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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Influence of mountain waves and NAT nucleation mechanisms on Polar Stratospheric Cloud formation at local and synoptic scales during the 1999–2000 Arctic winter" *by* S. H. Svendsen et al.

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Reply to Interactive comments on "Influence of mountain waves and NAT nucleation mechanisms on Polar Stratospheric Cloud formation at local and synoptic scales during the 1999-2000 Arctic winter" by S.H. Svendsen et al.

We thank the anonymous referees for reviewing the manuscript. Below we address the issues raised in the reviews.

General Comments.

We agree with the referees' comments that due to lack of comparisons with observations, it is difficult to conclude whether or not the amount of solid particles produced

in the different hemispheric scenarios (with or without mountain wave effects and with or without NAT nucleation at temperatures above the ice frost point, T-ice) is realistic. However, we do believe that the findings in the initial part of the paper provide the necessary motivation for proceeding with the hemispheric study carried out in the second part of the paper. Since local-scale comparisons indicate that mountain waves alone cannot account for the presence of solid particles in local lidar observations, and that the inclusion of mountain wave effects, as well as an additional NAT nucleation mechanism which is active above T-ice seem to produce the best agreement with observations, it is of interest to establish to what extent these additional effects influence the production of solid PSC particles on a hemispheric scale. The substantial influence of these effects which is demonstrated in this paper may serve as motivation for proceeding with a comparison between hemispheric model data and observational data, e.g. from satellites. Such a comparison is planned for a future paper.

Specific Comments.

The Abstract

We agree with the referees that conclusions were not stated clearly enough and the abstract section has been expanded in order to accommodate this. The following paragraphs have been included in the abstract:

'Mountain waves are seen to have a pronounced effect on the amount of ice particles formed in the simulations. Quantitative comparisons of the amount of solids seen in the observations and the amount of solids produced in the simulations show the best correspondence when NAT formation is allowed to take place at temperatures above T-ice.'

'It is seen that regardless of the choice of microphysics, ice particles only form as a consequence of mountain waves whereas NAT particles form readily as a consequence of the synoptic conditions alone if NAT nucleation above T-ice is included in the simulations. Regardless of the choice of microphysics, the inclusion of mountain waves

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increases the amount of NAT particles by as much as 10%. For a given temperature scenario the choice of NAT nucleation mechanism may alter the amount of NAT substantially; three-fold increases are easily found when switching from the scenario which requires pre-existing ice particles in order for NAT to form to the scenario where NAT forms independently of ice.'

Nucleation rate used for NAT production above the ice frost point.

We are aware of the criticism and debate regarding the homogeneous surface nucleation rate suggested by Tabazadeh et al. (2002), see. e.g. Knopf et al. (2002}, and this is now mentioned in the revised manuscript. However, we feel that a number of current studies have indicated the need for NAT nucleation mechanisms active above the ice frost point in order to explain observations (Pagan et al. 2004, Drdla et al 2003, Irie et al. 2004, Larsen et al 2004). (The work presented in Irie et al. (2004) was not published at the time our manuscript was submitted, but has been added here for completeness). To our knowledge, the nucleation mechanism suggested in Tabazadeh et al. (2002) is the latest published available parameterisation of homogeneous hydrate nucleation out of STS, active at temperatures above the ice frost point. As already mentioned, this particular nucleation mechanism is currently debated, but we find its use, applying a correction as described in Larsen et al. (2004), justified in a study which is designed to investigate the effect of possible NAT nucleation at temperatures above the ice frost point. Our study is not designed to evaluate the validity of any given NAT nucleation mechanism (including heterogeneous nucleation); much more detailed laboratory investigations are needed to perform such an evaluation in a rigorous way. Instead, the idea is to examine the possible effects of NAT nucleation at temperatures above the ice frost point. In order to emphasize the uncertainties and debate regarding the choice of NAT nucleation, the following sentence has been included in the text:

'The proposed nucleation mechanism is currently debated, see e.g. Knopf et al. (2002), but it is, to our knowledge, the latest published parameterisation of homogeneous NAT nucleating out of STS at temperatures above T-ice and may as such be seen as a

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useful representative of scenarios allowing for NAT nucleation at temperatures above T-ice.'

It is suggested by the referees to test an additional NAT nucleation mechanism such as the volume-average NAT production rate given by Carslaw et al. (2002) which has been shown to produce number densities of NAT particles which compares well with observations. However, the NAT production rate used in Carslaw et al. (2002) is given as a production rate per cubic centimeter of air (s-1 cm-3 air) which is not easily compatible with the structure of the microphysical model used for this study, where particle size dependent nucleation rates are needed as production rates per volume unit of aerosol (s-1 cm-3 STS). A direct implementation of the suggested nucleation rate is therefore not possible without substantial changes to the model. In Mann et al. (2002) the volume-average NAT production rate of Carslaw et al. (2002) is stated to be 3.7x10-9 s-1 cm-3(air).

The restricted version of the NAT nucleation of Tabazadeh et al. (2002) used in this study is based on comparisons with observations as described in Larsen et al. (2004). Observations indicated a required hydrate particle production rate of 7x10-9 s-1 cm-3(air) which was then used to constrain the NAT nucleation rate. This value is within the same order of magnitude as the value given in Mann et al. (2002), and we should therefore not expect substantial deviations in NAT production using the two different approaches.

The Introduction.

We acknowledge the referees' criticism and have expanded the introduction and added references to current work in the field.

Comparison of model simulations with lidar measurements.

Maps of the two DC-8 flights, which have been analysed, have been added to the manuscript. The areas where no depolarisation data are present in the DC-8 mea-

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surements are omitted from the plots of the model data in order to improve clarity.

When calculating optical properties of aerosols a number of assumptions regarding the nature of the aerosol are made such as the value of the refractive indices and the shape of the different particle types. The choice of these parameters greatly influences the resulting optical properties, and it is our belief that the ensuing arbitrariness of the optical variables only justifies rough qualitative comparisons between measured and modelled optical variables and that good, quantitative, correspondence cannot be expected. These limitations of the calculated optical properties are emphasized in the section describing the microphysical model.

In addition to the uncertainties introduced by the choice of optical parameter values it is important to keep in mind that the inclusion of mountain wave effects is still rather rough, since the mountain wave fields are averaged on a 1x1 deg. grid. The uncertainties in the calculations (due to arbitrariness of optical parameters and the roughness of the temperature correction fields) point in favour of purely qualitative or statistical comparisons of the observations and the model results instead of a point by point comparison.

In order to emphasize the nature and limitation of the model-observation comparison, the plots comparing the observations and the modelled data have been changed to show particle types instead of calculated and measured values of the optical variables. The type classification is performed in accordance with the different classification schemes for observational and modelled data as described in the paper. The corresponding section of text has been changed. In accordance with the referees' recommendations a more detailed description of areas showing agreement and disagreement between model data and observations is given. Two additional figures are included showing comparisons of the model results in two different microphysical scenarios and a new section of text has been added describing these figures.

The 'banding' of modelled PSC types corresponds to the finite number of isentropic

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levels of the calculated airparcel trajectories. Examples of microphysical simulations along individual trajectories are considered out of scope of this paper, but examples of such simulations using the model are given by Larsen et al. (2004).

Lidar Classification.

A table displaying the lidar classification threshold values has been included in the text for clarity. The criteria used for the PSC typing from the lidar measurements are based on the values given in Table 1 of Browell et al. (1990). The lower limit for determining whether there was a PSC present or not was the scattering ratio had to be $>$ 0.18. This value was selected to be slightly above the background sulphate level. Once a PSC was present, it was determined if the depolarization was greater than or less than 2.5%. If it was less than 2.5%, it was automatically considered to be a type 1b PSC (2.5% was upper limit for type 1b PSC's discussed in above reference). If it was greater than 2.5%, it could either be a type 1a if the scattering ratio was less than 5 (actual type 1a values are typically $<$2, see above reference), or a type 2 if the scattering ratio was greater than 5 (typical type 2 values are $>$10, see above reference). Hence, the threshold criteria are consistent with the results in Browell et al., (1990).

Conclusions.

As suggested, a separate discussion section has been added prior to the conclusions.

Minor Comments.

As suggested, individual labels have been assigned to the different plots in the (revised) figures.

The spelling errors have been corrected.

Labels have been added to the different plots in figures 10 and 11 and references to them are included in the text.

References.

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Browell, E.V., C.F. Butler, S. Ismail, P.A. Robinette, A.F. Carter, N.S. Higdon, O.B. Toon, M.R. Schoeberl and A.F. Tuck, Airborne Lidar Observations in the Wintertime Arctic Stratosphere: Polar Stratospheric Clouds, Geophys. Res. Lett. 17, 385-388, 1990.

K. S. Carslaw, J.M. Kettleborough, M. Northway, S. Cavies, R.-S. Gao, D.W. Fahey, D.G. Baumgardner, M.P. Chipperfield, and A. Kleinböhl, A vortex-scale simulation of the growth and sedimentation of large nitric acid hydrate particles, J. Geophys. Res., 107(D20), 10.1029/2001JD000467, 2002.

K. Drdla, M.R. Schoeberl, and E.V. Browell, Microphysical modelling of the 1999-2000 Arctic winter: 1. Polar stratospheric clouds, denitrification, and dehydration, J. Geophys. Res., 107(D20), 8312,10.1029/2001JD000782, 2002, Printed 108(D5), 2003.

H. Irie, K.L. Pagan, A. Tabazadeh, M.J. Legg, and T. Sugita, Investigation of polar stratospheric cloud solid particle formation mechanisms using ILAS and AVHRR observations in the Arctic. Geophys. Res. Lett. 31(15), L15107, 10.1029/2004GL020246, 2004.

D.A. Knopf, T. Koop, B.P. Luo, U.G. Weers, and T. Peter, Homogeneous nucleation of NAD and NAT in liquid stratospheric aerosols: Insufficient to explain denitrification, Atmos. Chem. and Phys., 2, 207-214, 2002.

N. Larsen, B.M. Knudsen, S.H. Svendsen, T. Deshler, J.M. Rosen, R. Kivi, C. Weisser, J. Schreiner, K. Mauersberger, F. Cairo, J. Ovarlez, H. Oelhaf, and R. Spang, Formation of solid particles in synoptic-scale {A}rctic {PSC}s in early winter 2002/2003, Atmos. Chem. and Phys., 4, 1-13, 2004.

G.W. Mann, S. Davies, K.S. Carslaw, M.P. Chipperfield, and J.Kettleborough, Polar vortex concentricity as a controlling factor in Arctic denitrification, J. Geophys. Res., 107(D22), 4663, 10.1029/2002JD002102, 2002.

K.L. Pagan, A. Tabazadeh, K. Drdla, M.E. Hervig, S.D. Eckermann, E.V. Browell, M.J. Legg, and P.G. Foschi, Observational evidence against mountain-wave generation of

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ice nuclei as a prerequisite for the formation of three solid nitric acid polar stratospheric clouds observed in the arctic in early december 1999, J. Geophys. Res., 109(D4), D04312, 10.1029/2003JD003846, 2004.

A. Tabazadeh, Y.S. Djikaev, P. Hamill, and H. Reiss, Laboratory evidence for surface nucleation of solid polar stratospheric cloud particles, J. Phys. Chem. A, 106,10238-10246, 2002.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 4581, 2004.