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Atmospheric
Chemistry
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Discussions

Interactive comment on “Airborne observations of a subvisible midlevel Arctic ice cloud: microphysical and radiative characterization” *by* A. Lampert et al.

A. Lampert et al.

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1 Introduction

We would like to thank the reviewer for the valuable comments that helped to improve our manuscript. We re-structured the discussion section and added further details about the microphysical data retrieval. The detailed replies to the reviewer’s comments are given below.

2 Comment 1

Abstract : to be modified to introduce the microphysical representation and new information.

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We changed the part about the microphysical measurements to From individual ice crystal samples detected with the Cloud Particle Imager and the ensemble of particles measured with the Polar Nephelometer, we retrieved microphysical properties with a bimodal inversion algorithm. The best agreement with the measurements was obtained for small ice spheres and deeply rough hexagonal columns. We further determined the single-scattering albedo, the scattering phase function as well as the volume extinction coefficient and the effective diameter of the crystal population.

3 Comment 2

p600 : the temperature of mid-level cloud is not very cold. In a stable environment, it may be possible to find areas with super-cooled water droplets and others with ice crystals. Could this hypothesis (and its impact) be examined ?

The asymmetry factor (g) which is derived from the Polar Nephelometer instrument is a very sensitive parameter in order to distinguish water droplets from ice particles. Generally g is larger than 0.8 for water droplets and lower for ice particles. During the flight sequence into the thin Arctic cloud the asymmetry parameter was 0.77 on the average without any indication (even on short distance, see Fig. 7) of water droplets. For lidar measurements, areas smaller than the horizontal resolution (930 m) consisting of supercooled liquid water droplets decrease the depolarization values, which was not observed (Fig.5). Hence this particular cloud predominantly consisted of the ice phase.

4 Comment 3

p 602, section 3.1, p602 in general : this section should introduce more explicitly the possibility of a direct determination of optical depths and lidar ratios from the signal attenuation as further discussed in section 4.2.

We added in Sect. 3.1 the following sentence with a reference to the discussion in Sect. 4.3 (see new structure proposed at Comment 12):

However, for calculating the extinction coefficient, the assumption of the lidar ratio is

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crucial (cf. discussion in Sect. 4.3). Assuming a lidar ratio of 21 sr, the extinction coefficient in the cloud varied between 0.006 and 0.1 (+/- 0.003) km-1.

5 Comment 4

p602, line 3 :after 12:00 UTC a cirrus: the cirrus cloud is indeed observed in Fig. 9 after 12:02. It is not shown in figure 5a, which should present the overview. Vertical scale in Fig 5a should thus be extended up to 7 km.

We would like to leave the vertical scale of Fig. 5a unchanged, as it is easier to compare the cloud in Fig. 5a and b with the same vertical scale. The signal to noise ratio of the depolarization signal is too low for a height above 4 km, so it is not possible to change the scales for both subfigures. Additionally, the meteorological data are clearer in the zoom representing only the cloud. We added a remark in the caption pointing out that the cirrus at 6 km is shown later in Fig. 9.

6 Comment 5

p 602 : describe Fig 5b. Give limits observed for depolarization ratio. Large values with an extension in vertical bands are artifacts.

We added to the caption the information about artefacts. In the text about the depolarization, we included another sentence:

To obtain information about the particle shape and cloud phase, we analyzed the volume depolarization (Fig. 5b). Below the cloud, the depolarization signal had low values around 1.4 %, typical for air molecules (free troposphere with low aerosol load). The signal showed significantly enhanced values allover the cloud with values up to 40 %. This clearly indicates the existence of non-spherical ice crystals in the observed subvisible midlevel ice cloud (You et al., 2006).

7 Comment 6

p603, line 3 : presentation of LR value comes too early, as it is discussed in the following paragraph. Values given here should be referred to as a preliminary first guess. Indeed references are corresponding to mid-latitude observations. Although the temperature is similar, formation processes may be different and it would be worth finding additional references and discuss this point.

We did not find much information about typical lidar ratios for Arctic cirrus clouds in the literature. For the Raman lidar system operated in Ny-Ålesund, Svalbard, a lidar ratio of 20 was determined for cirrus clouds (Ritter, personal communication). We changed the text to:

The lidar ratio is set to 21 sr as a preliminary first guess, which is a typical value for ice clouds (Ansmann et al., 1992, Giannakaki et al., 2007).

8 Comment 7

p603, line 24 : multiple scattering can be excluded but not diffraction. This leads to apparent smaller optical depth and lidar ratio (Nicolas et al, Lidar effective multiple scattering coefficients in cirrus clouds, Appl. Opt., Vol. 36 Issue 15, pp.3458-3468, 1997), when determined directly from lidar observations (as in section 4).

We propose to add this comment on p. 613, l. 2:

From Eq. (6), the extinction in the cloud (between z_b and z_t) can be determined. According to Nicolas et al. (1997), this value constitutes an upper limit, as diffraction leads to enhanced effective optical depths. The inspection of the lidar signal led to the estimation that multiple scattering did not decrease the LR by more than 2 sr, which is included in our error bars.

9 Comment 8

p606, line 25 : this discussion on the extinction measured by the nephelometer and determined from lidar should be placed in the discussion section 4. errors due to the contribution of small particles not detected by the PN need more discussion as small particles are essential to the analysis.

We placed the discussion of the extinction measured by lidar and in situ in Sect. 4. It is written in the text that the polar nephelometer (PN) measures the scattering phase function of an ensemble of cloud particles from a few (around 3) micrometers to 800 μm. So small ice crystals can be detected by the PN, at least those contributing to the extinction. We do not have additional information on the small spheres from the CPI or FSSP, as the measured concentration was too low. We added information about the errors in the text:

The average errors of the measurements of the angular scattering coefficients lie between 3% to 5% for scattering angles ranging from 15° to 155° (with a maximum error of 20% at 155°) (Shcherbakov et al., 2006). The uncertainties of the derived extinction coefficient and asymmetry parameter from PN measurement are estimated to be in the order of 25% and 5% respectively (Gayet et al., 2002).

10 Comment 9

p608, line 26 "in agreement" to be rephrased as no evidence has been provided of the detection of small ice spheres except a better fitting of PN data at large scattering angles. Needs more evidence.

We propose to use the phrase "which allows to reproduce": In conclusion, a microphysical model composed of small spherical ice particles and larger deeply rough hexagonal column crystals leads to optical and, to a certain extent, microphysical properties (asymmetry parameter, extinction and ASC), which allows to reproduce the measurements.

11 Comment 10

p608, line 29, same remark on lidar ratio as before

We placed the retrieval of the lidar ratio from in situ measurements and the discussion in Sect. 4.3. (see answer to Comment 12 for new structure)

12 Comment 11

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p609, section 3.3 Multiple wavelength spectrometers have been flown, and radiances are used as a closure for comparison to radiative transfer calculations using lidar optical depth. Can near infrared measurements be used to check cloud phase ?

Downwelling spectral radiance was measured in the VIS part only. Therefore, no information on ice or liquid water absorption is available from these measurements. The downwelling spectral irradiance was covered at wavelengths including ice and liquid water absorption features (350-2100 nm). However, the irradiance is less affected by the thin cloud integration over the radiation field of the upper hemisphere. Thus, no evidence of the subvisible cloud was found in these data.

13 Comment 12

p607-613, Section 3 and 4 : in general separate more clearly instrument and data presentation in section 3 from the analysis (section 4). A specific section on the microphysical model adjustment would be worth adding in section 4. Discuss in this sub-section depolarization as a function of particle mixture.

We changed the structure of Sect. 4 and moved comparison and discussion of the different data to this Section. Now the subsections are as follows:

4.1 Microphysical properties

4.2 Simulation of measured radiation

4.3 Lidar ratio

4.4 Cloud radiative forcing

Changing the inversion code to derive depolarization values from the PN data would be very time-consuming and is far beyond the scope of this paper. In Subsection 4.1 we included the sentences

The low asymmetry parameter (˜ 0.78) of the PN measurements is consistent with the enhanced depolarization measurements of up to 40 % and the CPI images indicating non-spherical ice crystals. It is not possible to distinguish the particle shape from the values of lidar depolarization measurements, not even for clouds composed entirely of one kind of ice particle habits, as was evidenced by Monte Carlo simulations of You et al. (2006).

14 Comment 13

p609, section 4 : this section would be more adequately present and discuss microphysical parameters from in situ measurements first, then the optical depth retrieval from lidar, and finally from radiative transfer and radiometry. We took this point into account (see answer to Comment 12).

15 Comment 14

P613, line 5: the LR value of 15 given here is an apparent (or effective) value. This needs more discussion. What horizontal resolution can be used to retrieve LR accurately enough ? Due to SNR it should be possible to get a few samples in the cloud. It should be also possible to determine related optical depths, so to infer OD variation and compare to radiometry results (Figs 9 and 11) and to better achieve closure.

We added in the discussion of the lidar ratio the following sentence:

We retrieved 6 single values and their error bars for the LR with a horizontal resolution of 930 m between 11:54 and 12:00 UTC. The mean effective value for the cloud was found to be 15 (+/- 10) sr. We included a new figure showing the cloud optical depth determined from radiometric measurements and from lidar measurements with different lidar ratios (15, 21 and 27 sr).

16 Comment 15

P 628, fig 5 : what is the unit on both figures ? We added the units of the backscatter coefficient (m-1 sr-1) and volume depolarization (%) in the caption.

17 Comment 16

p633, Fig. 10 : What is the relative difference between measured and simulated radiances (outside absorption lines) and why ?

The ratio between simulated and measured downwelling radiance (Figure 11) and the following paragraph were included in the revised manuscript:

The ratio between simulated and measured downwelling radiance ranges between +/- 10 % for most wavelengths (Fig. 10, lower part). As the simulations were fitted by varying the cloud optical depth, the best agreement was found at 532 nm wavelength. The deviations at other wavelengths result from a) uncertainties of the spectrometer and b) the aerosol optical depth assumed for the radiative transfer simulations. The aerosol optical depth applied to the simulations was scaled by the Ångstrom formula with an Ångstrom exponent of alpha =1.51 and an aerosol optical thickness at 1μm wavelength of alpha = 0.03. Both coefficients were obtained from sun photometer measurements at Ny-Ålesund on 7 April 2007 using a SP1A sun photometer (Herber et al., 2002). As the airborne measurements were conducted about 370 km away from Ny-Ålesund, a different aerosol optical thickness may have been present in the vicinity of the subvisible cloud. However, as Figure 10 shows, the ratio between measurements and simulations is similar for the cloud free and cloudy case. This implies that variations in the SMART-Albedometer data (cloud free, cloudy) result only from changes of the cloud properties and not from aerosol properties. The scattering properties of cloud particles in the visible wavelength range are almost independent of the wavelength, whereas aerosol scattering decreases exponentially with a power law with increasing wavelength in this wavelength range.

18 Comment 17

Lines 22 and 23 in the conclusion p 614 : the sentence "the cloud optical depth is accurate for a lidar ratio of 21sr " is presently not a conclusion.

We removed this sentence.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 595, 2009.

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