ACP Review (preprint on EGUsphere at: https://egusphere.copernicus.org/preprints/2023/egusphere-2023-155/)

Title: Radiative effect by cirrus cloud and contrails – A comprehensive sensitivity study
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General Comments:

The overall concept of this study is commendable and very useful, but there are problems with this study that need to be addressed and resolved before this study can be published. In spite of these problems, the results still appear valid. For example, the authors attempt to treat cirrus cloud properties (effective radius r_{eff} or diameter D_{eff}, IWC and N_{ice}) using Euclidean geometry (i.e., as spheres), and as with earlier attempts like this, at least one of these variables ends up serving as the "dust bin" (i.e., becomes corrupted, N_{ice} in this case) due to this flawed approach. But since it appears that D_{eff} and IWC are calculated accurately, and the radiation transfer (RT) calculations in libRadtran do not use N_{ice}, the results of this study still appear valid.

Another major drawback of this study is that the cirrus cloud geometrical thickness Δz is fixed (i.e., it never varies), having a value of 0.20 km. It appears that Δz is fixed to enable mathematical closure; otherwise Figure 1 is not possible. More importantly, Δz = 0.2 km is fine for contrails, but not for natural cirrus clouds, which are typically ~ 1.2 km on average. Since this study claims to be representative of natural cirrus clouds, the authors need a compelling argument to justify using a fixed Δz of 0.2 km for such clouds.

The paper is well written and organized, with good quality of figures, and the results should be useful to the atmospheric radiation community. I therefore recommend publication after major revisions. Detailed comments addressing the paper's drawbacks now follow.

Major Comments:

1. Equation 1: In some conventions, $F^{\downarrow}$ is taken to be positive while $F^{\uparrow}$ is taken to be negative, in which case $\Delta F = F_c + F_{cf}$. To avoid any confusion, please mention that all flux quantities are taken to be positive.

2. Lines 127-128: Cirrus clouds are typically ~ 1 km in geometrical thickness; why was a thickness of 0.2 km selected? It is not clear how this unrealistic value impacts the

analysis under “Results”; please explain why the findings of this study are realistic in relation to this choice for geometrical thickness.

3. Equation 6: Petty and Huang (2011) was consulted for the calculation of ν_{eff}, where it was discovered that ν_{eff} has no general analytical solution, making Eq. 6 here unpractical. If there is an analytical solution, it should be given here. For the special case of an exponential particle size distribution or PSD, $\mu = 0$ and $\nu_{eff} = 1/3$, but libRadtran has set μ to a value of 1.

4. Lines 155-157 and Eq. 7: Please mention that this D_{eff} definition is the same definition derived in Mitchell (2002, JAS), provided that ice volume V is evaluated at the bulk density of ice (0.917 g/cm^3), as shown by the following derivation that begins with Eq. 7:

   $$D_{eff} = D_V^3/D_A^2 = (6V/\pi)/(4A/\pi) = (3/2)\,(V/A) \qquad (1)$$

   where V is the ice crystal volume at bulk density and A is the mean projected area of the ice crystal, as defined on lines 159-160. But on line 164, the paper states: “where V and A are the average volume and projected area of the crystal population, respectively”. It seems like a leap of faith to apply this D_{eff} derived for an ice crystal to a PSD, but in Mitchell (2002) it is shown that this can be done, so please justify this leap of faith and mention the implicit ice density.

5. Equation 11: This could be done more elegantly and accurately by simply selecting appropriate power-law mass-dimension expressions for aggregates, droxtals, hex-plates. From Eq. 29 in Mitchell et al. (2006),

   $$N_{ice} = \Gamma(\mu+1)\ IWC\ \Lambda^{\beta} / (\alpha\ \Gamma(\beta+\mu+1))\ , \qquad (2)$$

   where Γ denotes the gamma function, μ and Λ are from Eq. 5 of this paper, and α and β are the prefactor and exponent of the ice particle mass-dimension power law relationship (i.e., $m = \alpha D^{\beta}$). The r^3 dependence in Eq. 11 is an artifact of the Euclidean geometrical framework imposed and leads to false interpretations later in the paper, like the top of page 12. For example, from Petty and Huang (2011), $\Lambda = 3/r_e$ for exponential PSDs, giving

   $$N_{ice} = 3^{\beta}\ IWC/(\alpha\ \Gamma(\beta+1)\ r_e^{\beta}\ ). \qquad (3)$$

   Thus, N_{ice} has a β dependence on ice particle size (not a cubic dependence as shown in Eq. 11), where β tends to be ~ 2 for aggregates, ~ 2.4 for hex-plates and 3 for droxtals.

6. Lines 199-200: The cloud absorption optical depth is also very important in determining RT in the TIR; please mention this.

7. Equation 13: Is this equation used in libRadtran? If not, what is the point in mentioning it? Cloud property input to libRadtran consists of IWC and r_e, suggesting the zero-scattering approximation might be used for TIR hemispheric fluxes:

   $$\varepsilon = 1 - \exp(-5\,\tau_{abs}/3) \qquad (4)$$

   where ε is cloud emissivity and τ_{abs} is the cloud absorption optical depth. Please indicate whether ε is calculated in libRadtran, and how it is calculated if applicable.

8. Lines 209 – 213 and Eq. 14: Eqn. (14) appears flawed since, in principle, there should be an emissivity term (ε) for both the surface and the ice cloud. But since typically ε ≈ 1 at the surface, does ε in (14) correspond only to the ice cloud? If so, it would be incorrect to multiply it by T_{sfc}^4 (which Eq. 14 does). Later, ΔF_{tir} is shown for IWC, r_e, and ice crystal shape, so it appears that ε refers to the ice cloud and therefore ε < 1, but how then does ε depend on IWC, r_e and ice particle shape? The dependence of ΔF_{tir} on cloud properties is a complete black-box mystery and this needs to be explained.

9. Figure 1: Fixing the cloud thickness appears to be required to get closure for the system of equations producing these four figures. If so, this analysis may not be representative of natural cirrus clouds in some respects since the geometric cloud thickness Δz is fixed at 0.2 km corresponding to extremely thin cirrus or contrails. For example, obtaining a typical range of cirrus cloud optical depth requires anomalously high IWC to compensate for the small Δz, based on the relationship: $\tau_{vis} = 3\ \mathrm{IWC}\ \Delta z/(\rho_i\ D_{eff})$. At a minimum, the authors should explain how they obtain mathematical closure to produce these plots.

10. Figure 9a: N_{ice} here has units of cm^{-3} with some values exceeding 100 cm^{-3}. In natural cirrus clouds, N_{ice}_ice rarely exceeds ~ 2 cm^{-3}. This appears to be a consequence of the r^{-3} dependence of N_{ice} in Eq. 11. As shown in Eq. 3 above, the dependence of N_{ice} on r_e is $r_e^{-\beta}$ where β typically lies between 1.7 and 3.

11. Lines 258-259: As noted in (1) above, N_{ice} is related to r_{eff} by the power of -β (not -3 as stated here).

12. Lines 295-296: How do ice particle shapes affect ΔF_{tir}, given the above comments in 8?

13. Lines 307-314: The aspect ratio strongly impacts the scattering phase function and therefore the asymmetry parameter g (Fu, 2007, JAS; Van Diedenhoven et al., 2012, AMT; 2013, ACP). Please consult these studies and revise this discussion accordingly.

14. Figure 3 caption: What do the numbers refer to in Fig. 3 a-c?

15. Lines 327-329: Macke and Grosklaus (1998) addressed lidar (SW radiation). While their finding about PSDs may be true for SW radiation, Mitchell (2002, JAS) and Mitchell et al. (2011, ACP) found that PSD shape matters considerably for LW radiation.

16. Line 358: This refers to Fig. 5a, correct? Here the upper boundaries are becoming more negative with increasing θ.

17. Figure 5 caption: What do the numbers next to the boxes indicate? They appear to correspond to median, 25th and 75th percentile values, but this should be called out.

18. Line 378: As far as I can tell, Fig. 2 shows that r_{eff} is the primary factor controlling ΔF, not IWC.

19. Lines 506-508: This could have been described more clearly under "Methods" unless I missed something.

Technical Comments:

1. Figure 2 caption: Typo where r_{eff} = 5 µm; should be 45 µm?

2. Line 349: ΔF_{tir} => ΔF_{net}?