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.