Reply to Reviewer #3 Report #3
(Referee comment on "Radiative effect by cirrus cloud and contrails – A comprehensive sensitivity study" by Kevin Wolf et al., EGUsphere, 2023)

In the following, the Reviewer's comments are highlighted in **bold**, comments from our side are given in standard font, and changes in the manuscript are given in *italic*.

<u>Major issues:</u>

1. **The results provided in the look-up table, which is intended for public use, contain incorrect results for more than 50% of the cases: Varying surface albedo has been neglected for the clear-sky thermal irradiance simulaCons, affecCng the upward, downward flux (Fup_Cr, Fdn_Cr) as well as the net radiaCve effect (RE_net) for all cases with surface albedo > 0. For a given surface temperature, the results have constant values for all albedo values in [0.15, 0.3, 0.6, 1.0], whereas they are expected to vary with surface emissivity (= 1 – albedo), see libRadtran manual for reference. Assuming the results and figures presented in the manuscript rely on the same database, they will have to be revisited as well.**

Surface albedo, as is customary in atmospheric sciences, refers to the albedo of the surface in the solar part of the electromagnetic spectrum. In the infrared we assume an emissivity of 1 (see line 130 in the last version of the manuscript), which is a reasonable assumption for most surfaces. Of course, the radiative quantities in the terrestrial infrared do not depend on surface albedo in the solar spectrum and solar zenith angle. For ease of use, all the radiative quantities in the database are provided with the same dimensions (incl. surface albedo and solar zenith angle). In this way the fluxes or RE in the solar and terrestrial parts of the spectrum can be summed easily to produce net quantities. The comment by the Reviewer that the calculations are incorrect for > 50% of the cases is unfounded.
For the sake of clarity, we now specifically mention that surface albedo is for the solar spectrum in a revised version of Table 4.

2.The optical thickness for a given IWC and effective crystal radius will vary across ice crystal habits. If the optical thickness is determined only for droxtals and assumed constant for plates and column-aggregates, this approach will lead to incorrect results for these other habits.

The sentence is taken out of context. The first paragraph of section 3 describes the relation of ice crystal radius, ice water content, ice crystal number concentration, and ice cloud optical thickness for droxtals (only). We already specified that this „overview' is for droxtals, hence, we do use the verbose output of libRadtran for droxtals.

Concerning the look-up-table: One of the dimensions in the database is the ice water content. The ice cloud optical depth for a given ice water content differs with the different crystal habits. This is why we provide the ice cloud optical depth in the database, where it can be checked that ice cloud optical depth varies across crystal habits as it indeed should. Furthermore, for ease of use, ice cloud optical depth is provided with the same dimensions as the other quantities but only varies with ice water content for a given crystal habit.

We further clarified caption of Fig.1:

Calculated ice crystal number concentration Nice (in cm^{-3}*) and simulated cloud optical thickness* τ_{ice} *at 550 nm wavelength as a function of ice water content IWC (in* $g\ m^{-3}$*) and effective crystal radius* r_{eff} *(in µm) assuming droxtals [...]*

Other technical issues to be addressed:

3.Please provide quantitative info about the bias introduced by choosing REPTRAN coarse vs. fine, as well as by limiting the thermal spectrum to 75,000 nm instead of 100,000 nm – both on the solar, thermal, and net radiative effect. It would be sufficient to run one simulation based on an extreme case of parameters (for which the largest effect is expected). This information is important for potential future users of the look-up table results.

We estimated the uncertainty in the simulations when using REPTRAN 'coarse' instead of 'fine' by simulating one particular cloud case. The selected simulation is defined by: a SZA of 70º, for a long and slanted path through the atmosphere to maximize the impact of molecular absorption; an ice cloud temperature of 231 K, as the center of the parameter space; a surface albedo of 0.15, for moderate surface reflection; an IWC of 0.012 g m^{-3}; a surface temperature of 300 K, to select the tropical atmospheric profile with the highest water vapor concentration; and an intermediate effective radius of 25 µm. No underlying liquid water cloud is simulated.
This set up has been simulated with REPTRAN 'coarse' and 'fine' leading to relative differences in the solar, TIR, and net radiative forcing of 0.4%, 0.2%, and 1.9%, respectively. The following section is added to the manuscript in the Appendix C.

[...] We estimated the uncertainty that is associated with the REPTRAN 'coarse' parameterization instead of the 'fine' resolution by simulating one particular cloud case and running the simulation with both options. The selected simulation is characterized by: a solar zenith angle $\theta = 70^{\circ}$*,* for a long and slanted path through the atmosphere to maximize the impact of molecular absorption*; a cirrus temperature* $T_{cld,ice}$ *of 233 K, as the center of the parameter space; a surface albedo* $\alpha_{srf} = 0.15$*, for moderate surface reflection; an ice water content IWC = 0.012* $g\ m^{-3}$*, a surface temperature* $T_{srf} = 300$ *K, to select the tropical atmospheric profile with the highest water vapor concentration; and an ice crystal effective radius* $r_{eff} = 25$ *µm. Based on the two simulations, relative differences in the solar, TIR, and net radiative forcing* ΔF *of 0.4 %, 0.2 %, and 1.9 % were determined, respectively.*

The bias introduced by considering a limit of 75 µm instead of 100 µm for terrestrial quantities is 0.7 %, as we already discussed in line 105 of the last version of the manuscript.

Minor issues:

4. Please use the full term "moderately rough aggregates of 8-element columns", "8-element columns" is not specific enough in this case, since there are three different roughness levels provided by Yang et al. 2013 (see original comment above). This

applies in a similar way to Figure D1: Please change “8--column aggregates (called 'aggregates' thereafter)” to “aggregates of 8-element columns with moderate surface roughness (called 'aggregates' thereafter)”. Please double-check throughout the manuscript.

The abbreviation ‘Aggregates’ is now introduced with the full description ‘moderately rough aggregates of 8-element columns’ provided by the Reviewer. The title of Fig. D1 was changed to ‘aggregates’ only as the full name is too long and the abbreviation ‘aggregates’ is explained in the caption:

[...]Aggregates are represented by moderately rough aggregates of 8-element columns[...]

5. Please double-check the literature, the references here are still not correct: Järvinen et al. 2018 report that 61 to 81% of the sampled ice crystals were found to be complex [meaning they had featureless phase functions; they do not mention aggregates here]. Later, they state that “severely roughened column aggregates” are found to best represent their observations. MODIS Collection 6 assumes severely roughened 8-element column aggregates as well. Forster and Mayer (2022) found mixtures of severely roughened (~60%) and smooth (~40%) 8-column aggregates to best match observations of (thin) cirrus. In fact, the latter more closely motivates the use of moderately rough 8-element columns in this study. Please note that the optical properties of aggregates closely resemble those of their components (e.g. the asymmetry factor of aggregates of columns is similar to that of individual columns), so it is important to be specific here about the type of aggregates, as well as the degree of surface roughness (cf. comment #4 above).

The citations have been corrected by following the Reviewers comments. The section has been rephrased as following:

[...] Several airborne in situ measurement campaigns that targeted cirrus and contrails imply that aggregates are the dominating ice crystal habit (Liu et al., 2014; Holz et al., 2016; Järvinen et al., 2018). For example, Järvinen et al. (2018) found that 61 to 81 % of the sampled ice crystals had complex shapes. They further noted that severely roughened column aggregates resemble their observations best. Such ice crystals are also assumed in current remote sensing applications of ice cloud, e.g., in the re-defined ice optical properties used by the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 product (Yang et al., 2013; Holz et al., 2016; Platnick et al., 2017; Forster and Mayer, 2022). Furthermore, Forster and Mayer, 2022 found mixtures of severely roughened (~60 %) and smooth (~40 %) 8-column-aggregates to best match observations of (thin) cirrus. As a compromise, we selected moderately rough 8–column–aggregates as the primary ice crystal habit. [...]

6. Please add REPTRAN (Gasteiger et al, 2014) to the table.

Table 3 has been updated and REPTRAN is added.

7.The sample libRadtran input file for the thermal-infrared specifies the solar zenith angle, which does not have any meaning in this spectral range. Even though this won’t have any impact on the simulation results, please remove this line as it potentially confuses future readers/users.

To avoid confusion for the reader, the line for the solar zenith angle is removed from the TIR input file.

8. A log scale would help here, or interrupting the y-axis at -400 W/m2 (solar) -200 W/m2 (net).

We prefer keeping the full, linear scale to show the full extent of the forcing, without any modification of the *y*-axis.