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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "On retrieval of lidar extinction profiles using Two-Stream and Raman techniques" *by* I. S. Stachlewska and C. Ritter

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We would like to thank the Anonymous Referee # 1 for his fast reply and interesting comments. In the following we give explanations to the issues raised.

General comments:

Referee: Two stream method proposed in this manuscript is very interesting and useful technique which can be applied to airborne or satellite together with ground base measurements. It allowed find large variability of the lidar ratio with altitude during 15 and 19 of May 2004. During this days the two stream and the Raman methods show reasonable agreement however unexpected behavior. The extinction and backscatter coefficients are independent which can be only explain by a large variability of aerosol size and chemical composition with altitude.

Referee: Page 20237, line 7: What value of aerosol Angstrom exponent was assumed in the Raman retrievals to related the extinction coefficient at 532 and 607 nm?

Authors: Herber et al., 2002 derived the Angstrom exponent from the photometer measurements, taking into account a broad variation depending on season and condition (e.g. occurrence of Arctic Haze, background aerosol, etc.), over almost a decade at the observational site at Ny Alesund, were the KARL's Raman measurements were taken. They reported a value of the Angstrom exponent of -1 on average for May. As the subvisible cirrus (larger particles - exponent closer to zero) are frequently detected in the lidar profiles at high altitudes at this site, we chose the Angstrom exponent of a slightly lower value of -1.2 for all Raman retrievals in the low troposphere discussed in this paper.

Herber, A., L. W. Thomason, H. Gernandt, U. Leiterer, D. Nagel, K.-H. Schulz, J. Kaptur, T. Albrecht, and J. Notholt, Continuous day and night aerosol optical depth observations in the Arctic between 1991 and 1999, J. Geophys. Res., 107(D10), 4097, doi:10.1029/2001JD000536, 2002.

Referee: How this assumption is influence the strong altitude variability of the lidar ratio (Fig. 1, 2)?

Authors: private communication with Maria Stock* revealed, that when a proper cloud screening is performed, the Angstrom exponent over Ny Alesund in May is between -1.5 and -1. If the Angstrom exponent was -1.5 the particle extinction retrieved at 532nm were 1.8% higher of the values that we obtained with the assumption of the Angstrom exponent of -1.2 and if the Angstrom exponent was -1 the particle extinction retrieved at 532nm were 1.2% lower. Hence, we consider the error due to the assumption of the constant Angstrom exponent (overall in troposphere) small and we reckon that this assumption does not influence significantly the altitude variability of the lidar ratio.

Stock, M. – private comm. on 10.11. 2009, Alfred-Wegener-Institute, Potsdam Unit; PhD thesis to be submitted by the end of 2009.

Referee: The large variability of the lidar ratio is caused by the variation of single scattering albedo or (and) backscatter phase function. However, the single scattering albedo is usually varied in smaller range (typically 0.9-1.0) in compare to scattering phase function. Therefore the last quantity is probably responsible for large lidar ratio variation with altitude. The scattering phase function is a function of aerosol size distribution and refractive index. Therefore variation of the lidar ratio corresponds to aerosol size variation with altitude. Assuming the constant Angstrom exponent in the Raman retrieval can significant influence these results.

Authors: We agree with the Referee. It is very probable, that the value of the single scattering albedo was close to unity, as we do not have any hints of an existence of a significant soot contamination nor a forest fire aerosol based on the backward trajectories calculated with the HYSPLIT and the FLEXPART models for 15 May and 19 May 2004. We agree that when the size and the shape of the scatterers vary with altitude then a large variation of the phase function are expected. Hence, one may argue, that indeed values of the Angstrom exponent derived from the photometer observations are not adequate and underestimate errors in the range close to the inversion layer. To clarify upon this and two previous issues we included in the manuscript: ‘For the particle extinction retrieval with the Raman method the Angstrom exponent must be predefined. In our case the Angstrom exponent of -1.2 assumed for the Raman profile obtained from the 532nm/607nm signals results is the error of the retrieved particle extinction of less than 2%. However, this error might be larger in the ranges directly below and in an inversion layer where the size, the shape and possibly even the chemical composition of the scattering particles may drastically change with altitude. The Two-stream approach is free of this error source as it utilizes directly two elastic signals, in our case the 532nm signals of each lidar, and therefore the Two-stream extinction profile is retrieved independently of the choice of the Angstrom exponent.‘

Referee: Page 20235 , Eq .5 Could you comment why you used correlation coefficient in this form instead of correlation coefficient based on the extinction coefficient.

Authors: The extinction coefficient is derived with the Two-stream approach, so its values are only known after the end of the calculation. Ritter et al. 2006 shown that unphysical large oscillations in the extinction profile can occur if the lidar profiles of both systems do not probe the same air. Hence, we looked for an a priori criterion for which profiles of both systems resemble in the best way a common state in the atmosphere. This was done as proposed in Eq.5, while principally other methods might be feasible as well. The reason that we chose the criterion as in Eq.5 was that the extinction profile influences the lidar profile in a smooth way, due to the 'exp$\times$integral' in the Lambert-Beer law. Hence, even if a wrong extinction is used in Eq.5 it does not affect the slope of the lidar profiles as strongly as different backscatter profiles and thus still reveals whether both lidars probed the same air. An alternative approach might be following: calculate the extinction for all data sets 1...n and 1...m for both lidars and seek the smoothest extinction profile (i.e. least variation in the derivative). However, as any temporal variations of the aerosol load are possible, in the latter case it would not be clear whether the smoothest solution is really close to the physical truth. We applied a criterion based on the input signals which do not depend on the results.

Ritter, C., Stachlewska, I. S., and Neuber, R.: Application of the Two-Stream evaluation for a case study of Arctic Haze over Spitsbergen, in: Proceedings of 23nd International Laser Radar Conference (ILRC 2006 in Nara, Japan), edited by: Nagasawa, C. and Sugimoto, N., 1, 507–510, ISBN 4-9902916-0-3, 2006. 20232, 20235

Referee: Page 20241 first paragraph. Authors has been written that the accuracy of retrieval the backscatter coefficient is below 2x10-7 1/m/sr. In opinion this small value is unrealistic which shows Fig.1 The extinction coefficient from two stream method is close to zero around at 1550 m while the backscatter non zero (close to molecular value 1x10-6 1/m/sr). This discrepancy shows that backscatter coefficient should be significant smaller because non zero backscatter coefficient lead to non zero extinc-

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tion coefficient. Therefore uncertainties of backscatter coefficient should be 2-3 times larger.

Authors: We are aware that on 15 May 2004 (Fig.1) at one particular height of 1580m an extreme low lidar ratio of ~3.5sr was retrieved by the Two-stream method and ~6sr at 1380m by the Raman method with the errors given in Fig.4 and Fig.5, respectively. The Two-stream retrieved at 1580m alpha_particle = 2.35e-6 m-1+- 2e-6m-1 (which roughly corresponds to a visibility of 280km, i.e. extremely clear air conditions) and beta_particle = 6.8e-7 m-1sr-1 +- 2e-7 m-1sr-1. Derived lidar ratio at this height is ~3.5 sr +- 2.5sr, i.e. lower than the molecular lidar ratio. The Vaisala RS90 radiosonde launched at Ny Alesund an hour after the lidar measurement revealed the boundary layer at ~1500m at 11:00 UT, i.e the wind direction changed from North to North-East by 50 degree and the wind speed increased of ~1m/s per 100m altitude (see Fig.1, this Iterative Comment). Taking to account the time delay of an hour, the very low lidar ratio obtained at 1580m seem to reside with this boundary layer. On the other hand the increased particle extinction and lidar ratios at 1800m and 900m reside with the two inversion layers at ~1800m and ~1200m on that day (discussed in the paper). Hence it is likely, that at the boundary layer the lidar ratio was very low and significantly higher few hundred meters above. However, as the Referee suggested, we could indeed overlook another type of error for the case of 15 May 2004 which was not considered in the error calculation given in Fig.4, an error due to a difference in the hight of the actually seen layer detected by each lidar separately. The correlation map for both entire signals might have been the best that could be achieved but for this particular height of 1580m the correlation could have been too low.

Referee: Page 20249 third sentence: Could you update Ansmann et al 1992 study of Cirrus lidar ratio.

Authors: Indeed, the cirrus cloud can have different lidar ratios which are, among others, related to their temperature and altitude of their occurrence, as these factors determine the form of the ice crystals in the cloud. Chen, et al., 2002 used the transmittance

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method (explained therein) to derive the Cirrus lidar ratio of 29sr +- 12sr and discussed their seasonal and physical variations over Taiwan. However, Reichardt et al., 2002 reported for a subarctic site the lidar ratios between 7sr and 30sr at 355nm lidar wavelength. For all cases presented in this paper we used a low lidar ratio of 12sr according with the results of the transmittance method applied to data at our Arctic site in Ny Alasund. To clarify this issue we added in the manuscript: ' ... (Ansmann et al., 1992, Reichardt et al., 2002). This relatively low and uniform lidar ratio of 12sr was confirmed by the results obtained with the transmittance method (Chen, et al., 2002) for the limited number of cases in this study.'

Chen W., C. Chiang, and J. Nee, "Lidar Ratio and Depolarization Ratio for Cirrus Clouds," Appl. Opt. 41, 6470-6476 (2002)

Reichardt, J., S. Reichardt, A. Behrendt, and T. J. McGee (2002), Correlations among the optical properties of cirrus-cloud particles: Implications for spaceborne remote sensing, Geophys. Res. Lett., 29(14), 1668, doi:10.1029/2002GL014836.

Referee: Page 20243, line 25: "The enhanced extinction, together with the high lidar ratios, the high relative humidity and the low volume depolarization . . . suggest that theses layers were composed of a very small spherical supercooled water droplets" Very small droplets have small lidar ratio due to larger backscatter coefficient in compare to larger droplets.

Authors: Indeed, this sentence seem misleading. To clarify this we replaced on page 20243, line 25: "The enhanced extinction, together with . . . suggest that theses layers were composed of a very small spherical supercooled water droplets" with the following explanation: 'The enhanced relative humidity indicate existence of more water particles in the layers than outside of it. The low temperature < -8 deg. C suggests supercooled conditions. The low depolarization ratios indicate spherical particles. The backward trajectory calculation gives no evidence of possible anthropogenic pollution which could contain absorbing particles. If the layers were dominated by spherical par-

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ticles which are very large or comparable with the interacting wavelength size it should show as enhancement in both extinction and backscatter profiles. We hypothesize, that only a highly concentrated and rather small spherical particles could give an enhanced particle extinction accompanied by a small particle backscatter, i.e. as in the layers at 900m and 1800m in Fig. 1 and at 1800m in Fig.2. Hence, we argue that these layers were mainly composed of a very small spherical supercooled water particles, which was confirmed with the results of the microphysical parameters retrieval.'

Authors: For the Referees interest we include in this Authors comment the result of the microphysical parameters retrieved from the KARL measurements for 15 May 2005 for the range of the layer and below it (see Fig.2, this Iterative Comment). For both cases the refractive index is typical for a water particle and its low imaginary part confirm that no absorbing particles are present. Clearly, in the layer these results are dominated by the small particle mode with effective radius ∼0.2 micrometers.

Specific comments:

Referee: Eq.5: The limits of integration is missing the same as the symbol "dh" in the first and und the second integral.

Authors: It is corrected now. In the Eg.5 we added [dh] for both integration variables and the integration limits in both transmission terms from [h^{KARL}_{gc}] to [h^{AMALi}_{gc}], which denote the height above the KARL lidar were its geometrical compression is completed (650m) and the height below the flight altitude were the geometrical compression of the AMALi lidar is completed (235m), respectively.

Referee: Page 20249 third sentence: the unit "sr" should be added to lidar ratio Bci

Authors: It is corrected now.

Please also note the Supplement to this comment.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 20229, 2009.

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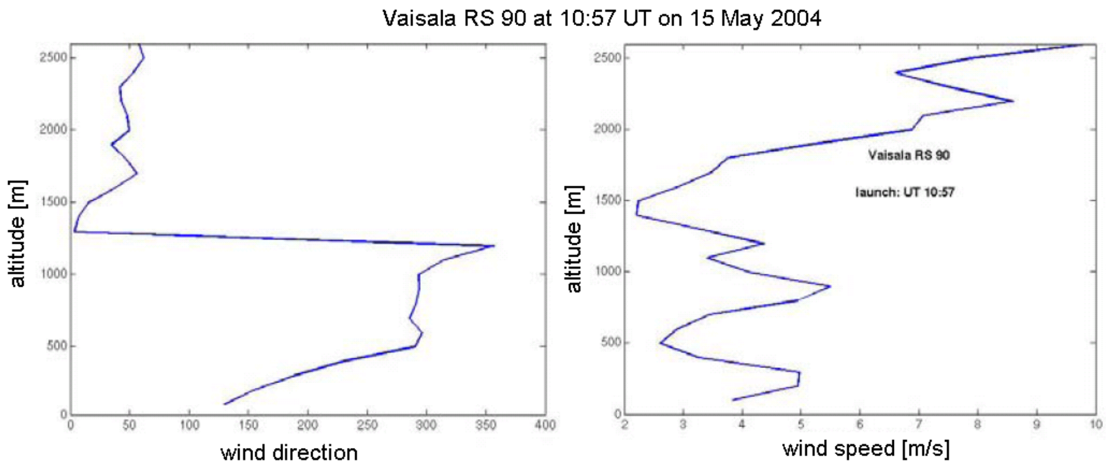

Fig. 1. Wind speed and direction from the radiosonding on 15 May 2004.

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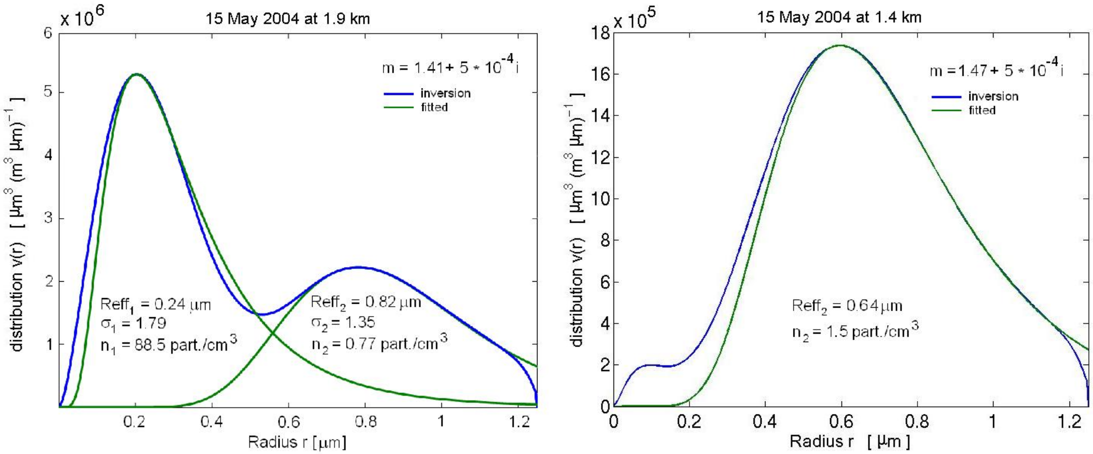

Fig. 2. Microphysical parameter retrieval on 15 May 2004.