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Atmospheric Chemistry and Physics Discussions

Interactive comment on "AMALi – the Airborne Mobile Aerosol Lidar for Arctic research" *by* I. S. Stachlewska et al.

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We would like to thank the Anonymous Referee # 1 for all of his valuable suggestions and comments, which certainly helped us to improve this paper and make it more concise and better structured.

In the following we give detailed answers and explanations to the issues raised.

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General comments

Referee: The paper gives a very detailed technical description of the airborne lidar AMALi. A lot of aspects are mentioned that are interesting not only for the lidar com-

munity. However, the data evaluation section contains mainly textbook knowledge and should be shortened.

Authors: Data evaluation is shortened.

Referee: The measurement examples shown illustrate the lidar capabilities, although error bars should be provided for conviction.

Authors: The error bars with the discussion in the text are provided.

Referee: A direct comparison between ground based and airborne measurements would be desirable.

Authors: A direct comparison between airborne and ground-based measurements on 19 May 2009 is discussed in details in Stachlewska and Ritter, 2009 in this ACP special issue 'ASTAR'. As the AMALi paper is already long and substantial we would rather not repeat this analysis here. We do however reference to the mentioned paper everytime the Referee suggested.

Referee: The paper is clearly written in good English language and can be recommended for publication with minor revisions.

Authors: Thank you, the detailed answers to the specific and technical comments are given below.

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Specific comments

Referee: page 18748: The outcome of the campaigns AMALi participated in could be given in a less itemized way, i.e. a paragraph describing not only the subject but also the achieved results.

Authors: Following the suggestions of the Referee we replaced the mentioned itemized case studies with following paragraph: 'The campaigns resulted in several aerosol and

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cloud studies involving the AMALi system. The attenuated backscatter data obtained by the ground based lidar and the AMALi overflying it were combined to obtain profiles of extinction and backscatter coefficient as well as lidar ratio profiles with no further assumptions necessary. This was done using the Two-stream approach which was compared with the corresponding Raman lidar retrievals (Stachlewska and Ritter, 2009). For the Two-stream retrievals a proper selection of the signals from both lidars which must be colocated in time and space signals is crucial (Ritter et al. 2006). The results obtained using the Two-stream approach were compared with optical depth obtained by sunphotometer and radiosonding profiles and interpreted as clean and polluted arctic conditions by the microphysical parameters retrieved from the Raman lidar and backward trajectories calculated with HYSPLIT and FLEXPART models (Stachlewska et al., 2005). Aerosol load distributions in the lower troposphere measured by the AMALi system around Svalbard during intense easterly winds were interpreted with the ECMWF model (Stachlewska and Dörnbrack, 2006a) and further modelling of the extent of the local dust plume was simulated with EULAG model (Dörnbrack et al., 2009). Different cases of lidar cloud observations of boundary layer, mixed-phase and multi-layer Arctic clouds were interpreted in the context of the meteorological situation. The influence of the atmospheric state was found substantial e.g. even in the free troposphere, multi-layer clouds formed by a disturbance of the wind field near Svalbard. (Lampert et al., 2009b) The mixed-phase clouds in lower troposphere were observed during airborne AMALi lidar measurements and allowed to guide the aircraft into areas within these clouds for measuring in situ their microphysical parameters (Stachlewska 2006b, Stachlewska 2006c, Gayet et al., 2007). The boundary layer mixed-phase clouds observed by airborne lidar, radiation and in situ instrumentation were glaciated completely at the intersection of two different air masses. This effect was confined to a small band along the air mass mixing zone (Richter et al., 2008). The cloud phase of boundary layer mixed-phase clouds was identified based on spectral radiation, in situ and airborne lidar measurements. In the predominantly liquid cloud top layer also a much smaller amount of ice crystals was found (Ehrlich et al., 2008). Measurements and

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simulations of the properties of a subvisible Arctic ice cloud and its impact on the radiation budget were performed. The combined lidar, in situ and radiation instruments evidenced an ice cloud of very low particle concentration. Some large ice crystals and more small spherical ice crystals were observed. The radiative impact of the cloud was calculated as - 3.2 W/m2 in the solar wavelength range and + 2.8 W/m2 in the terrestrial wavelength range. (Lampert et al., 2009a).

Referee: page 18751: Can you give the percentage of polarization of the emitted light? 99.xx%?

Authors: To clarify this point we added the following explanation 'Prior to the installation of the laser in the AMALi system we performed measurements of the laser beam shape, laser energy and degree of polarization using rotating lambda/2 plate. The output polarization of the 532nm wavelength was vertical in (x,y) with value of 99.99%. The 1064 nm wavelength was elliptical. To assure that the polarization of the 532nm remain unchanged when the laser beam is emitted via the window, the latter one was used at the Brewster angle and its position was adjusted for the strongest transmission. After the integration of the third-harmonic generation (THG) crystal, the linear polarization at 532 nm was found to be poor (above 90%). Therefore, additionally to the dual wavelength waveplate, a Glan Taylor polarizer was included. The waveplate was adjusted by maximizing the signal at the 532 nm parallel detector and minimizing the signal at the 532 nm perpendicular detector of the AMALi system. The Glan Taylor polarizer was then adjusted to minimize the signal at the 532 nm perpendicular detector. After the adjustment the degree of linear depolarization of the transmitted beam was not measured but we believe it was high as the extinction ratio of the Glan Taylor polarizer is 5$\times$10-5 according to the manufacturer.'

Referee: page 18752: What SNR is sufficient?

Authors: To clarify this we add the following explanation on page 18752 in line 11: 'In the case of the AMALi system a SNR of 15 leads to errors of 5% in the determination

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of the backscatter ratio, which is acceptable. The SNR does not vary from case to case as we do not modify measurement parameters, i.e. the laser runs stable and the high voltage applied to the PMTs is kept unchanged. Hence, both the signal strength and the SNR are very similar from case to case. At a SNR of 15 or higher the total error in the retrieval of the backscatter coefficient is not dominated by the noise but it is dependent on the choice of the the boundary condition value, the precision of the atmospheric density profile and the choice of the lidar ratio. When the boundary condition (with the lidar constant C known) can be obtained using the iterative method described in this paper and the atmospheric density profile is retrieved from radiosonde launch in Ny Alesund, only the choice of the unknown lidar ratio will be the dominant source of errors for the AMALi retrievals.' Further on page 18759 line 17 we replace 'sufficient signal-to-noise ratio' with 'SNR above 15' to avoid confusion and on page 18760 line 6 we cancel ' an acceptable' because it is now explained on p18752.

Referee: page 18753/18754: The eye-safety chapter is very detailed and may be shortened.

Authors: We consider the eye safety calculations an important detail which can be of interest for technically oriented persons as well as a good reference for present and future airborne lidar systems. As this calculations do not contain a purely scientific intent we shortened it according to suggestions of all Referees and moved it into an Appendix of this paper.

Referee: page 18755: Why is the UV beam diameter only 1 mm? 6 mm are specified for this laser at all wavelengths.

Authors: We did calculate the widening of our laser beam with the true laser divergence and the laser beam diameter which is 6 mm for all wavlengths. The MPE values have absolutely nothing to do with the AMALi system and we just to explained where they come from: They are based on the amount of energy that gets into the eye of the observer. To take into account the sensitivity of the human eye to different wavelengths

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the MPE uses a different aperture of the eye for the calculations, that is 1 mm in the UV and 7 mm in the VIS.

Referee: Receiver subsystem: Why is it not necessary to use an aperture that is completely rotationally symmetric with AMALi? In contrast to other lidar systems or what did the authors wanted to express here?

Authors: Indeed, this is misleading. To clarify we replace 'In the AMALi system, it is not necessary to use an aperture that is completely rotationally symmetric, and hence we could use the off-axis optics to minimize the system size weight and costs, and at the same time to maximize its efficiency' by 'Generally for backscatter lidars it is not necessary to use a primary mirror that is completly rotationally symmetric. We used an off-axis primary mirror which was cut off a larger parabolic and rotationally symetric mirrow in a way that the focal point of it is outside the mirror and not in the center of the mirror. If we had used a symmetric parabolic mirror we would have to face astigmatism problems.The off-axis mirror itself has rotationally asymmetric aperture but it gives a rotationally symmetric aperture stop (pinhole). This choice assures a diffraction limited optical system without astigmatisms and at the same time it allows keeping small the lidar diamensions (size and weight) due to a compact folded optical design.'

Referee: page 18756: This is a difficult sentence - please try to disentangle: The mirror surface accuracy is high with figure (defines mirror roughness) of l/10 wave peak to valley at 632.8nm over 99% of the 10 clear aperture and slope (defines mirror shape) of l/8 waves per inch at 90%.

Authors: Indeed, this sentence is difficult. We replaced it with: 'The accuracy of the mirror's surface is high. The mirror's roughness is low with the figure of lambda/10 wave-peak to valley (measured at 632.8 nm over 99% of the clear aperture). The mirror's shape is good with the slope of lambda/8 waves per inch at 90%.'

Referee: page 18757: What is a "double plain mirror"?

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Authors: To clarify we replace ‘A double plain mirror, with high reflectance for the two lidar wavelengths in use is mounded’ with ‘A planar mirror which is highly reflecting for the two wavelengths in use is mounted’

Referee: For the polarizing beam splitter cube and IF no companies are mentioned, whereas the companies selling the laser, the waveplate, and the primary mirror are explicitly given. page 18758: Laptop, data acquisition, and PMT companies explicitly are mentioned.

Authors: To keep consistency we added the following sentence ‘The polarizing beam splitter is provided by Laseroptik Garbsen, Germany, the IF filters for 355 nm and 532 nm are provided by Barr, USA, and Andover Corporation, USA, respectively.’ Additionally, accordingly to the suggestions of Referee # 2 we left only the most important specifications for the laptop.

Referee: page 18760: Here, for the fist time, the acceptable value of the SNR is given! Please also give a number on the previous page and further back.

Authors: On page 18759 we replaced ‘with a sufficient signal-to-noise ratio’ with ‘SNR above 15’ and on page 18760 we cancel ‘an acceptable’ as it is now explained on page 18752.

Referee: The whole description of the data display of the acquired data is very detailed and may be convenient during the lidar operation but is of muss less interest for the reader. Please shorten. Thus, also Figures 5 and 6 are dispensable. Too many screens are shown on too little space. However, the last paragraph on page 18761 is indeed of interest and one of the screens of Figure 6 could be used to illustrate the ability of the quick-looks to detect invisible cirrus.

Authors: The description of the data display is shortened. Concerning the figures, we agree that some can be skipped (e.g. we removed one of the photographs showing integration of the AMALi in a zenith-aiming configuration on Fig.2). However, we reckon

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the online display an important and characteristic property of the AMALi and, hence, there should be at least one figure showing these capabilities. As the Referee suggested we chose two bottom screens of Fig. 6 to illustrate the ability of the quick-looks to detect an invisible cirrus cloud. The caption of the Fig. 6 is changed to 'The quick-look displays of the AMALi online software for the zenith-aiming configuration on board the Polar 2 aircraft. We show here the display of the range and background corrected signals evolution at 532 nm and the depolarization ratio at 532 nm, both provided in real-time during the flight. These quick-looks allowed for an 'in flight' detection of an ice cloud at 3 km.'

Referee: The whole chapters 3 and partly 4 and 5.1 contain mostly textbook matter which is not new and is thus not suitable for publication in a scientific article. Instead, rather give an overview over the products AMALi can deliver under the different configurations and sum them up in table together with their limitations. This would also reduce this quite long paper.

Authors: As suggested by the Referee # 1 and Referee # 2 a table summarizing the configurations and the evaluation schemes of the AMALi is now provided within the paper. This table is also available via the ACPD Interactive Discussions.

Referee: Solely special data evaluation variations of the Klett_Fernald-Sarasano method may needed to be explained in more detail to the reader, i.e. the iterative method described in 4.2.2., and, if necessary, supplementary parts from the other subsections. If 4.2.2. is used, the Newton-Raphson method needs a few more clarifying words.

To clarify on page 18769 line 17 after 'The knowledge of beta(hgc)' we include 'and the partial derivative deltha beta(hgc) / deltha beta(href)'. Further we replace in page 18769 line 24 'is chosen again accordingly to the iterative Newton-Raphson method' to 'is calculated accordingly to the classical numerical Newton-Raphson iterative approach for finding zeros of real valued functions' and in line 25 we add sentence 'Gen-

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erally less than 5 iterative steps are required'. Additionally we add on page 18776 in line 4 the following explanation: 'The Newton Raphson iterative is the classical numerical approach for finding zeros of real valued functions, applied to the standard Klett evaluation in lidar data. Two following assumptions are made: the standard Klett solution is applicable and the lidar constant C in Eq. 1 is known by calibration (Stachlewska and Ritter, 2009 this ACP special issue 'ASTAR') or other means. In the case of the AMALi operated in the nadir-looking mode from an aircraft the largest insecurity in the retrieval is due to the choice of a reference value near the ground and far off the system. Then the method simply works like this: 1) The extinction in the overlap region is estimated to calculate the transmission term of the lidar equation. In our case in the Arctic the losses of the AMALi laser signal due to extinction in the 235m of its overlap can be neglected (for an extinction coefficient of 2x10-5 per meter and 235m overlap range the exp(-2 x 2x10-5 x 235) = 0.99, i.e. only 1% loss is due to extinction) and, hence, we simply assume the transmission term is equal unity. 2) This means that the backscatter coefficient at the end of the overlap can be directly determined out of the lidar equation. 3) The Klett approach is performed with an arbitrary boundary condition beta(href) 4) with knowledge of the partial derivative delta beta(hgc) / delta beta(href) the boundary condition beta(href) is changed in a Newton-Raphson scheme until the value of backscatter in the Klett betaˆKFS(hgc) matches to the value at the end of the overlap beta(hgc).

Referee: page 18775: Why is "Noise in the signals and/or the detection efficiencies of both instruments are of no concern"? Error bars for both lidar profiles would substantiate this statement.

Authors: This is due to the high SNR. In the case of the KARL at 4.8 km SNR about 140 leads to the error of the backscatter ratio < 0.01 due to noise. Similar holds for the AMALi. All remaining errors due to the choice of the lidar ratio, the choice of the reference value in the aerosol free stratosphere and the error in the air density profile are greater than the error due to noise in the signal. The errors added on the plots

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make them difficult to read. Hence, to clarify this we add the following explanation at the end of the Section 5.2: 'None of the lidars have any specific problem with the raw signal. The error in the backscatter ratio due to the noise in the data is negligible (at 4.8 km < 0.01) and becomes weaker when the SNR becomes stronger, i.e. the closer it is measured from the lidar). The error due to the lidar ratio assumption is a main error source, by far. It affects both systems in the same way as we used identical and constant lidar ratio value of 30 sr (studied in detail by Sasano et al., 1985).'

Referee: page 18777: The accuracy of the backscatter coefficient is assumed here? Why not calculated? Why is the backscatter coefficient denoted with sigma_bsc and not with b here?

The accuracy of the backscatter profiles was calculated for different cases and is given in Table 3. Based on this and to simplify we assume, that the general accuracy of the backscatter coefficient is 2x10-7 (i.e. above the highest value in Table 3). The sigmaˆIK_bsc denotes the accuracy of the backscatter coefficient b. To avoid confusion we replace 'sigmaˆIK_bsc' with 'Delta betaˆpart' as well as 'sigma_mol' with 'Delta etaˆbmol' for consistency.

Referee: Do any ground based lidar profiles from KARL exist for comparison with the shown example?

Authors: Yes, during this flight Ny Alesund was overflown and during the overflight period the KARL lidar was operated. This is published in this ACP special issue 'ASTAR' and hence we would rather not repeat this here but to clarify this we added the following explanation at the end of the Section 5.3: 'At about 9:35 UTC on 19 May 2009 the AMALi flew over Ny Alesund were the KARL lidar was operated. The extinction and backscatter coefficient profiles were derived from both lidars and compared. This results together with two more overflights during other days in clean and polluted conditions are published in Stachlewska and Ritter, 2009 in this ACP special issue 'ASTAR'.'

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Referee: Are there other cases where ground based and airborne lidar profiles could be compared?

Authors: As we aim at a technical paper we reckon that one example per case should be enough to illustrate the system abilities and hence we would rather not include more on the AMALI and KARL intercomparison. However, at the end of the Section 5.2 we will add sentence 'Further examples on AMALi and KARL intercomparison of the backscatter extinction are discussed in Stachlewska 2006c, Ritter et al. 2006, Stachlewska and Ritter, 2009 (this ACP special issue 'ASTAR').' to fulfill the suggestion of the Referee.

Referee: A discussion of the AMALi capabilities compared to other airborne aerosol lidars is missing.

Authors: We added the following paragraph 'The AMALi results were compared with the in situ instrumentation installed on board of the aircraft for the studies involving various cloud systems (Gayet et al. 2007, Lampert et al. 2009). So far, the AMALi has not been compared directly to other airborne lidars. The differences in the technical details prove the AMALi as a good compromise of cost, size, safety, performance and potential to obtain physical results e.g. the AMAli has quite a large field of view (∼10-3) in comparison with other airborne lidars (∼10-4 of the NASA's CPL) which was chosen to assure the eye-safety of the low flying nadir-aiming aircraft. Unlike large and complex three-wavlengths airborne lidars (e.g. the DLR's ALEX) and easily portable but single-wavelength lidars (e.g. the CEA/CNRS's LUAVA) the AMALi utilizes 'two-wavelengths plus depolarization' scheme (with choise of 355/532nm or 532/1064nm) to compromise between obtaining additional information (backscatter ratio, color ratio) and keeping the lidar itself small and compact.'

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Technical corrections

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Referee: page 18755: Two abbreviations used for ultraviolet: "UV" and "UVA"

Authors: It is changed to ‘UV’ for all cases.

Referee: page 18758: parallel (not parallelly)

Authors: It is changed as suggested.

Referee: page 18760: Each second one display screen... can be misunderstood: Each second, a screen displays...

Authors: It is changed as suggested.

Referee: Figure 3: Too small, too many details. Please provide larger images.

Authors: Accordingly to the request of the Reviewer #2 Fig. 3 (right) is removed. We also enlarged the Fig.3 (left). The caption for Fig.3 is changed to ‘The AMALi optical assembly with schematically drawn ray-tracking at 532nm (green) and 1064nm (red). The numbers indicate the main components in the assembly; 1.laser head 2.directing mirror in piezo motor 3.window with Brewster’s angle 4.off-axis parabolic mirror 5.first folding mirror 6.pinhole 7.second folding mirror 8.achromatic lens 9.beam splitter 10.interference filter for 1064nm channel 11.APD for 1064nm detection 12.interference filter for 532 nm channel 13.polarizing cube 14.thin film polarizing filter 15.PMT for perpendicular 532nm detection 16.PMT for parallel 532nm detection 17.optical bench 18.springs 19.posts 20.base plate. In present configuration the IR detection channel is replaced with the UV channel comprising interference filter and PMT for 355nm detection’.

Referee: Figure 4: Nothing new, can be left out.

Authors: It is left out as suggested.

Referee: Figure 5 and 6: Only show one example of a screen.

Authors: We left two bottom screens of Fig. 6 which illustrate the ability of the quicklooks to detect an invisible cirrus cloud. The caption of the Fig. 6 is changed to ‘The

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quick-look displays of the AMALi on-line software for the zenith-aiming configuration on board the Polar 2 aircraft. We show here the display of the range and background corrected signals evolution at 532 nm and the depolarization ratio at 532 nm which is provided in real-time during the flight. These quick-looks allowed for an 'in flight' detection of an ice cloud at 3 km.'

Referee: Figure 7: Please add error bars to the profiles.

The sense of Fig. 7 should be the KARL and the AMALi intercomparison and neither the Klett method accuracy nor the atmospheric variability. We see also the point of the Referee but the errors added directly on the plots make them difficult to read. Hence, we added the explanation at the end of the Section 5.2 (see our comment for page 18775). If the Referee thinks that this is not sufficient we could add one more plot of the error due to the noise in the profiles and the error of the Klett method itself (i.e. combined error due to the lidar ratio, the reference value and the air density) separated, to not confuse the reader.

Referee: Figure 8: In case a ground based profile exists, it could be included here for comparison.

Authors: As we already mentioned such a ground based profile exists and is published in Stachlewska and Ritter, 2009 in this ACP special issue 'ASTAR' and hence we would rather not repeat this here.

Please also note the Supplement to this comment.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 18745, 2009.