

# ***Interactive comment on “The MIPAS/Envisat climatology (2002–2012) of polar stratospheric cloud (PSC) volume density profiles” by Michael Höpfner et al.***

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We thank referee # 2 for the very valuable comments and corrections. Our answers are given below. The original referee comment is repeated in **bold**, changes in the manuscript text are printed in *italic*.

## **General comments**

**In this new study, Höpfner et al. introduce a new retrieval scheme for PSC volume densities from the Envisat MIPAS instrument. The scheme is based on a number of simplifying assumptions, e.g., use of NAT refractive indices for all PSC types**

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and neglecting of scattering effects in the radiative transfer calculations. However, the implications of this approximations are thoroughly discussed and seem to be justified. The scheme is used to process retrievals for the entire Envisat mission, and the MIPAS PSC volume density climatology for the years 2002-2012 is presented.

Overall, this is an interesting study and the paper fits in the scope of AMT. The manuscript is mostly well written and concise. I would recommend it for publication in AMT subject to fixing of some minor comments listed below.

### Specific comments

#### **p2, l2-4: Please consider adding a reference for the denitrification process.**

We have added references to Fahey et al. (1990) and to the review article of Solomon (1999).

*Fahey, D. W., Kelly, K. K., Kawa, S. R., Tuck, A. F., Loewenstein, M., Chan, K. R., and Heidt, L. E.: Observations of denitrification and dehydration in the winter polar stratospheres, Nature, 344, 321–324, <https://doi.org/10.1038/344321a0>, 1990.*

*Solomon, S.: Stratospheric ozone depletion: A review of concepts and history, Rev. Geophys., 37, 275–316, <https://doi.org/10.1029/1999RG900008>, 1999.*

#### **p3, l6-7: You are listing the global number of MIPAS vertical scans per day, but how many profiles are measured in the polar regions (which are relevant for PSC observations)?**

We agree that these numbers are also relevant and have appended the text accordingly:

*In regions poleward of 60° latitude about 170 and 240 profiles per day have been obtained during each period, respectively.*

#### **p4, l17-18: Maybe add reference to Rodgers (2000) for retrieval theory?**

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We will add this reference.

*Rodgers, C. D.: Inverse Methods for Atmospheric Sounding: Theory and Practice, Vol. 2 of Series on Atmospheric, Oceanic and Planetary Physics, World Scientific, 2000.*

**p4, I20: I was wondering if you applied a constant Jacobian  $K$  or if you considered variations with the state, i.e.,  $K_i$ ?**

The Jacobians depend on the iteration. Thus, the correct notation should have been  $K_i$ . This will be revised.

**p5, I21: The link to the ECMWF data is pointing to surface data rather than profiles?**

The link has been corrected to <http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=pl/>.

**p5, I27-30: Why did you specifically select top altitudes of 6 and 8 km for the low-level clouds?**

This choice was driven by the wish to introduce scenes in-between the two extreme cases of having scattering with no cloud below (“scat\_nocld” in Fig. 2), which results in the highest limb radiances and no scattering (“noscat”), leading to the lowest limb radiances. To set 8 km as the highest tropospheric cloud was motivated in order keep an altitude separation between tropospheric clouds and PSCs from the in-situ dataset (reaching down to 10 km altitude). The 6 km cloud case was chosen as an intermediate between “cld8” and “nocld” since it often lead to retrieval errors half between those two adjacent cases (see Fig. 2).

**p7, I9: Which trace gases have been considered in the radiative transfer calculations? Where did their concentrations come from?**

The information about the trace gases simulated, has been added in the new version of the manuscript:

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*The following trace gases have been considered within the radiative transfer simulations: H<sub>2</sub>O, CO<sub>2</sub>, O<sub>3</sub>, N<sub>2</sub>O, CH<sub>4</sub>, HNO<sub>3</sub>, C<sub>2</sub>H<sub>6</sub>, CFC-11, CFC-22.*

The information about the source of the concentration altitude profiles is already provided on p. 5, l. 26 of the AMTD version: “Trace gas profiles are obtained from polar winter standard atmospheres (Remedios et al., 2007).”

**p7, l19.23: Why did you not consider using a classification scheme for PSC types (e.g., Spang et al., 2016) instead of selecting the NAT refractive indices for all PSC types? Spang, R., Hoffmann, L., Höpfner, M., Griessbach, S., Müller, R., Pitts, M. C., Orr, A. M. W., and Riese, M.: A multi-wavelength classification method for polar stratospheric cloud types using infrared limb spectra, Atmos. Meas. Tech., 9, 3619-3639, <https://doi.org/10.5194/amt-9-3619-2016>, 2016.**

We have decided not to use a-priori data on composition in the retrieval process but rather to develop a retrieval set-up which is as far as possible robust with respect to composition (and particle size). This has been motivated by the observations that very often PSCs do not consist of a single type (see. e.g. Pitts et al., 2018, Fig. 10, <https://doi.org/10.5194/acp-18-10881-2018>). Especially given the large field-of-view volume a limb-sounder like MIPAS is covering in one observation (3-4 km in the vertical, 30 km horizontal across-track and several 100 km along track), frequently PSC particles of different composition will contribute to the spectral radiances. Further, in the MIPAS composition classification like in Spang et al. (2018) (<https://doi.org/10.5194/acp-18-5089-2018>) there are still ambiguities between e.g. STS and large NAT particles which could increase the uncertainty of a retrieval depending on exact composition information further.

**p9, Fig. 3: The third plot in the upper row seems to show a rather poor retrieval result, considering that it refers to a NAT case?**

In the text (p. 7, l. 28) with regard to this Figure it is explained: “In case of NAT as the predominant composition, the volume densities are generally overestimated, since

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scattering is neglected in the retrieval. It can well be observed that the less scattering contributes from the troposphere, which is the case for a cold tropospheric cloud at 8 km, the better the result fits the reference". This means that in spite of the fact that NAT refractive indices are used, there is still the uncertainty of the particles size leading, through the unknown amount of scattered radiation, to the uncertainties in the retrieved profiles. As this has been shown to be the largest error contribution, we have decided to provide minimum/maximum profiles as the result of our MIPAS retrievals.

**p11, Fig. 4: The caption refers to "PSC volume densities in case of equilibrium".  
What is this?**

Right, an explanation is missing here. Therefore we have changed the Figure caption to:

*The forth column contains the PSC volume densities in case of thermodynamic equilibrium (see text).*

In the main text (p. 13, l. 17), we have added an explanation:

*Retrieved profiles of particle volume densities can be compared to the volume, solid or liquid PSC phases can reach under thermodynamic equilibrium conditions (Hanson and Mauersberger, 1988; Carslaw et al., 1994). We have calculated these profiles using temperatures from ECMWF, standard polar winter concentration profiles of HNO<sub>3</sub> and H<sub>2</sub>O (Remedios et al., 2007) and 0.3 ppbv of H<sub>2</sub>SO<sub>4</sub>.*

*Hanson, D. and Mauersberger, K.: Laboratory studies of the nitric acid trihydrate: Implications for the south polar stratosphere, Geophys. Res. Lett., 15, 855–858, <https://doi.org/10.1029/88GL00209>, 1988.*

*Carslaw, K. S., Luo, B. P., Clegg, S. L., Peter, T., Pringle, P., and Crutzen, P. J.: Stratospheric aerosol growth and HNO<sub>3</sub> gas phase depletion from coupled HNO<sub>3</sub> and water uptake by liquid particles, Geophys. Res. Lett., 21, 2479–2482, <https://doi.org/10.1029/94GL02799>, 1994.*

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Remedios, J. J., Leigh, R. J., Waterfall, A. M., Moore, D. P., Sembhi, H., Parkes, I., Greenhough, J., Chipperfield, M. P., and Hauglustaine, D.: MIPAS reference atmospheres and comparisons to V4.61/V4.62 MIPAS level 2 geophysical data sets, *Atmos. Chem. Phys. Discuss.*, 7, 9973–10 017, <https://doi.org/10.5194/acpd-7-9973-2007>, <https://www.atmos-chem-phys-discuss.net/7/9973/2007/>, 2007.

**p14, Fig. 6: What about the other PSC types, i.e., NAT and ice?**

As we have mentioned in the manuscript (p. 10, l. 10): "... (Pitts et al., 2018). Their estimated uncertainties of volume density derived in case of STS PSCs are in the range of 0.05–1.0  $\mu\text{m}^3/\text{cm}^3$ . For NAT mixtures and ice PSCs, the CALIOP volume density values are mostly lower limits and can be underestimated by factors of 10 and up to 30 for NAT and ice PSCs, respectively". Thus, unlike for STS, we do not think that systematic comparisons between CALIPSO and MIPAS retrievals in case of NAT and ICE PSCs are of any help to assess the accuracy of our MIPAS dataset. Nonetheless, in Figures 4 and 5 we have plotted single comparisons also for NAT and ICE which already show the difficulties in comparing those observations.

**p15, l14-19: Are cirrus clouds really a likely explanation for the enhanced background values in the polar regions? I would not expect to see cirrus clouds up to 15 km of altitude in the polar winter hemisphere.**

Due to the limited vertical resolution of MIPAS we cannot exclude that cirrus clouds (which have a much larger optical thickness in limb direction than PSCs) at 12-13 km altitude may influence the retrievals up to 15 km. To make this point clearer, we have slightly modified the text:

*... by the influence of tropospheric cirrus, which e.g. at 12-13 km reach the lower edge of the vertical field-of-view of MIPAS pointing at 14-15 km tangent height.*

**p15, l24-26: I was wondering how limited the computer resources really are? How many CPU hours were needed to process the entire mission?**

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Considering this comment, we have come to the conclusion that the related text passage "... to develop a retrieval approach applicable within limited computer resources" is not entirely convincing given the large variability of computer capacities at different institutions. We have therefore decided to skip this part.

**p16, I9-10: The new PSC data did not seem to be available at the given web site when I checked the link?**

The data is available now.

### Technical corrections

**p8, Fig. 2: x-axis labels have been cropped/clipped.**

Corrected.

**p13, I15: fix "shows values of than about"**

Corrected.

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