii for contrail and cirrus ice will deviate from estimates where these variables are allowed to change?

→Our equation 5 is significantly changed now in order to consider the full dependence of diffusional growth on ice crystal sizes. We include now in our estimate of ice crystal loss in the vortex phase the competition of contrail and cirrus ice crystals before vortex descent. We calculate the temporal evolution of both contrail and cirrus ice crystals in order to have a good estimate of ice crystal sizes before the vortex descent. Afterwards we use equation 5 in order to estimate the cirrus ice water that sublimates in the time that it takes the contrail ice crystals to sublimate without updating the ice crystal sizes. Since the changes in the ice crystal survival due to the impact of cirrus ice crystals is very low, we do not think that inclusion of this would have a large effect on the simulations.

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