

We thank the editor and Anonymous Referee #2 for their time and careful reading of our manuscript, and for their constructive comments, which helped us improve it. Below, the referee's comments are reproduced in *italics*, followed by our responses. Changes to the manuscript are highlighted in blue in the revised version.

- *General comment/summary: In this study the effect of gravity waves in combination with large scale waves on tropical tropopause cirrus clouds is investigated using a detailed microphysical model, which is driven by local dynamics. It is found that GWs can lead to a longer life time of very thin (e.g. subvisible) cirrus clouds. This is a meaningful contribution to ACP. The overall findings are not really surprising, however somewhat expectable; the enhanced growth by fluctuating gravity waves and thus extension of life time is quite obvious from former studies of some of the authors. Nevertheless, the detailed investigation adds some new insights to our knowledge about ice clouds in the TTL. Generally, this is a well written manuscript that constitutes a valuable contribution to ACP. However, I have some concerns on the (missing) description of the model and other issues. Therefore I recommend major revision for the manuscript, before it can be accepted. In the following I will explain my concerns in detail.*

We would like to clarify the main finding of the study, which we believe is more nuanced than the reviewer's summary suggests. Gravity-wave cooling fluctuations do indeed promote ice crystal growth, but the same waves also produce rare, high-amplitude warming events that can fully sublimate the ice population. Cirrus lifetime therefore emerges from a competition between these two effects: clouds whose crystals grow large enough can enter a stabilization regime controlled by sedimentation, while the others are terminated by complete sublimation. As a result, stronger gravity-wave activity generally *shortens* cirrus lifetime. To our knowledge, this threshold behavior, its modulation by low-frequency waves, and the reproduction of the strongly skewed lifetime distribution inferred from BeCOOL observations (Lesigne et al., 2025) have not been shown before.

We have slightly revised the abstract to state this more clearly.

- *(1) Missing description of the model: The model is not really explained in the manuscript, it is just referred to a former publication. Actually, it is not even stated in a meaningful or understandable way what kind of model is really used (in terms of bulk, bin, superdroplets etc.). I would guess that the authors use a superdroplet method, when they refer to the “simulation ice particles (SIP)”, but this is not explained well. The same applies for the description of the relevant processes. Only the growth/evaporation process is described in the appendix A; however, the procedure for the sedimentation of particles is not explained at all. I can understand that the authors do not want to repeat their model description in details; however, in the current state the model and the following results cannot be understood without given more information. In addition, basic assumptions (as e.g. the shape of ice particles – probably spheres) are missing or are just provided in a sparse way. There is a long explanation about deriving the mean radius from LIDAR measurements, but on the other hand the authors do not mention any value for the typical number concentrations (although the pairs (n,m) are described in the same paragraph).*

I suggest to rewrite section 2 in order to provide enough information about the general setting of the model. Details might be shifted into the appendix.

We thank the reviewer for their comment and we agree that the model description was too brief, especially since the reference describing the model in detail (Kärcher and Corcos, 2025) was not yet published at the time of the submission (**it is now and the reference was updated**).

We have added the missing elements to Section 2 to make the manuscript more self-contained. Here are the details we added :

- naming the SIP approach
- a few words explaining the diffusional growth and sublimation, citing Kärcher and Corcos 2025
- the sedimentation, including the fall-speed formulation
- the spherical ice crystals.
- the kelvin effect (see reviewer's last comment)

We note that the initial number concentration was given in Sect. 2.3 ($n = 0.009 \text{ cm}^{-3}$ for the mean observed extinction), and its distribution is shown in Fig. 3 (green curve). We keep these elements intact.

- (2) *Inconsistency in modeling ice physics and radiation.* As far as I understand the model really describes the evolution of a size/mass distribution of ice particles, i.e. it is a very detailed model. On the other hand, the calculations of the radiative properties, a very simple radiation model (Corti and Peter, 2009) is used. This model is even simpler than a standard two-stream radiation code, which usually uses inputs of ice water content and effective radius. It is not clear why the authors do not make a larger effort to calculate the radiative effects directly from the model output, however instead use this very crude approximation based on optical depth. The comparison by Lotti et al. (2017) shows that there can be a large difference between the Corti and Peter model and a standard (not even sophisticated) radiation code – in contrast to the statement in the manuscript. I would suggest to use at least a standard radiation model (e.g. Fu and Liou, 1993) for the calculation of the radiative properties.

We respectfully disagree that a more detailed radiative transfer model is needed here. The study does not compute cloud radiative effects as a result: Appendix A serves only to justify neglecting radiative heating in the cloud dynamics, for which an upper bound is sufficient. This upper bound is derived from the Stefan–Boltzmann law and the emissivity at the largest optical depth of the BeCOOL subset (0.002). The Corti–Peter model is only used to estimate the (cooling) shortwave contribution. This upper bound is about 20 times smaller than the peak temperature tendency of the LF wave ($\approx 6 \text{ K d}^{-1}$) and more than two orders of magnitude smaller than GW-induced tendencies. Even large errors in the Corti–Peter estimate, such as the differences of up to 65% in net TOA forcing reported by Lolli et al. (2017), would therefore not change this conclusion.

Following the reviewer's comment, we have revised Appendix A to state its purpose explicitly, to clarify our method, and compare the radiative heating explicitly with wave-driven temperature tendencies.

- (3) *Representation of results* The description of the results is hard to understand, especially the figures. For instance, it is not really clear what is shown on the left panel of figure 4. It is not really helpful that two different labels are used for describing the processes AND the number concentration itself – by the way this is the only place where values of the number concentration are shown.

We thank the reviewer for this comment. In figure 4 left panel, the two x-axes are equivalent: the bottom axis gives the number concentration and the top axis gives the same quantity as a fraction of the initial concentration. All three curves can therefore be read on either axis. We agree this was not explained and misleading, and **we have revised the caption to state it explicitly, renamed the curves ("remaining in cloud", "sedimented", "sublimated"), and corrected the tick labels of the concentration axis.** We also note that initial ice crystal number concentrations are shown in Fig. 3 (green curve, top axis). **We now labelled it "ice crystal number concentration (cm^{-3})" instead of "ice crystal density" to avoid ambiguity.**

- *(4) Processes for small ice particles: Two of the authors (BK and EJ) have recently published an article about gravity waves and ice clouds in the tropical tropopause region (Jensen et al., 2024), claiming that the Kelvin effect might play a very important role for the sublimation of very small particles (smaller than 10 micro meter). Since in this model study the ice particles are of the same size, this effect might be important for the surviving of small ice particles. Is this effect included in the model? If not, why not, is there a good argument why to leave this effect out?*

We thank the reviewer for this question. The Kelvin effect is included in the model: each ice crystal grows or sublimates relative to its own equilibrium water vapour mixing ratio, $q_{\text{sat,ice}} (1 + r_K/r)$, with a Kelvin radius $r_K = 2 \text{ nm}$ (Kärcher and Corcos, 2025).

We have added this to the model description in Sect. 2.

We note that for the crystal sizes simulated here, the curvature correction is 0.2% at $r = 1 \text{ }\mu\text{m}$ and 0.04% at $r = 5 \text{ }\mu\text{m}$. This is one to two orders of magnitude smaller than typical GW-induced supersaturations. Jensen et al. (2024) identified the Kelvin effect as important in anvil cirrus. With ice concentrations of about 2 cm^{-3} , ice uptake keeps the vapour close to ice saturation: without waves, a quasi-steady state establishes with slight supersaturation over crystals larger than $\sim 10 \text{ }\mu\text{m}$ and subsaturation over smaller ones, driving mass transfer from small to large crystals. Here, in the very thin TTL cirrus considered ($n \approx 0.01 \text{ cm}^{-3}$), ice uptake is slow and the supersaturation is mainly set by wave-driven temperature fluctuations. The Kelvin effect is therefore represented in our simulations but plays a very minor role compared with GW forcing.

Jensen, E. J., Kärcher, B., Woods, S., Krämer, M., and Ueyama, R.: The impact of gravity waves on the evolution of tropical anvil cirrus microphysical properties, J. Geophys. Res. Atmos., 129, e2023JD039887, <https://doi.org/10.1029/2023JD039887>, 2024.

Kärcher, B. and Corcos, M.: On the lifetimes of persistent contrails and contrail cirrus, J. Geophys. Res. Atmos., 130, e2025JD044488, <https://doi.org/10.1029/2025JD044488>, 2025.