Reply to anonymous Referee#3

We thank the reviewer for the helpful comments and suggestions on the manuscript. Please find below our detailed replies and the changes to the manuscript.

General Comments:

Bayes' theorem with strong (naive) independence assumptions: More background information on this basic concept is appreciated. Are there any references?

Reply: We present now more background and references on the method. The paragraph is modified as follows:

Methods for the combination of multiple classification schemes like in the sections above, sometimes entitled in the literature the term multiple discriminant analyse are described for example in Wilks (2005, Chapter 13.3, with Chapter 13.3.3 on the Bayesian approach). Bayesian methods have been applied in recent and former studies on cloud properties, mainly for algorithms on cloud detection for nadir sounders (Hollstein et al., 2015 and references therein). Here, we apply the method to combine the information content of the individual classification methods (classifier) into a single estimate of the most probable PSC type dominating the measured IR spectrum, in the following referred to as Bayesian classifier (BC).

Specific comments:

P3L28: VFOV base width of 4 km and top width of ~2.8 km: What is the meaning of these parameters? Does base/top refer to tangent height?

These parameter refer to the sensitivity function defining the FOV, which is approximated by a vertical trapeze. We changed the sentence to:

The vertical field of view (FOV) of MIPAS can be described by a trapezoid-like sensitivity function with a base width of 4 km and a top width of ~2.8 km around the tangent point.

P5L11: How was the optimized list created?

Part of the MIPclouds study (Spang et al., 2008, 2012) was the selection of the spectral windows. The selection has been performed by calculating broadband Jacobians with respect to aerosol extinction at tangent levels with and without trace gas contribution. The quotient of these Jacobians is in first order equal to the gas-transmission spectra at tangent altitude. The rational of these simulations was to exclude regions of the spectrum with strong interference of trace gases and of already opaque intervals. A transmission limit of 0.9 has been defined to select the wavelength regions (Spang et al., 2008). A corresponding explanation is now included in the manuscript under Sec. 2.3, 2nd paragraph:

The selection of the spectral windows have been performed by calculating broadband Jacobians with respect aerosol extinction at tangent levels with and without trace gas contribution. The quotient of these Jacobians is to first order equal to the gas-transmission spectra at tangent altitude. The rational of these simulations was to exclude regions of the spectrum with strong interference of trace gases and of already opaque intervals (Spang et al., 2008). In addition, wavelength regions used in former studies (Spang et al., 2003, 2004, 2005a/b, Höpfner et al., 2006a/b) were taken into account.

P6L7: single scattering properties of spherical particles: Is the effect of non-spherical particles (e.g. ice) negligible in this spectral range?

This is an important aspect, which we didn't considered in the manuscript, but is investigated in former and parallel studies. A similar point with respect to NAT was raised by reviewer#2. Therefore we included the following paragraph in Sec. 2.2:

T-Matrix calculations with realistic bulk properties for cirrus clouds show that the scattering properties in the size range of PSC ice particles (effective radius < 10 μm) can be well approximated by Mie calculations and the influence of non-spherical particle shapes is negligible (Baran et al., 2003, Young et al., 2005). For NAT clouds Woiwode et al. (2014) found in balloon based IR measurements indications that aspherical particles might modify the spectral shape of the characteristic spectral NAT feature at 820 cm^{-1} (Fig. 1). This very recent finding has been investigated in more detail in a parallel study (Woiwode et al., 2016) and is not considered below.

Table 1: Cloud minimum bottom height=12: Is this the general lower boundary of all clouds simulated? AND: Why is the PSC cloud top height restricted to 21.5km?

Sorry, this was misleading and the table included a typo. The table is now corrected and improved. Cloud top heights were running from 28.5 down to 12.5 with 1 km spacing. The cloud thickness / vertical extent is variable (0.5, 1, 2, 4, 8 km), and only the lower bound (cloud bottom height) was restricted to 12 km. Consequently, for a CTH at 12.5 km only a single cloud thickness of 0.5 km with cloud bottom height of 12 km is part of the database.

P6L15: various cloudy path lengths: The clouds has to be modelled as layers. How can the path lengths be varied? Is the model able to simulate PSC/clouds with a vertical extent below the instrumental VFOV?

The model can only model cloud layers filling the tangent height layers homogeneously. However, by modelling tangent heights below the cloud bottom height, smaller cloud paths are inherently part of the database. We describ the variable path length now in more detail:

These geometries results in variable lengths of cloud segments along the line of sight. For example, a homogeneous cloud layer of 2 km thickness creates a maximum cloud path of 320 km exactly for a tangent height at the cloud bottom. But due to the spherical shape of the cloud layer the line of sight of tangent heights below the cloud bottom is crossing twice the cloud layer above. For example 3 km below the cloud bottom of a 2 km thick cloud layer the effective cloud path shrinks to 2 x 57 km = 114 km, for a cloud layer of only 0.5 km thickness a cloud path of ~31 km remains.

Fig.1: The 3 cloud type spectra differ in time and latitude, but also in tangent height? Does this have an effect on the radiance? While NAT has a clear nose at 820, ICE and STS look rather similar.

Main effects for the radiances in the atmospheric window regions is expected by changes in temperature. This will result in an offset at all wavenumbers, but should not affect the spectral gradients. The superimposed Planck curves are highlighting the slightly different spectral gradients between ice and STS in the window regions (e.g., 830 to 960 cm^{-1} and 1225 to 1410 cm^{-1}). These relatively small differences are better analysed with brightness temperature differences and are used in the scatter and PDF diagrams presented later for the classification approach.

Fig.3: What is the cloud height range for the PDFs?

This is now homogenized for all MIPAS PDF plots and mentioned in each Figure caption (16-30 km).

New additional References:

Baran, A.J.: On the scattering and absorption properties of cirrus cloud, Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 89, Issues 1-4, 17-36, doi:10.1016/j.jqsrt.2004.05.008, 2004.

CALIPSO Science Team: CALIPSO/CALIOP Level 2, Polar Stratospheric Cloud Data, version 1.00, Hampton, VA, USA: NASA Atmospheric Science Data Center (ASDC), accessed in July 2015, doi:10.5067/CALIOP/CALIPSO/ CAL_LID_L2_PSCMask-Prov-V1-00_L2-001.00, at https://eosweb.larc.nasa.gov/project/calipso/cal_lid_l2_pscmask-prov-v1-00_table, 2015.

Griessbach, S., Hoffmann, L., Spang, R., and Riese, M.: Volcanic ash detection with infrared limb sounding: MIPAS observations and radiative transfer simulations, Atmos. Meas. Tech., 7, 1487-1507, doi:10.5194/amt-7-1487-2014, 2014.

Hollstein, A., Fischer, J., Carbajal Henken, C., and Preusker, R.: Bayesian cloud detection for MERIS, AATSR, and their combination, Atmos. Meas. Tech., 8, 1757-1771, doi:10.5194/amt-8-1757-2015, 2015.

SPARC, Stratosphere-troposphere Processes And their Role in Climate: Polar Stratospheric Cloud Activity, http://www.sparc-climate.org/activities/polar-stratospheric-clouds/, latest access Feb 21st, 2016.

Strawa, A. W., Drdla, K., Fromm, M., Pueschel, R. F. Hoppel, K. W., Browell, E. V., Hamill, P., and Dempsey, D. P.: Discriminating Types Ia and Ib polar stratospheric clouds in POAM satellite data, J. Geophys. Res., 107(D20), 8291, doi:10.1029/2001JD000458, 2002.

Woiwode, W., Grooß, J.-U., Oelhaf, H., Molleker, S., Borrmann, S., Ebersoldt, A., Frey, W., Gulde, T., Khaykin, S., Maucher, G., Piesch, C., and Orphal, J.: Denitrification by large NAT particles: the impact of reduced settling velocities and hints on particle characteristics, Atmos. Chem. Phys., 14, 11525-11544, doi:10.5194/acp-14-11525-2014, 2014.

Woiwode, W., Höpfner, M., Bi, L., Pitts, M. C., Poole, L. R., Oelhaf, H., Molleker, S., Borrmann, S., Klingebiel, M., Belyaev, G., Ebersoldt, A., Griessbach, S., Grooß, J.-U., Gulde, T., Krämer, M., Maucher, G., Piesch, C., Rolf, C., Sartorius, C., Spang, R., and Orphal, J.: Spectroscopic evidence for large aspherical β-NAT particles involved in denitrification in the December 2011 Arctic stratosphere, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-146, in review, 2016.

Wilks, D. S.: Statistical methods in the atmospheric sciences, Academic Press, International Geophysics Series Vol.100, 2nd edition, 2005.

Yang, P., Wei, H., Huang, H.-L. Baum, B. A., Hu, Y. X., Kattawar, G.W., Mishchenko, M. I., and Fu, Q.: Scattering and absorption property database for nonspherical ice particles in the near- through far-infrared spectral region, Appl. Opt. **44**, 5512-5523. 2005.

Zasetsky, A. Y., Gilbert, K., Galkina, I., McLeod, S., and Sloan, J. J.: Properties of polar stratospheric clouds obtained by combined ACE-FTS and ACE-Imager extinction measurements, Atmos. Chem. Phys. Discuss., 7, 13271-13290, doi:10.5194/acpd-7-13271-2007, 2007.