Radiative impact of thin cirrus clouds in the lowermost stratosphere and tropopause region
egusphere-2023-1234

Reinhold Spang, Rolf Müller, Alexandru Rap

November 10, 2023

1 General remark

Thanks to both reviewers (Andrew Heymsfield and Blaz Gasparini) for their valuable comments and suggestions to improve the quality of the manuscript. Both reviewer had concerns regarding the particle types and effective radii used in the radiative effect calculations. We have enlarged the parameter space of our study by applying an even smaller effective radius of 5 μm on top of the 10 and 30 μm so far, and applied an additional cirrus particle type of hexagonal crystals. In addition, we highlighted more clearly that the analyses are not based on global observations and changed consequently the title of the manuscript by adding '... in the extratropical lowermost stratosphere and tropopause region'. Finally, we have formulated the abstract in a shorter and better readable form like suggested by reviewer 2. For details see the replies to the corresponding point-by-point comments of the reviewer as well as the new version of the manuscript.

We have highlighted the more detailed changes and new paragraphs in red in the revised version of the manuscript but also repeated most of the changes related to reviewer comments already here in this reply (roman font). Comments of the authors with respect to the reviewer comments are in italic letters.

2 Point-by-point reply to the comments of reviewer 1: Andrew Heymsfield

This study examines the radiative properties of thin cirrus observed in the troposphere region by the CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA-2) instrument during the second space shuttle mission in 1997. The article has similarities with the Spang et al. (2015) article, which I've gone through. What the article adds to that study is the use of the radiative transfer model SOCRATES, which is used to examine the bulk radiative flux properties of the thin cirrus layers, 161 cirrus, limb sampled on 9 August 1997. Basically, the question examined is whether the layers have a net positive or negative radiative effect.

Effective radii of 10 and 30 microns are assumed in the model, and ice particle aggregates-an 8-monomer hexagonal ice crystals, and spheres are assumed. With those assumptions, assumed cloud top height, and path length of 200 km for the CRISTA-2 measurements, the ice water content and ice water path are derived.

The article is clearly written, makes interesting use of the CRISTA measurements, and will be a valuable contribution. What I feel is needed is improved estimates of the effective radii and ice crystal shapes.

- Regarding the ice particle shapes, aggregates of ice crystals usually have sizes of 100-200 microns diameter and above. The assumed ice crystal aggregates are similar to bullet rosette ice crystals. And the spheres are designed to mimic droxtals. However, the ice particles in the TTL region are much more likely to be single crystals, such as hexagonal columns and trigonal crystals (see Heymsfield, 1986, JAS). Although in that study the temperatures were considerably below those studied here, the single crystal habit mode, and probably hexagonal plates or columns, is much more likely.

We followed the helpful suggestions of the reviewer and added a third particle type for the model calculation (see following reply).

- Also see Bailey and Hallel (Q. J. R. Meteorol. Soc.(2002),128, pp. 1461–1483). An important reference is Kikuchi et al. https://doi.org/10.1029/2020JD033562.

- I also feel that the assumed sizes are too large. See the figure below for concentrations and size distributions in subvisual TTL cirrus (Heymsfield,1986).

We followed the suggestions by the reviewer and added a further effective radius of 5μm (now 5, 10 and 30 microns) and an additional particle shape of hexagonal ice particles (following Baran et al. optical parameterisation). The results are presented in the new version of the manuscript and show generally larger amplitudes for CRE, although aggregates and hexagonal ice particles show only slight differences in amplitude, with larger values for hexagonal particles.

Page 6 we added following paragraph:

In this study we use properties of three particle shapes: (a) aggregates, a specific composition of ice crystal habits (Baran, 2003; Baran et al., 2014, 2016; Yang et al., 2005), (b) spherical ice particles as a simplification for the in situ observed quasi-spherical particles in the cloud top region, which are typically best described by droxtals (Yang et al., 2003; Zhang et al., 2004) or Chebyshev particles (Rother et al., 2006; McFarquhar et al., 2002), and (c) hexagonal cylinders (or columns, or prisms). Heymsfield and Platt (1984) reported that the ice crystals observed in high cirrus clouds (with cloud temperature $< -50°C$) were predominantly hallow or solid hexagonal columns. As described for example by Rodríguez De León et al. (2018) the parameterised optical properties for the hexagonal ice particle are based on Baran et al. (2001) and Yang et al. (2000) over a parameterised bimodal particle size distribution from McFarquhar and Heymsfield (1997).

- I recognize the desirability of using the SOCRATES model. Can any sensitivity studies be done, with smaller effective radii, for example. Can another radiative transfer model be used, that has the ability to do single columnar or hexagonal plate crystals incorporated? The changes will affect the net radiative effect of the cloud layers.

As described above we followed the suggestions by modifying the setup of the SOCRATES runs (in particular smaller radii) and have incorporated the results in the new manuscript.

2.1 Minor comments

- Figure 2. What are the units of IWC.

IWC is presented like SH in kg/kg, but SH is divided by 100. For better clarity this is now mentioned in the figure caption.

- 122. "form" to "from"

corrected.

- 127. What was the reason for choosing this path length?

The typical limb path length through the tangent height layer has been used in the analysis for the cloud path. The length depends on the vertical resolution of the instrument which defines the vertical coverage but indirectly by the observation geometry also the horizontal extent. This quantity is not retrievable from the measurement and need a priori information. We used the geometrical extent of the tangent height layer for a vertical field of view of 1.5 km (270 km) reduced it slightly to 200 km. In addition, we added a new paragraph giving more explanations on this issue in Section 2.3 of the manuscript:

Where along the limb path (line of sight) the cloud is located, for example in front of or behind the tangent point, and how long the cloud is extended along the line sight is unknown in limb measurements and cannot be retrieved. Simplified assumptions, e.g. a fixed horizontal cloud extent, are necessary to solve this issue in a retrieval process for target parameter like IWC or extinction (e.g. Wu et al., 2008; Spang et al., 2015; Bartolome Garcia et al., 2021).

- 185. seems

corrected.

References

Baran, A. J.: Simulation of infrared scattering from ice aggregates by use of a size-shape distribution of circular ice cylinders, Appl. Opt., 42, 2811–2818, https://doi.org/10.1364/AO.42.002811, 2003.

Baran, A. J., Havemann, S., and Mackowski, D.: A database of hexagonal column optical properties for wavelengths ranging between 0.2 microns to 30 microns, produced for ANNEX 7. Contract No. 4b/3/02, DEFRA, UK, 2001.

Baran, A. J., Hill, P., Furtado, K., Field, P., and Manners, J.: A Coupled Cloud Physics–Radiation Parameterization of the Bulk Optical Properties of Cirrus and Its Impact on the Met Office Unified Model Global Atmosphere 5.0 Configuration, Journal of Climate, 27, 7725 – 7752, https://doi.org/10.1175/JCLI-D-13-00700.1, 2014.

Baran, A. J., Hill, P., Walters, D., Hardiman, S. C., Furtado, K., Field, P. R., and Manners, J.: The Impact of Two Coupled Cirrus Microphysics–Radiation Parameterizations on the Temperature and Specific Humidity Biases in the Tropical Tropopause Layer in a Climate Model, Journal of Climate, 29, 5299 – 5316, https://doi.org/10.1175/JCLI-D-15-0821.1, 2016.

Bartolome Garcia, I., Spang, R., Ungermann, J., Griessbach, S., Krämer, M., Höpfner, M., and Riese, M.: Observation of cirrus clouds with GLORIA during the WISE campaign: detection methods and cirrus characterization, Atmospheric Measurement Techniques, 14, 3153–3168, https://doi.org/10.5194/amt-14-3153-2021, 2021.

Heymsfield, A. J. and Platt, C. M. R.: A Parameterization of the Particle Size Spectrum of Ice Clouds in Terms of the Ambient Temperature and the Ice Water Content, Journal of Atmospheric Sciences, 41, 846 – 855, https://doi.org/https://doi.org/10.1175/1520-0469(1984)041<0846:APOTPS>2.0.CO;2, 1984.

McFarquhar, G. M. and Heymsfield, A. J.: Parameterization of Tropical Cirrus Ice Crystal Size Distributions and Implications for Radiative Transfer: Results from CEPEX, Journal of the Atmospheric Sciences, 54, 2187 – 2200, https://doi.org/https://doi.org/10.1175/1520-0469(1997)054<2187:POTCIC>2.0.CO;2, 1997.

McFarquhar, G. M., Yang, P., Macke, A., and Baran, A. J.: A New Parameterization of Single Scattering Solar Radiative Properties for Tropical Anvils Using Observed Ice Crystal Size and Shape Distributions, Journal of the Atmospheric Sciences, 59, 2458 – 2478, https://doi.org/10.1175/1520-0469(2002)059<2458:ANPOSS>2.0.CO;2, 2002.

Rodríguez De León, R., Lim, L. L., Lee, D. S., Bennett, M., and Krämer, M.: Simple Versus Complex Physical Representation of the Radiative Forcing From Linear Contrails: A Sensitivity Analysis, Journal of Geophysical Research: Atmospheres, 123, 2831–2840, https://doi.org/https://doi.org/10.1002/2017JD027861, 2018.

Rother, T., Schmidt, K., Wauer, J., Shcherbakov, V., and Gayet, J.-F.: Light scattering on Chebyshev particles of higher order, Appl. Opt., 45, 6030–6037, https://doi.org/10.1364/AO.45.006030, 2006.

Spang, R., Günther, G., Riese, M., Hoffmann, L., Müller, R., and Griessbach, S.: Satellite observations of cirrus clouds in the Northern Hemisphere lowermost stratosphere, Atmospheric Chemistry and Physics, 15, 927–950, https://doi.org/10.5194/acp-15-927-2015, 2015.

Wu, D. L., Jiang, J. H., Read, W. G., Austin, R. T., Davis, C. P., Lambert, A., Stephens, G. L., Vane, D. G., and Waters, J. W.: Validation of the Aura MLS cloud ice water content measurements, Journal of Geophysical Research: Atmospheres, 113, https://doi.org/https://doi.org/10.1029/2007JD008931, 2008.

Yang, E.-S., Cunnold, D. M., Newchurch, M. J., and Salawitch, R. J.: Change in ozone trends at southern high latitudes, Geophys. Res. Lett., 32, L12812, https://doi.org/doi:10.1029/2004GL022296, 2005.

Yang, P., Liou, K. N., Wyser, K., and Mitchell, D.: Parameterization of the scattering and absorption properties of individual ice crystals, Journal of Geophysical Research: Atmospheres, 105, 4699–4718, https://doi.org/https://doi.org/10.1029/1999JD900755, 2000.

Yang, P., Baum, B. A., Heymsfield, A. J., Hu, Y. X., Huang, H.-L., Tsay, S.-C., and Ackerman, S.: Single-scattering properties of droxtals, Journal of Quantitative Spectroscopy and Radiative Transfer, 79-80, 1159–1169, https://doi.org/https://doi.org/10.1016/S0022-4073(02)00347-3, electromagnetic and Light Scattering by Non-Spherical Particles, 2003.

Zhang, Z., Yang, P., Kattawar, G. W., Tsay, S.-C., Baum, B. A., Hu, Y., Heymsfield, A. J., and Reichardt, J.: Geometrical-optics solution to light scattering by droxtal ice crystals, Appl. Opt., 43, 2490–2499, https://doi.org/10.1364/AO.43.002490, 2004.